THE SEMIPALATINSK TEST SITE:

Creation, Operation, and Conversion



A monograph edited by

Professor Vladimir S. Shkolnik

Minister for Energy & Material Resources

Republic of Kazakhstan

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PREFACE

In preparing the monograph, the editors drew upon archive data and documents from recent years. The book presents information describing historic events and the Test Site's military and scientific activities from the cold-war period through the present day. It discusses the results of the many years of scientific research at the Republic of Kazakhstan's National Nuclear Center, and analyzes the prospects for conversion.

The monograph does not include political or social analysis or emotional assessments of various events, which usually entail classification of these events as "right" or "wrong." The aim of the book is to tell the Test Site's story in accessible language, relying where possible on unbiased witnesses—official documents, research reports, and the assessments of professionals.

This monograph was prepared and published under the joint Kazakhstani-American project between the Republic of Kazakhstan Institute of Nonproliferation and the Cooperative Monitoring Center of Sandia National Laboratories.

The editors would like to thank their American colleagues for assistance in preparing the materials, arranging their translation into English, and publishing the monograph.

TABLE OF CONTENTS

List of Tables

List of Figures

Abbreviations Used

Note: English abbreviations in parentheses are for information only; they represent transliterations of the corresponding Russian abbreviations and are used in the text only immediately after the full expansion: “Ministry of Internal Affairs (MVD).”

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
(DK_B)	Allowable radionuclide concentration for Group B population	$ДК_Б$	Допустимая концентрация радионуклидов для населения группы Б
(*Gidromet-sluzhba*)	Hydrology and Meteorology Service	Гидромет-служба	Гидрометеорологическая служба
(*GNTs-KI*)	Kurchatov Institute State Nuclear Center	ГНЦ-КИ	Государственный научный центр–Курчатовский институт
(*Gosagro-prom*)	USSR State Agroindustrial Committee	Госагро-пром	Государственный агропромышленный комитет СССР
(*Gosgor-tekhnad-zor*)	Mining Safety Oversight Committee	Госгортех-надзор	Комитет по надзору за безопасным ведением горных работ
(*Goskom-ekologiya*)	RF State Environmental Protection Committee	Госком-экология	Государственный комитет по охране окружающей среды
(*Goskom-priroda*)	State Committee for Nature Conservation (USSR, various republics)	Госком-природа	Государственный комитет по охране природы
(*Goskom-sanepid-nadzor*)	Russian Federation State Sanitary and Epidemiological Oversight Committee (defunct)	Госком-санэпид-надзор	Государственный комитет санитарно-эпи-демиологического надзора Российской Федерации
(*Gossan-nadzor*)	Republic of Kazakhstan State Sanitary and Epidemiological Oversight Committee	Госсаннад-зор	Государственный комитет Республики Казахстана санитарно-эпидемиологиче-ского надзора
(*Gosstan-dart*)	State Standardization Committee (USSR or republic level)	Госстан-дарт	Государственный комитет по стандартизации
(GOST)	State Standard	ГОСТ	Государственный стандарт
(*IGI*)	Institute of Geophysical Research	ИГИ	Институт геофизических исследований

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
(*IGKE*)	Institute of Global Climate and Ecology (Russian Committee on Hydrology and Meteorology and Russian Academy of Sciences)	ИГКЭ	Институт глобального климата и экологии Роскомгидромета и Российской академии наук
(*IRBiE*)	Institute of Radiation Safety and Ecology	ИРБиЭ	Институт радиационной безопасности и экологии
(*IRMiE*)	Institute of Radiation Medicine and Ecology (Kazakh SSR Ministry of Health)	ИРМиЭ	Институт радиационной медицины и экологии (Министерства здравоохранения Казахской ССР)
(*Kazgipro-vodkhoz*)	Kazakh SSR Design-Engineering and Scientific Research Institute of Water Management Construction	Казгипро-водхоз	Проектно-изыскательный и научно-исследовательский институт водохозяйственного строительства Казахской ССР
(*MID*)	Russian Federation Ministry of Foreign Affairs	МИД РФ	Министерство иностранных дел Российской Федерации
(*MIFI*)	Moscow Engineering Physics Institute	МИФИ	Московский инженерно-физический институт
(*Minzdrav-medprom*)	Russian Federation Ministry of Health and the Medical Industry	Минздрав-медпром	Министерство здравоохранения и медицинской промышленности Российской Федерации
(*MVD*)	USSR Ministry of Internal Affairs	МВД СССР	Министерство внутренних дел СССР
(*MVS*)	USSR Ministry of Armed Forces	МВС СССР	Министерство вооруженных сил СССР
(*NIIR-MEP*)	Scientific Research Institute of Regional Medical and Environmental Problems	НИИР-МЭП	Научно-исследовательский институт региональных медико-экологических проблем
(*NITs SSK*)	Quality Certification System Scientific Research Center (USSR Ministry of Defense)	НИЦ ССК	Научно-исследовательский центр систем сертификации качества
(*NKRZ*)	National Radiation Protection Commission	НКРЗ	Национальная комиссия по радиационной защите

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
(*NRB*)	Radiation Safety Standard	НРБ	Норма радиационной безопасности
(RF FAS)	RF Federal Archive Service	ФАС	Федеральная архивная служба РФ
(*RNTs-KI*)	Kurchatov Institute Russian Nuclear Center	РНЦ-КИ	Российский научный центр–Курчатовский институт
(*SKZM*)	Soviet Committee for the Defense of Peace	СКЗМ	Советский комитет защиты мира
(*TsFTI*)	Central Physical-Technical Institute (RF Ministry of Defense)	ЦФТИ	Центральный физико-технический институт
(*VNIIEF*)	All-Union (now All-Russian) Scientific Research Institute of Experimental Physics	ВНИИЭФ	Всесоюзный (ныне Всероссийский) научно-исследовательский институт экспериментальной физики
(*VNIPI-Promtekh-nologiya*)	All-Union (now All-Russian) Scientific Research and Design Engineering Institute of Industrial Technology	ВНИПИ-Промтех-нология	Всесоюзный (ныне Всероссийский) научно-исследовательский проектно-изыскательный институт промышленной технологии
AF&F	arming, fuzing and firing	—	автоматика (подрыва и взрыва)
Area B	Balapan Area	площадка “Б”	площадка “Балапан”
Area G	Degelen Area	площадка “Г”	площадка “Делеген”
Area M	residential and administrative center (of Semipalatinsk test site)	площадка “М”	жилой и административный центр (семипалатинского полигона)
Area N	technical area for physics package devel-opers	площадка “Н”	производственная площадка разработчиков ядерного заряда
Area O	experimental research area (of Semipalatinsk test site)	площадка “О”	опытно-научная часть (семипалатинского полигона)
Area S	Sary-Uzen and Murzhik Area	площадка “С”	площадка “Сары-Узень и Муржик”
Area Sh	headquarters area	площадка “Ш”	штабная площадка
CG	Coordinating Group	КГ	Координационная группа
cGy	CentiGray	сГр	Сантигрей
cSv	Centisievert	сЗв	Сантизиверт

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
CTBT	Comprehensive Test Ban Treaty	ДВЗЯИ	Договор о всеобъемлющем запрещении ядерных испытаний
DNA	US Defense Nuclear Agency	—	Ядерное оборонное агентство США
DOE	US Department of Energy	—	Департамент энергетики США
DSWA	Defense Special Weapons Agency (US Department of Defense)	—	Агентство специальных типов вооружений Министерства обороны США
GAN	Russian Federation Nuclear and Radiation Safety Federal Oversight Committee	Госатом-надзор РФ	Федеральный надзор Российской Федерации по ядерной и радиационной безопасности
GI tract	gastrointestinal tract	ЖКТ	желудочнокишечный тракт
GPS	global positioning system	—	глобальная система определения координат
ICBM	intercontinental ballistic missile	МБР	межконтинентальная баллистическая ракета
ICRP	International Commission on Radio-logical Protection	МКРЗ	Международная комиссия по радиологической защите
LANL	Los Alamos National Laboratory	ЛАНЛ	Лос-Аламосская национальная лаборатория
MAC	maximum allowable concentration	ПДК	предельно допустимая концентрация
NPT	Nuclear Arms Nonproliferation Treaty	ДНЯО	Договор о нераспространении ядерного оружия
NPT-1968	1968 Nuclear Arms Nonproliferation Treaty	ДНЯО-1968	Договор 1968 г. о нераспространении ядерного оружия
NTBT	1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water ("Nuclear Test Ban Treaty")	—	Договор 1963 г. о запрещении ядерных испытаний в трёх средах
rem	roentgen equivalent in man	бер	биологический эквивалент рентгена
RF	Russian Federation	РФ	Российский Федерация
RK	Republic of Kazakhstan	РК	Республика Казахстан
RK NNC	Republic of Kazakhstan National Nuclear Center	НЯЦ РК	Национальный ядерный центр Республики Казахстан

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
S/A	Selected Availability	—	селективный доступ
SALT-1	Strategic Arms Limitations Treaty 1	СНВ-1	Договор о “стратегических наступательных вооружениях” (т.е. об ограничении ядерных вооружений)
STS	Semipalatinsk Test Site	СИП	Семипалатинский испытательный полигон
TTBT	1974 Treaty on the Limitation of Underground Nuclear Weapon Tests (“Threshold Test Ban Treaty”)	—	Договор 1974 г. о пороговом ограничении мощности ядерных испытаний
UNDP	United Nations Development Program	ПРООН	Программа Развития ООН
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation	НКДАР ООН	Научный комитет по действию атомной радиации Организации Объединенных Наций
VNIITF	All-Union (now All-Russian) Scientific Research Institute of Technical Physics	ВНИИТФ	Всесоюзный (ныне Всероссийский) научно-исследовательский институт технической физики
VNIITF	Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Technical Physics	РФЯЦ-ВНИИТФ	Российский федеральный ядерный центр–Всероссийский научно-исследовательский институт технической физики
WMD	weapons of mass destruction	ОМП	оружия массового поражения
	aircraft spray rig	ВАП	выливной авиационный прибор
	annual uptake limit	ПГП	предел годового поступления
	annual uptake limit for general public	$ПГП_{нас.}$	предел годового поступления радионуклидов для населения
	Capital Construction and Building Supervision Section	ОУС-310	Отдел капитального строительства и руководством строителей
	command post	КП	командный пункт
	dose limit	ПД	предел дозы
	excavating explosion	ВВГ	взрыв с выбросом грунта
	exposure dose rate	МЭД	мощность экспозиционной дозы
	field seismic complex	ПСК	полевой сейсмический комплекс

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
	First Main Directorate	ПГУ	Первое главное управление
	full camouflet explosion	ВКП	взрыв камуфлетный полный
	Health Regulation	СП	Санитарные правила
	human radiation spectrometer	СИЧ	спектрометра излучений человека
	Institute of Atomic Energy	ИАЭ	Институт атомной энергии
	Institute of Biophysics (now the RF State Research Center/ Biophysics Institute)	ИБФ	Института биофизики (ныне ГНЦ РФ-ИБФ)
	Institute of Chemical Physics	ИХФ	Институт химической физики
	Institute of Geosphere Dynamics	ИДГ	Институт динамики геосфер
	Institute of Nuclear Physics	ИЯФ	Институт ядерной физики
	Interdepartmental Expert Commission for Assessment of the Radiation and Environmental Safety of Nonnuclear Experiments	МВЭК-НЭ	Межведомственная экспертная комиссия по оценке радиационной и экологической безопасности неядерных экспериментов
	International Antinuclear Movement	МАД	Международное антиядерное движение
	Kazakh State Scientific Production Center of Explosives	КГЦВР	Казахский государственный научно-производственный центр взрывных работ
	Kazgidromet State Enterprise (formerly Republic of Kazakhstan Main Directorate for Hydrology and Meteorology)	Казгидромет	Государственное предприятие “Казгидромет” (бывшее Главное управление по гидрометеорологии Республики Казахстан).
	Main Customs Directorate (RF Ministry of Finance)	ГТУ	Главное таможенное управление
	maximum allowable exposure level	ПДУ	предельно допустимый уровень облучения
	Methodological Instructions	МУ	Методические указания

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
	Methodological Instructions on Monitoring Methods	МУК	Методические указания по методам контроля
	military radioactive material	БРВ	боевое радиоактивное вещество
	Military-Industrial Commission	ВПК	Военно-промышленная комиссия
	military-industrial complex	ВПК	военно-промышленный комплекс
	missile silo	ШПУ	шахтная пусковая установка
	mountain seismic station	ГСС	горная сейсмическая станция
	natural radioactive background	ПРФ	природный радиоактивный фон
	nonstandard radiation situation (incident)	НРС	нештатная радиационная ситуация
	(*n*-th) Main Directorate	ГУ	(*n*-ое) Главное управление
	nuclear explosion	ЯВ	ядерный взрыв
	observation area	ЗН	зона наблюдения
	partial camouflet explosion accompanied by slight leakage of radioactive noble gases into the atmosphere	ВНК-РИГ	взрыв неполного камуфлета, сопровождавшийся незначительным истечением в атмосферу радиоактивных инертных газов
	partial camouflet explosion with nonstan-dard radiation situation	ВНК-НРС	взрыв неполного камуфлета с нештатной радиационной ситуацией
	peaceful nuclear explosion	МЯВ	мирный ядерный взрыв
	public health station (“sanitary and epi-demiological station”)	санэпид-станция	санитарно-эпидемиологическая станция
	public health station (“sanitary and epi-demiological station”)	СЭС	санитарно-эпидемиологическая станция
	radioactive noble gases	РИГ	радиоактивные инертные газы
	radioactive substances	РВ	радиоактивные вещества
	Republic of Kazakhstan Cabinet of Ministers	КМ РК	Кабинет Министров Республики Казахстан
	Republic of Kazakhstan Ministry of Defense	Минобороны РК	Министерство обороны Республики Казахстан

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
	Republic of Kazakhstan Ministry of Ecology and Bioresources	Минэкологии и биоресурсов РК	Министерство экологии и биоресурсов Республики Казахстан
	Republic of Kazakhstan Ministry of Finance	Минфин РК	Министерство финансов Республики Казахстан
	Republic of Kazakhstan Ministry of Health	МЗ КазССР	Министерство здравоохранения Казахской ССР
	Republic of Kazakhstan Ministry of Internal Affairs	МВД РК	Министерство внутренних дел Республики Казахстан
	"Russia Does It Herself" (Russia's first warhead)	РДС-1	боеголовка «Россия Делает Сама»
	Russian Federation Federal Service for Hydrology, Meteorology, and Environmental Monitoring	Росгидромет	Федеральная служба Российской Федерации по гидрометеорологии и мониторингу окружающей среды
	Russian Federation Ministry of Atomic Energy	Минатом РФ	Министерство атомной энергии Российской Федерации
	Russian Federation Ministry of Defense	Минобороны РФ	Министерство обороны Российской Федерации
	Russian Federation Ministry of Defense	МО РФ	Министерство обороны Российской Федерации
	Russian Federation Ministry of Emergency Situations	МЧС России	Министерство чрезвычайных ситуаций Российской Федерации
	Russian Federation Ministry of Health	МЗ РФ	Министерство здравоохранения Российской Федерации
	Russian Federation Ministry of Health	Минздрав РФ	Министерство здравоохранения Российской Федерации
	Russian Federation Ministry of Internal Affairs	МВД РФ	Министерство внутренних дел Российской Федерации
	Russian National Commission on Radiation Protection	РНКРЗ	Российская научная комиссия по радиационной защите

English Abbr.	English Expansion	Русское сокр.	Полная русская форма
	Scientific Production Association	НПО	научно-производственное объединение
	Semiconductor detector	ППД	полупроводниковый детектор
	Special Comprehensive Research Program	ЦКПИ	Целевая комплексная программа исследований
	standard spectrometric γ source	ОСГИ	образцовый спектрометрический гамма-источник
	State Central Scientific Research Test Site 2	Гос-ЦНИИП-2	Государственный центральный научно-исследовательский испытательный полигон No. 2
	State Special Design Institute 11	ГСПИ-11	Государственный специальный проектный институт No. 11
	Strategic Missile Forces	РВСН	Ракетные войска стратегического назначения
	Structure 12P (AF&F command post)	сооруже-ние 12П	командный пункт автоматики
	Town M (later the city of Kurchatov)	населен-ный пункт "М"	(в последующем город Курчатов)
	Training Test Site 2 (UP-2)	УП-2	Учебный полигон No. 2
	USSR State Committee for Hydrology, Meteorology, and Environmental Monitoring	Госком-гидромет	Государственный комитет СССР по гидрометеорологии и контролю природной среды
	vector (direction) I	радиус (направле-ние) I	северо-восточный(-ое)
	vector (direction) II	радиус (на-правление) II	юго-восточный(-ое)
	vector (direction) III	радиус (направле-ние) III	юго-западный(-ое)
	yearly uptake	ГП	годовое поступление

INTRODUCTION

The operation of the Semipalatinsk Test Site, which began August 29, 1949 and ended in 1989, is one of many pages in the history of the former Soviet Union, and the cleanup after that operation is one of the first pages in the history of a new nation, the Republic of Kazakhstan (local name Qazaqstan).

Under today's conditions, the results of an objective assessment of the scale and levels of radioactive contamination of the natural environment during the conduct of atmospheric and underground nuclear testing at the site, as well as the extent of their effects on the health of people living in nearby areas, are extremely important to the Republic of Kazakhstan.

The principal aim of this monograph is to acquaint the scientific community and the general public, as well as members of various government agencies, with information documenting:

- the current environmental radiation levels at the test site and in its test areas;
- the scope of activities to clean up the nuclear testing infrastructure and aftermath of the closure of adits and to clean up vertical shafts and ICBM launch silos;
- the scale and levels of radioactive contamination of the Semipalatinsk region;
- current source data for possible establishment of a database of various radiation parameters needed for making decisions relating to the transfer of the grounds of the former nuclear test site to civilian use.

An objective assessment of the results of the Semipalatinsk Test Site's operation is impossible without exploring the historical phases of its creation, the conduct of nuclear tests, and conversion. In this monograph, we present the most important facts that have affected the test site's operation and the consequences of that operation.

Various publications have appeared in recent years on the history of the development of Soviet nuclear weapons, the possible scale of environmental radioactive contamination, and the effect of nuclear testing on human health. Unfortunately, however, most of these publications, in addition to truth and a scientific presentation of information on the problem, contain many conjectures, inaccuracies, and uneducated guesses. These are especially common in publications containing information on the extent of radiation's effects on the health of residents of the inhabited areas that were contaminated by radioactive substances during atmospheric nuclear testing.

One participant in the nuclear epic wrote in his memoirs that the scientific director of the Soviet nuclear program, Igor Vasilyevich Kurchatov, for whom the Semipalatinsk Test Site's administrative and research center was named, often repeated in the last five years of his life that "We must write. The time has come to tell about our work. We absolutely must write about everything that happened and how it happened, without embellishment or fabrication. If we don't do it now, everything will be distorted, confused, and pulled apart, and our own mothers won't recognize us."

In this light, the publication of several books by a team of authors under Russian Academician Viktor Nikitovich Mikhaylov, from the series *USSR Nuclear Tests*,[1,11] as well as the monograph, *The Semipalatinsk Test Site: Assurance of the General and Radiation Safety of Nuclear Tests*,[12] has been very important. We have drawn upon these publications in preparing this monograph, which is dedicated mainly to the current environmental radiation levels in and around the Semipalatinsk Test Site, and to issues of the cleanup of nuclear testing infrastructure and problems of the transfer of test site land to civilian use.

In writing this monograph, we also used archival data describing the major events that occurred at the test site during nuclear testing and various nuclear physics experiments.

The Republic of Kazakhstan National Nuclear Center (the RK NNC) and its research institutes are making a major contribution to the objective assessment of the results of the operation of the Semipalatinsk Test Site. The RK NNC was established in 1993 based on the research center of the former Semipalatinsk Test Site. For a long time, the Center's General Director was Yury Semënovich Cherepnin; it is now managed by Shamil Toregulovich Tukhvatulin.

To study environmental radiation levels in and around the Semipalatinsk Test Site, the RK NNC established the Institute of Radiation Safety and Ecology (*IRBiE*), whose first director was Samat Kabdrasilovich Smagulov, the former head of the Radiation Safety Service at the Semipalatinsk Test Site. The institute is currently directed by Murat Abdrashitovich Akhmetov and his Scientific Deputy Larisa Denisovna Ptitskaya.

We must accord IRBiE's employees their due for the tremendous research that they have carried out during the study of current environmental radiation levels in and around the test site. The results of this very important work were used in the preparation of this monograph.

PART 1. ESTABLISHMENT OF THE TEST SITE. SOVIET NUCLEAR PROGRAMS AND NUCLEAR TESTS

The history of nuclear testing at the Semipalatinsk Test Site began August 29, 1949, when the former Soviet Union detonated its first nuclear explosion. The nuclear weapons developers and test supervisors at the site exclaimed, “Yes!” “It worked!” “We did it!” The explosion was the end of the US nuclear weapons monopoly, which had tremendous military and political significance for the USSR and the entire world.

The appearance of a nuclear weapon as one possible practical use of nuclear energy resulted from the development of nuclear physics as a science. Nuclear weapons must be recognized as an inextricable part of modern reality that strongly influences mankind’s fate today and will continue to do so in the future.

Thus, Semipalatinsk was the site of the USSR's first nuclear weapons test. But before the test could be conducted, a whole series of complex scientific and practical problems had to be solved: the possibility of creating a nuclear bomb had to be assessed and its design had to be verified; the production of components of the "new" type of weapon had to be organized; new industrial plants had to be built; all the bomb's structural assemblies had to be put together; the location and people had to be selected for the nuclear weapons test; all the necessary nuclear testing infrastructure had to be created; etc.

GEOGRAPHIC LOCATION

One of the first tasks in the complex set of steps required to organize nuclear testing was to select a location for the test site. The Soviet Union's most important military proving grounds were located in Kazakhstan. In geophysical terms, you simply could not find a better place. Forty percent of the Kazakh SSR's land area was desert, 23% was semidesert, 20% was steppe, 7% was forest-steppe, and 10% was mountainous. So naturally attention turned to that region.

The developers' main criteria in choosing a location for construction of the nuclear test site were that the area be practically uninhabited, free of agricultural lands, and large in area. In addition, the area had to be close to transportation arteries, and permit construction of a local runway for cargo planes, since they would have to carry in large quantities of cargo, and establish permanent operational communications.[1, 2] Preliminary calculations indicated that the diameter required for the test site should be at least 200 km.

After a long search, taking the main criteria into account, a suitable area was found in the steppes of Semipalatinsk Region, Kazakhstan. The nuclear test site was located in the steppes near the Irtysh River, about 140 km west of Semipalatinsk (Figure 1). This part of the Kazakh SSR was and is now an arid steppe with scattered seasonal wells. The southwestern part of the area is low mountains with massifs dissected by valleys and washes. In the east is the valley of the Shagan River (Russian *Chagan*), a left-bank tributary of the Irtysh. Here there are shallow salt lakes that dry up in summer.

The climate is continental. Its principal features are aridity, with a cold, relatively snow-free winter and a relatively short, hot summer. Precipitation is low. Strong winds are frequent. In winter, the temperature reaches –40°C, and in summer it exceeds 30°C. Annual precipitation ranges from 200 to 300 mm, most of it falling in the summer. Snow depths of 100-200 mm produce small amounts of meltwater and deep freezing of the soil (down to 1.5-2 meters). In winter and spring, prevailing winds are from the southeast, averaging 4-5 m/s; in summer, winds are typically from the north, with dust storms. Wind speeds and directions are quite variable in the region, even during a single day.

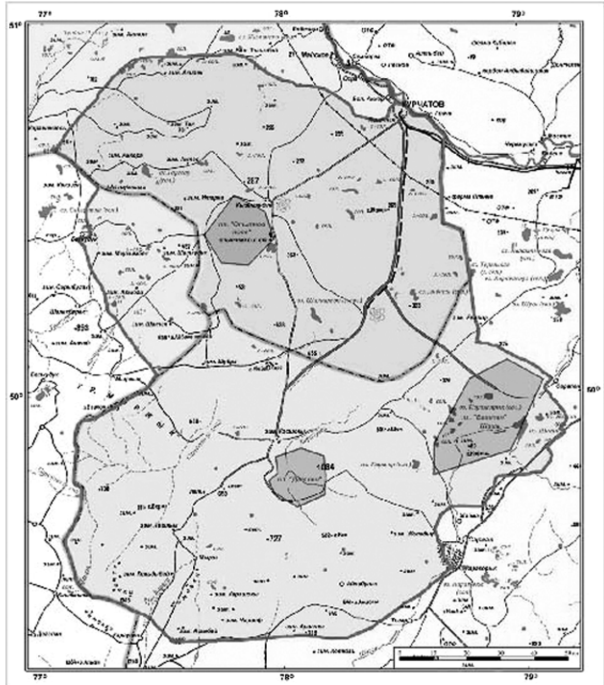


Figure 1. Map of the Semipalatinsk Area.

The area's main river is the Irtysh, a major tributary of the Ob, one of the most important navigation routes in Kazakhstan. The second most important river in the area is the Shagan, a left-bank tributary of the Irtysh. However, this river is low, reaching a width of 10 meters on stretches, and a depth of up to 2 meters. Its water is salty, and the river dries up in late summer in the driest years. All other small rivers carry little water, drying up practically completely in summer.

Economically, the area was poorly developed. Inhabited areas were mainly small agricultural villages along the Irtysh and Shagan River valleys. The practically barren steppe was traditionally used by local residents, primarily Kazakh nomads, for grazing livestock. Temporary summer and winter camps were scattered across the area.

The site of the future test complex was a plain about 20 km in diameter, surrounded on three sides (south, west, and north) by low mountains. To the east of this unique valley were small hills.[3] At one time, ages ago, the plain had been a sea floor. By the late 1940s, only a shriveled-up lake with very salty water was left alongside the place that would become the site's Test Field. In this plain, construction of the nuclear test site was begun in 1947.

MAJOR PHASES OF FACILITIES CONSTRUCTION AND EQUIPMENT

The second phase of the creation of the USSR's nuclear shield began with the very first geodetic surveys of the selected location. The precise moment is difficult to define, however, since preparation for testing of the first physics package actually began simultaneously with the development of the package itself. Pursuant to an August 1947 resolution of the USSR Cabinet of Ministers and the CPSU Central Committee, the site came to be called "Mountain Seismic Station, 'Facility 905,' for Full-Scale Nuclear Weapons Testing."

Design of the equipment of the test site's Test Field, as well as that of other facilities needed for its successful operation, was carried out under technical assignments from the Institute of Chemical Physics at a special design institute, GSPI-11, of the First Main Directorate of the Council of People's Commissars. The Institute of Chemical Physics also employed noted scientists such as D. A. Frank-Kamenitsky, Yury Borisovich Khariton, Yakov Borisovich Zeldovich, A. F. Belyayev, A. Ya. Apin, B. M. Stepanov, and others.

Under the design, the test site was to be a complex branching structure with all necessary life-support components, with scientific and technical infrastructure meeting the requirements of the time, with a large number of buildings and structures located in various areas on the grounds. Construction work was begun by engineering troops of the Armed Forces. The first group of builders, officers of the 36th Defense Construction Directorate, arrived on the grounds of the future test site in the uninhabited steppe in September 1947. The formation of military units, the conduct of surveys, and the design of site facilities were all carried out simultaneously.

In 1948, Facility 905 was renamed as "Instructional Test Site 2" (UP-2) of the USSR Ministry of Armed Forces, and later it came to be called "State Central Scientific Research Test Site 2 (GosTsNIIP-2)," and finally the "Semipalatinsk Test Site" (STS).

The test site was placed directly under a Special Section of the Armed Forces General Staff. The section was headed by Major General of Engineering and Technical Service Viktor Anisimovich Bolyatko, an energetic and demanding commander. The section was built around Lt.

Colonels A. A. Osin and Ye. F. Lozovoy, Major V. S. Tyutyunnikov, and others. They all later became top managers.

We should note that various specialized organizations were enlisted to design the test site facilities. For example, the experimental fortification structures were designed by a special design engineering bureau of the Engineering Troops, and the airfield structures were designed by the Air Force's Central Design Institute. And the series of jobs including erection of technological and instrumentation structures at the Test Field, outfitting of areas for experimental animals, creation of the power supply system for the instrumentation structures, laboratories, and the housing complex, power facilities, waster supply, and road construction was performed by the special design institute in Leningrad (GSPI-11).

Work at the site's areas was supervised and structures were approved for use by the test site command and its units. The site's first head was Guards Lt. General of Artillery Pëtr Mikhaylovich Rozhanovich, who had commanded an artillery corps in World War II.

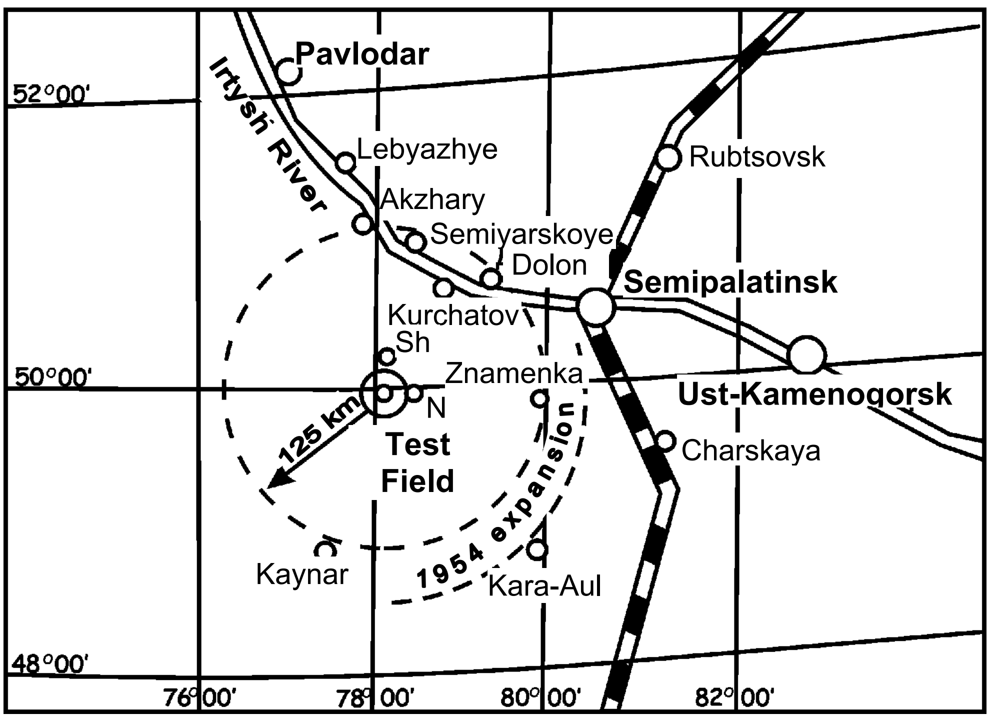


Figure 2. Diagram of the Arrangement of the Test Field and Main Areas of the Semipalatinsk Test Site.

The test site was a large and complex facility including three major areas: the Test Field, the headquarters area, and the administrative center. Figure 2 diagrams their arrangement.

The Test Field, where various test areas and instrumentation structures were located, consisted of a nearly perfect circle 20 km in diameter (Figure 3). Around the Test Field was a safety zone with an area of about 45,000 km^2.

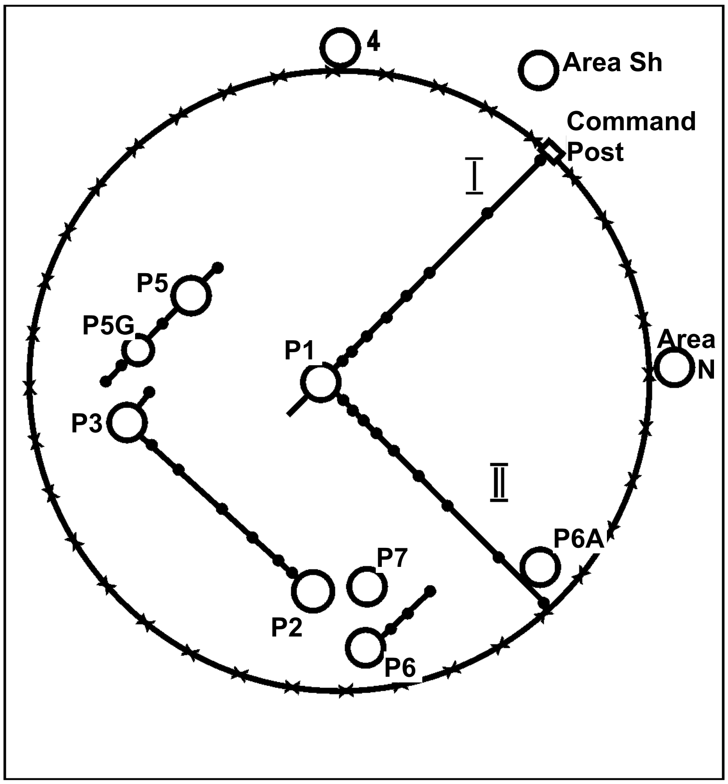


Figure 3. Main Test Areas
and Instrumentation Facilities of the Test Field.

Symbols:

- Test Areas
- Instrumentation Facilities
- I Northeast Instrumentation Line
- II Northwest Instrumentation Line
- Test Field Perimeter

1 0 1 2 3 4 5 6 7 8 km

The headquarters area ("Area Sh"), intended for temporary accommodation of testers, issuance of personal protective equipment, dosimeters, and sanitary processing and decontamination, was built 14 km northeast of the center of the Test Field.

Erection of the site's housing and administrative center ("Area M"), on the banks of the Irtysh River some 60 km northeast of the Test Field, began simultaneously with construction of the test areas. Later the center became the city of Semipalatinsk-21, and it is now the city of Kurchatov.

Along an edge of the residential area, "Area A" began to go up; it would later become a military station housing numerous military units with their depots, motor pools, and other necessary facilities. On the edge of the residential area, along the road to the Test Field, construction of "Area O," the site's experimental research section (Sector 5), with laboratory buildings, began (Figure 4). This area is now the site of the Institute of Radiation Safety and Ecology (*IRBiE*), a unit of the Republic of Kazakhstan National Nuclear Center (RK NNC). Near Area O was the field's airstrip, with an unpaved runway, where cargo planes and helicopters were based.

In Area M on the banks of the Irtysh, the site's headquarters building was built (Figure 5), a two-story cottage for the site director, where Lavrenty Pavlovich Beriya and his security stayed when they visited the site, an Officers Club, hotel, and other support facilities for soldiers, officers, and their families and for the testers.

We should note that during the period of nuclear testing, both in the atmosphere and underground, the central area of the test site was always Area M, the city of Kurchatov, since it was the location of the site's management, research base, and residential and barracks complexes. The city's total area was 3200 hectares.

Near the Test Field, along its eastern vector, "Area N," with a good view of the Test Field structures, was equipped, so it was decided to build a blockhouse there, along with several facilities for the physics package developers.

Beginning in 1948, all matters relating to the site's preparation for nuclear weapons testing came under the scientific direction of Mikhail Aleksandrovich Sadovsky, Deputy Director of the USSR Academy of Science's Institute of Chemical Physics.

During the harsh winter of 1947-48, there were over 9000 military builders from the Capital Construction and Building Supervision Section

Figure 4. One of the buildings (the former Computing Center) on the grounds of the Experimental Research Unit of the Semipalatinsk Test Site ("Area O").

(OUS-310). The organization of construction and siting of numerous support bases and workshops was as follows:

- The main depot was located on the edge of Semipalatinsk, near Zhana-Semey Station, which received trains carrying equipment, assembled structures, materials, foodstuffs, etc. Ancillary shops for making reinforcement and formwork, carpentry products and cinder blocks were also built there, permitting recruitment of qualified workers from Semipalatinsk;
- The mechanical center, repair shops, motor pool, and construction management itself were located in the site's residential construction area (Area M);
- Systems for mixing concrete and mortar were installed in each area of the site;
- Plans called for using the navigable Irtysh River to transport large structures and heavy cargoes from central stores to Area M, where mooring and cargo handling facilities were installed;
- Major unpaved roads were kept passable year round in all weather, requiring considerable efforts on the part of the builders.

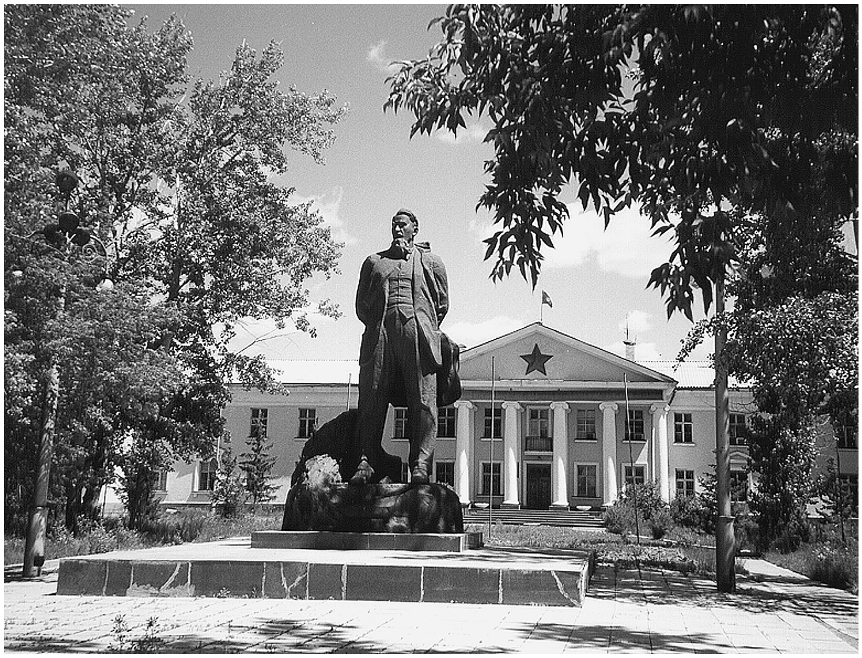


Figure 5. The headquarters of the Semipalatinsk Test Site
and the monument to Igor Vasilyevich Kurchatov.

The large volume of work involved in the construction of complex and diverse structures, and the lack of nearby manufacturing infrastructure and qualified workers, made the task of the site management and builders extremely difficult. The builders' working conditions were very hard, especially in the first winter (1947-48). Every task had to be accomplished literally from scratch. The endless barren steppes, open to hurricane-force winds and ferocious blizzards in winter and Santa Ana winds and dust storms in summer, the extreme shifts in weather and temperature, the shortage of drinking water, especially in the Test Field, where 50% of the builders worked, and the complete lack of paved roads, power lines, and communications near all site facilities all substantially slowed construction.

For nearly two years, officers and men were housed in tents and dugouts. In winter, the officers and men experienced cases of frostbite requiring amputation of fingers and toes. The builders worked two and three shifts in all areas. In a word, the living conditions differed little from those at the front: dugouts, monotonous campaign stew, kit and food certificates, separation from their families, and tight security. Each letter bore the stamp, "Approved by Military Censor." So construction of the test site, which cost some 183 million rubles in the hard pre-war prices, can be counted among the people's achievements.

To the great regret and sadness of all site workers, its first head, Pëtr Mikhaylovich Rozhanovich, passed away unexpectedly in early 1948. Command of the site (Military Unit 52605) passed to his assistant, Maj. General Sergey Georgiyevich Kolesnikov.

With the arrival of spring 1948, construction proceeded simultaneously in all areas of the site, and its intensity rose substantially. Construction of major structures in the Test Field, the site's main facility, was especially rapid.

The summer of 1949 was especially intense. In the Test Field, all structures were being completed, while installation of equipment and instruments was proceeding simultaneously. The command staff finished forming units and training personnel to operate the instrumentation. Additionally, they required operations specialists to monitor construction of various structures, and to participate in their preliminary acceptance from the builders and testing of technological systems, equipment, etc.

To determine the absolute readiness of test areas for the scheduled beginning of tests (August 1949), a commission headed by A. A. Osin, head of the Special Section of the General Staff, came to the site. The commission, together with the Capital Construction and Building Supervision Section (OUS-310), reviewed the volume of work to build the primary structures and set a firm startup minimum. Construction was cut back on barracks facilities and housing, the building of unpaved roads was limited, and other simplifications and restrictions were also imposed. Given the specific situation, these decisions were apparently justified. The startup minimum was approved by Marshal of Engineering Troops Mikhail Petrovich Vorobyëv, who was on site at the time. He established a firm schedule and order of commissioning of the structures. This applied primarily to the structures of the Test Field.

TEST FIELD FOR ATMOSPHERIC TESTING OF NUCLEAR WEAPONS

During the setup and conduct of the first nuclear tests, the "Test Field" referred to the parcel of land with all structures and equipment where the "special item" was to be detonated. Additionally, it also referred to one of the site's main staff units, which consisted of three research sectors:

- the Physical Measurements Sector, headed in early 1949 by Engineers Colonel Anatoly Valerianovich Yenko;
- the Biological Research Sector, headed by Professor Stepan Sergeyevich Zhikharev, a Colonel of Medical Service;
- the Weapons Sector, with temporary acting head Engineers Colonel Aleksandr Anatolyevich Molchanov.

Colonel Boris Mikhaylovich Malyutov had been appointed head of the Test Field back in 1948.

In early 1949, the main objectives of the research team working in the Test Field were to develop programs and methods for the planned research, and to deliver various types of weapons and animals to the test areas and install them. The animals were used to study the consequences of exposure to harmful effects of nuclear explosions on the living body.

As we have already noted, the Test Field was a relatively flat area. The nuclear item was to be placed in its center.

The majority of the various measuring instruments and optical equipment was placed in the instrumentation facilities, the so-called "geese," built along the northeasterly and southeasterly vectors of the Test Field (Figure 6). All the instrumentation structures were aimed at the center of the area, where the metal tower was located. The tower, some 30 meters high, with underground and elevator systems, was where assembly and checkout of the physics package took place.

Numerous sensors and indicators were installed outdoors on the ground and in the combat equipment, on fortifications, and on other structures, and also at the locations of experimental animals.

The instrumentation facilities, or "geese," came in three types, designated by the letters A, B, and V. The staff lovingly referred to them as *annushki*, *bukashki*, and *verochki* ("Annas, bugs, and Veras"). *Annushki* were specially hardened structures placed in the immediate vicinity of the epicenter, at distances of 500, 600, 800, and 1200 meters. Enclosures for installation of recording equipment (electromagnetic oscillographs, etc.), remote control devices, and batteries in *annushki* were 3-5 meters underground. The walls of the underground casemate had more than a meter of

Figure 6. Instrumentation facility ("goose") for physical observations with measuring equipment installed on top (in "cigar").

concrete and were lined with thick lead plating. A shielded entrance to the structure was made in the form of a vertical shaft or well, with a very simple hatch made of lead-lined steel. Above the underground casemate rose a ten-meter triangular frame of cast-in-situ concrete with an embedded steel tower topped by a cigar-shaped container 20 meters above the ground.

The idea to create these structures is interesting. Its essence is described in the memoirs of the former head of the Physical-Technical Sector of the Test Field, Vasily Vladimirovich Alekseyev.[3] When Alekseyev was being trained at the Institute of Chemical Physics in 1948 to work at the test site, an important source of information on nuclear testing was a book by the American professor Henry DeWolf Smyth, *Atomic Energy for Military Purposes*, published in translation in 1946 by the State Transportation Railroad Publishers (*Transzheldorizdat*).[4] This was an official report on the development of the atom bomb under the supervision of the US Government. At the same time, it was the only one that described the effects of a nuclear explosion. The book published a photograph of a brilliant nuclear explosion performed July 16, 1945 on a steel tower at a test site in New Mexico. The photo showed the bright area distorted along the contact with the ground surface.

Specialists Mikhail A. Sadovsky, G. L. Shirman, and others from the Institute of Chemical Physics conjectured, based on the photo, that a shock-wave front could be similarly distorted. To test the hypothesis, they decided to place instruments recording parameters of the atmospheric shock wave (arrival time, overpressure in the shock-wave front, wind speed) not only on the ground surface, but also at heights of 3 and 20 meters. This determined the special design of the instrument structures located along two perpendicular vectors at various distances from the center of Test Area P-1 at the Test Field. The phenomenon was actually observed, and called the "atmospheric shock-wave anomaly."

A description of the instrument structures in the Test Field would be incomplete without a brief description of their two types. *Bukashki* referred to structures of type 2PB, built at a distance of 1800 meters. They were intended to accommodate optical equipment and movie cameras, including high-speed cameras. The structures consisted of above-ground nearly square four-story towers with external metal ladders on their rear walls. The front walls of the three upper stories contained steel shields with large, thick glass windows. To protect the movie film from exposure by the nuclear explosion's γ-rays, the steel plates were backed with lead, and the movie cameras did not look directly out the windows, but at mirrors placed behind the windows. The tower was topped by the same tower and container as for *annushki*.

Verochki referred to type 2PV structures placed at distances of 3000 and 5000 meters. They were exact duplicates of *bukashki*, but lacked the complex shielding from penetrating radiation, since the effects of that factor were limited to distances of 2500-3000 meters.

On the ground some 10 km from the center of the Test Field, along both vectors, stood one-story reinforced concrete structures 11P-I and 11P-II. The front walls of these flat-roofed "boxes" had steel shielding with windows for movie photography. Beside each structure rose a 20-meter large-diameter steel pipe, topped once again by the same cigar-shaped container of measuring equipment. These structures also served as relay stations for remote control signals from the AF&F command post (structure 12P).

Note that Roman numerals I and II at the end of the official designation of each structure indicated the structure's location to the northeast (vector I) or southeast (vector II) of the epicenter, and Arabic numerals indicated its distance from the center of the Test Field in meters. There was also a short southwesterly vector III, but only a 2PB-1800-III structure stood there.

The command post consisted of a one-story cast-in-situ reinforced concrete building with a flat roof. It had three independent sections with fortified entrances. On the side facing the Test Field, the building was half-buried in earth. The flat roof with railings served as an observation platform. The building housed a transformer substation, physics package detonation batteries, electromagnetic oscillographs, a programmable device for starting the recording equipment and firing the physics package, a 100-line automatic telephone system, government RF communications equipment, offices for the test director and the representative of the Ministry of Internal Affairs, and other ancillary facilities.

Behind the command post, fenced off with barbed wire, was the technical area for the physics package developers (Area N). It was intended for storage, assembly, and preparation for testing of physics packages. Several special-purpose structures were erected in the area: a Federal Archive Service (*FAS*) building (for equipment setup and document storage); Building VIA (a lab for checking AF&F equipment), Buildings MAYa-1 and MAYa-2 (shops for storing separate physics package components and assemblies); Building Z2P (for temporary storage of assembled physics packages); a mechanical repair shop; and a water tower, boiler room, relaxation areas, cellars, etc. Electric power was delivered to Area N and the command post from a substation that drew it via an underground cable from a diesel generator in Area Sh.

Construction of facilities in the Test Field was not limited to preparation for the first nuclear test. We should note that the rate of nuclear testing began to accelerate, mainly due to the need to perform both above-ground and atmospheric tests of various intensities, creating a need for new test areas. We can identify two basic reasons for this need. First was the increase in the number of industrial prototypes developed for various purposes (airborne, missile, artillery, naval, etc.; see Figure 7). Second, the Test Field contained only one test area, P1. Moreover, the thermonuclear explosion of August 1953 created a huge crater in the center of that area and produced heavy radioactive contamination of the grounds, preventing further use of most of the instrument-ation structures built there.

Construction of new test areas for atmospheric nuclear explosions began. Above-ground tests, which naturally produced the heaviest environmental contamination, were carried out in Areas P1, P2, P3 (four tests each), and in Areas P5 and P7 (3 and 13 tests, respectively). In all, 31 above-ground nuclear tests were performed at the Semipalatinsk Test Site; available documents do not specify the location of three of the above-ground tests.

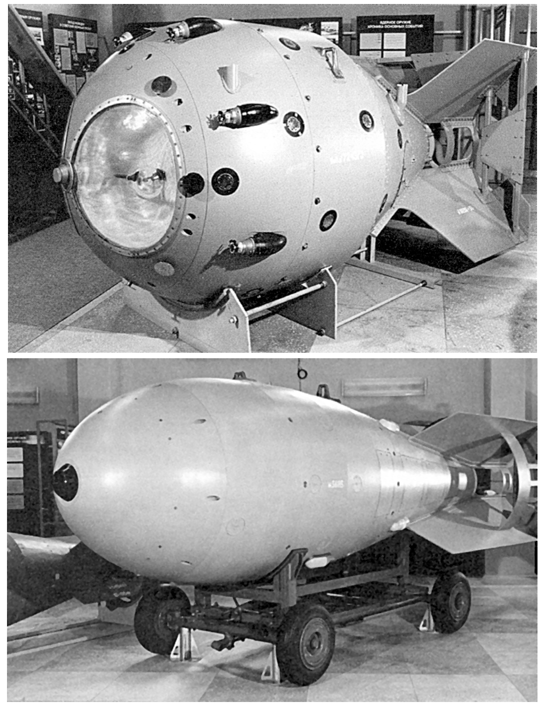


Figure 7. Different nuclear weapon models in the museum at the All-Russian Scientific Research Institute of Experimental Physics in Sarov.

Nearly all atmospheric tests were carried out in Areas P3 and P5, whose centers were designated by white crosses of chalk and white clay to ease visual targeting. Corner reflectors were set up at the very centers. New underground casemates were built for the instruments, and special mobile structures were built for the movie and still cameras.

Special tests were carried out in Areas P6 and P6A.

Military radioactive materials were tested in Area P4, near the northern outposts outside the limits of the Test Field. These tests were headed by V. P. Goncharov of Military Unit 51105,[9] with the active participation of I. F. Volodin, V. V. Kolosov, V. A. Logachev, K. F. Uspensky, and others.

So-called “model experiments” were performed under field conditions in Area P2G (P7).[10] These experiments, which are not classified as nuclear tests, could be of two types:

- hydrodynamic tests: explosive experiments involving physics packages during which no nuclear energy was released;
- hydronuclear tests: the same explosive experiments involving physics packages, but during which the quantity of nuclear energy released was comparable to the energy of chemical explosive charges.

The major test areas at the site can be precisely located using the coordinates of Area P5 (40°46'20" east longitude, 50°27'20" north latitude). The (x, y) coordinates of the other test areas relative to Area P5 are given in Table 1.

Table 1. Conventional Coordinates of Test Areas of the Test Field[10]

Coordinate	Quantitative Description of Coordinates of Areas Relative to P5, km						
	P5	P1	P2	P3	P6A	P7	N
X	0	4.2	4	–2.3	11.5	5.7	14
Y	0	–2.2	–9	–4.2	–8	–8.6	–1.6

As we have already noted, all atmospheric and above-ground nuclear tests were carried out in the Test Field. The last nuclear test there was performed on December 24, 1962: a 28-ton ground test, done in the interests of research on accident conditions that could arise in the use of nuclear weapons. The last model test in Area P2G of the Test Field was carried out on August 12, 1965. Later, all hydronuclear experiments were shifted to other areas. So the use of the Test Field for nuclear experiments was terminated.

We should note that from the very beginning of the Test Field's use, it was fenced off with barbed wire, remnants of which can be seen in the photo (Figure 8), and secured by personnel from four companies consolidated into a special security battalion. The perimeter had 12 outposts, near each of which was a permanent post. In daytime, security was provided from two observation towers outfitted with telephone lines and field telephones. At night, paired patrols went out in both directions from each outpost. These were required,

Figure 8. Remnants of the barbed-wire perimeter of the Test Field.

paying special attention to the barbed-wire fencing, to proceed as far as the boundary with the neighboring outpost and exchange tokens with patrols from that outpost. Company officers monitored the patrols' performance. The outposts were surrounded by perimeters with trenches dug to the height of a man. All officers and men lived in dugouts.[12, 13]

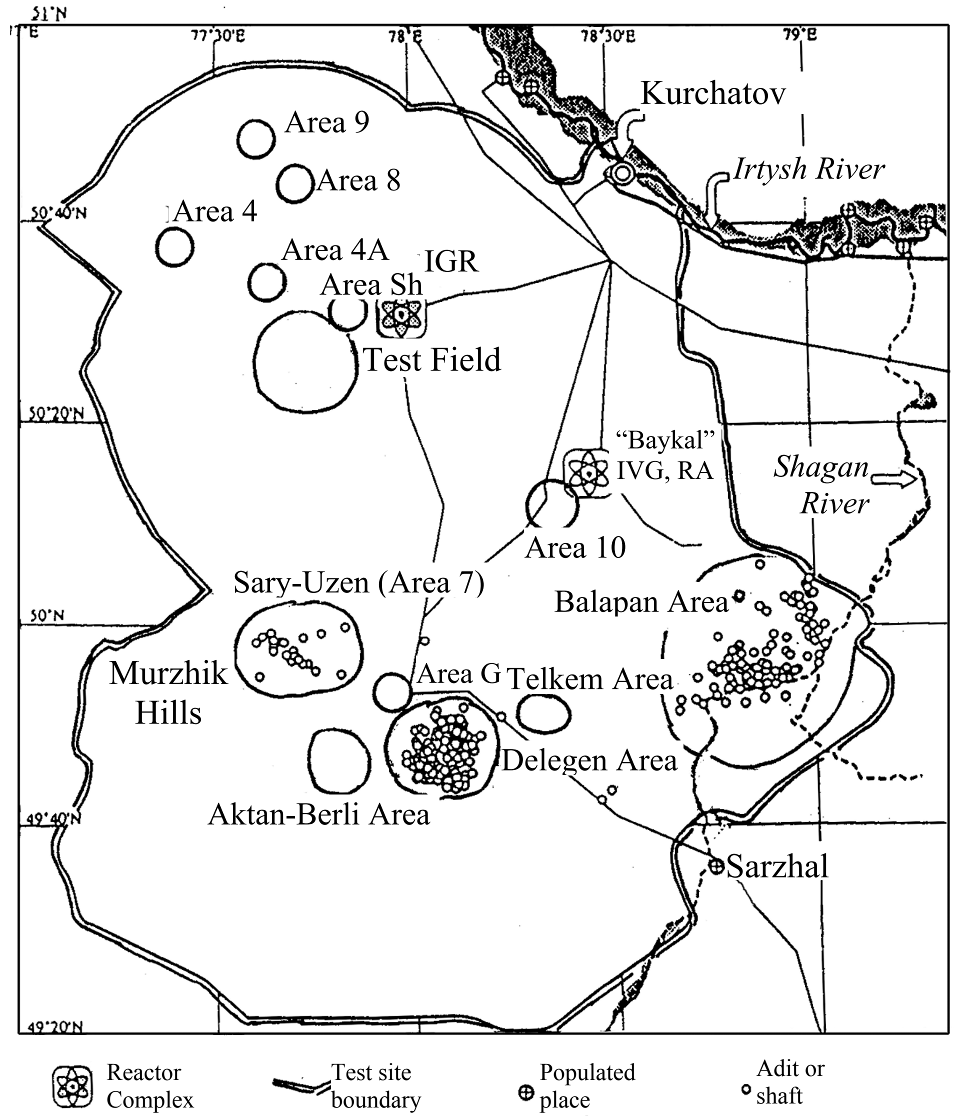


Figure 9. Map of the locations of test areas at the Semipalatinsk Test Site, designed for underground nuclear testing.

Test Areas for Underground Nuclear Explosions

Underground nuclear tests between October 11, 1961 and October 19, 1989 were performed mainly in three working areas at the site:

- Area G (Delegen). Its total area within the Delegen Massif was 33,100 hectares. This area was used for underground tests in adits or tunnels;
- Area B (Balapan), whose total area was approximately 100,000 ha. This area was used for underground tests in shafts;
- Area S (Sary-Uzen and Murzhik) was an auxiliary area for shaft tests.

The locations of these areas at the site are shown in Figure 9.

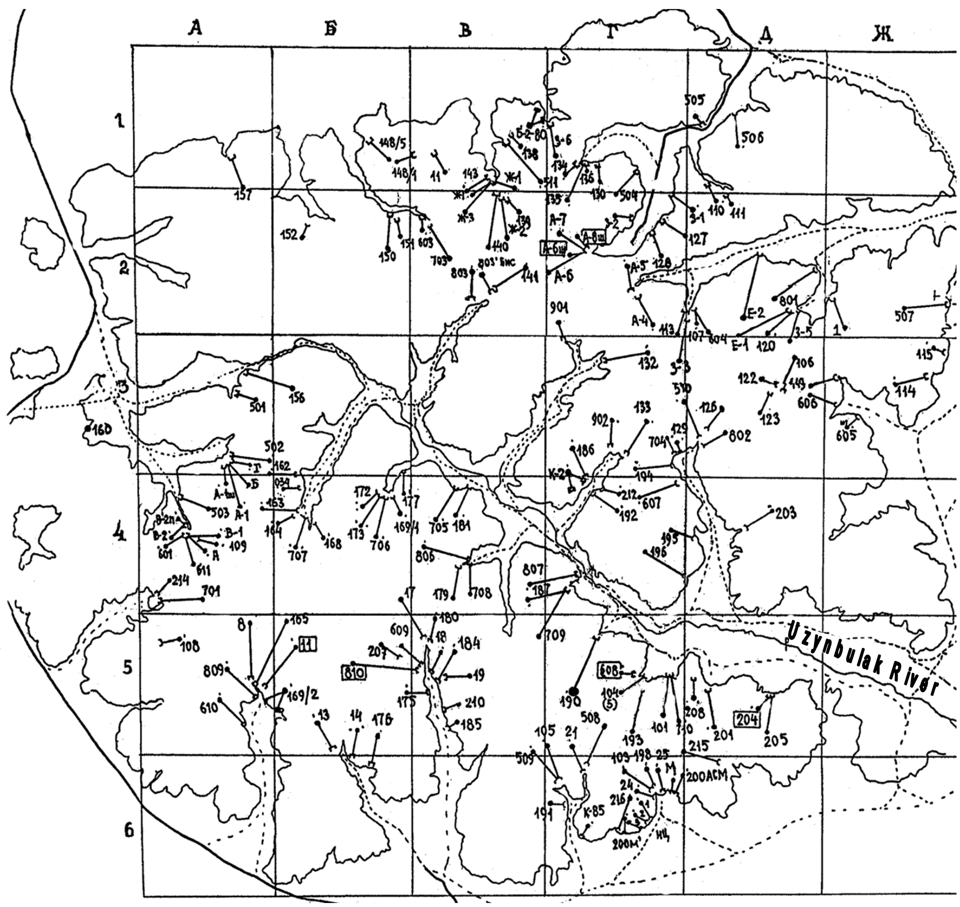


Figure 10. Map of the locations of adits in the Delegen Massif ("Area G").
Key: —(adit portal; ● explosion cavity.

The Delegen Massif was used for adit testing of relatively low-yield physics packages. The principal aim of these tests was to perform irradiation experiments to resolve materials-science issues, determine the radiation hardness of materials, study the interaction of radiation with matter, and verify the operability of various assemblies of special items. This massif, according to design institute workups, could support 180-200 adits. The adit locations are shown in Figure 10. The last test in Delegen Area was conducted October 4, 1989 in Adit 169/2.

The scientific and administrative center for underground nuclear testing in the adits of Delegen Massif was Area G, the site of the headquarters, technical units, hotels, barracks, etc. An exterior view is given in Figure 11. During the setup and conduct of each test, a State Commission worked in Area G.

The Delegen Massif is a dome-shaped uplift 17-18 km across. High points have various shapes, from sharp crests to domes and mesas. The slopes are dissected by numerous washes, often with seasonal streams at their bottoms. Geologically, the massif is a large granite batholith. Granitic rocks occur over 75-80% of the territory of Delegen Area.

Figure 11. Exterior view of Area G, with main service and production buildings.

Ground water occurs in the heavily weathered zone and partly in loose Quaternary sediments. The ground water throughout the area is fresh, and can serve as a local water supply source. The massif is cut by relatively narrow valleys with runoff in various directions. The valley of Uzynbulak Creek, which flows to the southeast, is the largest watershed. The Delegen mountains are the source of Karabulak Creek's surface waters, which discharge primarily to the north. Baytles and Takhtakushuk Creeks flow to the south.

Hydrologically speaking, the Delegen Massif is a zone of transition from atmospheric precipitation, which soaks through a system of connected fractures to produce fracture waters. Sublatitudinal and north-south faults maximize inflow of ground water into adits, which can be as much as 60 liters per minute.[14]

Balapan Area, which was located on the left bank of the Shagan River, was intended for nuclear explosions of up to 100-200 kilotons in shafts. Here, the developers could prepare a large number of vertical emplacement holes at an average spacing of one shaft per km^2. Over 100 shafts were used, with the last explosion being detonated October 19, 1989, before the site was closed.

Balapan Test Area, where shaft tests were performed, was located in the middle course of the Shagan River, occupying its valley, ancient gullies, and some of its hummocky areas. The terrain is a flat plain, with an overall gentle slope to the northeast. The prevailing surface elevations do not exceed 300-330 meters above sea level.

The rocks consist of beds of sandstone and mudstone, as well as clayey shales. Below are sandstones, mudstones, and coaly or coaly-clay shales with interbedded coal seams up to 2 meters thick.

The hydrology is characterized by a ubiquitous fracture water horizon in a weathering zone 50-100 meters thick. Below the weathering zone, ground waters occur only in areas of tectonic faulting. The depth of the water table is usually 5-15 meters.

During the entire period of test preparation and conduct in Balapan Area, 118 shafts (vertical mine workings) were drilled, 10 of which remained unused. The shafts were most closely packed in the eastern and southeastern parts of the area.

In 1965, a 140-kiloton underground nuclear test produced a ground excavation in this area, at the confluence of the Shagan and Ashchi-Su Rivers, forming an artificial reservoir that the locals call "Atom Lake."[12]

Near Balapan Area and the Baykal Reactor Complex, is the operational Kara-Zhira Coal Field. The shafts in which the nuclear tests were carried out are 1-3 km from the coal field, so they could not present any danger to the coal-bearing structures.

We should note that nuclear shaft tests have had some impact on the topography, usually producing strongly warped annular structures and other deformations of the Earth's crust. At the mouths of most shafts, subsidence craters 10-30 meters across and up to several meters deep have appeared. At the bottoms of the craters, ponds overgrown with rushes have formed. Changes can also be observed in the percolation characteristics of aquifers and the physical properties of the rocks.

Sary-Uzen Auxiliary Area in the Murzhik Hills, where 22 shafts were drilled, has the same geology as Balapan Area. The hydrology is also similar. Twenty-one underground nuclear tests were carried out in the shafts of Sary-Uzen Area.

Naturally, the above information on the main phases of construction at the test site does not fully reflect the enormous volume of construction work that was carried out in a short period of time under the severe conditions of the post-war period.[16-20]

CONTENT OF THE USSR'S MAJOR NUCLEAR PROGRAMS

The creation of the Semipalatinsk Test Site and the conduct of nuclear tests in its areas is an important page in the history of the entire Soviet people. At this test site, the USSR realized its main research programs to develop nuclear weapons and study their harmful effects, and developed and validated basic measures to ensure the safe conduct of tests of this type of weapon.

For the USSR, nuclear weapons were a military technological guarantee of the country's national security. Their power could practically rule out the possibility of foreign aggression both against the USSR and against its former allies.[1] It is also important that nuclear weapons were not aimed against any nation or group of nations in the modern world. However, in case of realistic threats, they could perform their functions of guaranteeing security against any enemy. To this end, the condition of nuclear weapons had to be maintained at a level of constant battle readiness and safety. This objective could be realized only at the country's test sites.

Between 1949 and 1990, the Soviet Union carried out 715 nuclear tests and nuclear explosions for industrial purposes. The entire period of nuclear testing at Semipalatinsk and Novaya Zemlya Test Sites in the former USSR can be divided into several phases:

- *Phase One* (August 29, 1949 to November 3, 1958) began with the testing of the first physics package and ended with the declaration of the first nuclear test moratorium;
- *Phase Two* (September 1, 1961 to December 25, 1962) began with the end of the moratorium due to worsening of military political conditions and ended with the cessation of atmospheric testing;
- *Phase Three* (March 15, 1964 to December 25, 1975) began with implementation of the USSR's nuclear testing program under the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water ("the Nuclear Test Ban Treaty") and ended with the cessation of underground nuclear explosions exceeding 150 kilotons when the 1974 Treaty on the Limitation of Underground Nuclear Weapon Tests (the "Threshold Test Ban Treaty," or "TTBT") went into effect;
- *Phase Four* (January 15, 1976 to July 25, 1985), detonation of underground nuclear explosions under 150 kilotons; ended with the Soviet Union's unilateral declaration of a nuclear test moratorium;
- *Phase Five* (February 26, 1986 to October 24, 1990, with a hiatus between October 19, 1989 and October 24, 1990) was characterized by test site operation under conditions of Mikhail S. Gorbachëv's policy of moving toward ending nuclear testing in the USSR.

Phases one and two can be consolidated as the period of "atmospheric (ground and atmospheric) nuclear testing," and phases three through five can be consolidated as the period of "underground nuclear testing."

In the Soviet Union, 1962 can be considered the year of peak intensity of atmospheric nuclear testing. During this year, the USSR carried out 79 tests, 41 of them at the Semipalatinsk Test Site with yields ranging from 0.001 kiloton to several tens of kilotons.

Nuclear tests at the Semipalatinsk and Novaya Zemlya Test Sites were considered a basic component of the USSR's nuclear weapons development technology. The technology itself for developing this type of weapons, whose chief component was and remains the physics package, consisted of the following elements:

- design of physics packages using various physical principles and the requester's tactical and technical requirements;
- development and fabrication of a prototype;
- laboratory studies (engineering) of the physics package using simulators;
- site tests of the prototype physics package;
- modification of the prototype, with possible retesting at the site;
- development and production of serial models;
- site tests of the serially produced physics packages (if necessary);
- special full-scale tests of the physics package to verify the nuclear, explosive, and fire safety of the warhead.

This list shows how important the test site's tests were in the development of physics packages for various types and branches of the USSR Armed Forces.

Additionally, the development of certain models of physics packages required special tests, as well as studies relating to the modeling of situations that could potentially make them susceptible to damage by countermeasure systems such as antimissile defenses.

At the first phase of implementation of the USSR's nuclear program, the main objectives of tests at the site were to improve the weight and dimensional parameters of the nuclear warheads, make more efficient use of fissile materials, and improve the stability of various parameters (yield, etc.). Work was carried on to improve the mechanism of the transfer of explosive energy from chemical explosives to the fissile mass and to improve the system of fusing and neutron initiation of the chain reaction in the physics package, and methods of improving the efficiency of nuclear explosives were also studied. The developers worked to improve the quality of fissile materials and neutron reflectors.

During the nuclear testing period at the site, the developers considered it very important to obtain results from certifying the parameters of new warheads, and also to accumulate data necessary for the development of an efficient physics package design system.

THE PHYSICS PACKAGE DESIGN AND DEVELOPMENT SYSTEM

The physics package design phase, which is the first in the series of jobs that must be completed to develop new types of physics packages or upgrade existing ones, is inextricably linked to the conduct of nuclear tests. This link is characterized by the results obtained in the development and testing of various types of physics packages. The beginning of this work was the development of systems for physical and mathematical modeling of the processes occurring in the physics package.

A nuclear explosion is not a single event, but a sequence of several processes that occur over time periods of various lengths in spaces of various sizes. In physics packages that form the bases of nuclear warheads, both fissile isotopes with heavy nuclei and isotopes with light nuclei capable of fusion to form heavier isotopes can be used to create explosive effects. The heavy isotopes of hydrogen, deuterium, and tritium are such isotopes. Thermonuclear reactions are accompanied by an energy release three to four times greater than the fissile reactions of ^{235}U or ^{239}Pu per unit of mass, but they require very high temperatures, that is, the reacting hydrogen isotope nuclei must be raised to energies of several hundred electron volts. In nuclear physics packages, the energy is provided by an explosion of fissile materials. Thus, the explosive process in any nuclear physics package begins with a conversion of fissile material to a supercritical state, that is, a state in which an uncontrolled explosive fission reaction begins in the primary of the nuclear physics package. Then conditions must be created for thermonuclear reactions in the secondary of the physics package with a minimal amount of expensive fissile materials in the primary.[21]

Historically, nuclear weapon systems, in those countries that possessed them, have been based on plutonium as the main fissile material used in primary modules of combination physics packages or compact low-yield warheads. The use of plutonium, which has good neutron-breeding properties, permitted considerable reduction in the size and weight of physics packages and adaptation of the physics packages to the operating conditions of the various types and branches of the USSR Armed Forces. At the same time, it created the problem of the radiation explosion hazard of nuclear weapons and possible environmental contamination with biologically hazardous plutonium due to accidents.

During the conduct of site tests, developers determined parameters of the efficiency of compression of the plutonium "pit," and also estimated the degree of influence of changes made to the system of various physics packages on those parameters. Site tests, as well as hydrodynamic and hydronuclear experiments, along with neutron-physics tests performed on critical assemblies, helped to form a complete picture of the behavior of units with plutonium under various explosive loading conditions that could arise during the firing of various nuclear warhead modules.

In his book, the noted nuclear weapons tester I. F. Turchin writes: "Weapons developers understood that the test of truth in any theory is experimentation. Only site tests could finally answer the question whether an idea had been realized and a weapon created…."[22]

The main point in physics package development technology was the degree of reliability and universality of the mathematical-physics modeling system. The quality of models, as we know, is determined by two things: by the level of development of the physical models themselves and the capabilities of the computers, and by the results of necessary verification of data obtained using those models, taking into account the specific situations that may arise during nuclear tests. So the results of site tests of each particular physics package embodying any specific physical idea were always very important, even independently of whether the test was successful or unsuccessful. Every test was a contribution to the overall technology of nuclear physics package design, although the size and importance of the contribution might vary. The capabilities of the physics package design system, according to specialists, depend on the particular nature of the problems to be solved.[23, 24] Naturally, as experimental data are accumulated and mathematical models are improved, the design system can replace nuclear tests for many, but not all, questions. The existence of an elaborate design system determines today's capabilities for maintaining the existing nuclear arsenal at the level of present requirements, as well as the advisability of developing new types of physics packages under the conditions of the existing nuclear testing moratorium.

Of course, for the initial phase of the evolution of nuclear weapons, experiments were justified. At the same time, specialists have no doubt that at present, the physics package design and development system is adequate for the development of similar physics packages without nuclear site tests.

THE STATE SYSTEM FOR ORGANIZATION OF NUCLEAR TESTING

During the period of atmospheric testing, the nuclear scientists, as well as specialists in the country's research, design, and production teams, made every effort and drew upon all their knowledge to keep from falling behind the enemy in nuclear warhead improvement. During this period, they created the infrastructure of the state nuclear testing system diagrammed in Figure 12.

It is difficult to overestimate the importance of the Semipalatinsk Test Site in the history of nuclear weapons development and improvement in the former USSR. This test site had to provide the organization, setup, and conduct of experimental and serially manufactured nuclear warheads, as well as experimental nuclear devices. The employees of the test site and the entities that participated in the testing performed a huge job in the collection, processing, analysis, and interpretation of the test results.

The principal aims of nuclear tests at the site were:

- to verify the operability and basic characteristics of physics package types to be used in armaments;
- to perform full scale testing of various intermediate nuclear devices;
- to verify the stability of the physics packages' basic parameters after certain storage periods;
- to perform physical irradiation tests on military weapons and materiel for radiation hardness;
- to study the harmful effects of nuclear explosions;
- to investigate the results of exposure to the harmful effects of nuclear explosions on various military equipment and materiel models, and on various facilities and structures.

During preparation for testing of each nuclear physics package, objectives were identified, a work program was developed, necessary structures were designed and built in the work area of the test site, and recording and measuring equipment was installed and checked out. After the explosion, the test results were analyzed, interpreted, and studied, the resulting data formed the basis for required reports and other documents.

The operation of the Semipalatinsk Test Site followed a longer-term plan during the underground nuclear testing period than during the atmospheric test period. This was because a large amount of extremely laborious work to construct adits with end boxes in rock or sink large-diameter shafts into the ground had to be performed before each test.

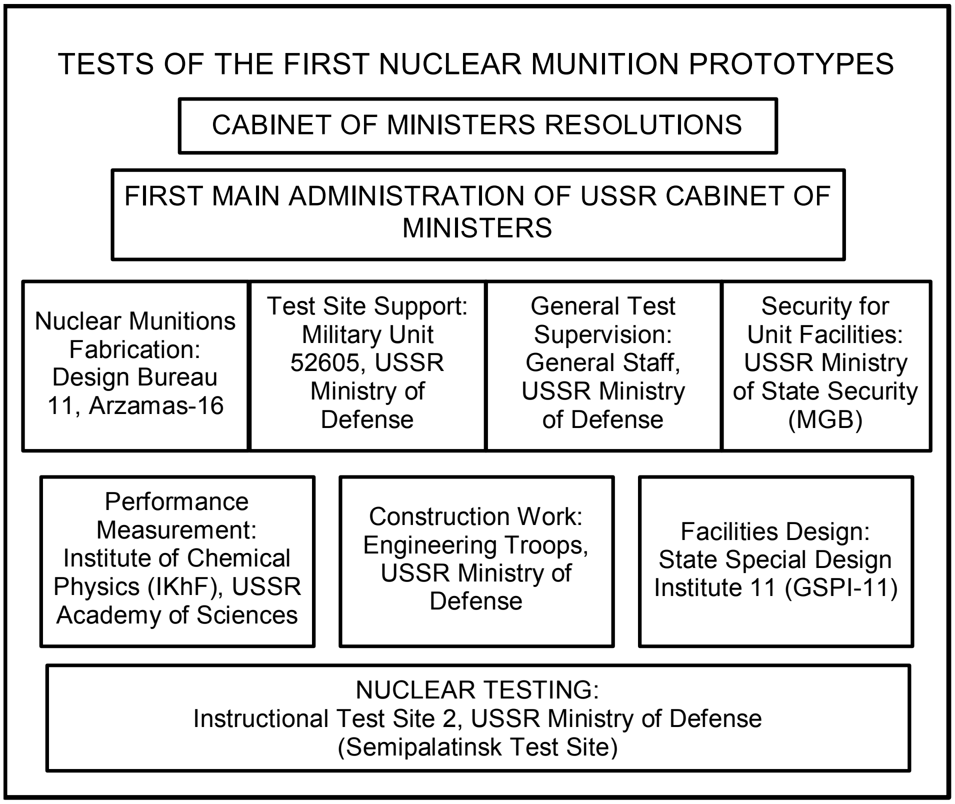


Figure 12. Formation of the infrastructure of the state nuclear testing system (from the first bomb test to establishment of the USSR Ministry of Medium Machine-Building, 1947-1953).

Before each test, the necessary guidelines had to be developed, specifically:

- a USSR Government Resolution and a USSR Minister of Defense Order defining the annual volume of testing and capital investment allocated for it;
- a test schedule for the current year;
- general and specific test programs for the current year;
- engineering design documentation for making and equipping the emplacement holes, for the equipment of the areas around the openings and the external structures, and for providing electric power and communications;

- a list of measures to ensure the seismic and radiation safety of personnel and the public during tests;
- the finding of an expert commission on the safety of the test;
- an official acceptance of the facility by the State Commission;
- a list of supervisors and officials (commission members), including the responsible representative of the USSR Ministry of Health, who bore the full measure of responsibility for the safety of test participants and the public in areas adjacent to the test site;
- an operational plan for the actual setup and conduct of the test.

For setup and conduct of underground nuclear tests, a uniform two-year planning procedure was established, requiring preparation and approval of a plan and annual defense of that plan in two phases. The first phase ended when the USSR Ministry of Medium Machine-Building (now the Russian Ministry of Atomic Energy) and the USSR Ministry of Defense prepared a final schedule of tests for the first planned year. Most of the work in the second phase consisted of pinning down the specific types of physics packages to be tested and the test dates during the first planned year, and reviewing the scientific and technical research program in the tests of the second planned year.

All work in the setup and conduct of nuclear weapon tests at the Semipalatinsk Test Site proceeded under the auspices of the USSR Ministry of Defense and the USSR Ministry of Medium Machine-Building, with the participation of various entities and departments as identified in special resolutions of the USSR Council of Ministers. The setup and conduct of a particular nuclear test was supervised by test site officials and a State Commission specially created for each test, which had to include a representative of the USSR Ministry of Health, who monitored decisions on all matters relating to the assurance of safety for personnel and the public.

Special services of the test site ensured test safety, which in turn helped the Soviet Union perform obligations contained in current international agreements.

It is especially noteworthy that all work related to nuclear testing was performed in strict compliance with applicable provisions for secrecy, which should have completely prevented any leakage of information obtained through testing or from the processing and analysis of the test results. The secrecy of all construction and equipping of the test site, nuclear weapon development, and reports containing the test results was protected by the USSR Ministry of Internal Affairs (*MVD*). The MVD appointed officers for all Test Field facilities where work involving physics packages and components thereof was conducted. During the first five years of nuclear testing at the site (1949-1953), all reports were written by hand on paper, every sheet of which was accounted for, and knowledge of their contents was highly restricted. Secrecy was imposed on the results of exposure to harmful effects of nuclear explosions with various yields or the physical characteristics of nuclear physics packages, the degree of radioactive contamination of environmental systems and the terrain outside the grounds of the test site, possible outdoor and indoor public exposure doses, and the effect of radiation and other factors, such as seismic ones, on the health of residents of areas adjacent to the test site. All this promoted a negative attitude on the part of local residents to the activities at the test site, especially in its later years, and distrust of the truthfulness of information published. Reports on the scale and extent of radioactive contamination in areas affected by nuclear testing did not become available to the general public until the early 1990s during the Semipalatinsk Test Site–Altai Research Program.[5-8, etc.]

Much attention was paid to strict compliance with various instructions, requirements, and regulations. For example, the construction and equipment of facilities needed for testing had to comply strictly with the design documentation. All work to prepare physics packages and other special items for tests, as well as all operations during those tests, had to be carried out in full compliance with the provisions contained in instructions, regulations, and other documents approved by officials in charge.

The test site's current statute and the official duties of its administration defined the objectives to be accomplished at the Semipalatinsk Test Site:[12]

- direct supervision of the setup and conduct of tests of nuclear physics packages and nuclear warheads;
- participation in the development of testing programs for nuclear warheads in the arsenal, as well as tests intended to study the battle properties of nuclear weapons and their harmful effects on military personnel, equipment and materiel;
- monitoring of the results of tests of nuclear warheads developed for the USSR Ministry of Defense;

- performance of scientific research independently and jointly with other entities to study the harmful factors and battle properties of nuclear weapons;
- storage of the primary results of experimental research (flash reports, summary reports, photographs, oscillograms, etc.) obtained by specialists from all entities involved in work at the test site;
- provision of personnel, equipment, and various materials for testing and scientific research in the volumes specified by testing and research programs coordinated with the site administration;
- performance of necessary measures to ensure the safety of test participants and the public, accounting for applicable health regulations and orders of the USSR Ministry of Health;
- aviation and weather support for testing;
- provision of electric power, communications, water, transportation, food, housing, and production facilities, as well as protective and radiation monitoring devices, to testing facilities and test participants;
- receiving and temporary storage of weapons, materiel, and equipment for testing, and delivery of same to test areas;
- maintenance of the secrecy and confidentiality of work performed at the test site.

All test participants, who numbered over a thousand at the Semipalatinsk Test Site over its operating life, noted that the site administration, despite difficulties created by outside factors, basically performed its assigned duties successfully. Numerous reports and publications confirm this.[22-24,26 29, etc.]

G. V. Voronin [30] lists the military units deployed at the Semipalatinsk Test Site. Their personnel participated in atmospheric and underground nuclear weapon tests from 1949 to 1989. The list contains the numbers of 57 military units placed under the command of the Semipalatinsk Test Site director.

We must note that the site director was burdened with various duties. He supervised all work relating to the logistical support of nuclear tests, the safe conduct of those tests, and the preparation and implementation of cleanup activities in the event of unfavorable situations after nuclear explosions. A list of the directors of the Semipalatinsk Test Site over its entire operating life from 1947 through 1992 is as follows:

Lt. General Pëtr M. Rozhanovich
Maj. General Sergey G. Kolesnikov
Lt. General Anatoly V. Yenko
Maj. General I. N. Gureyev
Maj. General N. N. Vinogradov
Maj. General A. T. Smirnov
Maj. General M. K. Kantiyev
Maj. General V. I. Stupin
Lt. General A. D. Ilyenko
Maj. General Yu. V. Konovalenko

The site director usually was not a member of the State Commission that actually set up and conducted the nuclear tests.

The State Commission was responsible for resolving scientific and technical issues and for the results, while the site director was responsible for all forms of support for the work.

During setup for an explosion, the State Commission met to hear from the supervisors of testing and research teams, as well as the heads of various services at the test site. The heads of services at the site were not formally subordinate to the State Commission, but since the deputy site director was required to be a member, they had to provide any required reports to it.

It is important to note that the site director was required to notify the first secretaries of the Semipalatinsk and Pavlodar Regional Party Committees and the heads of Regional Executive Committees of each test. These individuals, together with the responsible parties (officers) of the test site, the so-called "representatives of the military command," decided all questions related to public safety in areas adjacent to the site. The former First Secretary of the Semipalatinsk Regional Committee of the CPSU, Keshrim Boztayevich Boztayev, provides objective information about this in his book.[17]

Usually the chairman of the State Commission, who was also the test director, was a top-flight specialist in nuclear science from the management of the USSR Ministry of Medium Machine-Building or the USSR Ministry of Defense. As a rule, these were the chief designer, research director, or one of their deputies from industry, or the deputy site director for research and testing from the USSR Ministry of Defense. The most frequently named test directors were Yevgeny Nikolayevich Avrorin,

A. I. Veretennikov, F. M. Gudin, A. V. Devyatkin, V. P. Zharkov, Boris Vasilyevich Litvinov, Yevgeny Arkadyevich Negin, V. Z. Nechay, Yu. A. Romanov, Yury Aleksandrovich Trutnev, I. F. Turchin, Georgy Aleksandrovich Tsyrkov, and others from the USSR Ministry of Medium Machine-Building, and B. A. Kryzhov, A. V. Malunov, F. F. Safonov, M. L. Shmakov, and others from the USSR Ministry of Defense.[1]

We should note that the tasks performed by members of the State Commission during the setup and conduct of each test varied, but the task of ensuring general and radiation safety of test participants and the public always remained paramount.[9, 33]

NUCLEAR TESTING AND ASPECTS OF SUBSEQUENT RADIATION LEVELS

The results of a study of the consequences of nuclear weapon testing at the Semipalatinsk Test Site are important both for military science and sociopolitically. Nuclear testing at the site realized all major programs for the development and testing of various types of nuclear weapons, as well as programs to study the harmful effects of these weapons and methods of protecting against them. Of the 32 ground nuclear explosions conducted by the Soviet Union at the test site, 30 produced local radioactive plumes on the ground with relatively high levels of contamination of environmental systems by biologically hazardous radionuclides and with public exposure doses exceeding allowable levels! This caused Republic of Kazakhstan President Nursultan Abishevich Nazarbayev to appeal to the world community for assistance in cleaning up the damage done by the site's activity to the public and environment of Kazakhstan. At the 19th session of the UN General Assembly, he said, "Kazakhstan proposes to materialize the nuclear powers' responsibility in the form of an international fund to restore the health of people and nature in areas that have suffered the consequences of nuclear testing…."[34]

It cannot be denied that nuclear weapon testing at the Semipalatinsk Test Site caused radioactive contamination both on and off the site. However, the scale and levels of this contamination varied, and as the data that follow show, depended greatly on the nuclear explosion's type and yield.

A study of radiation levels after nuclear tests at the site found that of all the types of explosions (ground, atmospheric, underground), ground nuclear explosions produced the heaviest radioactive contamination of the outdoor environment, both on the test site grounds and off site.[35] Data on the number of nuclear tests and their TNT equivalents, as well as the quantities of biologically hazardous radionuclides released into the atmosphere, are summarized in Table 2.

Table 2. Basic Characteristics of Nuclear Tests Conducted from 1949 to 1989 at the Semipalatinsk Test Site

Type of Test	Number of Tests (Explosions)	TNT Equivalent, Megatons	Quantity of Radionuclides Released into the Atmosphere during Testing, MCi		
			^{137}Cs	^{90}Sr	^{239,240}Pu
Ground	30 (30)	0.6	0.056	0.035	0.006
Air	86 (86)	6.0	0.200	0.120	0.020
Underground	340 (500)	11.1	~ 0.020	~ 0.010	~ 0
• adit	212 (307)				
• shaft	128 (193)				
Total	456 (616)	17.7	~ 0.28	~ 0.17	~ 0.026

Notes:

1. For underground explosions, the number of tests does not equal the number of nuclear physics packages detonated, since several (as many as five) physics packages were frequently detonated simultaneously in one test.
2. The total number of underground nuclear tests includes seven tests (nine explosions) for commercial purposes to resolve technological problems of the industrial physics packages themselves with minimum energy release from fission (under 5%).

Analysis of the patterns of radioactive contamination of the outdoor environment after various types of nuclear explosions shows that the distribution of radioactive substances in various media differs considerably after atmospheric and ground explosions. After ground nuclear explosions, most of the radioactive substances fall out near the explosion crater and in a nearby (local) plume, producing heavy radioactive contamination of the outdoor environment and significant ground radiation doses. Ground radioactive contamination after atmospheric and especially after high atmospheric high-yield explosions is mainly associated with the semiglobal and global fallout of radioactive substances over practically the entire northern hemisphere.

Table 3 presents parameters of ground nuclear explosions conducted at the Semipalatinsk Test Site that made major contributions to the radiation levels in areas adjacent to the test site.

Table 3. Chronology and Parameters of Ground Nuclear Explosions at the Semipalatinsk Test Site[6, 19]

No.	Date	Energy Released (TNT Equiv.), kilotons	Height of Explosion, meters	Biologically Significant Radionuclides Released into the Atmosphere, Ci		
				^{90}Sr	^{137}Cs	$^{239,240}Pu$
1	8/29/49	22	30	1,500	4,200	360
2	9/24/51	38	30	2,700	7,500	300
3	8/12/53	400	30	22,000	29,000	280
4	10/5/54	4	0	300	840	105
5	10/19/54	0	15	0	0	215
6	10/30/54	10	50	750	2,100	100
7	7/29/55	1.3	2.5	120	300	245
8	8/2/55	11.5	2.5	1,050	1,800	200
9	8/5/55	1.2	1.5	105	180	215
10	9/21/55	1.2	1.5	105	180	215
11	3/16/56	13.2	0.4	1,600	2,500	240
12	3/25/56	5.5	1	360	600	190
13	8/24/56	26.5	100	2,200	3,800	90
14	9/9/61	0.4	0	42	70	225
15	9/14/61	0.4	0	42	70	250
16	9/18/61	0.004	1	—	—	250
17	9/19/61	0.003	0	—	—	250
18	11/3/61	0	0	—	—	230
19	11/4/61	0.15	0	11	19	195
20	8/7/62	10	0	930	1,600	200
21	9/22/62	0.2	0	17	29	280
22	9/25/62	7	0	650	1,100	205
23	11/5/62	0.4	15	40	70	190
24	11/11/62	0.1	8	8	13	210
25	11/13/62	0	0	—	—	210
26	11/24/62	0	0	—	—	140

No.	Date	Energy Released (TNT Equiv.), kilotons	Height of Explosion, meters	Biologically Significant Radionuclides Released into the Atmosphere, Ci		
				^{90}Sr	^{137}Cs	$^{239,240}Pu$
27	11/26/62	0.03	0	—	—	210
28	12/23/62	0	0	—	—	210
29	12/24/62	0.007	0	—	—	250
30	12/24/62	0.03	0	—	—	295

Note : 1 Ci = 3.7×10^{10} Bq (becquerels).

The nuclear explosions that caused the heaviest contamination of the outdoor environment and the highest public radiation doses include the four ground nuclear explosions conducted August 29, 1949, September 24, 1951, August 12, 1953, and August 24, 1956. These were the principal exposure-producing explosions. The rest either had very low yields or were carried out in weather conditions such that the radioactive plumes were confined almost exclusively to the test site's exclusion zone.

After each nuclear weapon test or series of nuclear weapons tests, specialists from the test site's Radiation Safety Service measured ground γ dose rates using aerial and ground radiation survey equipment, studied the level of contamination of environmental systems and locally grown foodstuffs, and assessed the extent of the effect of radiation factors on the health of test participants and the local populace.[36-39]

Specialists from the test site's Radiation Safety Service, the Institute of Biophysics, the USSR Ministry of Health's Third Main Directorate, the Institute of Applied Geophysics of the USSR State Committee for Hydrology, Meteorology, and Environmental Monitoring (*Goskomgidromet*), etc. jointly interpreted the data obtained in the course of radiation surveys and developed methods of predicting radiation levels in the near and far zones of nuclear explosion plumes and methods of calculating outdoor and indoor exposure doses in the general public.[40]

In 1959, associates from the USSR Ministry of Health's Institute of Biophysics and agencies under other departments combined all the documents available at the time containing the results of radiation surveys and compiled the first album of the radioactive contamination plumes on lands adjacent to the Semipalatinsk Test Site.[36] By then, the test site had carried out 12 ground and 37 atmospheric nuclear explosions. From November 4, 1958 to August 1, 1961, no nuclear tests were conducted due to a declared moratorium.

In 1960, 1961, and 1963, the test site conducted 38 ground

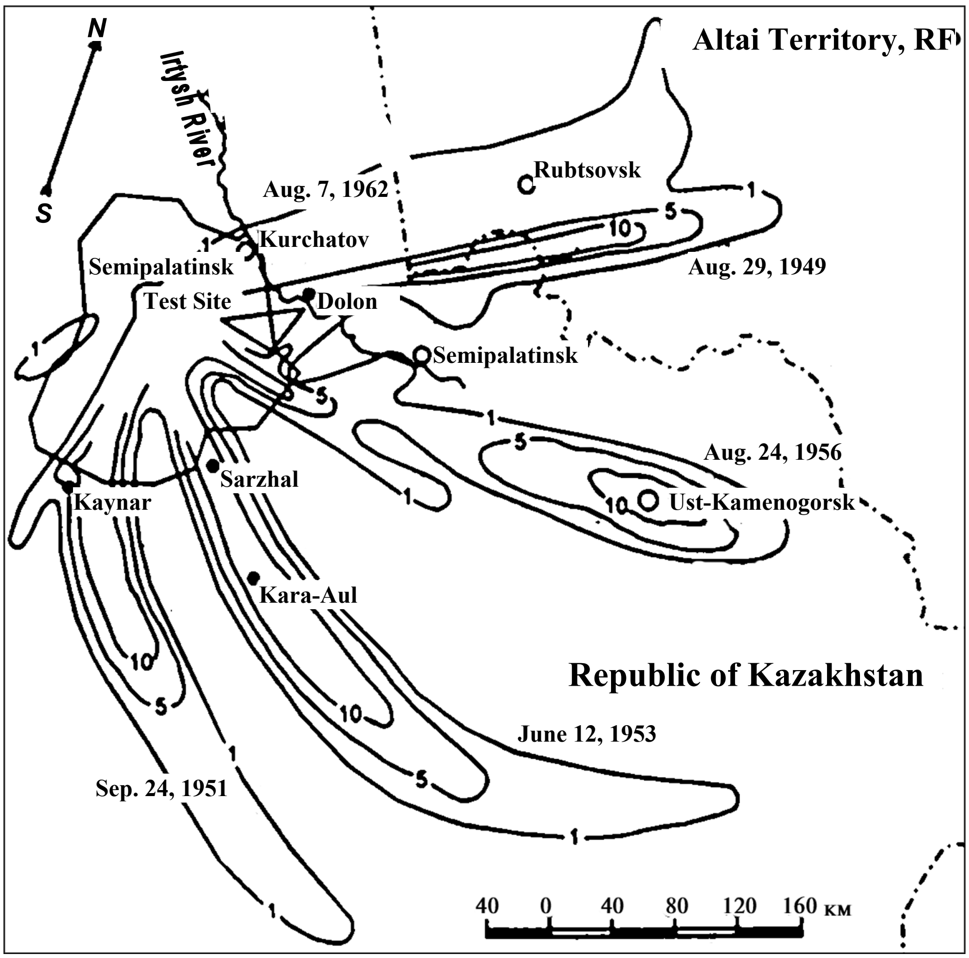


Figure 13. Positions of the principal dose-forming plumes of ground nuclear explosions carried out at the Semipalatinsk Test Site, showing γ-ray doses on the ground before total decay of radioactive substances.

hydronuclear experiments, which differed from one another in the quantity of α activity released into the atmosphere and the height attained by the top of the explosion cloud. In certain experiments, the difference in the amount of α activity released was as much as 400 times, and the height reached by the clouds ranged from 250 meters (the experiment of October 1, 1963) to 1280 meters (July 1, 1961). The total α activity of plutonium dispersed during the hydronuclear experiments was some 800-900 curies, which could have produced radioactive contamination of the region around the test area.[11, 12]

When testing was resumed, the radiation surveys and study of the levels of radioactive contamination of environmental systems was continued, providing new information to clarify the locations of major radioactive contamination plumes.[43, 44] Figure 13 shows the locations of major radioactive contamination plumes within which the outdoor exposure dose before decay of radioactive substances exceeded 1 roentgen (about 10 mGy). It is clear from the figure that the plumes hardly overlap at all, so there is no need to add radiation doses. When plumes from several nuclear explosions at different times overlap, the doses can be added. For example, 15 clouds produced by atmospheric nuclear explosions and underground excavating explosions passed over Kurchatov from 1953 to late 1965.[45] After one of them, detonated August 7, 1962, the ground radiation dose was 38 mGy, while the others together totaled only 7 mGy. The exposure of Kurchatov residents after the explosion of August 7, 1962 can be considered accidental, since a ground explosion occurred instead of the planned atmospheric test. However, the total exposure dose of the city's residents did not exceed 50 mGy, which is the allowable limit in view of the data presented by V. M. Loborev *et al*.[45]

It is especially noteworthy that the results of analysis of archival documents containing radiation survey data, together with information on environmental radioactive contamination obtained by specialists on radiological teams in laboratories of public health stations of the USSR Ministry of Health and the network of the USSR State Committee for Hydrology, Meteorology, and Environmental Monitoring (*Goskomgidromet*), formed the basis for reconstruction of the location of radioactive plumes of nuclear explosions, the creation of an objective database on radiation levels, and retrospective assessment of public exposure doses.

Aspects of the Organization of the First Nuclear Test

A very important event, for the test site as well as for the entire nation, and even for the world community, was the first nuclear test, conducted in August 1949.

For the first nuclear weapon test at the Semipalatinsk Test Site, a metal tower 37.5 meters high, designed to hold the nuclear physics package, was built at the center of Area P1 of the Test Field. Figure 14 shows the tower and assembly complex built for the first nuclear test.

The entire circular space around the tower was divided into sectors, in which various test objects were to be installed and test animals were to be placed on the ground surface and in shelters.

In Sector 1, at distances of 250, 500, 750, 1000 and 1250 meters from the tower, trenches were dug with various linings, trench shelters, light shelters, wire fencing, and antipersonnel and antitank mines.

In Sector 2, at distances of 250, 500, and 750 meters from the center of the Test Field, NPS-3 spotting and machine-gun pillboxes and heavy wood and earth shelters were built, and at distances of 250 and 500

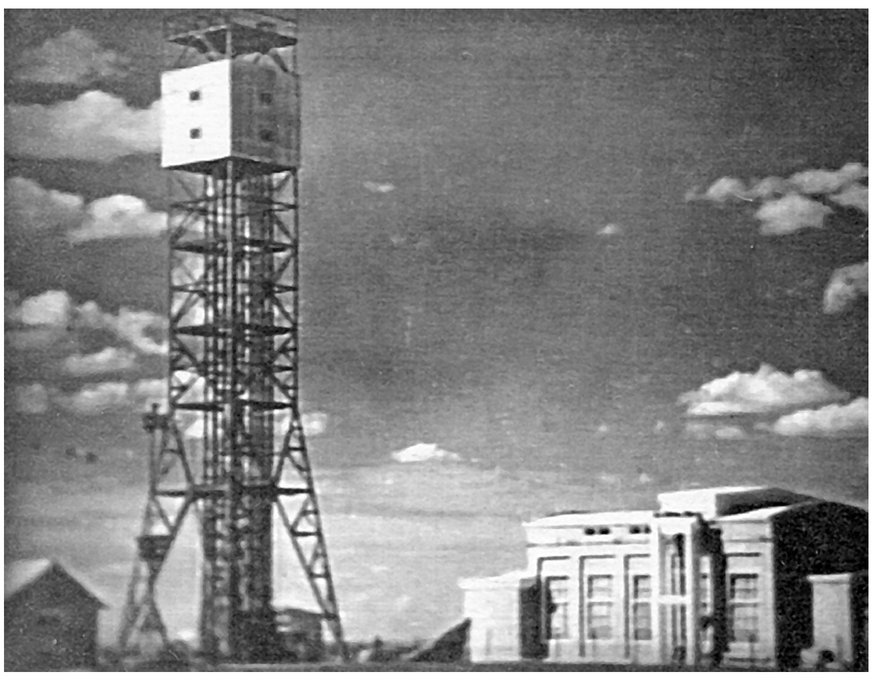


Figure 14. The tower and assembly complex at the Test Field for the first nuclear test.

meters, reinforced concrete gun casemates were built. In addition, in Sector 2, to test the protective properties of various building materials, stands were installed containing specimens of these materials: metal plates 1 to 5 cm thick, reinforced concrete slabs 20-50 cm thick, barite concrete slabs 30 cm thick, samples of combination pavements of wax and metal and of earth and reinforced concrete. Behind the samples of various building materials, hard chambers for sheep were installed. The entrances to the chambers were closed with shields and blocked with sandbags; ventilation was from regenerative units employed in submarines. The degree of penetrating radiation injury to the animals penned in the chambers allowed the designers to judge the protective qualities of the building materials.

Sector 7 was designed for biological research. Here, various species of animals were grouped into "biopoints" outdoors on the ground. They were placed at various distances from ground zero, providing unique information after each test on the extent and consequences of exposure to various harmful effects of the nuclear explosion on the living organism, from death on the spot to complete absence of any harmful effect, depending on the distance. We should note that in the early tests, the animals were placed more than irrationally: every 250 meters. This was because in those years, the researchers had no objective data on the extent of each of the harmful effects of the explosions on biological systems.[1]

Sector 10 was designed for testing various types of warplanes, from interceptors to heavy bombers. The planes were set up at distances of 500 to 2500 meters from ground zero.

In Sectors 8 and 12, the testers constructed industrial and civilian facilities for hardness testing. They placed two three-story brick apartment buildings with basements 800 and 1200 meters from the center of the Test Field, two single-story frame houses at 1000 and 1500 meters, and a fragment of an industrial shop at 1500 meters.

Figure 15 diagrams the locations of various structures in Area P1 of the Test Field.

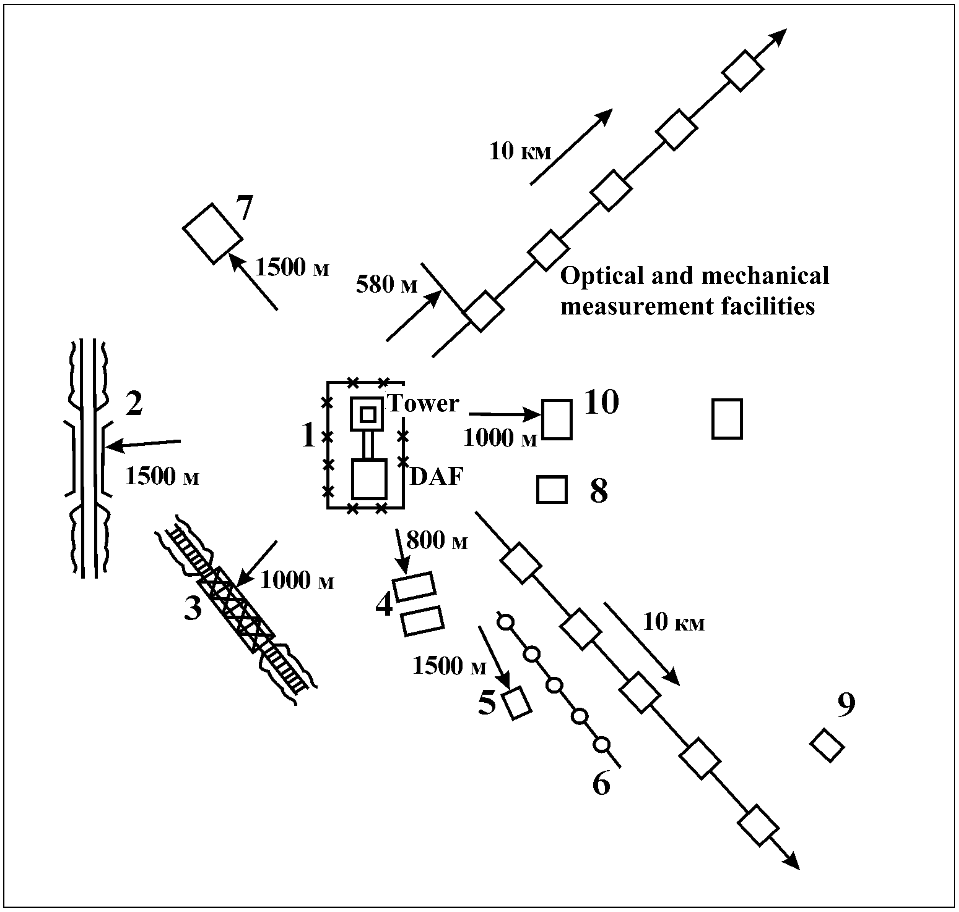


Figure 15. Locations of facilities in Area P1 (Test Field centered 10 km from Building 12P in Area N). Key: *1*—mechanical tower at center of Area P1 for installation of nuclear device. Next to the tower was a wooden building containing underground equipment, and 25 km from the tower was a reinforced concrete production building with a traveling crane in hall for final assembly of physics package (DAF Building); *2*—section of highway with reinforced concrete bridge; *3*—section of railroad with metal bridge; *4*—two three-story houses; *5*—power station building; *6*—power transmission line; *7*—brick and concrete industrial building with traveling crane; *8*—underground Building 10P for placement of measuring equipment; *9*—dugout for preliminary detonation of explosive charges; *10*—physical measurements sector.

During preparations for the first nuclear test, the testers installed 53 airplanes of various types, 32 armored vehicles, as well as various “assets” of various types and branches of the armed forces: the Navy, communications, chemical, engineering, rear, etc., in the 14 sectors of Test

Area P1 of the Test Field at various distances from ground zero. The conditions of these items after the explosion could be used to judge the results of exposure to harmful effects of the nuclear explosion. For biomedical research, 1538 animals were put out, including 417 rabbits, over 170 sheep and goats, 64 piglets, 129 dogs, 375 guinea pigs, and 380 white mice and rats. Three hundred sixty-eight of the animals died instantly; those that survived were taken the same day to a vivarium for observation of their condition.

Thermonuclear Weapon Tests

A whole series of basic problems related to the invention and development of nuclear weapons was resolved during the period of testing at the Semipalatinsk Test Site. In the mid 1950s, two-stage nuclear physics packages were tested. These are packages in which a second module containing source materials for thermonuclear reactions is “ignited” by implosion (compression from all sides), which in turn is caused by the explosive energy of a primary module containing fissile materials.

A bomb containing this type of physics package (the RDS-37) was detonated November 22, 1955. This nuclear explosion, with a yield equivalent to 1600 kilotons of TNT, was the most powerful at the Semipalatinsk Test Site. The results of this test formed the basis for a substantial increase in the absolute and relative energy release of nuclear weapons and a considerable increase in the megatonnage of nuclear arsenals.[1]

From information on the State Commission’s work in setting up and conducting this test, we can get a good idea of the scope of the work it performed during each test at the site.

Before each test, the Commission usually listened to weather forecasters, as well as specialists in the estimation of ground radioactive contamination. Because a megaton-class physics package was to be tested, special attention was paid to the forecast of the harmful effects of the shock wave in the far zone. The extent of these effects depended on the vertical distribution of air temperature, the wind direction and speed at various altitudes, and other conditions. These estimates were made under the supervision of Academician Sergey Alekseyevich Khristianovich. At a State Commission meeting, the director of the test site headquarters made a detailed report on the possibility that test participants and the public would be within the danger zones, and which villages and towns around the test site would have military representatives ready to arrange public evacuations in case of unforeseen circumstances. The Director of the Experimental Research Unit (Sector) reported the Test Field and unit personnel ready for the test. The Deputy Site Director usually reported last, summarizing what had been done and offering a finding on the site's readiness for testing. Each of the speakers presented a formal written report forecasting the consequences of the explosion for his own issue, and these were attached to the State Commission's decision to conduct the explosion. The heads of the various services at the test site and attached expeditions and organizations were invited to the State Commission meeting.

In 1955, the State Commission Chairman was Igor V. Kurchatov. The commission included Academicians Yury B. Khariton, Yakov B. Zeldovich, Andrey Dmitriyevich Sakharov, Yevgeny Konstantinovich Fëdorov, USSR Academy of Sciences Corresponding Member Mikhail A. Sadovsky, Marshal of Artillery Mitrofan Ivanovich Nedelin, Lt. General Viktor A. Bolyatko, Lt. General of Medical Service Avetik Ignatyevich Burnazyan, Colonel G. I. Benetsky, Site Director Maj. General Anatoly V. Yenko, and Sector Head Colonel I. N. Gureyev.

Several days before the explosion, on November 11, 1955, a major decision was made during a discussion of public safety issues: the test would be conducted if the wind was blowing in any direction except toward Semipalatinsk, provided its mean speed did not exceed 90 kph. On November 14, all representatives of the military command assigned to Safety Area 2 were sent to the largest towns: Kaska-Bulak, Kara-Aul, Akkora, Ushkun and Karkaralinsk. In the cities of Semipalatinsk and Ust-Kamenogorsk, equipment was set up to determine the parameters of the shock wave.

Three days before the test—it was scheduled for November 20—all representatives of the military command were given instructions to begin public relations in the affected areas and make appropriate preparations to buildings for a possible shock-wave impact. On the appointed day, November 20, the entire populace of the affected areas was evacuated from their homes outdoors or sheltered in specially equipped rooms. However, at 11:50 AM, due to unfavorable weather conditions, the administration canceled the test.

For the next few days, weather prevented an explosion. Meteorologists could not foresee an improvement. Then Igor V. Kurchatov proposed to risk breaking some windows in the nearest towns, but still ensuring the public's complete safety. The State Commission concurred. Several rail

Figure 16. Detonation of the RDS-37, seen from Kurchatov.

cars of window glass were rushed to the test site. Window repair teams were formed and prepared to leave for the towns immediately.

The State Commission met in the morning and the evening. Finally, meteorologists reported a forthcoming wind shift away from Semipalatinsk, so in terms of radiation safety, the test could be conducted. The Commission scheduled it for November 22, and so notified all safety service units and military command representatives on November 21.

According to plan, on the morning of the test date, Truck Columns 1 and 2 formed up in full battle readiness at Town M. They were intended to evacuate the populace in the event of unfavorable radiation levels due to radioactive fallout.

Two hours before detonation—the test was scheduled for 10 AM—the public in affected areas and Town M was evacuated from their homes to open areas or sheltered in specially equipped hard rooms in accordance with safety instructions.

The RDS-37 nuclear bomb, equipped with a drogue chute, was dropped from a TU-16 airplane at an altitude of 12,000 meters over Test Area P5. An explosion with a yield of 1600 kilotons occurred at an altitude of 1550 meters, when the plane was 15 km away from ground zero. Figure 16 shows the instant of detonation of the RDS-37.

According to visual observation data from the airplane crews, the base of the cloud when it had completed its ascent was at an altitude of 1200-1400 meters. Unfortunately, due to cloudiness in the test area, they were unable to observe the entire development of the cloud, but they did report that its top reached an altitude of 28,000 meters.

Per directive of the chairman of the State Commission, the populace of the affected areas and Town M was completely sheltered in rooms after the shock wave had passed until radiation levels could be measured.

The radiation reconnaissance involved three YaK-12 airplanes and one Li-2. Reconnaissance established that the axis of the radioactive plume was at azimuth 70°, that is, toward the northeast, and at its maximum range from the test area, 200 km, the plume had a width of about 70 km, with a γ dose rate of approximately 8 μR/hr at a height of 50 meters three hours after the explosion.

We must note that the radiation levels after the explosion presented no risk to the personnel or public. Ground γ doses off the test site did not exceed 0.5 cGy, i.e., they were within allowable limits.

In Test Area P5, radiation levels two hours after the test were 1.2 cGy/hr at ground zero and about 1 cGy/hr 800 meters away from ground zero.

Inasmuch as the radiation reconnaissance data on the emitted dose from the total decay of radioactive substances in the ground within the planes' flight range was considerably under 0.5 roentgen, it was decided not to perform ground radiation reconnaissance. At 2 PM on November 22, the villages and towns within the affected areas were restored to normal status, and the trucks allocated for evacuation returned to their units.

In this test, the chief concern of the site's safety service had to do with the effects of the shock wave in the far zone. The range of the shock wave exceeded calculated values. The shock wave from the explosion broke doors, frames, light walls, etc. in Kurchatov, and knocked out windows. Additionally, it was accompanied by a strong acoustic effect, evidence of the explosion's high yield. The various types of structural damage were noted in 59 villages and towns around the test site, including Semipalatinsk. Unfortunately, there were also some tragedies—human fatalities, bumps and bruises, and cuts. For example, in the village of Malyye Akzhary, a ceiling collapsed in one house that had not been evacuated, killing a three-year-old girl, and in the waiting area 36 km away from ground zero, six soldiers of the security battalion were buried in dirt, and one of them died of suffocation.

This test showed that it is very difficult to ensure total safety, and mainly to exclude shock-wave damage to various structures in areas adjacent to the test site, in the testing of megaton-class physics packages. The grounds of the Semipalatinsk Test Site were incapable of conducting high-yield explosions.

A special resolution of the CPSU Central Committee and the USSR Council of Ministers followed, shifting the tests of new powerful nuclear physics packages to the Novaya Zemlya Test Site.

Nuclear Explosion Near Aralsk

The official catalog of nuclear explosions,[35] and an article published in 1996 in the newspaper *Trud* ("Labor")[46] contain information on the testing of a medium-range R-5 missile on February 2, 1956 before its deployment. This missile was launched from the Kapustin Yar Missile Test Site to its full range of some 1200 km into an uninhabited area of sandy desert near Aralsk. The yield of the missile warhead's nuclear unit was reduced to 0.3 kiloton by replacing the active part of the physics package with inert material.

Calculations suggest that the superlow-yield ground explosion could have produced a crater and a radioactive contamination plume 15-20 km across. However, these were buried fairly quickly by the shifting sand, so locating the missile's point of impact and the residual radioactive contamination is now practically impossible. We have no information on any instrument measurements performed in the area of the explosion.

UNDERGROUND NUCLEAR TESTS

We should note that radioactive contamination of the natural environment occurred both after atmospheric nuclear tests and after underground excavating nuclear explosions.

Underground nuclear tests were conducted at the Semipalatinsk Test Site from October 11, 1961 through October 19, 1989 in three of its working areas:

- Delegen Massif (in adits),
- Balapan Area (in shafts),
- Sary-Uzen and Telkem Area (in shafts).

In all, 340 underground nuclear tests involving 500 physics packages were conducted at the site. Seven tests were conducted at this test site for peaceful (industrial) purposes (two in adits and five in shafts); these were intended to achieve a broad range of commercial objectives (creating bodies of water, canals, and harbors; excavating foundation pits; stimulating oil and gas production; extinguishing flares; seismic sensing of the Earth's crust, etc.).

The most significant environmental contamination outside of the test site's exclusion zone occurred after two underground nuclear excavating explosions. These were on January 15, 1965 in Shaft 1004 and on October 14, 1965 in Shaft 1003. The maximum environmental contamination occurred after detonation of a 140-kiloton physics package at a depth of 178 meters in Shaft 1004. The aim of the experiment was to create an artificial reservoir in the arid steppe by blocking the channel of the Shagan River with an earthen dam formed by the explosion at the confluence of the Shagan and Ashchi-Su Rivers.

The first underground test at the Semipalatinsk Test Site with a TNT equivalent of about 1 kiloton was conducted October 11, 1961 in Adit V-1. The principal aim of the test was to verify calculations and develop technologies for performing underground nuclear explosions with containment of radioactive substances within the cavity. Thus, in connection with the drafting of the Nuclear Test Ban Treaty, which would ban nuclear tests in space, air, and water, the USSR began preparing to conduct tests of nuclear weapons and physics packages underground, i.e., in emplacement holes.

With reference to tests of nuclear weapons underground, there is a fundamental difference between the concepts *nuclear test* and *nuclear explosion*. A single underground nuclear test may involve several nuclear explosions. For this reason, the number of nuclear tests often did not match the number of nuclear explosions. Under the 1963 Moscow Treaty and the Protocol to the 1974 Treaty between the USSR and the US on the Limitation of Underground Nuclear Weapon Tests [the "Threshold Test Ban Treaty," or "TTBT"], *nuclear test* meant either a single underground nuclear explosion or two or more underground nuclear explosions detonated within 0.1 second at a test site within an area defined by a circle two kilometers in diameter, such that the total yield of all explosions was the yield of this nuclear test.[116] For example, five nuclear explosions were detonated simultaneously in one test at the Semipalatinsk Test Site.[35]

Tables 4 and 5 give the total number of underground nuclear tests, along with nuclear explosions for peaceful purposes, as well as the number of physics packages and nuclear explosive devices, detonated by the former Soviet Union underground, including those at the Semipalatinsk Test Site.

Table 6 gives data on the number of underground tests and peaceful nuclear explosions conducted in various years at the Semipalatinsk Test Site.

Table 4. Number of Underground Nuclear Tests and Underground Nuclear Explosions for Peaceful Purposes in the USSR from 1961 to 1990

Location of Physics Package	Number of Underground Nuclear Tests in the USSR			
	Total	Semipalatinsk Test Site	Northern Test Site, Novaya Zemlya	Outside of Test Sites
Adits	245	209	33	3
• for peaceful purposes	5	2	—	3
Shafts	251	131	6	114
• for peaceful purposes	119	5	—	114
Total	496	340	39	117
• for peaceful purposes	124	7	—	117

Table 5. Number of Nuclear Physics Packages and Nuclear Explosive Devices Detonated in the USSR Underground from 1961 to 1990

Location of Physics Package	Number of Nuclear Physics Packages and Devices Detonated by the Soviet Union Underground			
	Total	Semipalatinsk Test Site	Northern Test Site, Novaya Zemlya	Outside of Test Sites
Adits	433	304	126	3
• for peaceful purposes	5	2	—	3
Shafts	317	187	7	123
• for peaceful purposes	130	7	—	123
Total	750	491	133	126
• for peaceful purposes	135	9	—	126

Table 6. Rate of Nuclear Tests and Peaceful Nuclear Explosions at the Semipalatinsk Test Site from 1961-1989

Year	Number of Tests	TNT Equivalent, kilotons	Remarks
1961	1	1	
1962	1	0.001-20	
1963	—	—	From January 1, 1963 to April 15, 1964, no nuclear testing performed in connection with the preparation of the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space, and Under Water ("Nuclear Test Ban Treaty")
1964	7	90	Two "nonstandard radiation situations" (incidents)
1965	12	250	Including two peaceful nuclear explosions in Shafts 1004 and 1003
1966	14	420	One incident
1967	15	220	One incident
1968	14	120	Including peaceful nuclear explosion in Shafts T-1 and T-2. One incident
1969	14	270	
1970	12	150	
1971	15	300	Including peaceful nuclear explosion in Adit 148/1. One incident
1972	14	450	Two incidents
1973	9	310	One incident
1974	15	150	Including peaceful nuclear explosions in Shaft R-1 and in Adit 148/5. Two incidents
1975	12	210	
1976	16	300	One incident
1977	15	350	
1978	20	620	
1979	20	960	
1980	18	600	One (last) incident
1981	15	610	
1982	10	470	
1983	14	440	
1984	14	1,130	
1985	8	45	

Year	Number of Tests	TNT Equivalent, kilotons	Remarks
1986	—	—	From July 26, 1985 to February 26, 1987: nuclear testing moratorium
1987	16	1,000	
1988	12	670	
1989	7	300	
Total	340	10,456	

Principal Characteristics of Underground Tests

All the underground nuclear explosions at the Semipalatinsk Test Site can be classified into four categories according to the nature of the radiation levels actually observed:[118]

1. *Excavating explosion:* an underground explosion with external action, accompanied by destruction and movement of rock near the epicenter and release of radioactive products into the atmosphere in the form of aerosols and gases. An excavation crater is formed on the Earth's surface. Four such tests were conducted at the test site, in Shafts 1004 (January 15, 1965), 1003 (October 14, 1965), T-1 (October 21, 1968) and T-2 (three explosions on November 12, 1968).
2. *Full camouflet explosion:* In this type of explosion, all radioactive products remain within the explosion cavity. This type of radiation situation was observed in 50% of all explosions conducted during the underground nuclear testing period at the Semipalatinsk Test Site.
3. *Partial camouflet explosion accompanied by slight leakage of radioactive noble gases into the atmosphere:* This type of underground tests comprised 45% of all tests at the Semipalatinsk Test Site.
4. *Partial camouflet explosion with nonstandard radiation situation ("incident"):* This type of explosion was accompanied by an early pressurized leak of vaporous or gaseous radioactive explosion products into the atmosphere due to accidental disruption of the normal testing process and/or consequences not foreseen by the design that could or did expose people to radiation above the established level or cause material damages. Partial camouflet explosions with

> incidents could cause considerable accidental exposure of personnel and, due to the great dilution of the emission cloud along its path away from the test site, could also cause slight public exposure in areas adjacent to the test site (below allowable dose limits).

Table 7 presents summary data describing 13 partial camouflet explosions with nonstandard radiation situations, indicating that of the 13 nonstandard radiation situations that occurred at the Semipalatinsk Test Site during underground nuclear tests, six nonstandard radiation situations occurred in Delegen Area, 4 in Balapan Area, and three in Sary-Uzen Area.

Similar accidents occurred in the US, too, during adit tests of low-yield physics packages. These were the October 1958 "Tamal Pays" and "Evans" nuclear explosions with yields of 72 and 55 tons, respectively. During these tests, testers "observed a large release of radioactivity in adits, but no breakthrough of explosion products near the epicenter."

Table 7. Underground Nuclear Tests with Nonstandard Radiation Situations Occurring at the Semipalatinsk Test Site[6]

Date	Location, TNT Equivalent	Primary Radiation Effect, Current Residual Ground Contamination
8/18/1964	Adit A-6Sh, Area G, 0.001-20 kilotons	Rapid dynamic breakthrough of vapor-gas mixture into adit and atmosphere, when radiation levels in test area exceeded 150 R/hr. No current radioactive contamination near adit.
9/30/1964	Adit A-6Sh, Area G, 0.001-20 kilotons	Same primary effect. Radiation levels in test area did not exceed 18 mR/hr 24 hours after explosion. No current radioactive contamination near adit.
12/18/1966	Shaft 101, Area S, 20-150 kilotons	Explosion of approximately 10% of radioactive products of explosion into atmosphere through strata and dome of crushed rock. Radiation levels on earthen embankment exceeded 1000 R/hr. Elevated radioactive contamination; health exclusion zone established.

Date	Location, TNT Equivalent	Primary Radiation Effect, Current Residual Ground Contamination
5/28/1967	Reusable Adit 11P, Area G, 0.001-20 kilotons, 0.001-20 kilotons	Rapid dynamic breakthrough of vapor-gas mixture into adit and atmosphere, with subsequent percolation of radioactive noble gases (RNGs) and volatile radionuclides through adit seal. Radiation levels in test area exceeded 1000 R/hr. No current radioactive contamination near adit.
1/7/1968	Adit 810, Area G, 0.001-20 kilotons	Same primary effect. No residual contamination near adit.
10/9/1971	Shaft 111, Area S, 12 kilotons	Rapid, intense release of RNGs through vertical emplacement hole and cracks in epicenter zone. Radiation levels reached 200 R/hr. No residual contamination observed in area.
2/10/1972	Shaft 1007, Area B, 16 kilotons	Rapid and dynamic release of gaseous and vaporous radioactive products through vertical emplacement hole, with subsequent combustion of mixture. Ground radiation dose 1 km away downwind was 14 R over a six-hour dosimeter exposure. No residual contamination of area.
12/10/1972	Shaft 1204, Area B, 140 kilotons	Breakthrough of explosion products during dome collapse. Radiation levels in epicenter zone exceeded 1000 R/hr. Elevated ground contamination observed; health exclusion zone established.
11/4/1973	Shaft 1069, Area B, 0.001-20 kilotons	Rapid dynamic breakthrough of gaseous and vaporous explosion products along shaft. Radiation levels one kilometer away reached 500 R/hr. No residual ground contamination.
4/16/1974	Shaft 1301, Area B, 0.001-20 kilotons	Rapid and dynamic release of gaseous products in epicenter zone, with combustion. Ground radiation levels exceeded 10 R/hr. No residual ground contamination.

Date	Location, TNT Equivalent	Primary Radiation Effect, Current Residual Ground Contamination
11/28/1974	Shaft 215, Area S, 0.001-20 kilotons	Dynamic release of gaseous explosion products through vertical emplacement hole. Radiation levels in epicenter zone reached 110 R/hr after 20 minutes. No residual ground contamination.
3/17/1976	Reusable Adit 608P, Area G, 0.001-20 kilotons	Rapid dynamic breakthrough of explosion products into adit and subsequent percolation through adit seal. Radiation levels in test area reached 60 R/hr. No ground contamination near adit.
12/5/1980	Reusable Adit 204PP, Area G, 0.001-20 kilotons	Rapid, intense release of RNGs in epicenter zone. Ground radiation levels reached 300 R/hr. No residual ground contamination.

During powerful shaft tests in Areas B and S of the Semipalatinsk Test Site, in order to prevent violations of the 1963 Moscow Treaty, the nuclear physics package had to be placed at a depth that would prevent the radioactive gases from escaping into the atmosphere for 10-20 minutes after the explosion. Only that would practically eliminate the radionuclide ^{89}Kr (half-life 3.07 minutes), which decays to the biologically hazardous radionuclide ^{89}Sr contained in radioactive fallout, from the gases escaping into the atmosphere. Thus, even after escape of some of the radioactive gases, this prevented residual ground radioactive contamination, thereby ensuring compliance with radiation safety regulations.

During underground nuclear tests in the rocks of Area B, which contain relatively high amounts of gaseous substances, leakage or percolation of radioactive gases into the atmosphere along the line of least resistance, that is, along the shaft, was observed fairly often. The reason for this phenomenon was the creation of a large gas overpressure in the nuclear explosion cavity. Most of the gases were produced by the evaporation of water and the combustion of flammable components of shale and coal beds. Incidentally, after the closure of the Semipalatinsk Test Site and transfer of part of its grounds to civilian use, commercial mining of bituminous coal was begun near Area B.[119]

The above implies that the more gaseous substances the rock contains, the greater the overpressure in the explosion cavity will be, and the earlier the radioactive gases will escape into the atmosphere. It was important to take this fact into account in developing radiation safety measures for underground nuclear tests.

As the soil properties were being studied at the Semipalatinsk Test Site, experimental studies were begun to determine the size of the fusion, crushing, and fracturing zones in underground nuclear explosions in emplacement holes. Of special interest was the quantity of molten rock as a function of the nuclear explosion's yield, because this artificial formation contained most of the radioactive substances produced by the explosion, and the properties of the formation determined the later ability of the radionuclides to migrate and penetrate various environmental media. Solving this problem required scientists to penetrate the explosion cavity and collect and thoroughly analyze samples of the molten and fused rocks. A tunnel was drilled to the cavity produced by the first underground nuclear explosion of October 11, 1961 in Adit V-1. The properties of the radioactive samples from the explosion cavity were studied by test site personnel from S. L. Turapin's [Radioactive Contamination Study] Section, and also by associates from the Leningrad Vitaly Grigoryevich Khlopin Radium Institute (its former name) under the supervision of Yury Vasilyevich Dubasov.

The results of experimental measurement of the amount of molten rock, together with measurements of the size of the cavity and determination of the rock's ability to produce gases, allowed the researchers to estimate the overpressure in the cavity of the underground explosion by the time its formation was complete. It turned out—and this was confirmed experimentally—that an explosion in granite with a water content of 0.5-1% by weight produced a pressure measured in the cavity that was below atmospheric. With a rock "gassiness" of 2-3%, the pressure in the cavity exceeded atmospheric, which could cause radioactive gases to escape into the atmosphere. By fixing the precise time when radioactive gases began escaping into the atmosphere, and knowing other required variables, specialists learned to quantitatively estimate the permeability of the rocks in which the underground nuclear explosions were detonated. Later, this knowledge enabled them to develop a methodology for predicting radiation levels after underground nuclear tests, which considerably enhanced the radiation safety of test participants and the public.

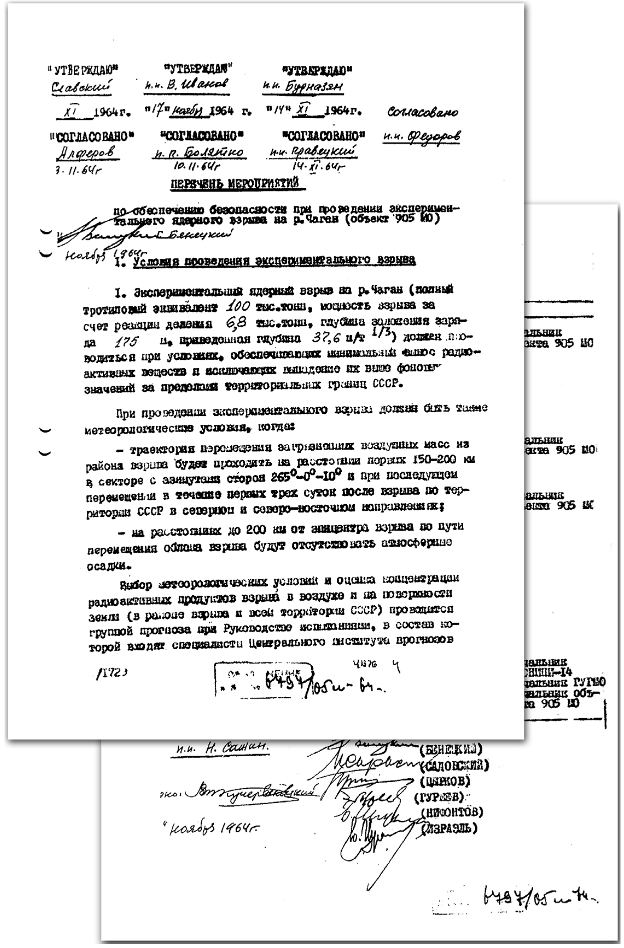
During the period of underground nuclear testing at the Semipalatinsk Test Site, the scientists resolved problems relating to improving the performance of nuclear physics packages and devices and developing measures to ensure the safety of test participants and the public, as well as issues of the safe conduct of peaceful nuclear excavating explosions that were necessary for the development of manmade bodies of water and canals.

Prototype Explosions Conducted at the Test Site

A mandatory requirement of the 1963 Moscow Treaty was to prevent the spread of radioactive products of underground nuclear explosions outside the territory of the country conducting the tests. Consequently, a method of conducting underground nuclear explosions had to be developed that accounted for both assurance of the radiation safety of the test site personnel and the public and for the requirements of the Moscow Treaty. This approach to the problem required study of both the patterns of escape (breakthrough) of radioactive explosion products into the atmosphere over a wide range of test conditions and the possible effective regulation of the escape of radioactive substances into the atmosphere in compliance with special requirements, for example, the use of nuclear physics packages whose detonation released minimal energy due to fission reactions of fissile materials. The requirements of economy of all practical recommendations that assured the radiation safety of underground nuclear explosions had to be taken into account in realizing the grandiose projects developed from the 1960s to the 1980s (diversion of Siberian rivers to the south, creation of manmade bodies of water, canals, harbors, etc.). Moreover, the possible use of underground nuclear explosions was considered for a wide range of commercial objectives such as foundation pit excavation in construction, stimulation of oil and gas production, the killing of gas flares and oil blowouts, seismic sensing of the Earth's crust to find minerals, creation of underground repositories, etc.

Naturally, such a broad range of objectives required careful study of radiation levels after underground nuclear explosions, since various jobs had to be performed in the explosion areas, and the lands adjacent to these areas contained villages and towns. Naturally, many ministries and departments faced a completely new, extremely complex scientific and technical problem having to do with both the successful performance of the underground nuclear weapon test program and the program of setting off nuclear explosions for commercial purposes within the terms of the 1963 Moscow Treaty.[120]

During the operating life of the Semipalatinsk Test Site, seven underground nuclear explosions were detonated on its grounds for industrial purposes. These were (in order) in Shafts 1004 and 1003, T-1, T-2, in Adit 148/1, in Shaft R-1 (“*Lazurit*”) and in Adit 148/5. We should note that with the exception of the first peaceful nuclear explosion at Shagan in Shaft 1004, the radioactive plumes after all nuclear explosions formed wholly within the grounds of the test site, presenting no danger to the public, and these plumes have no residual radioactive contamination today.



"УТВЕРЖДАЮ" "УТВЕРЖДАЮ" "УТВЕРЖДАЮ"

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"СОГЛАСОВАНО" "СОГЛАСОВАНО" "СОГЛАСОВАНО" Согласовано

ПЕРЕЧЕНЬ МЕРОПРИЯТИЙ

по обеспечению безопасности при проведении экспериментального ядерного взрыва на р. Чаган (объект 905 МО)

I. Условия проведения экспериментального взрыва

I. Экспериментальный ядерный взрыв на р. Чаган (полный тротиловый эквивалент 100 тыс. тонн, мощность взрыва за счет реакции деления 6,8 тыс. тонн, глубина заложения заряда 175 м, приведенная глубина 37,6 м/т 1/3) должен проводиться при условиях, обеспечивающих минимальный выброс радиоактивных веществ и исключающих выпадение их выше фоновых значений за пределами территориальных границ СССР.

При проведении экспериментального взрыва должны быть такие метеорологические условия, когда:

– траектория перемещения загрязненных воздушных масс из района взрыва будет проходить на расстоянии порядка 150–200 км в секторе с азимутами сторон 265°–0°–10° и при последующем перемещении в течение первых трех суток после взрыва по территории СССР в северном и северо-восточном направлениях;

– на расстояниях до 200 км от эпицентра взрыва по пути перемещения облака взрыва будут отсутствовать атмосферные осадки.

Выбор метеорологических условий и оценка концентрации радиоактивных продуктов взрыва в воздухе и на поверхности земли (в районе взрыва и всей территории СССР) проводится группой прогноза при Руководстве испытаниями, в состав которой входят специалисты Центрального института прогнозов

(БЕНЕЦКИЙ)
(САДОВСКИЙ)
(ЦЫРКОВ)
(ГУРЕЕВ)
(НИФОНТОВ)
(ИЗРАЭЛЬ)

Figure 17. “List of Measures to Ensure Safety during Conduct of an Experimental Nuclear Explosion on the Shagan River (Ministry of Defense Facility 905).”

The Shagan explosion in Shaft 1004, which was detonated especially to form an artificial body of water, produced residual contamination that can still be detected. This justifies more detailed attention to the features of radioactive contamination of environmental systems after the first commercial nuclear explosion in the USSR, and also to aspects of the measures taken to ensure public radiation safety.

Principal Characteristics of the Shagan Explosion and Aspects of Subsequent Radiation Levels

The first industrial pilot test was carried out in order to obtain information on the possible use of underground nuclear explosions to form deep craters, and to demonstrate the usefulness or even the need to use nuclear physics packages to create reservoirs in arid parts of the country. It was carried out on January 15, 1965 at the confluence of the Shagan and Ashchi-Su Rivers in the Balapan Hills. The explosion was set up and detonated according to a special plan containing a series of measures to ensure public radiation and seismic safety.

The plan, whose development involved specialists from several leading institutes of the former USSR, was to produce a crater and a radioactive explosion cloud as a result of ground excavation, as well as a radioactive contamination plume. A complete "List of Measures to Ensure Safety during Conduct of an Experimental Nuclear Explosion on the Shagan River (Ministry of Defense Facility 905)" was attached to the plan (Figure 17). To ensure public safety, the plan called for establishing several zones in the sector where the radioactive plume might form: an evacuation zone, a zone of notification and evacuation of people and livestock from structures during passage of the seismic wave, and a monitored zone (health protection zone and observation zone). People were to be temporarily evacuated from the zone of heaviest radioactive contamination in order to reduce their dose burdens to values allowed by health standards. The predicted zonation of the contaminated lands during setup and conduct of the Shagan explosion is diagrammed in Figure 18.

The inner boundary of the observation area, that is, the boundary nearest to ground zero, corresponded to a distance from the explosion at which there was no longer any need for any restrictive measures for the public.

The dimensions of the areas established before the explosion were refined without fail after the explosion and a series of studies to determine the actual radiation levels. Then, based on the patterns of decline in radiation exposure levels, dates were set for review and reduction of their sizes to permit resumption of normal commercial activities on land that had previously been within the health protection zone.

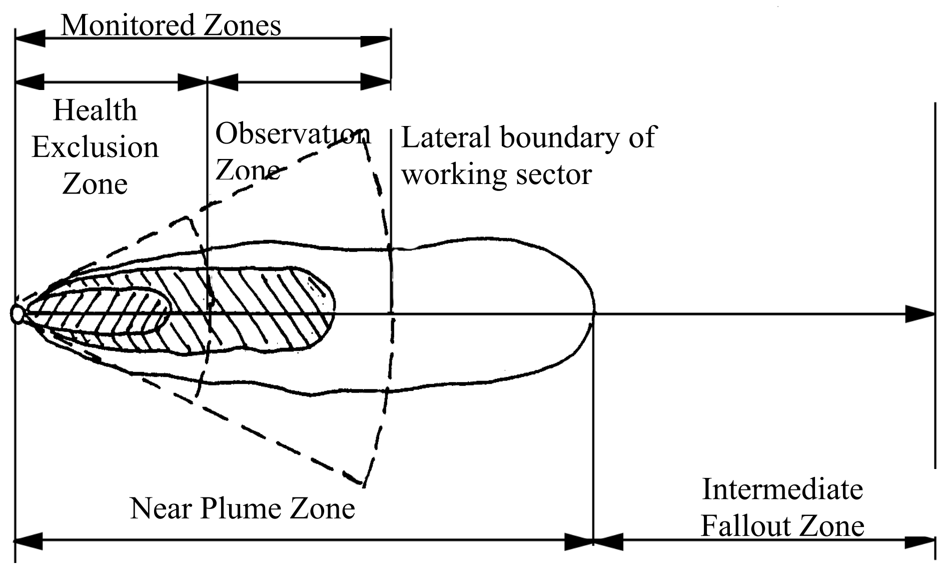


Figure 18. Diagram of Surface Zones during Preparation and Conduct of an Underground Nuclear Excavating Explosion.

The mechanical effects of the detonation of a 140-kiloton physics package placed at a depth of 178 meters produced a crater 100 meters deep, 520 meters across at the crest of the earthen embankment, and containing a volume of approximately 6 million m^3. The earth thrown out of the crater formed an embankment 20-35 meters high, blocking the channel of the Shagan River.

Figure 19. Lake formed by nuclear explosion in Shaft 1004.

According to the plan, the crater was to be filled with water from the Shagan River's spring flood, for which it specified construction of a canal. After all construction work was complete, two large bodies of water formed—an inner one in the crater, and an outer one due to filling of the bottom lands of the Shagan and Ashchi-Su Rivers. Figure 19 gives a good view of both reservoirs and the canal connecting them.[121] After two years, fish appeared in both reservoirs (lake roach [*Rutilus rutilus lacustris*], tench [*Tinca tinca*], European carp [*Cyprinus carpio carpio*], etc.), and the local people began using water from the reservoirs for their livestock.

This project should be considered unique in terms of its methods of construction, specifically due to the use of a nuclear physics package for its creation, and also in terms of its structural configuration. Figure 20 diagrams the structural configuration of the manmade reservoir.

We should note that the assessment of radiation levels in the manmade lake and on adjacent lands received much attention from specialists of numerous scientific institutions, both those performing various types of comprehensive radiation research programs (Yury Antoniyevich Izrael, S. I. Makerova, V. A. Logachev, V. N. Petrov, Feliks Yakovlevich Rovinsky, V. G. Ryadov, A. A. Ter-Saakov, S. L. Turapin, etc.), and those carrying on various specific radiation ecology inspection programs that continued for many years (Yury V. Dubasov, K. I. Gordeyev, V. M. Zavyalov, A. B. Ivanov, A. S. Krivokhatsky, Vladimir Mikhaylovich Loborev, Anatoly M. Matushchenko, L. B. Prozorov, Ye. D. Stukin, G. A. Shevchenko, S. G. Chukhin, etc.). The study of the radiation ecology of the reservoir and the surrounding area was continued in the 1990s, now under international observation monitoring programs (Anatoly Alekseyevich Iskra, Yury V. Dubasov, V. A. Logachev, Anatoly M. Matushchenko, Samat K. Smagulov, A. K. Chernyshev, and many others).[121] Specialists from the Republic of Kazakhstan National Nuclear Center, which is on the territory of Kurchatov, the former administrative and research center of the now-defunct Semipalatinsk Test Site (Shamil T. Tukhvatulin, Murat A. Akhmetov, Larisa D. Ptitskaya, V. R. Burmistrov, O. I. Artemyev, and others) are making a major contribution to the study and assessment of contemporary radiation levels near Lake Shagan, or as it is also called, "Atom Lake."

The external picture of the explosion cloud's development is certainly interesting. About 40 ms after detonation of the physics package, water

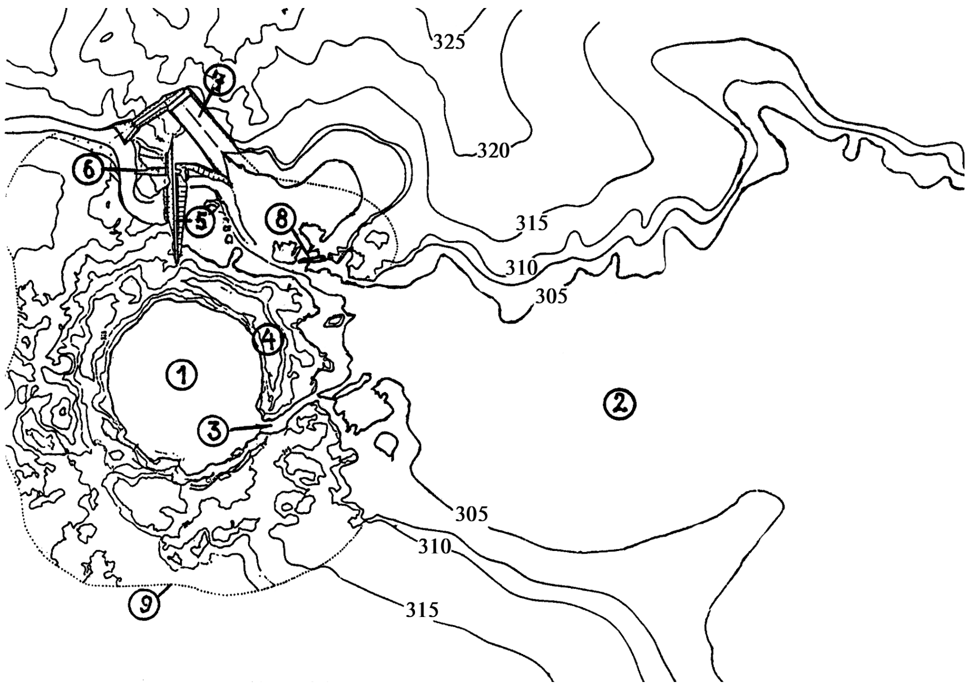


Figure 20. Diagram of the configuration of structures of the artificial reservoir on the Shagan River. Key: *1*—inner lake; *2*—outer lake; *3*—feed channel; *4*—earthen embankment; *5*—rock-fill dam; *6*—bottom inlet; *7*—storm trench spillway with lateral overflow; *8*—remnants of destroyed dam; *9*—boundary of earthen embankment zone.

began gushing out of the shaft, and the characteristic soil heaving about 600 meters across at the base could be seen. The initial rate of ascent of the soil dome at ground zero was 100 m/s. At 2.5 seconds, observers noted a breakthrough of incandescent gases through the broken rock, producing glowing areas visible to the naked eye. By this time the rock's upward speed was 160 m/s, that is, it had reached its peak, and then began to decline slowly.

At the end of the sixth second a rapidly expanding condensation cloud formed in the upper part of the column. In about the 10th second, the excavation column reached its maximum altitude of 950 meters, and its diameter was 800 meters.

The falling and crumbling of the soil at the base of the excavation fountain began to form a base wave, consisting of an annular dust cloud, which spread slowly in various directions. When the diameter had reached a size of about 5000 meters and the height of the dust had reached 500-750 meters, the base wave front practically ceased. Later the base wave cloud drifted to the northwest, while the central dust cloud was carried by the wind to the northeast.

Over the next 30 minutes, most of the dust in the area of the explosion dissipated, and an earthen embankment up to 20-35 meters high and 900-1000 meters across around the resulting crater became visible on the Earth's surface. By this time, the explosion cloud, which had risen to an altitude of 4800 meters, had split into two parts in accordance with the wind directions at various altitudes, forming a local radioactive contamination plume. Fifteen minutes after the explosion, the peak radiation levels in the explosion cloud were 180 R/hr, but after 3.5 hours, they had fallen to only 0.1 R/hr.

Radiation levels are shaped largely by weather conditions, and most of all by the state of the atmosphere. The weather in the area of the Shagan explosion when it occurred was caused by the eastern periphery of a low-pressure area and the influence of a warm front to the southwest. Continuous stratus clouds floated at 2200 meters, while the 5-point clouds below extended down to about 800 meters. Horizontal visibility was 8-10 km in light haze, and the air temperature was –2.4°C.[122]

The explosion cloud and the radioactive plume were both formed in an abnormal temperature and wind profile vs. altitude. The layer of atmosphere from the Earth's surface to the maximum altitude reached by the cloud, 4800 meters, had the following characteristics:

- below 750 meters was a confining layer of air with an isothermal temperature profile;
- between 750 and 2500 meters was a confining layer with a temperature inversion, where the air temperature rose with altitude;
- above 2500 meters was a layer of air with normal temperature profile, that is, the higher above the Earth's surface, the lower the temperature.

In addition to this unusual temperature profile, a considerable shift was also observed in wind direction with increasing altitude (nearly 100° to the right [clockwise] within the maximum altitude reached by the cloud). The combination of these factors produced a local radioactive plume with a complex configuration, which is diagrammed in Figure 21. Thus, radioactive aerosols in the 0- to 750-meter layer shifted 330° in azimuth and produced ground contamination due to fallout from the base wave. The lower part of the explosion cloud, located in the 750- to 2500-meter layer, formed the "northern branch" of the plume with an axis at azimuth 40-47°, while the upper part, which rose above 2500 meters, moved along azimuth 70° to form the "southern branch" of the plume. The wind speed was 22 kph during formation of the northern branch, and 40 kph for the southern one, and the base wave front moved at 17 kph.

Data on radiation levels in the axes and the northern and southern branches of the plume are given in Table 8.

Table 8. Gamma Dose Rates in the Radioactive Plume of the Underground Nuclear Excavating Explosion in Shaft 1004 (Shagan Explosion) 24 Hours after Detonation[122]

Plume Axis	Radiation Levels at T+24 hrs., mR/hr, at Various Distances in km from Ground Zero										
	1	3	6	8	15	24	30	37	49	60	70
Northern Branch	25,000	3,300	875	460	160	50	35	45	26	7	4
Southern Branch	—	—	—	—	35	30	17	12	7	5	4

We should note that elevated radiation levels were also recorded in Semipalatinsk, where γ dose rates peaked at about 8 mR/hr three hours after the explosion (3 PM local time). This may have been caused by an elevated release of radioactive products into the atmosphere, which specialists estimate at 20%, due to the fact that a physics package with a rather large energy release (140 kilotons), had been emplaced at a depth corresponding to its design yield of 100 kilotons. The cloud's passage over the city took about three hours, but radiation levels on dosimeters had begun to decline by 5 PM local time. According to data presented by V. G. Ryadov *et al.*,[123] the exposure dose from the passing cloud could have been about 0.05 mSv, and the dose from radioactive fallout on the ground

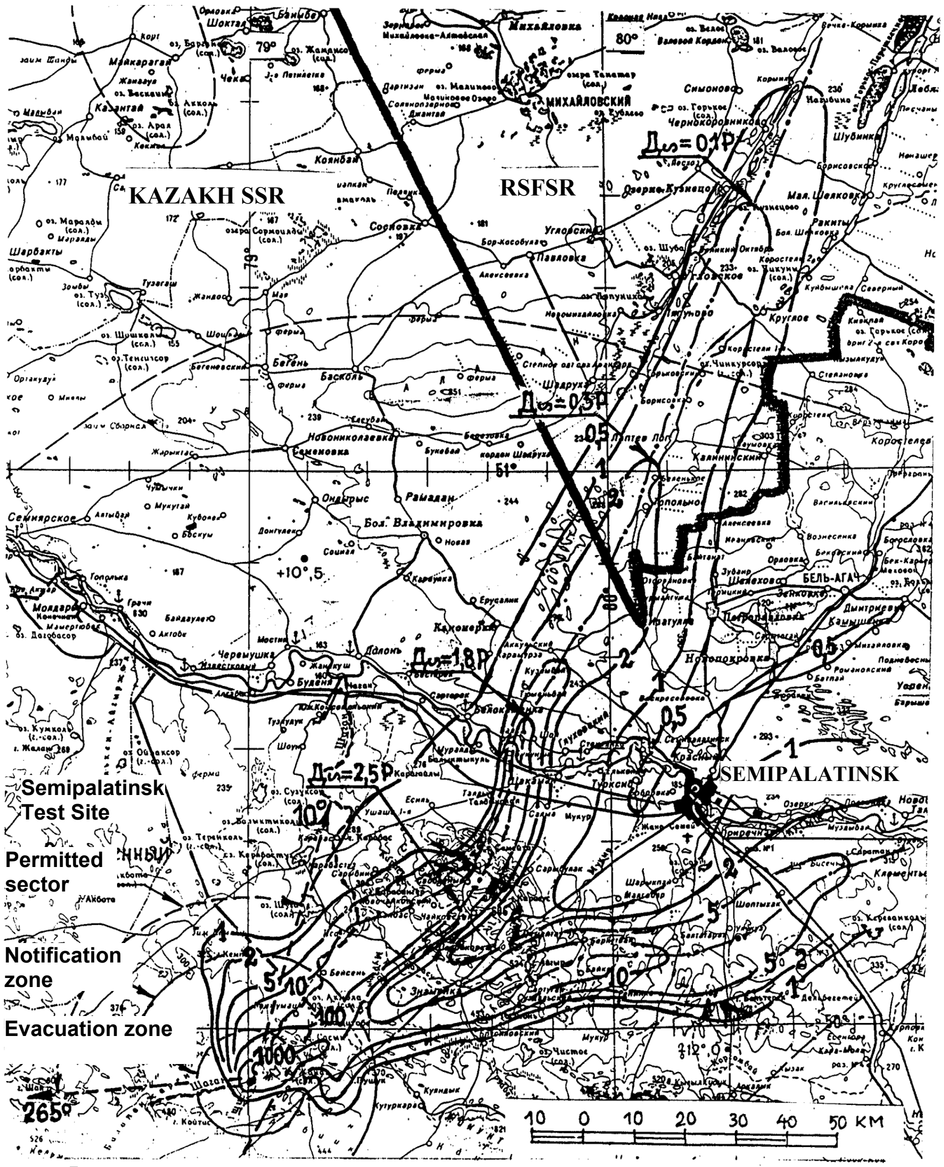


Figure 21: Map of the plume of radioactive contamination and safety zones after the underground excavating explosion (Shaft 1004), designed to create an artificial lake.

Key:

——5—— - γ-ray exposure dose in mR/hr 24 hours after explosion;

Дси - dose in roentgens on the ground before complete decay of radioactive substances;

——·—— - plume axis.

could have been 1.0-1.5 mSv. Gamma dose rates in Semipalatinsk returned to background levels 10 days after the explosion. In several villages and towns in the cloud's path but closer to ground zero, namely Znamenka and Isa, radiation levels took 30 days to return to background, and in the town of Sarapan they remained elevated for 18 months.

The position and dimensions of the radioactive plume, with the various boundary parameters (numerical values of isolines) can be determined using the plume diagram given in Figure 21. Naturally, the radioactive decay and migration of radionuclides gradually reduced the area of the contaminated land. Whereas the area of the plume bounded by the 0.5 R/yr isoline (the maximum allowable public outdoor radiation dose) was about 140 km^2 as of June 1965, it had shrunk to 50 km^2 after a year (mid-1966), and after another year, that is, in 1967, it was down to about 17 km^2.

The time taken by the plume to shrink by half was 250 days. After about five years, the monitored area of the plume was less than 1 km^2.

The fallout of radioactive explosion products contaminated the territories of some 10 villages and towns with a total population of about 2000. Table 9 gives data describing radiation levels in the most heavily contaminated ones.

As the data show, the largest town in terms of population where the possible human exposure dose exceeded one roentgen was Znamenka. Residents of this town worked mainly on a state farm with a strong grain orientation. Most of the families had their own milking livestock that grazed on land in the immediate vicinity. In winter, the cattle were stalled. The village's development primarily consisted of adobe-type houses. The water supply was from wells, which were mostly uncovered (had no roofs). The town's produce supply came from trade, which the residents supplemented with other locally grown products such as milk, milk products, and meat (mutton, horsemeat), as well as potatoes and vegetables stored in their cellars.

Table 9. Radiation Levels in 1965 in Towns and Villages Most Heavily Contaminated by Radioactive Fallout from the Shagan Explosion[124]

Village or Town	Population	Distance from Ground Zero, km	Radiation Levels at T+2 hrs., mR/hr	Ground γ Doses in 1965, R
Sarapan	162	13	4400	5.8
Iirbala	10	22	700	6.7

Village or Town	Population	Distance from Ground Zero, km	Radiation Levels at T+2 hrs., mR/hr	Ground γ Doses in 1965, R
Beysen	8	24	1300	2.8
Shcherbakovka	—	48	300	2.6
Isa	66	30	110	0.9
Znamenka	980	40	170	2.4
Musa	22	33	190	1.3
Toreygyr	11	32	270	2.3

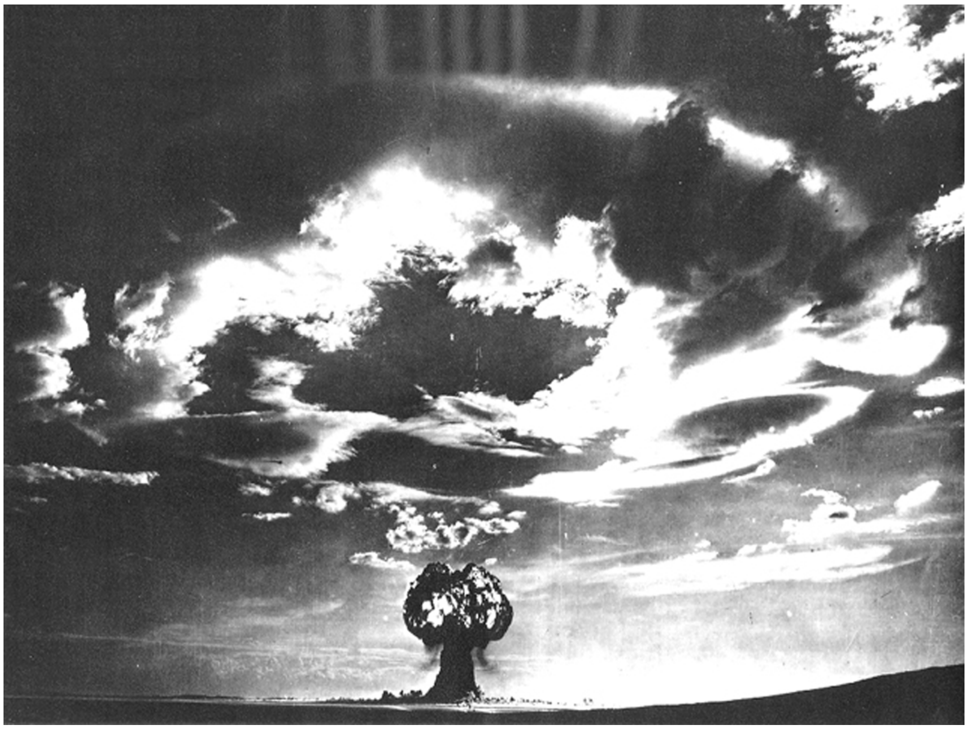
The results of calculations of outdoor and indoor exposure doses of residents of Sarapan, accounting for tritium uptake, are presented in Table 10. The data show that in Sarapan, as in other villages and towns in the radioactive plume of this explosion, the children, whose main critical organ is the thyroid gland, received the greatest exposure in the first year after the Shagan explosion. Prolonged residence in a radioactively contaminated area could roughly double bone-tissue and whole-body exposure doses.

Table 10. Possible Outdoor and Indoor Doses of Critical Organs in Sarapan Residents from January 1965 to April 1966[125]

Critical Organ	Exposure Doses of Various Population Segments, cGy (cSv)					
	Children			Adults		
	Outdoor	Indoor	Total	Outdoor	Indoor	Total
Thyroid	1.7	14.4	16.1	2.6	1.1	3.7
Bone	1.0	6.7	7.7	1.5	0.3	1.8
Whole Body	1.7	2.4	4.1	2.6	0.5	3.1
Skin	—	—	20.0	—	—	20.0

We must acknowledge that during the period of nuclear testing, the site was a potential source of environmental radioactive contamination. This is why special attention was paid throughout its operating life, up until its closure in 1989, to issues of ensuring public safety and studying radiation levels.

PART 2. PUBLIC SAFETY PROVISIONS AND RADIATION LEVELS DURING THE NUCLEAR TESTING PERIOD



We should note that during the period of nuclear testing, each site in the former USSR paid quite a bit of attention to radiation safety issues. For example, each nuclear test at the Semipalatinsk Test Site, with the sole exception of the first one on August 29, 1949, was set up in compliance with requirements for assurance of the public's general and radiation safety and regulations applicable in the country by the date of the specific test.

SAFETY PROVISIONS DURING VARIOUS TESTING PERIODS

The entire period of atmospheric nuclear testing at the Semipalatinsk Test Site can be conveniently divided into three periods in terms of the scale of protective measures, the intensity of the collection and storage of information on radiation levels (specifically, γ dose rates at various points in the plume outside the grounds of the test site), public outdoor and indoor exposure doses and concentrations of radioactive substances in people's bodies, the degree of contamination of various environmental systems, and their levels of biologically hazardous radionuclides, and so forth.

During the first period (1949-1951), practically no public radiation safety measures were implemented, unless we include the prediction-based selection of the most uninhabited sector for the possible formation of a radioactive plume after the second ground nuclear explosion, yielding 38 kilotons, on September 24, 1951 on a tower 30 meters high.

Detonation of the first experimental explosion was considered such an important military and political event at the time that the testers were permitted to disregard unfavorable weather conditions and conduct the test on a rainy day with strong wind gusts.

For the first nuclear test at the site a complex control and instrumentation system was installed, and a whole series of buildings and structures intended to be destroyed was also built. The test program for the first nuclear physics package, the RDS-1 ("RDS" stands for "Russia Does It Herself"), formulated in USSR Council of Ministers Resolution 2142-564 of June 19, 1947, was aimed at achieving two principal objectives: first, to assess the operability of the physics package design in terms of efficient use of the nuclear explosive material (^{239}Pu), and second, to obtain data needed for study of the consequences of exposing various military equipment, structures, and animals to the new type of weapon.

Special attention was paid to the radiation survey at ground zero, accomplished by outfitting two tanks, minus their gun turrets, with additional lead shielding and dosimetry equipment. Avetik I. Burnazyan, the head of the State Radiation Safety Service and Director of the USSR Ministry of Health's Third Main Directorate, was personally involved in the conduct of this study on the first tank.[72]

Archive documents[39, 73] reveal that in early September 1949, that is, several days after the nuclear explosion, the test supervisors (Igor V. Kurchatov, Avetik I. Burnazyan, etc.) decided to organize a radiation survey using aircraft and ground vehicles to assess the actual radiation levels prevailing outside the test site. The radiation level measurements were used to determine the location of the radioactive contamination plume. The largest town in the plume was the city of Biysk, located in Altai Territory 570 km from the site's Test Field.

The decision to conduct a radiation survey outside the test site after the USSR's first nuclear test has a story behind it. According to eyewitnesses,[3] soon after the explosion, the commander of the Test Field security battalion came to Site Director Sergey G. Kolesnikov and reported that they had discovered the shell of a weather balloon, broken off on the day of the test by a strong gust of wind, lying on the ground near the field boundary. The shell had bits of fairly large fused particles embedded in it. The site director called in Vasily V. Alekseyev, and together with the battalion commander and a dosimetrist, sent them to where the balloon had been found. Yury B. Khariton, who observed the conversation, wanted to join the little expedition. It turned out that the little particles lay on the balloon itself and on the ground, so Khariton asked for a matchbox and collected several bits himself for analysis. From then on, the radioactive particles were called *kharitonki*.

The whole group followed the fallout plume in a truck to the northeast from the boundary of the Test Field, guided by the readings of a PR-6 microroentgenometer. They learned that the plume extended far beyond the boundaries of the Test Field, and possibly even those of the test site as well. They reported this to the test director. The discovery of a plume of radioactive contamination far outside the boundaries of the Test Field proved to be a complete surprise. American professor Henry D. Smyth's book on the first nuclear test in the U.S. in 1945, which the Soviet scientists had used for guidance, said nothing about a radioactive contamination plume in the direction of the average wind.[54] The lack of experience and factual data on the possible scale of ground radioactive contamination after a ground nuclear test was the reason why the USSR's first nuclear weapon test was conducted without any special public protection measures.[74]

All this formed the basis for a decision to conduct a ground and aerial radiation survey on the right bank of the Irtysh River and in Altai Territory. The routes of the radiation survey crews are shown in Figure 22, which is a copy of a map from a 1949 handwritten report.[39] During the aerial survey, the plane, beginning at the edge of the Irtysh River, crossed the plume axis at least 15 times. The crew fixed the maximum γ dose rates at their flight level and referenced these values to the ground on each crossing. The survey participants noted that when they crossed the plume axis at distances of up to 300 km from Test Area P-1, they observed a sharp rise in the radiation intensity, but at greater distances, the dose rate increase on the plume axis was small, and seemed "blurred" over the cross section. This was quite sufficient to identify and fix the plume axis's location on the ground to within ± 2.5 km.

The land where the outdoor ground γ dose could exceed 1 roentgen until the radioactive substances had completely decayed extended from the boundary of the security area in a gradually widening band for a distance of up to 300 km, with a maximum width of 40-50 km.[74] The territories of Novopokrovka and Beskaragay Districts in Semipalatinsk Region and several districts in Altai Territory were radioactively contaminated. The maximum dose, recorded near the town of Dolon, was over 200 roentgens.

A generalized version of the radioactive plume that formed after the USSR's first nuclear explosion is given in the summary report[73] that was prepared at the initiative and under the supervision of Avetik I. Burnazyan, the USSR Deputy Minister of Health and head of its Third Main Directorate.

The accumulated experience and results obtained during the setup and conduct of the first nuclear test spurred the development, during setup for the second ground explosion in 1951, of a series of steps aimed at reducing the harmful effects of the explosion on the residents of nearby areas. For example, it was decided to wait for a wind direction that first, would move the explosion cloud toward practically uninhabited land, and second, would avoid superimposing the radioactive plume from the explosion over that of the first explosion, thereby avoiding the addition of radiation doses.

These weather conditions were observed on September 24, 1951, and the second nuclear explosion was detonated on a newly built tower in the same Test Area P-1.

A radiation survey of the radioactive plume was carried out on an An-2 airplane following the following procedure: at various ranges from ground zero, the plane crossed the plume, and dosimetrists noted the locations with the greatest radioactive contamination, thereby determining the location of the plume axis.

In order to assess radiation levels one meter above the ground surface, the plane landed at several points for measurements. The results were used to determine the relation between readings on the dosimeter at the plane's flight level and on the ground surface.[3]

The radioactive contamination plume was located to the south and southeast of the test area. The lands, on which the γ dose could exceed 1 roentgen extended in a band up to 200 km from the boundary of the test

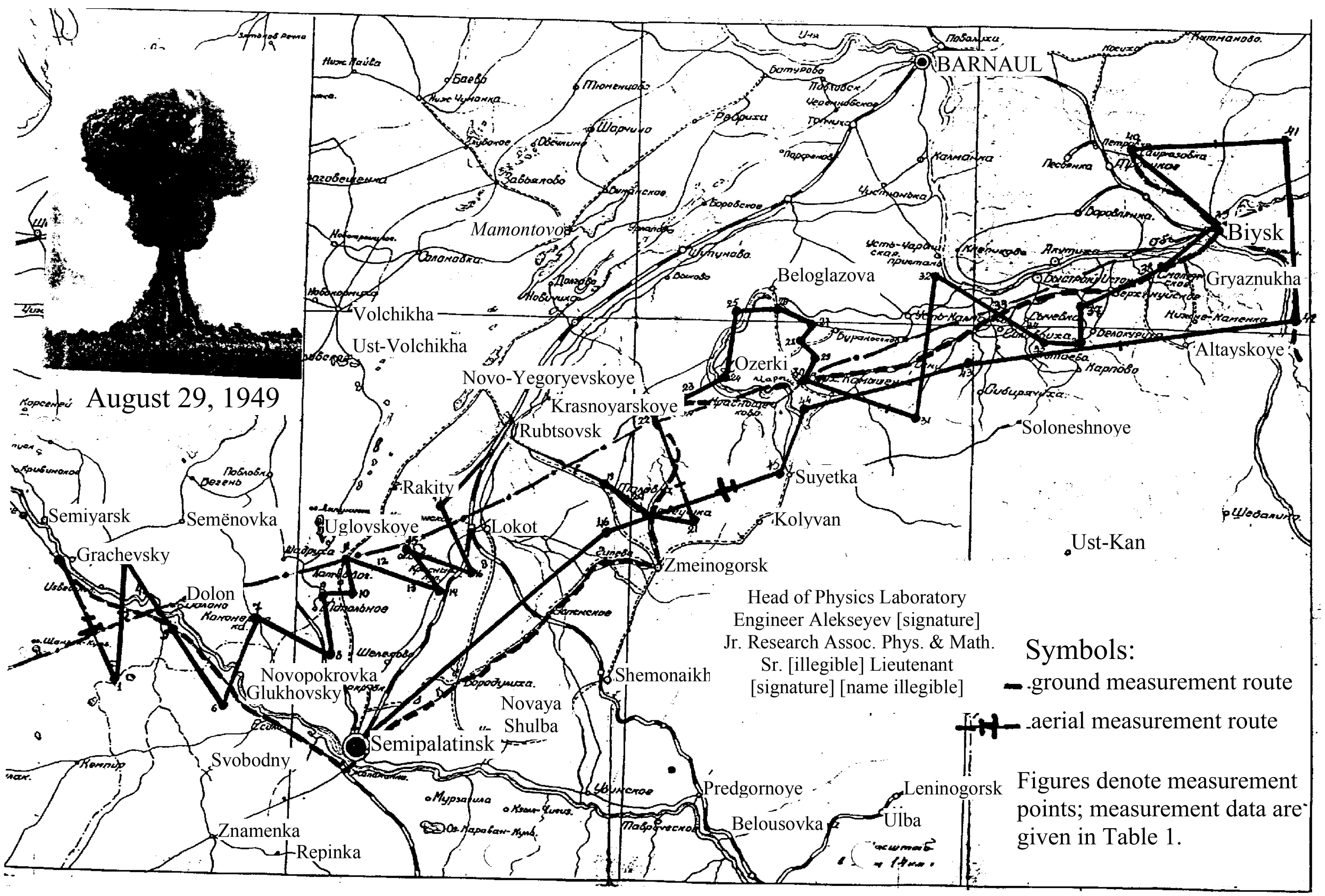


Figure 22. Map of aerial and ground observation routes.

site's security area. The area of radioactive contamination incuded Abay, Shubartau [Russian *Chubartau*], and Ayaguz Districts of Semipalatinsk Region.[74] A maximum radiation dose of 117 R was measured 30 km northeast of the town of Kaynar.

Less than a month after the second ground test, on October 18, 1951, the first atmospheric nuclear explosion was detonated at the Semipalatinsk Test Site, with a yield of 42 kilotons. This was the USSR's first test conducted by dropping a nuclear aerial bomb from an airplane.[12] We should note that the ground radioactive contamination after this explosion was slight.

No nuclear tests were conducted in 1952. At the test site, work proceeded on rebuilding structures in Area P-1 that had been destroyed in earlier nuclear tests, and new equipment was installed in the Test Field. A certain reorganization of one part of the test site's experimental research unit—the Physical-Technical Sector, which consolidated five sections: physical measurements, observations using optical devices, shock-wave research, radiochemical analyses, and automatic controls.[3] All the sections were working to interpret the site's experience conducting tests and preparing for measurements of physical parameters that biologists and other specialists needed to assess a nuclear weapon's harmful effects.

The test site's Radiation Safety Service, with the participation of specialists from the Institute of Biophysics, the USSR Ministry of Health's Third Main Directorate, and the USSR State Committee for Hydrology, Meteorology, and Environmental Monitoring (*Goskomgidromet*), interpreted the radiation survey data and developed procedures for predicting radiation levels in the plumes of nuclear explosions in the near and far zones, as well as methods of calculating public outdoor and indoor exposure doses. Despite the obvious inadequacy of experimental data, they developed recommendations for determining the sizes of zones and the levels of ground radioactive contamination along the cloud's path, the variation of radiation dose rates over time, and the allowable times people could stay on contaminated ground before they received a relatively safe dose, and for solving problems related to the temporary evacuation of residents from villages and towns predicted to be within the areas of radioactive contamination.

When predicting the location of the radioactive plume for each nuclear explosion, the scientists always accounted for possible changes of both wind direction and speed over time –the measurements had an error of ±5 kph—so the predicted direction of the radioactive plume axis could be in a sector with an angle on the order of 20-30°. When the nuclear explosion cloud formed in cumulonimbus clouds, ground radioactive contamination levels in some areas could be as much as 5-10 times higher than the calculated values.[12] The patterns they discovered were used to develop steps to ensure the general and radiation safety of personnel and the public during nuclear tests in the second (1953-1957) and third (1958-1962) periods, which were characterized by peculiarities in the implementation of safety measures. The setup and conduct of the biggest ground nuclear explosion in 1953, namely the test of the first thermonuclear device, marked the beginning of the second period, distinguished by measures to ensure public radiation safety.

Between 1953 and 1957, 78 nuclear tests were conducted, 10 of them on the ground. On August 12, 1953, a very powerful ground nuclear explosion (400 kilotons) with a thermonuclear additive made the largest contribution to the local radioactive contamination of land outside the test site. This testing period was characterized by the implementation of protective measures such as temporary evacuation of residents of villages and towns predicted to be in the areas of radioactive contamination with significant outdoor γ doses (over 50 roentgens). This protective measure was undertaken to prevent overexposure of the public.

When the ground nuclear explosion of August 12, 1953 was detonated, the principal step to ensure the safety of the local population was temporary evacuation of the sector where the radioactive plume was anticipated.

About two weeks before the explosion, on July 31, 1953, the Executive Committee of the Semipalatinsk Regional Council of Workers' Deputies adopted Decision 86, which read as follows:[18]

> *"1. The Executive Committees of Abay, Abram, and Zhana-Semey District Soviets of Workers' Deputies are hereby ordered to temporarily evacuate the residents and drive out livestock within five days from the area of exercises[1] to be conducted by the USSR Ministry of Defense, to a distance of 60-120 km from the center of Test Site 2 in the southeasterly and southerly directions to a safe location in coordination with Military Unit 52605.*

[1]—The test of the first thermonuclear bomb was set up under the pretext of preparing for a large troop exercise.

"If it becomes necessary during the exercises, at the order of the commander of Military Unit 52605, they shall perform additional evacuation and driving of livestock from certain locations more than 120 km from the center of the test site…

"2. The Regional Finance Office is hereby ordered to place funds at the disposal of the executive committees of district soviets for payment of compensation to the temporarily evacuated populace. Compensation is to be paid at a rate of 500 rubles per person.

"3. The district executive committees are hereby ordered to send comrades to villages and towns to perform public relations work to avoid possible misinterpretations.

"4. The chairmen of said district executive committees are hereby ordered to immediately send responsible district employees to the villages and towns to be evacuated to render assistance in the timely evacuation of the populace.

"5. The chairmen of the executive committees of the district soviets of workers' deputies are hereby ordered to take steps to prevent disclosure of information about the temporary public evacuation operation to be performed."

The residents of all settlements located in the sector, a total of 2250 people, were evacuated and over 44,000 head of livestock were driven out from the territory of a sector up to 120 km in radius from ground zero. The residents of villages and towns located 120 to 250 km away, along with some residents of settlements closer to the Test Field, a total of 12,794 people, were concentrated in nine villages and towns. They were kept in a continual state of readiness for possible subsequent evacuation in vehicles in case of a threat of radioactive fallout. Over 390,000 head of livestock were evacuated to a safe area.

The evacuation of the populace and assurance of their safety involved representatives of the Government of the Kazakh SSR and the Semipalatinsk Regional Executive Committee, as well as 163 officers and 205 sergeants and soldiers. The evacuation and maintenance of life support took 620 trucks. Residents of Kara-Aul (Abay) were returned to their homes 10 days after the explosion, but residents of the town of Sarzhal were not returned for 16 days, when the radiation had returned to safe levels.[41]

We should note that after the ground thermonuclear explosion of August 12, 1953, the resulting cloud, passing the area of Lake Zaysan, split into three parts. The lowest part (below 5500 meters) made a small turn near the cities of Berëzovka, Omsk, Karaganda, and Kounrad. The peak dose in this plume was no more than 500 mR. The middle part of the cloud, up to 12,000 meters, made a medium-sized turn over the towns of Berëzovka, Omsk, Kökshetau (Russian *Kokshetav*), Shadrinsk, Sverdlovsk, Nuraty near the Aral Sea, and Namangan. The peak γ dose before complete decay of the explosion products in this plume did not exceed 200 mR. The top part of the cloud (above 12,000 meters) moved toward Kyzyl (Tuva Republic) and Lake Baykal.[12] All doses registered in this area were under 10 mR, but they occurred over a large part of the territory of the former USSR.

In 1954, three ground tests were conducted. After the explosion of October 5, 1954, whose yield was 4 kilotons, ground contamination by radioactive fallout occurred to the southwest of the Test Field. The maximum γ dose did not exceed 2 roentgens. During the explosion of October 19, 1954 the first failure of a nuclear physics package occurred.[12] After the test of October 30, 1954, with a yield of 10 kilotons, the contaminated band extended to the southeast, covering parts of the territories of Abay, Novopokrovka, Charsk, and Georgiyevka Districts in Semipalatinsk Region and Nikitinka District in East Kazakhstan Region. The maximum dose in the plume outside the test site did not exceed 5 roentgens.

In the three ground nuclear explosions in 1955 (July 29, August 2 and 5), with yields from 1.2 to 12 kilotons, the maximum ground radiation dose did not exceed 2.7 roentgens.

Under the 1956 work program, three ground tests were conducted (March 16 and 25, and August 24). The most significant ground radioactive contamination followed the August 24, 1956 ground nuclear explosion with a yield of 27 kilotons. The band of contaminated ground after that explosion was located east of the Test Field and included several sections with maximum doses. The appearance of contaminated areas in the far zone was due to fallout in the form of rain. Novopokrovka and Charsk Districts in Semipalatinsk Region, Tavricheskoye, Predgornoye, Nikitinka and Serebryansk Districts in East Kazakhstan Region, and the regional capital of Ust-Kamenogorsk were partly contaminated.

The maximum outdoor γ doses in the plumes of the remaining ground explosions of 1956 did not exceed 4 roentgens.

After the explosion of August 24, 1956, when the leaders of the USSR Ministry of Health's Third Main Directorate received reports of significant ground radioactive contamination outside the test site, they sent a team of specialists from the Institute of Biophysics to districts adjacent to the test site to measure the radiation levels precisely and perform a public health assessment. In addition, they decided to organize annual comprehensive medical research expeditions in order to study the health status of residents of the contaminated districts. A State Commission headed by USSR Minister of Health Mariya Dmitriyevna Kovrygina was operating at the test site at this time.

In 1957, two clinics were organized for continuous observation of the health status of residents of the contaminated districts: Clinic No. 3 in Ust-Kamenogorsk, which was soon closed, and Clinic No. 4 in Semipalatinsk, which still forms the basis of the operational Institute of Radiation Medicine and Ecology (*IRMiE*).

In later years, right up until the end of atmospheric nuclear testing (the last explosion was detonated December 24, 1962), most tests were atmospheric. Ground nuclear explosions detonated at the Semipalatinsk Test Site now had superlow yields, so the radioactive plumes from these explosions were almost entirely confined to the grounds of the test site.

In high-altitude atmospheric tests, when the ground dust column produced at ground zero did not join the explosion cloud, the radioactive contamination was generally slight. The exceptions were tests conducted on August 7 and September 25, 1962, when "accidental" ground explosions occurred instead of atmospheric explosions in very low wind, that is, nearly calm weather.

In Kurchatov, located some 70 km from ground zero on August 7, 1962, radioactive fallout was first detected about 12 hours after the explosion. Obviously, the radioactive cloud had crossed the Irtysh River by then, and 30-32 hours after the explosion, a rise in γ background was recorded in the towns of Izvestkovy and Semiyarskoye.

Judging by the contamination of plotting boards put out on the grounds of Clinic No. 4, radioactive fallout arrived in Semipalatinsk 1.6 days (nearly 39 hours) after the same explosion. The average speed of the part of the cloud moving toward Semipalatinsk, was 4-5 kph. Most of the radioactive cloud from the explosion of August 7, 1962 reached Altai Territory, contaminating a large part of its territory with public outdoor exposure doses of 0.1 to 1.2 roentgens.

Gamma dose rates in mR/hr in several towns, calculated for 24 hours after detonation, were:

- Semipalatinsk 0.06-0.28
- Semiyarskoye 1.4
- Topolnoye 4.4
- Kanoperka 1.8
- Novopokrovka 1.0

Returning to a general assessment of the effect of nuclear testing on the scale of radioactive contamination of lands adjacent to the Semipalatinsk Test Site, we should note that atmospheric explosions with low yields (under 10 kilotons) and medium yields (up to 100 kilotons) produced only a slight increase in γ background off the test site. But they never caused public exposure doses exceeding the allowable limits in the regulations of the time.

From the standpoint of the scale of protective steps taken, the third nuclear testing period at the Semipalatinsk Test Site (1958-1962) was characterized by adherence to severe restrictions on the conditions of testing. All these restrictions were developed based on the compilation and study of all prior development experience and observance of measures for ensuring the general and radiation safety of the public and the test participants.

The radiation safety of personnel and the public during underground nuclear explosions (from October 11, 1961 to October 19, 1989) had to be ensured by quality performance of all technological elements of the test, including the selection of the location for equipment to make the emplacement holes, accounting for factors that would nearly guarantee the underground confinement of radioactive products of the nuclear explosion. These factors included primarily:

- a lack of geologic faults and fractures near ground zero;
- minimum gas and water content in the rocks;
- sufficient distance of the detonation chamber (end box) from the ground surface and from prior explosions;

- a lack of carbonate or carbonaceous rocks in the explosion's heat-affected zone.

Whenever an emplacement hole was drilled, the rock mass was always studied visually and geographically by magnetic survey, seismic survey, and other methods in order to construct a geographic model from the physics package emplacement point to the ground surface (shortest distance to the earth's surface). If a tectonic fault filled with porous rock was discovered near the proposed detonation chamber, the test was moved to a safe distance.

To prevent the emission of radioactive explosion products into the atmosphere through the emplacement hole, a so-called stemming system was created, with high-strength seals, damping devices, gas blocks, etc.

Shafts were either cemented completely or cement plugs were installed with the gaps between them filled with rubble and sand. The stemming of shafts is diagrammed in Figure 23. To ensure reliable cementing of the space between cables, special cable spacers were used. Gas blocking devices were installed on the cables within the soil mass undisturbed by the explosion.

In adits, the stemming system consisted of the following components:

- a first section located at the end box and designed to prevent the initial pressure outburst of explosion products into the adit;
- a second section making up the force element that confined the overpressure produced in the explosion cavity. This section consisted of concrete wedges and rubble between them, into which wet cement was pumped under pressure (the method of separate cementing, which improved the sealing properties of the stemming).

The design of the adit stemming system is diagrammed in Figure 24.

When necessary, additional components were installed: sealing elements (concrete dampers) and sealing walls.[49] Cable lines were placed in metal boxes filled with wet cement. Gas blocking devices were installed on each cable to prevent gaseous radioactive explosion products from esaping along the cables.

Measures to select the location and depth of emplacement of the physics package and to seal the hole were intended to ensure reliable isolation of radioactive products from the biosphere, both during nuclear testing and for a prolonged period afterward, which should have prevented exposure of test site personnel and the public.

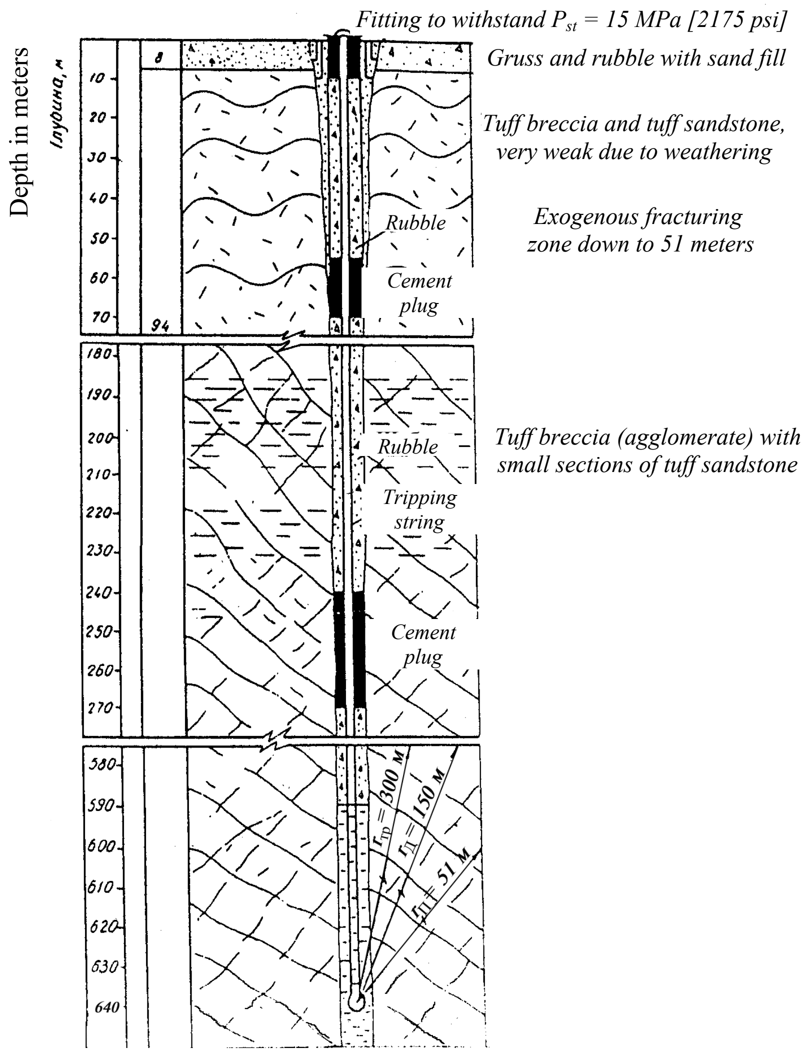


Figure 23. Diagram of a shaft and stemming, showing zones affected by the mechanical action of the explosion.
$r_{п}$—radius of cavity (51 meters); $r_{д}$—radius of crushing zone (150 meters); $r_{тр}$—radius of fracture zone (300 meters).

However, complete prevention of the entry of radioactive products of underground nuclear explosions into the atmosphere was not always planned. For example, when peaceful nuclear explosions were used, or when artificial bodies of water were created, the results were not always as designed or predicted.

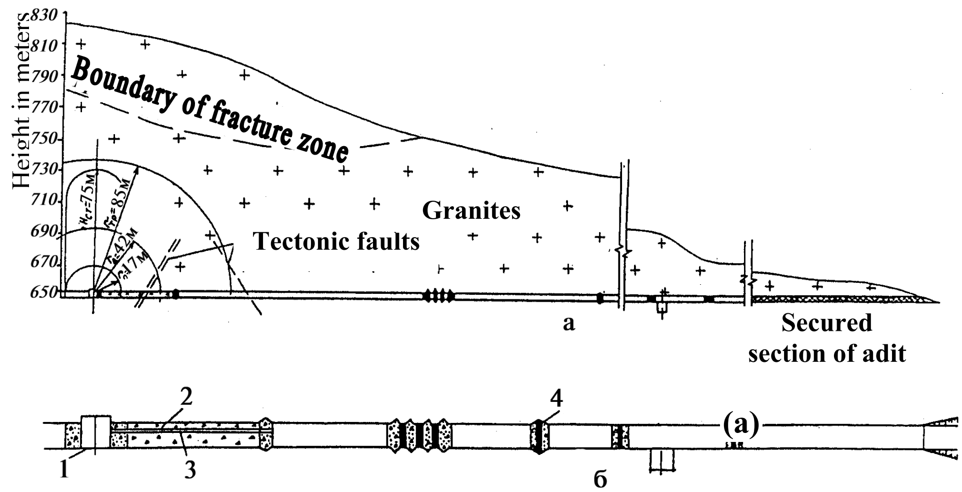


Figure 24. Diagram of the design of the stemming system for the zone affected by the mechanical action of the explosion (a); Section along the axis of the adit (b).

Key: *1*—end box; *2*—rubble; *3*—radiation emission channels; *4*—seals (adit cross section *h* × *b* = 3.0 × 3.3 meters). $r_{п}$—radius of cavity (17 meters = 56 **(b)**); $r_{д}$—radius of crushing zone (42 meters); $r_{тр}$—radius of fracture zone (85 meters); H_{st}—75 meters.

We should note that specialists making up an Interdepartmental Expert Commission predicted the level of radioactive contamination of environmental systems and assessed the possibility of accidents and their consequences. The commission’s forecast and opinion was then used to draw up the radiation safety assurance plan.

In developing the specific measures of the plan, the designers were guided by the “Regulations for Handling Radioactive Substances and Sources of Ionizing Radiation,” whose use was based on USSR Ministry of Defense Orders 136 of 1963 and 285 of 1983. Maximum allowable outdoor exposures and contamination levels of various systems could be used only in exceptional cases by special written permission of the test directors. If a likelihood of ground radioactive contamination outside the test site’s exclusion zone was predicted, for example, in cases of excavating explosions, then the site’s administration had to obtain a special permit from the USSR Ministry of Health to conduct the experiment, specifying the allowable outdoor and indoor human exposure doses.

As we have already noted, control measurements of γ levels were performed after each test using remote, ground, and aerial radiation survey equipment. Airplanes were used to monitor the movement of air masses from the explosion area.

Ground radiation survey inspectors were sent to contaminated grounds outside the test site to pin down data on radiation levels, and when necessary, perform radiometric inspections. The leaders of the USSR Ministry of Health's Third Main Directorate permitted specialists from Clinic No. 4 in Semipalatinsk to be recruited for this work.

If the contaminated lands contained inhabited villages and towns, special medical monitoring was established for their residents. Teams of doctors were sent to these villages and towns with the necessary laboratory and medical equipment. The teams included military doctors from the test site and specialists from Clinic No. 4. Residents needing hospitalization were evacuated to military hospitals: Hospital No. 242 in Semipalatinsk, or Hospital No. 132 in Kurchatov.

As we have already noted, ground nuclear tests had the strongest effect on the scale and levels of radioactive contamination of lands outside the test site. Naturally, most of the burden of implementing measures to protect the public fell on the Radiation Safety Service of the Semipalatinsk Test Site.

THE TEST SITE'S RADIATION SAFETY SERVICE

The test site's General and Radiation Safety Service can be regarded as the successor to the radiation safety service of nuclear industrial enterprises, which began to operate under the supervision of the USSR Ministry of Health's Third Main Directorate about three years before the beginning of nuclear testing. In those days, the country was already operating experimental and commercial reactors that produced, along with plutonium, hundreds of millions of curies of various radionuclides. So the GRSS had to ensure both the nuclear safety of the operation of nuclear industrial enterprises and the radiation safety of production personnel and the public living near those enterprises.

Understanding this, both nuclear scientists and medical personnel paid strong attention from the first days of the USSR's nuclear industry to the development of measures to ensure the radiation safety of personnel and the public.

As experience was gained in the handling of radioactive substances, methods and procedures for ensuring radiation safety were improved.

Medical radiologists began being trained to serve nuclear-industry workers. Dosimetry services were set up at facilities.

Industrial experience was used widely in setting up to conduct the first nuclear tests at the Semipalatinsk Test Site and developing methods of ensuring radiation safety. It was relatively easy organizationally to do this because the USSR Ministry of Health's Third Main Directorate supervised the establishment of radiation safety services both in industry and at the test site. The Institute of Biophysics studied the consequences of radiation exposure on the human body and developed all types of regulations for handling radioactive substances. These standards were then used to develop requirements for safety measures during nuclear testing at the Semipalatinsk Test Site. The test site's radiation safety service developed specific safety measures for the tests.

Preparation of the test site for nuclear tests required personnel to adhere to special safety measures, so a nuclear test safety service began to operate at the test site at the same time as the preparations for the first nuclear explosion on August 29, 1949.

The main purpose of creating this service at the test site was to ensure general and radiation safety of the participants in nuclear weapon tests, the personnel of military units in the garrison, the residents of Town M (later the city of Kurchatov), and the public living outside the test site. The site's safety service included a radiation safety service, whose methods were continually improved as data were gathered on the consequences of exposure to the harmful effects of nuclear explosions and views on allowable radiation exposure levels changed over time.

The site's safety service was assigned specific objectives, principally:

- to develop instructions for the general and radiation safety of personnel and the public, and make their contents known to all test participants, and to organize monitoring of compliance with their requirements;
- to organize and perform radiation surveys in the area around the explosion and in the radioactive plume;
- to gather data on γ dose rates at locations visited by personnel in the Test Field and in the radioactive plume;
- to provide individual protective devices and perform dosimetric monitoring of the exposure of personnel in the Test Field or in the radioactive plume or working with various contaminated objects at other locations on the test site;

- to regulate or restrict the time spent by personnel in areas exposed to ionizing radiation;
- to provide sanitary processing of personnel and decontamination of uniforms, gear, and vehicles;
- to organize and perform, together with the site's medical service, examinations of personnel and assigned outsiders enlisted to handle radioactive substances;
- to organize systematic monitoring of the exposure of personnel and the public, and to monitor, together with the site's medical service, the health status of people exposed to ionizing radiation;
- to interpret the results of monitoring of the health status of test participants who performed various jobs on ground contaminated by radioactive substances;
- to destroy or bury contaminated objects and radioactive waste produced by the operation of the test site.

The nuclear testing program drawn up by the test supervisors and approved by the national Government devoted considerable space to general and radiation safety assurance issues. The program established maximum allowable exposure doses for personnel and the public, as well as levels of radioactive contamination by β- and γ-emitting substances, for the setup and testing period.

During the nuclear testing period, special attention was paid to the development and implementation of measures to ensure the safety of the public living near the test site.

Before each series of tests was begun, a public safety assurance service was formed with a temporary staff. The specialists on this service, equipped with radio transmitters, dosimeters, and other instruments, were supposed to be sent to villages and towns to monitor radiation levels and take steps to protect the public.

When powerful explosions were detonated, beginning in 1953, representatives of the safety service in villages and towns with radio transmitters announced the time of the test and the scope of measures required to assure public safety. In particular, these measures included the evacuation of residents from houses so they would not be injured when the weak shock-wave front passed, leaving the windows and doors open, etc. For villages and towns lacking radio transmitters, message bags were dropped from airplanes or helicopters, specifying the detonation time and periods when necessary measures should be taken. After receiving the message, security service representatives worked to ensure the residents' safety.

To ensure that the site's safety service performed its assigned tasks, and especially during periods of frequent nuclear tests, the following units were organized and temporarily staffed:

- general safety section;
- radiation survey section;
- monitoring and dosimetric support section;
- personal exposure monitoring section;
- special processing stations at the Kurchatov and Semipalatinsk airports.

Thus, during periods of frequent tests, for example, in 1956, the Radiation Safety Service had a temporary staff of 33 officers and 113 sergeants and men. In addition, 250 dosimetrists were trained from among the employees of the testing groups and teams to monitor levels of radiation and radioactive contamination of environmental systems in areas receiving nuclear fallout.

Importance was accorded to the development of rule books and instructions on rules of conduct in areas of radioactive contamination and their distribution to persons involved in carrying out public protection measures.

The provision of special equipment and vehicles to the site's safety service, and the performance of radiation surveys, decontamination, and sanitary processing were mostly performed by members of a separate technical battalion. The provision of dosimetric equipment to radiation safety units and its calibration were assigned to the instrumentation office of the experimental research part of the test site (Sector 5 of Area O).

The personnel of units of the site's safety service were busiest during the setup period, that is, before the beginning of testing, and naturally, on the test day itself.

During the setup period, the Radiation Safety Service, staffed and logistically supported, performed the following jobs:

- develop new and revise existing instructions and plans to ensure the general and radiation safety of test participants and the public;

- carry out measures to ensure the safety of test participants in waiting areas and at monitoring sites, and also at population concentration areas;
- train members of its service to perform radiation surveys and dosimetric monitoring, and develop methods of surveying contaminated land using armored vehicles and trucks.

During the setup period, the personnel of units of the Radiation Safety Service refined their functional duties and verified the required working documentation. They conducted training and exercises for survey units, and trained inspectors to perform dosimetric monitoring of workers in contaminated areas and to precisely measure radiation levels in villages and towns.

The readiness of the general and radiation safety service to perform the forthcoming work was always checked at special, comprehensive, and general rehearsals conducted before the beginning of testing.

On the days of nuclear tests, at the time specified by the operational plan, the entire staff of the test site, along with personnel assigned from outside to participate in the tests, concentrated outside the danger zone in waiting areas and observation points. Personnel not directly involved in the conduct of the tests, as well as members of the public residing on lands that could possibly be affected by even one harmful effect of the nuclear explosion, were evacuated from their residences and concentrated in specially designated safe areas.

The waiting areas, observation points, and concentration areas for test site personnel and members of the public were designated in advance, i.e., before the beginning of testing, at locations with convenient vehicular access and egress, usually outdoors at a safe distance from any structures. The anticipated explosion yield, the type of test, and the weather conditions were all taken into account.

At each separate point where personnel and members of the public stayed, a post commander or commandant and an officer were appointed by order of the site director; they were responsible for safety. Dosimetrists from the Radiation Safety Service, vehicle inspectors from the road service, and doctors or physician’s assistants from the medical service with the necessary means of providing first aid were placed at the disposal of the post commanders or commandants. In addition, the required numbers of vehicles were assigned for simultaneous evacuation of the people in case of radioactive contamination of the village or town.

Great importance was accorded to the dosimetrists' reports on radiation levels on the test site grounds and in adjacent areas. A representative of the USSR Ministry of Health, who could order clarification of general conditions and radiation levels in areas if necessary, always read the reports.

PRINCIPAL USSR REGULATIONS GOVERNING ALLOWABLE RADIATION DOSES

Views of the criteria and methods of ensuring radiation safety have changed substantially as knowledge has been gained about the biological effects of ionizing radiation on living organisms. This is also important because different radiation safety standards have been in effect in various periods of nuclear testing. What was previously considered completely safe no longer conforms to modern standards.

For practical purposes, the development of scientifically valid criteria for the safety of nuclear enterprise personnel and the general public in the USSR began in 1946, when the Radiation Laboratory of the USSR Academy of Medicine and the Biophysics Department at the Institute of Labor Safety and Occupational Medicine were organized.[48] In order to expand the scope of research and accelerate the development of standards to ensure radiation safety, the Radiation Laboratory was reorganized in 1946 into the Institute of Biophysics, whose first director was active member of the USSR Academy of Sciences Gleb Mikhaylovich Frank.

In trying to solve the complex problems associated with radiation safety assurance, Soviet scientists also drew on international experience, where the leading role belonged to the International Commission on Radiological Protection (ICRP). Information contained in the materials and documents published periodically beginning in 1955 by the ICRP[49] was used in the Soviet Union to develop national standards and regulations for protecting people from exposure to ionizing radiation and radioactive materials. However, during the USSR's atmospheric nuclear testing period (1949-1962), especially in the initial phase (1949-1951), the country lacked a basic state regulation, the Radiation Safety Standard (NRB). The USSR did not adopt its first official Radiation Safety Standards, which governed "allowable" outdoor and indoor exposure doses, until 1969.[50]

We should note that the need to develop radiation safety assurance measures had already arisen during performance of scientific research involved with the production of nuclear explosive materials (^{239}Pu, ^{235}U, etc.), which was supervised by Igor V. Kurchatov.[51,52] But the need for protective measures became urgent with the commissioning of the first nuclear enterprises and the preparations for nuclear physics package tests at the Semipalatinsk Test Site.

Even before the startup of the USSR's F-1 nuclear reactor, where the first controlled nuclear chain reaction in Europe and Asia took place in December 1946, the country had created a State Radiation Safety Service headed by Avetik I. Burnazyan. He was charged with developing standards and regulations for handling radioactive substances, as well as methods and instruments for monitoring the exposure of specialists at leading institutes of the USSR Academy of Sciences and the USSR Ministry of Health.

Nuclear weapons development in the Soviet Union was supervised by the Science and Technology Council of the USSR Council of Ministers' First Main Directorate. Under this Council, which consisted of the country's leading scientists, Medical and Sanitary Monitoring Section No. 5 was formed, headed by future Academicians Vasily Vasilyevich Parin (chairman) and Gleb M. Frank (learned secretary). At its first meeting on April 24, 1946, Section 5 approved Yakov B. Zeldovich's proposal to organize individual film monitoring of the "radiant hazard" of ionizing radiation and to produce dosimetric instruments.

Associates from the Radiation Laboratory, and then from the Institute of Biophysics, developed integrating dosimeters equipped with thimble ionization chambers and photographic film. These dosimeters were desperately needed, both to assess the harmful effects of a nuclear explosion and to carry out radiation protection measures. They began to be used to monitor radiation levels, in the performance of various radiobiological experiments with animals, and in the setup and conduct of the first nuclear explosions.

Beginning in 1948, the Institute of Biophysics, which had been placed under the USSR Ministry of Health's Third Main Directorate, began to study the effects of radiation on the human body and to develop various standards governing work with ionizing radiation.[52]

Under the direction of the Third Main Directorate, an independent system of medical service for personnel employed at enterprises, research institutions, and other organizations in the nuclear industry was formed, along with a system for monitoring radiation safety assurance for nuclear test participants.

Measures for assuring the radiation safety of the populace residing near the nuclear test site had their peculiarities. Specifically, the possibility of public exposure was not monitored by measuring individual doses, but based on the results of observation of radiation levels. Public safety measures were developed using data obtained from observations of the formation and spread of radioactive clouds in the atmosphere depending on wind direction, the results of measurements of γ dose rates using airborne and ground sensors and the collection and analysis of environmental samples for radioactive substances, and data from predictions of radiation levels developed from mathematical models and statistical estimates.

We should note that during the period of atmospheric nuclear testing, the radiation safety of test participants and the public was monitored using temporary intradepartmental and interdepartmental documents of the USSR Ministries of Health, Medium Machine-Building, and Defense, whose development involved employees of the Institute of Biophysics and the USSR Ministry of Health's Third Main Directorate.

One of the first recommendations regarding the allowable exposure of human beings to ionizing radiation was developed in 1946 by Gleb M. Frank, Avgust Andreyevich Letavet, N. O. Panasyuk, and B. G. Dubovsky, titled *Tolerance Doses for Various Types of Radiation*.[53] According to the data presented in the recommendations, the "allowable exposure dose" for both the public and personnel was 0.2 roentgen per day or 60 roentgens per year. Based on these dose burdens, maximum allowable concentrations (MACs) for radioactive substances in air and water were calculated, without differentiation by isotope. Thus, the MACs in air were 2 nCi/l for β emitters and 10-100 pCi/l for α emitters, the corresponding values for water being 1 μCi/l and 10 nCi/l.

The 1948 recommendations halved the "allowable exposure dose" to 0.1 roentgen per day or 30 roentgens per year.[54] According to the recollections of participants in the first nuclear test in 1949,[55,56] the test supervisors sometimes permitted outdoor exposure of personnel to reach doses of 50-100 roentgens once or over the course of a year.

In 1953, the "allowable exposure doses" were reduced to 0.05 roentgen per day and 15 roentgen per year.[57] We should note that right up until 1957, no distinctions were made in allowable exposure doses of personnel working at nuclear enterprises, nuclear test participants, and the general public.[58-60]

The turnabout in the development of views on ensuring the radiation safety of the public residing on radioactively contaminated lands came with *Health Regulation SP-233-57*,[61] developed in 1957 by Institute of Biophysics employees N. Yu. Tarasenko, N. G. Gusev, A. N. Marey, and G. M. Parkhomenko.

Unlike the prior Health Regulation (SP-129-53), the new regulation contained a more detailed list of health standards. An appendix specified whole-body dose limits for outdoor γ exposure: 15 rems per year for personnel and 1 rem per year for persons not working directly with ionizing radiation sources, and the outdoor γ dose for the entire population of the country was not supposed to exceed the natural background dose. Thus, we can state that distinctions between the "allowable exposure doses" for personnel and the public appeared in the USSR for the first time in 1957. Health Regulation SP-233-57 essentially laid the foundation for domestic health law in the area of radiation safety, and the source was the noted military and civilian public health organizer Avetik I. Burnazyan. This Health Regulation was very important in resolving issues relating to the reduction of public dose burdens during the conduct of all nuclear tests in the atmosphere.

However, scientific concepts developed by specialists in the establishment of standards for human exposure to ionizing radiation were reflected most fully in *Health Regulation SP-333-60*.[62] It included data on MACs for a larger number of radionuclides that could be contained in water, workplace air, within the grounds of health protection areas, and most importantly, on the territories of inhabited villages and towns. These MACs were set differently to take account of the possible exposure of three groups of critical human organs according to their radiosensitivity. Unfortunately, this Health Regulation did not account for the very important factor of radionuclide migration through the food chain. But even with this deficiency, SP-333-60 was used in the Soviet Union right up to 1969, that is, until the appearance of the first state *Radiation Safety Standards (NRB-69)*.[50] The National Radiation Protection Commission (*NKRZ*), formed under the USSR Ministry of Health in 1965, made a great contribution to the development of NRB-69. Its first head was the noted scientist Avgust A. Letavet.[63,64]

In 1976, new *Radiation Safety Standards (NRB-76)* took effect.[65] These were developed based on the results of analysis of a large volume of documents containing information on the effects of radiation exposure on the human body, and drew upon experience gained in carrying out radiation monitoring measures at nuclear enterprises and measuring the concentrations of radioactive substances in environmental systems. Academician of the Russian Academy of Medicine Leonid Andreyevich Ilyin, Director of the Institute of Biophysics (now the RF State Research Center/Institute of Biophysics), who headed the National Radiation Protection Commission for many years, made a great contribution to the development of these Radiation Safety Standards. NRB-76 also introduced concepts such as allowable and monitored levels of radioactive contamination, allowable residual contamination of the integument after sanitary processing, allowable concentrations of natural radionuclides in building materials, etc. The values of "allowable exposure doses" remained unchanged both in NRB-76 and in its 1987 revision, *NRB-76/87*.[66]

In the early 1990s, the development of radiation safety standards in the Russian Federation was placed under the supervision of the Russian National Commission on Radiation Protection (*RNKRZ*), headed by Academician of the Russian Academy of Medicine Anatoly Fëdorovich Tsyb. It developed the NRB-96 radiation safety standards, which were then more precisely edited to account for international recommendations[67] and named *NRB-99*.[68] However, these recommendations should not be included with the events that occurred during the period of atmospheric nuclear testing, since most of the dose burdens of the past had already been nearly completely realized. We should note that NRB-96, developed in the Russian Federation, has been recommended by the Government of the Republic of Kazakhstan as the basic regulation for assurance of personnel and public radiation safety.

Table 11 shows, in chronological order, the change in values of "allowable exposure doses" under various radiation exposure conditions, and also lists the principal regulations.

Table 11. Allowable Exposure Doses for Personnel (Category A), and Part of the Public (Category B). Principal USSR Regulations Governing These Doses

Year and Category of People Exposed	Allowable Exposure Dose, roentgens (rems)		Literature Sources	Remarks
	per day	per year		
1946	0.2	60	9, 19	No differences existed between allowable outdoor exposure doses for personnel (test participants) and the public.
1950	0.1	30	14	An accidental one-time exposure dose of 25 R over a period of at least 15 minutes or 100 R over one year was permitted.
1953	0.05	15	13, 15	Same.
1957			17	Same.
• Category A	0.05	15		
• Category B (persons not working with radioactive materials)		1.5		
• Entire population		within natural backgrou nd		
1961			18, 20	An accidental one-time exposure dose of 25 R was permitted. Con- tamination of food- stuffs, water, air, and various environmental systems was regulated.
• Category A	—	5		
• Category B	—	0.5		
• Entire population	—	0.05		

Year and Category of People Exposed	Allowable Exposure Dose, roentgens (rems)		Literature Sources	Remarks
	per day	per year		
1969 (NRB-69) • Category A • Category B • Entire population	 — —	 5 0.5 0.17 (5 rems in 30 years)	3	The concept of "dose limit" for possible exposure of a limited part of the population (Category B) and the entire population (Category V) was introduced.
1976 (NRB-76) • Category A • Category B	 — —	 5 0.5	21	
1987 (NRB-76/87) • Category A • Category B	 — —	 5 0.5	22	
1999 (NRB-99) • Personnel: • Group A • Group B • Entire population	 — — —	 2 0.5 0.1	24	Basic dose limits specified in Radiation Safety Standards (NRB) were enacted effective January 1, 2000.

The data show that during the period of atmospheric nuclear testing (1949-1962), when local radioactive contamination could have formed, the main criterion for the hazardous effect of ionizing radiation was thought to be the public outdoor γ exposure dose, which was calculated using data from radiation surveys of radiation levels on the contaminated ground. Indoor radiation exposure doses were also estimated, but their contribution to the total effect was of secondary importance, and its size was roughly comparable to the measurement error of the outdoor exposure dose.[69,70]

With the passage of time, up to the cessation of atmospheric nuclear testing, as new information was gathered on the biological effect of radiation, allowable exposure doses were reduced, and from the early 1960s until late 1999 they actually remained unchanged for personnel and the public. Along with the reduction in allowable exposure doses, standards used in the nuclear industry—allowable concentrations of radioactive substances in air, surface contamination levels, and radionuclide concentrations in the human body—were also tightened. Standards became especially strict for α-active radionuclides (plutonium, polonium etc.). At the initiative of S. L. Turapin, head of the Radioactive Contamination Study Section at the Semipalatinsk Test Site, and with the support of the Radiation Safety Service, the systematic measurement of airborne α-active radionuclides both on and off the test site was organized.

During the period of nuclear testing, a variety of scientific studies were performed related to the assessment of biomedical and radiation-safety effects, and to the effects of ionizing radiation on the human body. The results were used to develop additional steps to reduce the public radiation exposure near the Semipalatinsk Test Site. For example, in two series of atmospheric nuclear tests, conducted in 1961 and 1962 (67 ground and atmospheric explosions), the yearly allowable public outdoor exposure dose was set at 1.5 roentgens. In addition, to improve public radiation safety, strict limitations were imposed on nuclear explosion yields and on the conditions under which tests were conducted, mainly weather.[9,71]

In the 1960s, it was thought—and this was coordinated with the leaders of Semipalatinsk Region and the Kazakh SSR—that compliance with the existing restrictions could ensure complete public radiation safety. So residents in areas adjacent to the test site were not warned of tests in advance. Later, this caused the local population to distrust the test site's activities and led to the formation of the Semipalatinsk Test Site-Nevada and other antinuclear movements.

The information presented above gives a certain idea of the changes in views of standards and methods of ensuring radiation safety that were used at various periods of nuclear weapon testing at the Semipalatinsk Test Site to ensure public safety.

ROLE OF THE USSR MINISTRY OF HEALTH REPRESENTATIVE AT THE TEST SITE

The group of test supervisors always included a representative of the USSR Ministry of Health, who was charged with monitoring the correct performance of measures to assure the safety of personnel and the public during nuclear tests. The test supervisors consisted of the heads of the USSR Ministry of Medium Machine-Building, the USSR Ministry of Defense, and the USSR Ministry of Health or their authorized representatives.

The test administration would approve a Statute on the Responsible Representative of the USSR Ministry of Health at each nuclear weapon test. One such statute, approved in 1958, included the following list of powers and duties:

> *"1. For the duration of each nuclear weapon test, the USSR Ministry of Health shall appoint a responsible representative.*
>
> *"2. The USSR Ministry of Health representative shall be charged with monitoring the organization of safety and security of public health during special weapon tests, and if necessary, together with the test site's administration, organizing the provision of medical assistance to victims.*
>
> *"3. To ensure complete performance of his tasks, the USSR Ministry of Health representative must be acquainted with plans necessary for his work and the nature of the forthcoming tests and their possible harmful effects. During the period preceding tests, the representative of the USSR Ministry of Health, together with the representatives of the Ministry of Medium Machine-Building and the Ministry of Defense, shall review and sign a list of measures to ensure public safety in areas adjacent to the test site and to respond to possible harmful effects of said tests.*
>
> *"4. The test site's command shall systematically acquaint the USSR Ministry of Health representative with meteorological reconnaissance data and data on the direction and speed of the radioactive cloud, radioactive fallout, and radiation levels before and after testing. The USSR Ministry of Health representative shall participate in meetings of the Test Supervisors to review specific conditions of work before each test and shall decide jointly with them to conduct tests.*
>
> *"5. The USSR Ministry of Health representative shall be authorized to inspect plans and reports and to participate in the discussion of test results.*
>
> *"6. The USSR Ministry of Health representative shall establish contact, jointly with the test directors' representative, with responsible supervisors of Soviet and Party agencies, and personally with public health agencies of districts, regions or territories, and national republics. He shall establish specific objectives for public health agencies to*

organize medical service to the population during evacuation for the duration of testing, and shall determine the necessary forces and assets, their deployment, and operating procedure in case of possible accidents or injuries and verfy their readiness.

"7. During his work, the USSR Ministry of Health representative shall establish working contact with representatives of the Army and Navy Military Medical Service, and with representatives of various medical research institutions, and place them in contact if necessary with local public health agencies in the interests of safeguarding the health of the local population.

"8. The USSR Ministry of Health representative shall be authorized to verify and clarify the correctness of data on radiation levels provided to the test site's command by dosimetric inspectors and laboratories of all departments.

"9. To ensure efficiency in the performance of the objectives assigned to the USSR Ministry of Health representative, and to verify and monitor the completeness and accuracy of performance of scheduled public security and safety plans and measures, the test site's command shall place the necessary vehicles and communications equipment at his disposal.

"10. During the course of testing, the USSR Ministry of Health representative shall inform the Test Director of the work he is performing, and upon completion of the work, shall write a report, one copy of which he shall send through the USSR Ministry of Defense to the USSR Minister of Health."

The head of the USSR Ministry of Health's Third Main Directorate, Avetik I. Burnazyan, sent special letters to the supervisors of nuclear test sites. These letters set forth the basic powers and duties of the responsible representative of the USSR Ministry of Health on the testing administration. They specified:

"In his work to assess radiation levels with respect to the population of areas adjacent to nuclear weapon test sites, the USSR Ministry of Health representative shall be guided by 'Temporary Maximum Allowable Outdoor Exposure Doses and Maximum Allowable Levels of Contamination of Food

> Products, Water, Air, and Various Systems by Radioactive Substances,' approved by Avetik I. Burnazyan on August 22, 1958 and endorsed by K. N. Pavlovsky on September 5, 1958."

It went on to specify that in the event that several radioactive plumes overlapped, the total outdoor and indoor exposure dose (due to consumption of contaminated food, water, and air) for residents of a single village or town should not exceed 2 roentgens per year.

Special attention was paid to the USSR Ministry of Health representative's participation in the discussion of the results of prediction of the possible radiation levels that could occur after a particular nuclear test.

Predicting ground radioactive contamination in nuclear tests was very important for ensuring the radiation safety of test participants and the public. Predictions drew upon the characteristics of the explosion (in particular the yield of the nuclear physics package) and the weather conditions, with mandatory determination of the wind direction and speed at various altitudes from the ground surface to the altitude reached by the top of the cloud, as well as the estimated role of atmospheric precipitation. The results of the prediction of the scale and level of ground radioactive contamination were compared with allowable doses and radiation levels that had been set for the period of the specific test.

Calculations, using relations set forth in special manuals and references, could determine the expected maximum radiation level (radiation dose rates) at the center or at ground zero and the exposure doses of test participants when they crossed the area around ground zero in vehicles with various shielding factors, and estimate the degree of contamination and the sizes of areas with various doses until complete decay of radioactive substances along the path of the explosion cloud. Due to errors in measurements of wind speed and direction, as well as its variability in time and space during plume formation, the effects of precipitation and topography, and other factors, the actual radiation levels often differed substantially from those predicted. This necessitated constant remeasurement of radiation levels. Using aircraft and ground vehicles, radiation surveys of the entire depth of the local radioactive contamination plume were conducted. In addition, in areas subject to radioactive fallout, radiation-safety inspections were arranged for the purposes of protective measures aimed at reducing public outdoor and indoor exposure doses.

The bases for hygienic assessment of radiation levels were regulations that defined the maximum allowable exposure levels and maximum allowable concentrations (MACs) of radioactive substances in food products, drinking water, and air. In winter, a somewhat higher ground contamination by radioactive substances was permitted because of the greater role of the shielding properties of buildings, where man spends most of his day. Moreover, the likelihood that radioactive substances will enter the body with food is considerably reduced in winter, since the food is made with products collected previously from the fields and gardens in storehouses and warehouses, and dairy cattle are not grazed in outdoor pastures.

Special attention in pinning down radiation levels was paid to villages and towns contaminated by radioactive substances. In such cases, detailed ground γ surveys were performed using field dosimeters, and the levels of radioactive contamination of all environmental systems and exposure doses were determined.

We should note that issues of radiation safety assurance during nuclear tests at the Semipalatinsk Test Site occupied the center of attention, both of the site director and his staff and of the USSR Ministry of Health's Third Main Directorate. Nearly every test was attended by its head, Avetik I. Burnazyan, along with leading specialists from the Institute of Biophysics, who interpreted data on the radioactive contamination of environmental systems, exposure doses of test participants and the public, and drew conclusions on the possible effect of ionizing radiation on human health.

The test site's Radiation Safety Service, although it was not directly subordinate to Avetik I. Burnazyan or other representatives of the USSR Ministry of Health, was still guided completely in its practical work by their recommendations and instructions. Thanks to his official position, authority, and personal relationship with Igor V. Kurchatov and other leaders of the nuclear program, Avetik I. Burnazyan was continually kept abreast of all problems facing the site's Radiation Safety Service, and helped it resolve many organizational and procedural issues.

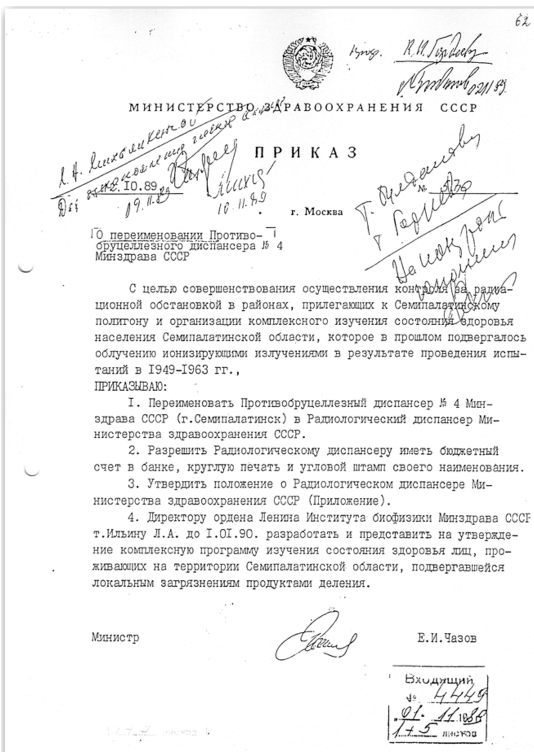
The USSR Ministry of Health representative, in addition to performing the duties described above, had to provide operational supervision of Clinic No. 4 at the test site.

There is no doubt, and this must be admitted, that it is difficult to overestimate the role and importance of the practical activity of the USSR Ministry of Health representative for the nuclear test administration in the cause of assuring the general and radiation safety of test participants and the public.

CLINIC NO. 4'S EXAMINATIONS OF PEOPLE LIVING IN ADJACENT AREAS

In 1957, the USSR Ministry of Health, in order to systematically monitor radiation levels and the health status of residents of contaminated areas, created two clinics: Clinic No. 3 in Ust-Kamenogorsk attached to Medical-Sanitary Unit No. 22 and Clinic No. 4 in Semipalatinsk. Each clinic would organize a clinical ward and a biophysical and other laboratories.

Since the level of ground radioactive contamination had declined considerably by 1960, and radiation levels had stabilized, it was decided to close Clinic No. 3.



МИНИСТЕРСТВО ЗДРАВООХРАНЕНИЯ СССР

ПРИКАЗ

г. Москва

О переименовании Противобруцеллезного диспансера № 4 Минздрава СССР

С целью совершенствования осуществления контроля за радиационной обстановкой в районах, прилегающих к Семипалатинскому полигону и организации комплексного изучения состояния здоровья населения Семипалатинской области, которое в прошлом подвергалось облучению ионизирующими излучениями в результате проведения испытаний в 1949-1963 гг.,

ПРИКАЗЫВАЮ:

1. Переименовать Противобруцеллезный диспансер № 4 Минздрава СССР (г.Семипалатинск) в Радиологический диспансер Министерства здравоохранения СССР.

2. Разрешить Радиологическому диспансеру иметь бюджетный счет в банке, круглую печать и угловой штамп своего наименования.

3. Утвердить положение о Радиологическом диспансере Министерства здравоохранения СССР (Приложение).

4. Директору ордена Ленина Института биофизики Минздрава СССР т.Ильину Л.А. до 1.01.90. разработать и представить на утверждение комплексную программу изучения состояния здоровья лиц, проживающих на территории Семипалатинской области, подвергавшейся локальным загрязнениям продуктами деления.

Министр Е.И.Чазов

Входящий

Figure 25. The USSR Minister of Public Health's Order renaming Clinic No. 4.

Clinic No. 4, created by USSR Ministry of Health Order 26s of March 26, 1956, operated under the name "Antibrucellosis Clinic No. 4 of the USSR Ministry of Health." In 1989, USSR Minister of Health Yevgeny Ivanovich Chazov ordered Clinic No. 4 renamed as the Radiology Clinic of the USSR Ministry of Health. Figure 25 shows a copy of the order.

The first staff of Clinic No. 4 were recruited in 1957 from the garrison military hospital in Semipalatinsk during the period when the USSR Ministry of Health's Comprehensive Expedition No. 3 was working on the territory of Semipalatinsk Region. A. N. Katkova was appointed Chief Physician of

Clinic No. 4, L. A. Zorina was appointed staff internist, G. G. Yorkh was placed in charge of the Biophysics Laboratory, V. I. Kozhin was named chief biochemist, and M. V. Stepucheva was appointed staff hematologist. All positions on the secondary, junior, technical, and custodial staffs were filled. For the times, the clinic was equipped with everything it needed—top-line medical equipment, janitorial and custodial tools and supplies, as well as special equipment. All clinic employees were given the requisite theoretical, methodological, and practical training.

The clinic was charged with tasks involving the study and assessment of radiation-safety conditions in areas adjacent to the Semipalatinsk Test Site, with assessing the extent of the effects of nuclear testing on public health, and with performing scientific research and practical work to ensure public radiation safety.

The research done by this atypical scientific-practical and treatment-and-prevention institution was carried on under the supervision of the Institute of Biophysics. For this purpose, the Head of the USSR Ministry of Health's Third Main Directorate, in his Order 18s of December 9, 1975, created the "Section of the Institute of Biophysics Learned Council for Coordination of the Scientific Research and Practical Work of Clinic No. 4." Its chairmen were Professors V. G. Ryadov and K. I. Gordeyev, and its learned secretary was L. A. Mikhalikhina (Logacheva).

The supervisors of practically all scientific research in the clinic were scientists and specialists from the USSR Ministry of Health's Institute of Biophysics: Angelina Konstantinovna Guskova, P. I. Burenin, K. I. Gordeyev, V. G. Ryadov, N. G. Darenskaya, V. A. Logachev, M. M. Saurov, and others. Most of the research reports from Clinic No. 4, as well as the chief physician's annual reports, were discussed at meetings of the Council Section. So practically all reports from this institution, dissertations by its specialists, and annual reports of its chief physician on the work of the clinic (enterprise V-8375) are in the archives of the Institute of Biophysics (now the RF State Research Center/Institute of Biophysics). The chief physician's annual reports reflect the results of all the clinic's units (clinical, radiation safety, etc.), with the focus being on issues of radiation levels and the extent of its effect on public health.

USSR Minister of Health Order 643 of December 4, 1989 placed Clinic No. 4 under the Kazakh SSR Ministry of Health. USSR Deputy Minister of Health Gennady Vasilyevich Sergeyev announced the decision November 22, 1989 at a rally in Semipalatinsk.

This institution operated as a clinic until 1992, when a decision by the Republic of Kazakhstan Ministry of Health—that is, after the breakup of the USSR—reorganized it into a specialized institute: the Institute of Radiation Medicine and Ecology (*IRMiE*).

After resolving personnel issues and equipping its laboratories as necessary, Clinic No. 4 began research under its program to study the long-term effects of exposure to low doses of radiation on the human body. To this end, it enrolled 10,000 people from three districts in Semipalatinsk Region (Abay, Beskaragay, and Zhana-Semey) whose lands had been contaminated by radioactive fallout during the period of atmospheric nuclear testing. About 12-15% of the populations of these districts had been exposed to radiation, with exposure doses ranging from 20 to 150 cSv. For comparison with the research results, an adequate control group of the same size was selected. The control group was made up of persons who lived in the same villages and towns, but moved there at times that ruled out the possibility of exposure, as well as persons who had lived in those villages and towns for at least five years.

We should note that for a long time, Clinic No. 4 operated a 15- to 20-bed inpatient facility for examining residents of the most contaminated towns (Dolon, Sarzhal, Kaynar, Kara-Aul, etc.). The organization of the inpatient facility and selection of the clinic's staff was largely accomplished by its Chief Physician, S. I. Makerova, who replaced A. N. Katkova in the position.

Inpatient examinations were performed using the time's most modern specialized laboratory methods. For example, it was learned by analyzing daily excretions (stool, urine) that the bodies of 42 persons from these villages and towns contained radioactive substances. It was also noted that in 50% of the examinees, the activity of daily excretions ranged from trace amounts to 14 nCi (after subtraction of the natural ^{40}K concentration).

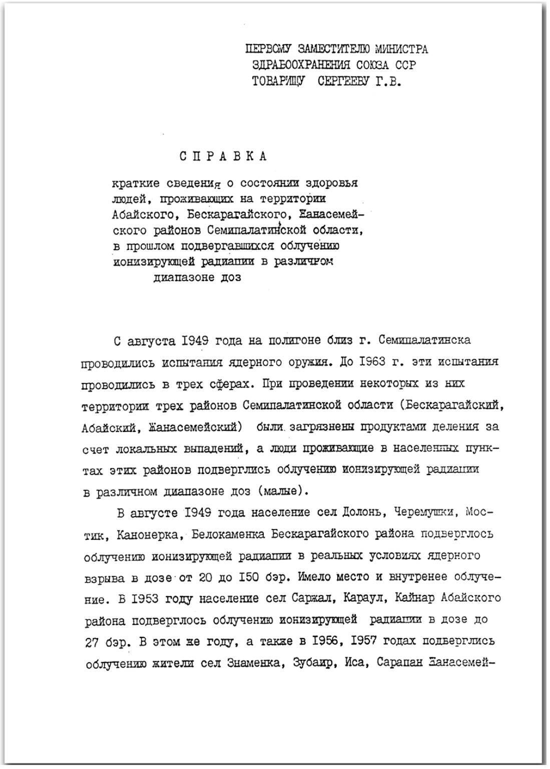
The results of dynamic monitoring of the concentration of radioactive substances in the daily excretions of patients at Clinic No. 4 indicated that within the first 2-5 days at the clinic, the activity of excretions declined considerably, reaching background values thereafter. This indicated the low solubility of the radioactive substances in bodily fluids, and also that they were ingested with locally produced food and subsequently passed through the gastrointestinal tract.

The various medical specialists at Clinic No. 4 constantly noted that differential diagnosis of common diseases (brucellosis, tuberculosis, rheumatism, etc.) and the sequelae of radiation exposure was made very difficult by the commonness of syndromes and symptoms. In many cases, even after admitting patients, the doctors could not finally discover the etiologies of functional disturbances of the nervous system or changes in blood counts. This was confirmed by analysis of quoted excerpts from case histories of residents of most of the inspected villages and towns.

The organization and methodology of all important scientific research performed at Clinic No. 4, was supervised by P. I. Burenin. This research entailed painstaking analysis of the medical and demographic characteristics of the study area. Researchers accounted for complex ethnic and age characteristics of the rural and urban population, previous trends in the structure of cancer morbidity, and many other factors, using appropriate mathematical tools to process the data. Leading specialists from Clinic No. 4—B. I. Gusev, N. I. Kaymak, T. S. Bukhtiyarova, Zh. Zh. Satkembayev, G. I. Kovretsky, R. B. Leongart, L. A. Blagov, and others—participated actively in these studies, as did Institute of Biophysics specialists M. Ya. Tereshchenko, A. K. Nikiforova, and others.

Analysis of the results of many years' dynamic medical research conclusively showed that there were no differences in the health status of persons in the main groups of both adults and children exposed to doses of less than 100 cSv and control groups. Only some persons exposed to more than 100 cSv exhibited cytogenetic markers of radiation exposure. Quite a few people showed signs of a certain decline in natural immunity. Due to the prevalence of middle-aged people in the main group, many showed signs of involutional processes (atherosclerosis) with fairly marked disturbances of hemodynamics. We should note that throughout the entire period of research, clinicians experienced certain difficulties in interpreting the results and establishing precise cause-effect links between the radiation factor and measurable disturbances in the health status of the monitored persons. The heavy general somatic background, with elements of marginal pathology (brucellosis, parasitic infections, vitamin deficiency, etc.) prevented reliable discovery of the extent of the radiation effect.[75]

Over the 35 years of its operation as a "special institution," that is, from the date it was formed until the breakup of the USSR, Clinic No. 4 examined some 20,000 persons from the most contaminated districts of Semipalatinsk Region. This number included persons from the control group as well, which numbered some 10,000. The health of 2000 children born of exposed parents was continuously monitored.



ПЕРВОМУ ЗАМЕСТИТЕЛЮ МИНИСТРА
ЗДРАВООХРАНЕНИЯ СОЮЗА ССР
ТОВАРИЩУ СЕРГЕЕВУ Г.В.

С П Р А В К А

краткие сведения о состоянии здоровья людей, проживающих на территории Абайского, Бескарагайского, Жанасемейского районов Семипалатинской области, в прошлом подвергавшихся облучению ионизирующей радиапии в различном диапазоне доз

С августа 1949 года на полигоне близ г. Семипалатинска проводились испытания ядерного оружия. До 1963 г. эти испытания проводились в трех сферах. При проведении некоторых из них территории трех районов Семипалатинской области (Бескарагайский, Абайский, Жанасемейский) были загрязнены продуктами деления за счет локальных выпадений, а люди проживающие в населенных пунктах этих районов подверглись облучению ионизирующей радиапии в различном диапазоне доз (малые).

В августе 1949 года население сел Долонь, Черемушки, Мостик, Канонерка, Белокаменка Бескарагайского района подверглось облучению ионизирующей радиапии в реальных условиях ядерного взрыва в дозе от 20 до 150 бэр. Имело место и внутренее облучение. В 1953 году население сел Саржал, Караул, Кайнар Абайского района подверглось облучению ионизирующей радиапии в дозе до 27 бэр. В этом же году, а также в 1956, 1957 годах подверглись облучению жители сел Знаменка, Зубаир, Иса, Сарапан Жанасемей-

Figure 26. The first page of B. I. Gusev's report.

During the life of Clinic No. 4, its specialists prepared 147 research reports, conducted 78 radiation-safety inspections of contaminated lands, wrote and published 22 articles in various medical journals, and defended nine candidate's dissertations on biomedical issues.

S. I. Makerova was replaced as Chief Physician of Clinic No. 4 by L. P. Sgibneva, who in turn yielded to Candidate of Medicine B. I. Gusev, a neuropathologist who began working at the clinic in 1962 after graduating from Semipalatinsk Medical Institute. Gusev headed the clinic from August 10, 1976 until the breakup of the USSR, and supervised a large volume of work.

Certain summary documents of the time, which assessed the extent of the effects of nuclear testing on public health, are of indisputable interest.

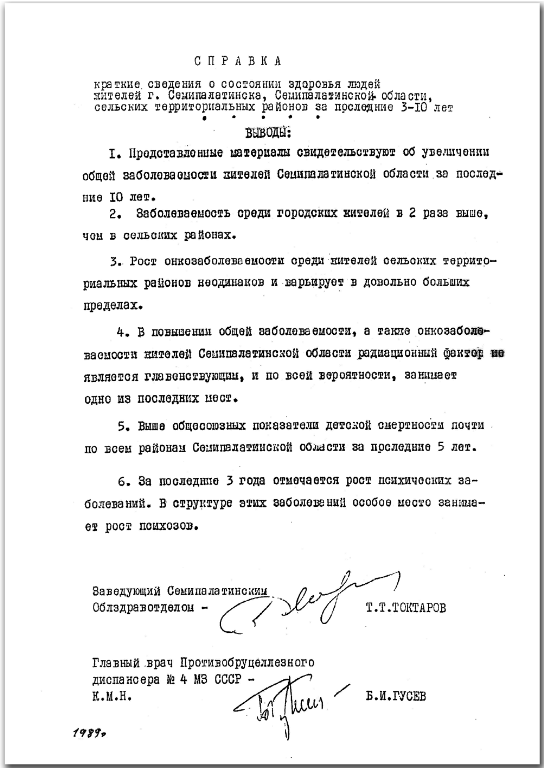
For example, in 1990, B. I. Gusev submitted a report to USSR First Deputy Minister of Health Gennady V. Sergeyev entitled, "Overview of the Health Status of Persons Residing on the Territories of Abay, Beskaragay, and Zhana-Semey Districts, Semipalatinsk Region Previously Exposed to Ionizing Radiation at Various Dose Ranges" (Figure 26), the full text of which is given in Appendix A. In the report, B. I. Gusev writes that residents of districts other than Abay, Beskaragay and Zhana-Semey Districts, "were not exposed to ionizing radiation" as a result of local ground contamination by fission products. He further notes that "not one case of acute or chronic illness has been discovered; no dose dependence of the number of chromosome aberrations can be seen," that is, the biological dosimetry showed nothing.

The report presented the following conclusions:

> *"1. The health status of persons exposed to ionizing radiation in the past at doses up to 100 rems* [one sievert] *is indistinguishable from that of the control groups of the population over the entire 30-year monitoring period.*
>
> *"2. Slight disturbances in natural immunity, cytogenetic effects, accelerated aging processes, and excess mortality were found in a small group of the population who had been exposed to ionizing radiation at doses up to 150 rems. The excess cancer mortality in these groups was 6.6 cases per million.* [Author's note: this figure is within the statistical error of calculation]
>
> *"3. Morbidity among children directly exposed to ionizing radiation, and among children born of exposed parents, does not differ significantly over all the years of research from the same measures for the control groups.*
>
> *"4. The mortality of children under one year of age exposed to radiation or born of exposed parents remained above the control values throughout the 25-year monitoring period."*

But a year earlier, in 1989, the head of the Semipalatinsk Regional Health Department, T. T. Toktarov, and the clinic's Chief Physician had submitted a report to the Kazakh SSR Ministry of Health entitled, "Overview of the Health Status of Residents of Semipalatinsk, Semipalatinsk Region, and Rural Territorial Districts in the Last 3-10 Years" (Figure 27), which drew the following conclusions:

> *"1. The information contained herein indicates a rise in the total morbidity of residents of Semipalatinsk Region in the last 10 years* [Author's comment: This was typical throughout the former USSR at the time].
>
> *"2. Morbidity is twice as high among urban residents as in rural districts.*
>
> *"3. The rise in cancer morbidity among residents of rural districts is irregular and varies over a fairly large range.*
>
> *"4. Radiation is not the dominant factor in the rise in general and cancer morbidity among residents of Semipalatinsk Region, and in all likelihood occupies one of the lower positions.*



СПРАВКА

краткие сведения о состоянии здоровья людей
жителей г. Семипалатинска, Семипалатинской области,
сельских территориальных районов за последние 3-10 лет

ВЫВОДЫ:

1. Представленные материалы свидетельствуют об увеличении общей заболеваемости жителей Семипалатинской области за последние 10 лет.

2. Заболеваемость среди городских жителей в 2 раза выше, чем в сельских районах.

3. Рост онкозаболеваемости среди жителей сельских территориальных районов неодинаков и варьирует в довольно больших пределах.

4. В повышении общей заболеваемости, а также онкозаболеваемости жителей Семипалатинской области радиационный фактор не является главенствующим, и по всей вероятности, занимает одно из последних мест.

5. Выше общесоюзных показатели детской смертности почти по всем районам Семипалатинской области за последние 5 лет.

6. За последние 3 года отмечается рост психических заболеваний. В структуре этих заболеваний особое место занимает рост психозов.

Заведующий Семипалатинским
Облздравотделом – Т.Т.ТОКТАРОВ

Главный врач Противобруцеллезного
диспансера № 4 МЗ СССР –
К.М.Н. Б.И.ГУСЕВ

1989г

Figure 27. T. T. Toktarov's Report, "Overview of the Health Status of Residents of Semipalatinsk, Semipalatinsk Region, and Rural Territorial Districts in the Last 3-10 Years."

"5. Measures of child mortality have exceeded Union averages in nearly all districts in Semipalatinsk Region for the last five years.

"6. In the past three years, we have seen a rise in mental illness. The rise in psychoses is espec-ially strong."

Naturally, these two documents are of great interest, from both the scientific and the historic standpoints.

We must note that specialists from Clinic No. 4 made a great contribution to the study of the effects of nuclear testing at the Semipalatinsk Test Site and to protecting the health of the people residing in adjacent districts whose territories had been contaminated by radioactive fallout.

In addition to the independent work to assess the extent of the effects of nuclear testing on public health, employees of Clinic No. 4 participated actively in all work by the USSR Ministry of Health's comprehensive expeditions, during which they examined residents of the most contaminated villages and towns.

AIMS, OBJECTIVES, AND RESULTS OF COMPREHENSIVE MEDICAL EXPEDITIONS OF THE USSR MINISTRY OF HEALTH

After the ground nuclear explosion of August 24, 1956, the USSR Ministry of Health received reports of radioactive contamination of the territories of certain districts adjacent to the Semipalatinsk Test Site. The leaders of the USSR Ministry of Health's Third Main Directorate responded by organizing the first comprehensive medical expedition to examine the residents of the contaminated districts. USSR Minister of Health Mariya D. Kovrygina was personally involved in organizing the expedition and in directly inspecting the conditions in the region.[9,76]

Two teams of specialists from the Institute of Biophysics were sent to these areas for additional confirmation of their radiation safety status.

The first team of specialists arrived at its destination in Ust-Kamenogorsk, East Kazakhstan Region, on September 6, 1956, and the second arrived in the same Semipalatinsk Region and at the test site on September 21, 1956. The two teams comprised a single group headed by A. N. Marey. The group collaborated with specialists and medical professionals from the Semipalatinsk Test Site.

The USSR Ministry of Health's first expedition laid the foundation both for systematic comprehensive medical examination of the population residing in contaminated areas and for inspection of these areas to assess their radiation-safety status.

The participants in the USSR Ministry of Health's first expedition were given the following tasks:

1. Assess the scale and extent of radioactive contamination of environmental systems (soil, water, vegetation, etc.) in the local plume produced by the explosion of August 24, 1956;
2. Determine the level of contamination of grain and decide whether it could be milled into flour products and consumed as food;
3. Assess the health status of the residents of contaminated areas.

To accomplish these objectives, the expedition participants took measurements of γ dose rates on the territories of the inspected districts and inside residences, collected soil, grain, plant, and produce samples for later measurement of their concentrations of radioactive substances. Sample medical examinations of the public consisted of clinical (outpatient) examinations by internists and neuropathologists, a gynecologist, and other specialists, as well as blood studies and radiometric measurements of bodily excretions (urine and stool).

Beginning in 1956, the Third Main Directorate organized a total of six such comprehensive expeditions, whose work included medical examinations of the residents of villages and towns and assessments of radiation levels and health conditions in the most contaminated areas of western East Kazakhstan and Semipalatinsk Region, southern Pavlodar

Region, and eastern Karaganda Region of Kazakhstan. Table 12 lists all the USSR Ministry of Health's comprehensive expeditions and their service areas.

In addition to specialists from the Institute of Biophysics, the USSR Ministry of Health's Third Main Directorate, the nation's Central Epidemiological Station, and the USSR Ministry of Defense, the work of the comprehensive medical expeditions also involved employees from the Kazakh SSR Academy of Sciences' Institute of Marginal Pathology (research directors B. A. Atchabarov, S. B. Balmukhanov), as well as employees from the office of a Dr. Aldynazarov, the Kazakh SSR Ministry of Health's Chief Radiologist, and from the Republic Public Health Station and other institutions of the Kazakh SSR.

Unfortunately, the tendentious position of certain specialists at the Kazakh SSR Academy of Sciences' Institute of Marginal Pathology promoted the appearance of certain positions in reports on the expeditions' work that did not agree with objectively analyzed data previously obtained and facts that had been verified many times. These positions and discussions of them led to an exaggeration of the extent of the effects of radioactive contamination on local public health against the background of many other unfavorable factors of decisive importance.

We should note that during the work of the comprehensive expeditions, a broad area of districts adjacent to the Semipalatinsk Test Site was inspected, some 30,000 environmental samples were collected and analyzed at 140 inspected villages and towns, and residents of the most contaminated villages and towns were medically examined.[73,75,77-80] The results enabled scientists to characterize radiation levels in each district and the extent of their effects on residents' health.

During the course of dynamic comprehensive monitoring of the same groups of people over several years, researchers identified a certain "oscillation" in the frequency of complaints and objective symptoms. They rose somewhat during 1956 and 1957, then began to decline by 1958. This type of trend was observed, for example, among examined residents of the town of Znamenka, Semipalatinsk Region, where a similar trend was noted in neurological changes. A decline in the frequency of cases of autonomic-vascular dysfunction and asthenic-autonomic manifestations was noted in 1958 versus 1957, along with a certain increase in the number of persons exhibiting no neurological illness. Inpatient examinations of residents confirmed the results of outpatient examinations and enabled clarification of previous diagnoses.

Table 12. List of Comprehensive Expeditions and Principal Areas of Medical Examinations of the Public and Radiation Safety Inspections of Contaminated Territories Near the Semipalatinsk Test Site

Year	Examining Organization, Supervisors and Examiners in Charge	Expedition Service Area	Principal Villages and Towns Where Examinations Were Performed	Total Samples and Analyses	Remarks
1949	Third Main Directorate, USSR Ministry of Health: Avetik I. Burnazyan, N. I. Shalnov, K. S. Kalugin	Semipalatinsk Region, Altai Territory	Biysk, Altai Territory	—	Plume survey, γ survey, sample analysis, dose calculation
1951	Third Main Directorate, USSR Ministry of Health: Avetik I. Burnazyan, N. I. Shalnov	Semipalatinsk Region	Kaynar and other towns	—	Plume survey, γ survey, sample analysis, dose calculation
1953	Third Main Directorate, USSR Ministry of Health: Avetik I. Burnazyan, N. I. Shalnov	Semipalatinsk Region	Taylan, Abay (Kara-Aul), Sarzhal	—	Plume survey, γ survey, sample analysis, dose calculation
1956	Expedition No. 1, USSR Ministry of Health: A. N. Marey, F. K. Levochkin, I. B. Keirim-Markus	East Kazakhstan, Semipalatinsk Regions	Ust-Kamenogorsk (and suburbs), Semipalatinsk, Znamenka, Abay (Kara-Aul)	3379	Gamma survey, sample analysis, dose calculation, examinations of the public

Year	Examining Organization, Supervisors and Examiners in Charge	Expedition Service Area	Principal Villages and Towns Where Examinations Were Performed	Total Samples and Analyses	Remarks
1957	Expeditions No. 2 and 3, USSR Ministry of Health: A. F. Kobzev, A. I. Shorokhov.Establishment of Clinics No. 3 (Ust-Kamenogorsk) and 4 (Semipalatinsk)	East Kazakhstan, Semipalatinsk Regions	Ust-Kamenogorsk, Semipalatinsk, Znamenka, Abay (Kara-Aul), Sarzhal (Telman Collective Farm)	592	Two expeditions: February-March and May-July. Organization of Clinics No. 3 and 4
1957	Clinic No. 3, USSR Ministry of Health	East Kazakhstan Region	Ust-Kamenogorsk, Zyryanovsk, Shemonaikha, Verkh-Uba, Bolshe-Narynsk, Leninogorsk, Belousovka, Vinnoye	1640	Gamma survey, sample analysis, dose calculation, examinations of the public
1957	Clinic No. 4, USSR Ministry of Health	Semipalatinsk Region	Semipalatinsk, Novopokrovka, Znamenka, Shelekhovo, Bel-Agach, Sarzhal, Urjar, Aksakovka	1725	Gamma survey, sample analysis, dose calculation, examinations of the public

Year	Examining Organization, Supervisors and Examiners in Charge	Expedition Service Area	Principal Villages and Towns Where Examinations Were Performed	Total Samples and Analyses	Remarks
1958	Expedition No. 4, USSR Ministry of Health; USSR Ministry of Defense: A. F. Kobzev, N. S. Prosyannikov, A. I. Shikhodyrov, Yu. S. Stepanov, Angelina K. Guskova, Yu. N. Degtyarëv	East Kazakhstan, Semipalatinsk, Pavlodar, Karaganda Regions	Ust-Kamenogorsk, Kanayka, Shemonaikha, Semipalatinsk, Sarzhal, Znamenka, Abay (Kara-Aul), Dolon, Semiyarskoye, Mostik, 30th Anniversary of Kazakhstan Collective Farm, Abay State Farm, Shoptykul	5040	Some residents of Town M (Kurchatov) were examined, including 46 children. In 1959, these towns were transferred from Pavlodar Region to Semipalatinsk Region
1958	Clinic No. 3, USSR Ministry of Health	East Kazakhstan Region	Ust-Kamenogorsk, Zyryanovsk, Novaya Bukhtarma, Kanayka, Belousovka, Verkh-Uba	2028	Gamma survey, sample analysis, dose calculation, examinations of the public
1958	Clinic No. 4, USSR Ministry of Health	Semipalatinsk Region	Semipalatinsk, Makanchi, Glukhovka, Belokamenka, Znamenka, Sarzhal, Urjar	2546	Gamma survey, sample analysis, dose calculation, examinations of the public

Year	Examining Organization, Supervisors and Examiners in Charge	Expedition Service Area	Principal Villages and Towns Where Examinations Were Performed	Total Samples and Analyses	Remarks
1959	Expedition No. 5, USSR Ministry of Health; USSR Ministry of Defense and Academy of Sciences; Ministry of Health of the former Kazakh SSR: A. F. Kobzev, Angelina K. Guskova, Yu. S. Stepanov, S. B. Balmukhanov	Semipalatinsk Region	Sarzhal, Abay (Kara-Aul), Dolon, Yernazar, Semënovka, Shadrinsk, Kaynar	2000	Gamma survey, sample analysis, dose calculation, examinations of the public. Mapping of radioactive plumes off the test site grounds
1959	Clinic No. 3, USSR Ministry of Health	East Kazakhstan Region	Ust-Kamenogorsk, Leninogorsk, Severnoye, Kanayka, Belousovka, Bobrivka	5595	Gamma survey, sample analysis, dose calculation, examinations of the public
1959	Clinic No. 4, USSR Ministry of Health	Semipalatinsk Region	Semipalatinsk, Kaynar, Dolon, Novopokrovka, Sarzhal, Urjar	2031	Gamma survey, sample analysis, dose calculation, examinations of the public
1960	Expedition No. 6, USSR Ministry of Health; USSR Ministry of Defense: A. F. Kobzev, Angelina K. Guskova, Yu. S. Stepanov, V. I. Dus	Semipalatinsk, Pavlodar Regions	Ayaguz, Sarzhal, Abay (Kara-Aul), Dolon, Kaynar, Zhanin, Znamenka, Mayskoye, Zhamantuz	> 2500	214 radiochemical analyses performed. Route auto γ survey 2700 km long. Examination of 75 children residing in Kurchatov

Year	Examining Organization, Supervisors and Examiners in Charge	Expedition Service Area	Principal Villages and Towns Where Examinations Were Performed	Total Samples and Analyses	Remarks
1961	Clinic No. 4, USSR Ministry of Health	Semipalatinsk Region	—	—	Gamma survey, sample analysis, dose calculation, examinations of the public
1962	Summary conference on results of comprehensive expeditions: V. N. Pravetsky, A. F. Kobzev, Angelina K. Guskova, A. I. Shorokhov, Yu. S. Stepanov, S. B. Balmukhanov	Principal areas of radioactive contamination		—	Disagreements arose with employees of Institute of Marginal Pathology, Kazakh SSR Academy of Sciences, over assessment of radiation levels and effect of radioactive substances on public health
1962	Clinic No. 4, USSR Ministry of Health: S. I. Makerova, Yu. S. Stepanov	Semipalatinsk and Pavlodar Regions, Altai Territory		—	Gamma survey, radiochemical analyses, dose calculation
1965	Clinic No. 4, USSR Ministry of Health: A. N. Marey, Ivan Yakovlevich Vasilenko, Yu. S. Stepanov	Semipalatinsk Region, area near manmade lake on Shagan River	Sarapan, Iirbala, Beysen, Shcherbakovka, Znamenka	> 1500	Calculation of public exposure dose. Radiation safety studies

Year	Examining Organization, Supervisors and Examiners in Charge	Expedition Service Area	Principal Villages and Towns Where Examinations Were Performed	Total Samples and Analyses	Remarks
1989	Clinic No. 4 of the USSR Ministry of Health; Comprehensive Research Expedition under Anatoly F. Tsyb	Semipalatinsk Region	Semipalatinsk, Kurchatov, other villages and towns	—	Assessment of radiation levels and their effect on public health

The most important result of the expeditions' work was that neither the STS doctors who examined the most contaminated villages and towns in the first days and weeks after the fallout of radioactive substances (Dolon in 1949, Sarzhal and Kara-Aul in 1953, etc.), nor the employees of local public health agencies, together with employees of Clinics No. 3 and 4, who continuously tracked the status of public health, nor the participants in comprehensive medical expeditions found any acute or chronic radiation sickness in the contaminated villages and towns.

A certain practically insignificant trend was noted in measures of the peripheral blood. Both early and late markers of exposure to ionizing radiation such as an increase in the number of chromosomal aberrations in lymphocytes were detected.

However, thorough examinations of the public performed during comprehensive medical expeditions consistently revealed various changes in the function of certain physiological systems. The most frequent changes were seen in the cardiovascular system and the gastrointestinal tract. These changes were especially interesting since they could also be observed in radiation sickness. However, the presence of similar changes in residents who had lived outside the areas of radioactive contamination (in workers at an automobile repair plant in Tomsk, one of the control groups; in residents of the uncontaminated part of Kuva District, Karaganda Region, etc.) means we cannot consider the effects of radioactive contamination the sole cause of these changes.

Of special interest were manifestations of hemorrhagic syndrome such as increased vascular fragility, bleeding gums, nosebleeds, etc., which were found in some of the people living in contaminated areas. Because hemorrhagic manifestations in the inspected areas generally were not accompanied by other changes typical of chronic radiation sickness, they cannot justify a link to the effects of ionizing radiation. At the same time, increased vascular fragility and loose and bleeding gums are among the early signs of Vitamin C deficiency. In view of the dietary deficiencies and the lack of fruits and vegetables, it is more realistic to regard these symptoms found in the population of contaminated and "clean" areas as signs of Vitamin C deficiency.

Later, R. S. Babayants discovered other signs as well (fissures in the corners of the mouth, dryness and thinning of the oral mucosa and lips) that result from Vitamin B_2 deficiency. Correction of these disorders was suggested on reexamination.

Dynamic observations of a strictly selected contingent offered clarity in resolving the question of the role of long-term consequences (sequelae) of radiation exposure. The results of these observations indicated that the likelihood of similar sequelae was slight.

Special attention was paid to the analysis of data on the frequency of adenomas and tumors of the thyroid gland, both from the results of *in vivo* studies at cancer clinics and institutions where surgery was performed on the gland and *post mortem* studies (based on autopsies). Despite a certain level of exposure to iodine radionuclides produced in nuclear tests and the region's classification as an area of moderate goiter endemia, no increase in malignant neoplasms of the thyroid was detected.

P. I. Burenin's analysis of data on the frequency of tumors of various parts of the body as of 1987 showed a certain correlation between the frequency of malignant neoplasms (cancers) and distance from the site's Test Field for persons who had reached the age of 45-55 by that time. The structure of cancer morbidity was typical of areas adjacent to the test site. Similar studies should be done, both in the study and control areas.

The results of a comparison of data from clinical hematological and other examinations of the population performed from 1960 to 1965 show a normalization of the major indices of public health. However, there are grounds for supposing that in addition to sanitary-hygienic and household conditions, ground radioactive contamination in the area affected by nuclear testing at the Semipalatinsk Test Site has also influenced changes in certain clinical hematological indices observed during examinations.

Since both radiation factors and non-radiation-related factors, including social and lifestyle factors, have influenced public health, information on the sanitation and safety conditions under which the populations of areas located in nuclear fallout areas lived may naturally be of some interest.

HEALTH AND SAFETY CONDITIONS IN NEARBY AREAS

We must take special note of the fact that in nearly all villages and towns inspected by comprehensive expeditions of the USSR Ministry of Health from 1957 to 1960, the population was engaged in farming, the principal areas of which are agriculture and animal husbandry. Industrial enterprises were located mainly in regional capitals and their suburbs. For example, Ust-Kamenogorsk had a lead-zinc integrated mining works, a defense plant, and two lumber mills; the town of Ablaketka had the Ust-

Kamenogorsk Hydroelectric Power Station and was building a capacitor plant; Semipalatinsk had and still has a large meat packing plant, and is building a cement plant.

Analysis of documents from the comprehensive examinations allows us to state that sanitation and safety conditions, both in cities and rural areas, did not fully comply with health standards. Human health is known to be most directly linked to the person's ability to use adequate amounts of quality water. However, the water supply to residents of the inspected villages and towns was extremely unsatisfactory.

In the 1950s, Semipalatinsk Region had only 11 operational water lines, six of them in Semipalatinsk. However, the population of Semipalatinsk drew most of its water from surface springs, whose water practically complied with the 1954 State Standard (GOST) in chemical and bacteriological terms. In summer, when water suppies were low, the city residents were forced to draw water directly from the Irtysh and Semipalatinka Rivers. Chemical and bacteriological analysis of the water from these rivers showed heavy pollution by sewage (oxidizability 32.3 mg/l, ammonia content 0.14 mg/l, particulates 24 mg/l). The principal river polluters were two sewer mains operating at the time: a general municipal sewer and a meat packing plant sewer, which lacked treatment facilities and discharged liquid waste straight into the rivers. Waste water from 38 of the city's industrial enterprises was also discharged untreated into the Irtysh River. This pollution adversely affected the water's biological status and was one cause of the increased intestinal infection morbidity of the population living along the river banks.[90,78,79]

The villages and towns of East Kazakhstan Region drew their water from shaft wells and open bodies of water—lakes, rivers, and springs. A regional capital such as Ust-Kamenogorsk lacked a common municipal water line, construction of which was not begun until 1953. The city drew its water from 19 local water lines that supplied water to only 40% of its residents. The principal sources of water were private wells and shafts 8-15-25 meters deep, as well as the Irtysh and Ulba Rivers, whose waters were chemically and bacteriologically substandard. Most of the river pollution resulted from the dumping of sanitary sewage and industrial waste water.[90]

The water lines operating in Ust-Kamenogorsk lacked a complete set of treatment structures; only 9 of the 19 water lines were equipped with chlorination systems. Continuous chlorination was performed only in

Ablaketka, where water was supplied to the public from underflow wells along the banks of the Irtysh River.

In chemical terms, the drinking tap water in Ust-Kamenogorsk and adjacent towns had reduced transparency (17-25 cm) and elevated turbidity (36-53 mg/l), oxidizability, hardness, and elevated levels of ammonia, nitrites, and nitrates (3 to 36 mg/l). Bacteriological water indices complying with the 1954 State Standard were maintained continuously in only six of Ust-Kamenogorsk's water lines. The remainder exhibited variations in coliform index, especially during the spring and summer, from 50 to 200. In public wells in the city and the region's rural towns, the water had coliform indices of 0.1 to 10, and in spring and summer, private wells fell below 0.1.

The water supply to most of the villages and towns in both Semipalatinsk and East Kazakhstan Regions, which came from springs, streams, and private and public wells, was extremely unsatisfactory. The wells hardly conformed to sanitary or hygienic requirements. Laboratory testing of water quality in the water sources in these districts was never performed.

Poor water quality was also noted in wells in villages and towns in Pavlodar and Karaganda Regions. Laboratory testing of water quality in bodies of water in these regions was also nonexistent.[90]

The air in the regional cities of Semipalatinsk and Ust-Kamenogorsk was heavily polluted by emissions from boiler rooms, thermal power stations, and various factories. According to data from public health stations in these cities, concentrations of many chemicals in the ambient air exceeded maximum allowable concentrations: lead by a factor of 30-300, arsenic by 2- to 5-fold, sulfuric anhydride by a factor of 3-66, etc.

The cities and towns of all four regions had very low proportions of asphalt pavement and street plantings, creating a very dusty environment. Streets were hardly ever washed or cleared of garbage, causing pollution with household wastes.[90]

The data on the extremely unsatisfactory sanitation and safety conditions of rural villages and towns are noteworthy. Rural areas had no baths, municipal services, regular garbage pickups, or clean water (since wells were hardly ever cleaned), and the population ate poorly and inefficiently.

The maintenance of human health is known to depend heavily on the makeup, quality, and calorie content of food. Diet is a critical factor in the development of several diseases of the digestive organs, as well as the occurrence of many endocrine disorders, diseases of the cardiovascular and excretory systems, congenital malformations, blood diseases, etc.[80,91]

The inspections revealed that the diets of both urban and rural residents was incomplete and monotonous. The staples were bread, meat, milk, and kumiss.[2] The diet, especially that of Kazakhs, contained practically no fruits or vegetables. The local population did not supply itself with fruits and vegetables because most of them lacked orchards or private gardens. Some of the residents engaged in nomadic livestock herding. Their diets were even less complete, and their living conditions were harsher.

Deliveries of foodstuffs, especially to rural areas, were irregular, and moreover, the produce delivered was less than ordered. For example, under existing standards, the residents of Semipalatinsk Region were allocated 30,000 metric tons of meat per year from 1956 to 1958, but only 2466 tons were actually sent in 1958; 134,000 tons of milk were allocated, but only 17,200 were delivered; 37,000 tons of fruit were allocated, but only 250 tons were delivered. Limits on fats, fish products, vegetables, candies and confections, and other products were low.

We must note here that for the entire nation, the 1950s were years of economic recovery after the difficult, exhausting war of 1941-1945, so the people shared many of these features of life and lifestyle with the population of the entire country.

However, in the later years, sanitation and safety conditions in the inspected areas left much to be desired, as shown by the work by a group of specialists under Academician Anatoly F. Tsyb in May 1989 in Semipalatinsk Region.[92] Their report noted:

> "… all rural areas lack sewers. The commercial operations of state farms are producing ubiquitous pollution of minor rivers and the Irtysh River.
>
> "We have discovered cases where cattle farms have not been cleaned since 1986. Chemicals are stored carelessly—in 95% of cases, in rooms poorly suited for the purpose; only a third of storehouses have sanitary areas. There is no proper accounting for chemicals—some have been kept since 1982-83. All this inevitably leads to pollution of water, soil, and feed. Pesticides in doses exceeding MACs are entering food products… The diet… does not conform to the principles of

[2]—Fermented mare's or camel's milk. Russian *kumys*, from Tatar *kumyz*.—*Trans.*

> efficient nutrition and is characterized by a marked shortage of animal products and orchard and garden produce and excessive consumption of flour and groat products…."[92]

Thus, analysis of information from comprehensive inspections of villages and towns whose territories had been contaminated in various years by radioactive substances after nuclear weapon tests at the Semipalatinsk Test Site has shown that the living conditions of residents of those villages and towns, specifically sanitation, hygiene and everyday life, did not conform to necessary health standards.

The inadequate municipal services in cities and especially in rural villages and towns, the lack of regular cleaning of their grounds, the nearly total lack of a sewer network, the low drinking water quality, and the incomplete, monotonous diet were causes of the high morbidity of gastro-intestinal and other chronic infections such as tuberculosis, brucellosis, syphilis, gonorrhea, trachoma, etc. Employees of public health stations in Semipalatinsk Region in 1957 admitted that nearly 45% of the population of inspected districts were suffering from brucellosis.

Clinical examination of the population by expedition doctors revealed that most residents of contaminated areas complained of gastrointestinal disorders. A study of data characterizing measures of general morbidity showed that in the territories of Semipalatinsk and East Kazakhstan Regions, the highest morbidity was that of intestinal infections.[16,17] The research doctors attributed to the people's poor sanitary habits, their consumption of substandard drinking water and monotonous incomplete diet, and unsatisfactory public medical service. Table 13 presents data on population morbidity in Semipalatinsk and East Kazakhstan Regions for various infectious and noninfectious diseases by etiology from 1955 to 1957.

The data indicate that in both regions, the most common illnesses were upper respiratory infections, flu, angina, measles, and scarlet fever; of the gastrointestinal diseases, the most common were dysentery, enteritis, and colitis. A certain decline in the acute dysentery morbidity in 1956 and 1957 is noteworthy. It can be explained by a partial improvement in the sanitation in certain contaminated villages and towns, an improvement in the detection and treatment of chronic dysentery after the work of the USSR Ministry of Health's first expedition in 1956, whose specialists noted the unsatisfactory work of local public health agencies as well as a practically complete lack of medical accounting and reporting, especially

Table 13. Measures of Population Morbidity for Various Infectious Diseases in Semipalatinsk and East Kazakhstan Regions in 1955-1957 (Based on Data from Regional Public Health Stations)

Disease	Cases per 10,000 Population					
	Semipalatinsk Region			East Kazakhstan Region		
	1955	1956	1957	1955	1956	1957
Acute Dysentery	88.0	61.0	71.0	131.3	73.9	70.7
Typhoid Fever	—	4.3	2.8	3.0	3.2	3.8
Paratyphoid Fever	—	1.2	1.0	—	0.4	0.5
Simple Dyspepsia	82.0	65.0	82.2	—	52.2	47.6
Toxic Dyspepsia	7.4	6.5	5.8	—	9.7	7.7
Enteritis or Colitis	85.0	81.0	96.0	—	53.3	54.0
Tick Typhus	—	—	0.1	0.15	0.2	0.3
Diphtheria	6.2	12.3	14.4	—	13.0	9.6
Scarlet Fever	39.6	16.5	10.4	—	44.6	23.0
Measles	88.0	52.6	63.4	—	72.6	128.9
Epidemic Hepatitis	—	16.5	12.1	—	15.6	15.8
Whooping Cough	—	42.4	14.7	—	43.8	50.6
Poliomyelitis	—	0.3	1.2	—	0.28	1.2
Angina	—	—	286.0	—	—	306.5
Viral Influenza	—	—	769.0	—	—	591.5
Upper Respiratory Infection	—	—	676.0	—	—	665.9

Note: Dashes represent a lack of data, since there was practically no medical accounting or reporting before 1956.

in rural areas. From our viewpoint, the true morbidities in past years could have been higher than those cited in official documents.

In addition to the diseases listed in Table 13, high population morbidity was detected for tuberculosis, brucellosis, trachoma, and sexually transmitted diseases (syphilis and gonorrhea). All these diseases cause various changes in the organs and systems of the human body similar to nonspecific reactions to chronic radiation exposure at relatively low doses. Therefore, the differential diagnosis of diseases, especially for outpatients, entailed certain difficulties.

During examinations of the public, special attention was paid to establishing the frequency of cancers, stillbirths, and deformities. Thus, Semipalatinsk Region exhibited a slight increase in cancers in 1957 compared to 1955 and 1956, but East Kazakhstan Region showed a reduction in 1957 compared to 1955 and 1956, but a doubling over the 1952 numbers.

The specialists attributed the observed increases in the frequency of cancers to improvements in doctors' detection of cancer patients and to the comparison of accounting records. With respect to tumor location, the cancers of the oral cavity (usually the lips) and stomach that are typical of the region were among the leaders in Semipalatinsk and East Kazakhstan Regions. Local oncologists tied the frequency of skin cancer to the locations' typical climate and weather: frequent dry winds, high insolation, sharply continental climate, etc., and in the cities, additionally, to exposure to toxic industrial wastes. Cancers were noted mostly in people over 40-60 years old.

Reporting data from 1955 to 1957 show no increase in neurological diseases.

Measures of stillbirths for each region as a whole, which were between 1.5% and 2.4%, barely exceeded the national average for the Soviet Union in those years. Nor were increases observed in congenital deformities, in particular, hydrocephaly, cleft palate, and harelip.

From 1955 to 1957, a 10-12% declining trend in infant mortality was observed.

Statistical reporting forms of the time contained absolutely no data on blood diseases.

We must make special note on the state of medical accounting and reporting in those years. An inspection of the statistical data available at local public health agencies has shown that the state of medical accounting and reporting, especially in rural areas, was very primitive. In some reports, over a third of all patients requesting medical care were left undiagnosed and listed under "other diseases," so it was difficult to establish the true morbidities. The first mass examinations of the local population, performed by expedition doctors, showed that the true morbidities were considerably higher than reflected in the official medical accounting records.

ASPECTS OF RADIOACTIVE CONTAMINATION OF THE TEST SITE GROUNDS

We have already noted above that during the period of nuclear testing at the Semipalatinsk Test Site in the atmosphere and underground (in emplacement holes), the scale and extent of radioactive contamination of the test site grounds and nearby districts varied and depended on the explosion types and yields.[12] This has been confirmed by the results of inspections of contaminated territories performed by USSR Ministry of Health expeditions.

After nuclear explosions, when the shock wave has passed and the action of visible light and penetrating radiation has ceased, the effect of one of the main harmful factors in such explosions remains: ground radioactive contamination. Unlike the other factors, whose action is manifested for a relatively short time after the explosion, radioactive contamination may remain hazardous for several weeks, and residual soil contamination by long-lived radionuclides may last for many years.

Radiation levels, depend on the extent of contamination of the environment by manmade (artificial) radionuclides. According to the *Environmental Protection Reference*,[89] “environmental contamination is the entry of any solid or gaseous substances or forms of energy into the natural environment in quantities exceeding the allowable level, that is, the level that will have no harmful effect on man, flora, or fauna.”

The ionizing radiation sources that determined the scale and extent of environmental radioactive contamination during the nuclear testing period were:

- fission products (“fragments”) of nuclear explosives such as ^{239}Pu, ^{235}U and ^{238}U;
- radionuclides that were produced in structural materials of the nuclear physics package and in the soil and other environmental systems exposed to the neutron flux of penetrating radiation (induced radioactivity);
- the unreacted portion of nuclear explosives (fissile materials) or dispersed amount of ^{239}Pu resulting from hydronuclear experiments, which are α-active substances with long half-lives.

The effect of each source on the contamination of the grounds of the Test Field and other test areas at the site depended on the explosion type and yield, design features of the physics package, and conditions under which other special experiments were performed.

Ground Contamination after Ground and Atmospheric Nuclear Tests

The radioactivity of the unreacted or dispersed portion of ^{239}Pu is known to be 60 curies per kilogram. The total activity of unreacted or dispersed ^{239}Pu is relatively small compared to the activity of “young” fission products, but it can create problems in the long term due to the high toxicity of α-active substances.

The most significant ground radioactive contamination in Test Area P1 of the site’s Test Field was produced by relatively high-yield ground nuclear explosions, both in the explosion area and along the paths of the explosion clouds. Radioactive plumes were formed both inside and outside the test site’s exclusion zone.

Before 1956, in the parcels where radiation levels did not exceed 4 mR/hr, the deployment of personnel from construction and security units was permitted in the intervals between tests.[12] In 1956, after dosimetric and radiometric inspections of the entire grounds of the test site and aerial γ surveys of the ground up to 500 km from the Test Field, deployment of construction personnel on the grounds of the Test Field was prohibited.

The results of the first, fairly detailed radiation survey using ground and airborne equipment by employees of the test site and the Institute of Applied Geophysics of the USSR Academy of Sciences in late 1956 are shown in Figure 28.

Measurements showed that as of December 1956, there were five areas on and off the test site with elevated γ backgrounds. During the measurements, the maximum ground radioactive contamination was detected along the path of the cloud from the explosion of August 24, 1956 (Zone 1). The highest radiation levels were found in the village of Znamenka (260 μR/hr) and in the city of Ust-Kamenogorsk (225 μR/hr), and the daily exposure dose of their residents could have been as high as about 4 mR.

Zone 2 was formed by the plume of an atmospheric explosion with a yield of about 1 megaton on August 30, 1956. We must note that the radiation survey of the territory of that plume was carried out four months after the explosion, that is, it was a relatively “young” plume. Radiation

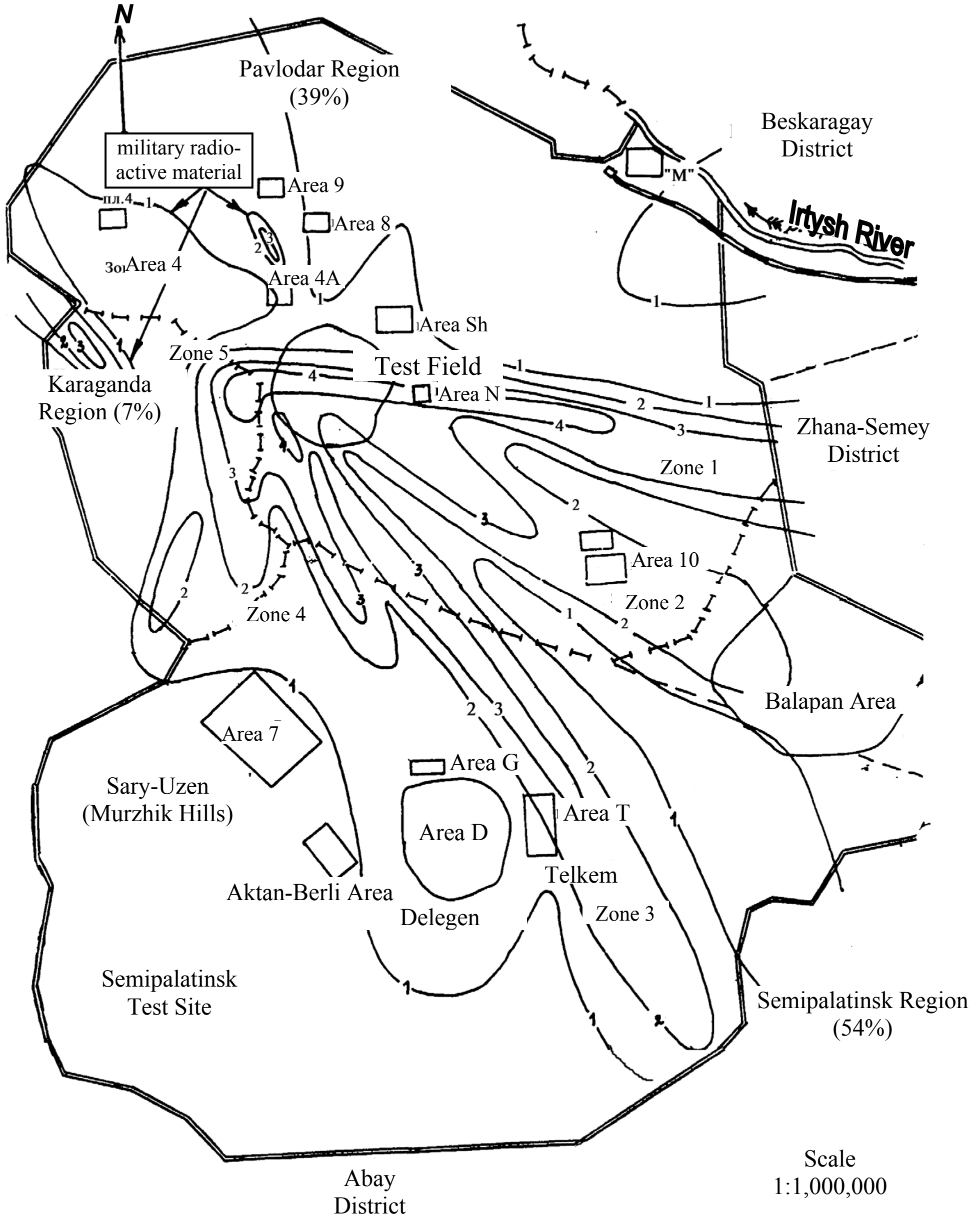


Figure 28. Map of radioactive contamination of the grounds of the Test Field and Semipalatinsk Test Site as of December 1956. Gamma-ray exposure doses are shown in μR/hr: *1*—12-40; *2*—40-100; *3*—100-1000; *4*—over 1000.

levels on its territory rapidly declined over time, reaching natural background levels after about six months.

Zone 3 consisted of the plume from the most powerful ground thermonuclear explosion, detonated on August 12, 1953. During the radiation survey, that is, three years after the explosion, at the village where the Telman Collective Farm was located, the radiation level was 57 μR/hr, and the daily exposure dose was about 1 mR.

Zone 4, produced by a series of nuclear tests from 1951 to 1956, did not cross the boundaries of the test site.

Information on the formation of Zone 5, which mostly resulted from experiments with military radioactive materials performed at the test site, is of some interest.[14,9,25,81-86, etc.]

Ground Contamination by Experiments with Military Radioactive Materials

In the early 1990s, specialists from the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*), consistently inspecting the grounds of the test site, discovered residual traces of various technical activities using military radioactive materials near the location of Areas 4 and 4A: fragments of exploded aerial bombs, missiles, craters, etc., with elevated levels of radioactive substances (Figure 29).[14]

Figure 29. Tail section of an aerial bomb found in 1999 at a site of munitions testing involving military radioactive materials.

An aerial γ-spectrometric survey of the ground performed during these inspections, that is, 35 years after the cessation of testing with military radioactive materials, recorded no increase in the density of ^{137}Cs contamination of the environment in this part of the test site.

This indicates that the radioactive decay of the radionuclides making up the military radioactive materials had reduced the density of contamination to background values, so there are no longer any serious problems with surface contamination of the grounds of the test site after tests with military radioactive materials. However, these tests, which have become a "radiation legacy," are still with us under the realistic conditions of the dismantling of the site's nuclear testing infrastructure.[81]

Thus, only underground repositories of contaminated objects and tanks with residues of radioactive formulations can now present a potential hazard near Areas 4 and 4A, mainly to participants in geologic exploration and drilling, although their activity has declined considerably in past years.[82]

In his memoirs,[82] Grigory Ilyich Krylov, who served at the former Semipalatinsk Test Site from 1951 to 1961 and was one of the research supervisors of studies performed at the test site, writes about the fact that tests of military radioactive materials were conducted by detonating individual munitions, dropping bombs from Il-28's, artillery and mortar fire, or using aircraft spray rigs. The extent and nature of contamination of ground, air, and objects set out as targets were determined. Test animals were also used.

Regarding the content of the "radiation legacy" of these experiments, Krylov writes:

> *"Due to the difficulty of decontaminating all equipment (tanks, pipelines, pumps, etc.) that had been used in tests of military radioactive materials, we had to bury them under five meters of dirt and place new security posts at the disposal site, already burdening the corresponding services of the test site…."*[82]

In 1975, the Soviet Union submitted a proposal to the UN to ban the development and production of weapons of mass destruction (WMDs), including "radiological weapons," a form of WMD whose action is based on the use of radioactive substances in liquid or powdered form.[87,88] This proposal formed the basis for the UN General Assembly's Committee on Disarmament to conduct several thorough discussions in 1976 and 1977 on the problem of banning various types of WMD, including radiological weapons.

The Soviet Union's struggle to ban WMDs produced definite results: in the course of bilateral Soviet-American consultations, a draft Agreement to Ban the Development, Production, Stockpiling, and Use of

Radiological Weapons. The term "radiological weapon" was defined as "any nonexplosive WMD based on the destructive effect of radioactive emissions and means of delivering same."[88]

We should note that in the USSR, this area of military technology had been discontinued in the mid-1950s based on results obtained through testing of munitions in military radioactive materials at the test site's Technological Areas 4 and 4A.

RADIOACTIVE CONTAMINATION OF THE SOIL AND OTHER OUTDOOR ENVIRONMENTAL SYSTEMS

Naturally, the radioactive contamination of various environmental systems (soil, vegetation, water, etc.) had an adverse effect on sanitation and safety conditions in radioactive fallout areas.

Contamination of Soil and Vegetation

The determination of the extent of radioactive contamination of soil and vegetation was very important for an assessment of outdoor exposure doses, which depended largely on the people's consumption of contaminated animal- and plant-derived foodstuffs.

A systematic assessment of the extent of radioactive contamination of soil and vegetation did not begin until after the ground nuclear explosion of August 24, 1956, which produced radioactive fallout, some of it with rain, on the territories of Semipalatinsk and East Kazakhstan Regions. The distribution of radioactive contamination densities over the plume from this explosion was uneven. The maximum ground radioactive contamination due to atmospheric precipitation occurred near Ust-Kamenogorsk.

Measurements performed after the explosion showed that the soil contamination level was proportional to the ground radiation levels. Data on soil and vegetation contamination levels as of September 25, 1956 in districts near the Semipalatinsk Test Site are given in Table 14.[90]

The data show, first of all, that the highest levels of soil contamination were noted in Semipalatinsk Region, where most of the radioactive plumes from ground nuclear tests were formed, and second, that the natural ^{40}K concentration in soil and vegetation was practically indistinguishable from the concentrations of nuclear explosion products in them, which must be taken into account when performing calculations.

Table 14. Radioactive Contamination Levels of Soil and Vegetation (Motley Grass) As of September 25, 1956

Village or Town Near Which Sample Was Taken	Distance from Center of Test Field, km	Concentration of Radioactive Substances in Samples, nCi/kg	
		Soil	Ground Vegetation
Rubtsovsk	350	400	4-2000
Semipalatinsk	160	800	50-800
Charsk	250	150	100
Ayaguz	330	700	30
Kara-Aul	200	600	100
Sarzhal	100	1300	60
Mayskoye	60	30	100
Bayan-Aul	150	70	50
Natural ^{40}K concentration (background)	—	10-20	10-20

An investigation of the layer-by-layer contamination of soils established that in virgin lands several years after the explosions, the surface layer of soil was the most contaminated, down to a depth of 1 cm. The surface layer had 5-10 times more activity than the soil layer at 3-4 cm. Contamination of plowed parcels reached the plowing depth, i.e., down to 16-20 cm.

After 1958, as radiochemical methods were introduced and spectrometric equipment became available, studies were begun to determine the concentration of biologically hazardous radionuclides such as ^{90}Sr, ^{137}Cs, and ^{131}I in various environmental systems. In the surface soil layer in the plume from the 1956 explosion, ^{90}Sr accounted for about 8% of the total activity.[93]

The radioactive substances in the soil penetrated into above-ground vegetation. In 1956, specialists from comprehensive expeditions of the Institute of Biophysics and the test site performed radiometric studies of grass and cereal samples. The results are given in Table 15.

Radiometric studies also showed that the concentrations of radioactive substances in the above-ground portion of plants and in the root system was approximately the same. Plants important for agricultural production

Table 15. Concentrations of Radioactive Substances in the Above-Ground Part of Vegetation As of September 25, 1956

Sample Location	Activity of Samples, nCi/kg		
	Pasture Motley Grass, Air-Dried	Above-Ground Part of Cereals	Prior Year's Hay or Straw
Semipalatinsk Region			
Sarzhal	26	19	22
Kara-Aul	16	—	9
Znamenka	20	9	—
Semipalatinsk	17	—	—
Zhana-Semey	12	—	—
East Kazakhstan Region			
Ablaketka	28	—	—
Lenin's Precepts Collective Farm	16	8	1
Brick Factory	23	—	—
Samsonovka	18	4	32
Ust-Kamenogorsk	20	—	—
Vanguard Collective Farm	14	13	—
Shemonaikha	30	—	—
*Pavlodar Region**			
Mostik	15	—	—
Mayskoye	19	9	9
Dolon	17	10	—
Besterek	16	—	—
Moldary	16	—	—
Karaganda Region			
Shoptykul	38	9	—
Abay State Farm	43	9	—
30th Anniversary of Kazakhstan Collective Farm	22	—	11
Natural ^{40}K concentration	5	—	—

*—In 1959, these towns and villages were transferred from this region to Semipalatinsk Region.

were found to contain ^{90}Sr in a mobile (water-soluble) form. The transition of radionuclides to a soluble state depended on the physical properties of the radioactive particles, most of which were in a fused state after the ground nuclear explosion.

In 1962, near Topolnoye after the explosion of August 7, and near Semipalatinsk after the explosion of September 25, the first field studies were performed to determine the concentrations of iodine radionuclides in vegetation rinses. The measurement results showed that the concentrations of iodine radionuclides in water rinses of vegetation one day after the explosion did not exceed 2.5% of the total radioactivity of nuclear explosion products contained in the vegetation (steppe motley grass).

Contamination of Open Bodies of Water

A comprehensive expedition in 1956 began inspecting open bodies of water to assess their radiation safety and sanitary status. It measured the concentrations of radioactive substances in the waters of the Irtysh and Ulba Rivers (at Ust-Kamenogorsk), the Little Ulba River (at Gornaya Ulbinka), Ayaguz (near Ayaguz Station), Lakes Air and Sagot, and in other water sources. As of September 25, 1956, the radioactivity of open bodies of water was between 0.4 and 2.2 nCi/l.

If we consider that the water mass contaminated by radioactive fallout from the explosion cloud had moved far downstream by the time the samples were collected, we can attribute most of the moderate water contamination to the wash-out of activity by rainwater from adjacent lands, that is, we can call this contamination a second-order effect.

The low and practically safe concentrations of radioactive substances in certain bodies of water supported the hypothesis that they were being rapidly bound by soil colloids. This was confirmed by the three- to four-orders of magnitude difference between the relative activity of water and bottom sediments. Higher levels of contamination of lake and river bottoms were recorded only in the local plumes. This indicated the low solubility of fused radioactive particles and their rapid precipitation to the bottom.

The most significant levels of radioactive contamination of aquatic plants were observed only in bodies of water with highly contaminated bottom sediments, as shown by analyses of samples collected from the former bed of the Irtysh River near the village of Korobeynikovo (6400 nCi/kg) and from a creek near the Oktyabrsky ["October"] neighborhood of Ust-Kamenogorsk (560 nCi/kg).

Analysis of the extent of contamination of bottom sediments and fish, which were sampled in various parts of the Irtysh River, showed that contamination levels declined with distance from the vicinity of Ust-Kamenogorsk. Thus, near the site's residential area (Town M) the activity of silt at the bottom of the Irtysh River ranged from 10 nCi/kg to 45 nCi/kg, but near the village of Yermak, Pavlodar Region, it was 6.4 nCi/kg.

The data presented above on the radioactive contamination of lands surrounding the test site suggests that the concentration of radioactive substances in water was somewhat higher immediately after plume formation. However, the possibility of more or less long-term public consumption of water with high concentrations of radioactive substances is low. As for fish caught in these waters, their levels of contamination were fairly low, so their use in food was no cause for concern.

The small excess radioactivity of bone vs. muscle in fish caught in these waters suggests the deposition of osteotropic radionuclides, specifically ^{89}Sr and ^{90}Sr, in bone.

Thus, the radioactive contamination of the waters of open sources was due both to the fallout of aerosols from the nuclear explosion cloud and also to the wash-out of radioactive particles from the surrounding soil surface by atmospheric precipitation and in spring floods. Moreover, the greatest, but continuous, desorption of activity from bottom sediments and biomass could have helped support the water's radioactive contamination.

The results of an assessment of the radiation safety of waters located in the area affected by nuclear testing at the Semipalatinsk Test Site showed that the observed levels of contamination in water and fish were not hazardous to public health, since the uptake of radionuclides by the human body from water and fish did not exceed allowable limits.[90,92]

The results of multiple radiometric studies of drinking water samples from wells in villages and towns in all four regions (Karaganda, Pavlodar, Semipalatinsk, and East Kazakhstan) surrounding the test site established that as of the date of inspection, the concentrations of radioactive substances in drinking water were also within allowable levels.

Contamination of Food Products

We should note that plant- and animal-derived foodstuffs are the final link in a biological chain through which radioactive substances can enter the human body directly. For this reason, determining the extent of radioactive contamination of foods eaten by residents of villages and towns in the area affected by nuclear testing was a necessary condition for a complete characterization of the radiation-safety of this area.

The foodstuffs that comprised the majority of the daily diet of local residents and with which the majority of the radionuclides entered the human body were especially interesting. These included primarily bread, meat, milk, and in some areas potatoes and vegetables.

In 1958, a thorough study of the level of radioactive contamination of food products in many villages and towns near the test site was performed. The results are given in Table 16.

The data show that the highest levels of contamination of 1957 wheat was seen in Sarzhal (Telman Collective Farm), in the village of Samsonovka, at Abay State Farm and at the 30th Anniversary of Kazakhstan Collective Farm. This agreed completely with radiation level data for areas located nearby. In particular, at Abay State Farm and the 30th Anniversary of Kazakhstan Collective Farm, radioactive fallout occurred with rain during harvest time after an atmospheric nuclear explosion with a yield of about 0.5 megaton on August 22, 1957.[94]

In 1958, when there were no powerful test explosions, the relative activity of milk was mainly at the level of the natural ^{40}K concentration. In only four villages and towns (Shemonaikha, Mostik, Mayskoye and Shoptykul) did the activity of milk samples reveal the presence of nuclear explosion products. The activity rate of bread in practically all the villages and towns listed in Table 16, which are located on contam inated lands, exceeded its natural ^{40}K concentration by two- to three-fold.

After the "accidental" nuclear explosions of 1962, which should have been atmospheric tests, associates from the Institute of Biophysics and Clinic No. 4 performed the first measurements of radioactive iodine isotopes in milk samples collected in the contaminated villages and towns of Semiyarskoye, Zharma, Znamenka, and Novopokrovka. The studies established that one day after the explosion, the ^{131}I concentration of milk was 2-12 nCi/l, about 90% of the milk's total activity.

To assess the indoor exposure doses of people living in radioactive contamination areas and consuming local food products contaminated by radioactive substances, the amount of radionuclides that could enter the human body with food and water had to be known.

Table 16. Concentration of Radioactive Substances in Foods Eaten by Residents of Villages and Towns in Semipalatinsk, East Kazakhstan, Pavlodar, and Karaganda Regions As of Early July 1958[75,90]

Sampling Location	Activity of Samples, nCi/kg					
	Wheat (1957 Harvest)	Bread	Meat	Milk	Potatoes	Vege-tables
Semipalatinsk Region						
Sarzhal	7.2	1.0	3.6	1.2	—	—
Kara-Aul	1.5	3.4	3.6	0.8	—	—
Znamenka	3.5	1.5	2.8	1.5	3.6	17.0
Semipalatinsk	1.7	—	2.7	0.7	2.0	4.0
East Kazakhstan Region						
Ablaketka	—	1.4	1.5	1.4	1.6	2.8
Brick Factory	—	0.5	—	1.0	4.6	1.9
Samsonovka	19.0	3.0	2.1	0.9	3.6	3.2
Shemonaikha	1.6	1.4	1.5	1.7	2.5	5.8
*Pavlodar Region**						
Mostik	4.1	3.7	5.2	1.7	4.3	0.9
Mayskoye	—	2.0	2.2	1.7	3.0	—
Dolon	2.8	3.3	—	1.4	3.8	2.0
Besterek	3.5	2.8	2.5	—	8.1	—
Moldary	—	6.4	3.4	1.3	—	—
Karaganda Region						
Shoptykul	7.9	2.9	3.2	1.7	—	—
Abay State Farm	36.0	2.6	3.3	1.1	5.7	10.5
30th Anniversary of Kazakhstan Collective Farm	28.0	2.6	3.8	1.1	—	—
Natural ^{40}K concentration	3.5	1.2	2.3	1.2	3.0	2.3

*—In 1959, these towns and villages were transferred from this region to Semipalatinsk Region.

Estimate of Human Uptake of Radioactive Substances with Food

Analysis of archives containing radiation-safety data for areas adjacent to the Semipalatinsk Test Site showed that the living conditions and diet of residents of these areas varied, and were largely determined by the social status and ethnic makeup of the population.

In view of these differences, the whole population of the inspected areas was divided into three main groups:

1. urban;
2. rural Russians;
3. rural Kazakhs.

The first group included the population of the cities of Semipalatinsk and Ust-Kamenogorsk and the settlements of Ablaketka, Brick Factory, Zhana-Semey, and Moldary. The second included residents of the villages and towns of Samsonovka, Shemonaikha, Kanayka, Vanguard Collective Farm, Abay State Farm, Dolon, Mostik, Mayskoye and Znamenka. The third group included the populations of the settlements of Shoptykul, 30th Anniversary of Kazakhstan Collective Farm, Kara-Aul, Telman Collective Farm (Sarzhal) and Besterek.

For each population segment, a model daily diet was drawn up from these studies,[90,94,95] which is given in Table 17.

Calculations showed that 4.1 nCi of natural ^{40}K entered the bodies of city residents, 2.9 nCi entered those of rural Russians, and 4.1 nCi entered those of Kazakhs.

Table 17. Approximate Daily Diets of Various Population Groups

Food Product	Consumption by Various Population Groups, Grams per Day		
	Urban	Rural Russians	Rural Kazakhs
Bread	600	900	800
Meat	100	250	1000
Vegetables	1000	300	—
Milk	200	300	1000
Water	2500	2500	2500

Based on the results of radiometric studies of food products, shown in Table 16, possible uptakes were calculated for radioactive substances into the human body with the daily diet typical of residents of the villages and towns examined. The results of these calculations are presented in Table 18. For comparison, sampling was done in villages and towns where the maximum daily uptake of nuclear explosion products was observed.

Table 18. Maximum Human Bodily Uptake of Nuclear Explosion Products with Daily Diets Typical of Residents of Several Rural Villages (Excluding Natural Radioactivity) As of Early July 1958

Village or Town	Dominant Ethnicity	Daily Uptake of Nuclear Explosion Products, nCi
Samsonovka	Russian	9.4
Mostik	Russian	3.5
Besterek	Kazakh	3.4
Sarzhal	Kazakh	5.0
Kara-Aul	Kazakh	3.2

The villages and towns with the highest radioactive contamination of their diets exhibited elevated ground radiation levels, as well as elevated contamination of soil, vegetation, and water.

To reduce public indoor exposure doses in areas adjacent to the test site, it was important to identify the food products with which the largest share of radioactive substances was entering the human body. Studies showed that the greatest amount of radioactive substances was entering the bodies of urban residents with vegetables and bread. The same could be said of ethnic Russian rural residents. The greatest uptake of radioactive substances into the bodies of ethnic Kazakh rural residents was tied mainly to their consumption of meat and bread, as well as kumiss. The diet of this population segment lacked vegetables, but meat and kumiss were staples of their daily diet.

In 1958, when the USSR Ministry of Health's first comprehensive expedition was working, the specialists comprising it turned their attention to several deficiencies in public radiation safety assurance during the conduct of nuclear tests at the Semipalatinsk Test Site.[78] They noted that before 1956, the extent of the effects of radiation from nuclear explosions on public health was assessed only by the outdoor γ exposure using mainly interdepartmental standards developed for accidents at nuclear enterprises or for emergencies. The contribution of indoor exposure due to uptake of radioactive substances inside the human body, unfortunately, was practically ignored. Nor was the health status of people living in areas adjacent to the test site subject to special systematic monitoring. Additionally, the specialists drew attention to the unacceptability of nuclear testing during the seasons of ripening and harvest, since this caused radioactive contamination of grain and forage.[96]

We have noted above that the cultural level and lifestyle of the people, specifically sanitation, hygiene and everyday life, were very primitive. There were no baths, sewer lines, regular cleaning of the territories of villages and towns, or clean water. The diets of residents of both cities and rural areas were incomplete and monotonous. All of these factors caused high population morbidity, especially with gastrointestinal and various infectious diseases (tuberculosis, brucellosis, syphilis, etc.), which in turn hindered identification of signs of diseases resulting from radiation exposure. An assessment of the possible public outdoor, and, very importantly, indoor exposure doses can give the fullest picture of the extent of the impact on public health of the radiation factor after nuclear explosions.

HUMAN RADIATION EXPOSURE DOSES

Determining human indoor and outdoor exposure doses has always involved difficulties due to the need to estimate these doses by numerical methods alone. Calculations with the requisite accuracy and reliability required a fairly large set of source data. However, the amount of data was usually insufficient due to certain difficulties. These difficulties mostly had to do with the lack of dynamic observations of the change in γ field characteristics during the passage of the explosion cloud or after ground radioactive contamination was complete; data on the variation in shielding factors over time due to the people's mobility; and the shortage of information on the radionuclide makeup of fallout and measures of radionuclide metabolism in people of various ages, genders, etc. The situation was difficult, but not hopeless, since the minimum required volume of knowledge and data had been gathered.

For this reason, calculated public exposure doses were and are approximate. However, we must emphasize that in those cases when difficulties arose in choosing a method of calculation, the option that produced a certain exaggeration of the dose was always used.

We should note that the methods of estimating public exposure doses were continually being improved. Moreover, the calculations were made with consideration for a variety of principles and bases that supplemented existing methods and produced more reliable dose values.[97,98]

Outdoor Radiation Exposure Doses

Given the selection of the critical population segment (shepherds, field workers, etc., that is, those who spent a lot of time outdoors), data on the level of γ shielding by buildings and structures, measures of radiation levels, and other information needed for the calculations, exposure doses in villages and towns located on the territories of the most significant local plumes from ground nuclear explosions were estimated. The results are presented in Table 19.

Table 19. Possible Public Outdoor Exposure in Radioactive Contamination Plumes in Various Years of Nuclear Testing[99-101]

Village or Town	Distance from Ground Zero, km	Radiation Dose Rates at Location When Measured, R/hr	Time after Explosion When Radiation Dose Rate Measured, hours	Dose at Location, cGy	Public Exposure Dose,[1] cGy
1949					
Cherëmushka	76	1.8	24	220	190
Mostik	90	0.01	173	17	14
Dolon (plume axis)	118	0.12	173	224	—
Dolon	118	—	—	185	134 (150)[2]
Belokamenka	122	0.000036	173	0.06	0.05
Lokot	240	0.016	220	31	28 (27)
Veseloyarskoye	250	—	—	15.6	20
Savvushka	320	—	—	6.5	4.6
Kurya	340	0.0036	227	9	5 (6)
Petropavlovka	480	0.00029	255	0.6	0.5 (0.6)
Biysk	560	—	—	0.4	0.3
Solton	653	0.00011	390	0.3	0.2
No testing in 1950					
1951					
Kaynar	150	0.27	10	9	7 (8)

Village or Town	Distance from Ground Zero, km	Radiation Dose Rates at Location When Measured, R/hr	Time after Explosion When Radiation Dose Rate Measured, hours	Dose at Location, cGy	Public Exposure Dose,[1] cGy
Molotov Collective Farm	225	0.17	20	14	12
Teskesken	410	0.004	20	0.3	0.2
Tespakan	460	0.002	20	0.12	0.1
No testing in 1952					
1953					
Taylan	100	3	36.6	1000	—
Sarzhal	110	1.2	25.7	250	42-49[3]
Kara-Aul (Abay)	200	0.18	84	150	13-22[3]
Aygyrzhal	300	0.04	25.8	6.6	5 (6)
1954					
30 km NW of Kaynar	117	0.22	3	2.7	—
28 km NE of Konyz	151	0.17	3	2.0	—
20 km NE of Kaska-Bulak	183	0.6	3	6.5	—
30 km E of Kazan-Chukur	32	0.1	3	1	—
1955					
Mostik	90	—	—	0.13	0.1
Uglovskoye	178	—	—	0.16	0.1
1956					
Isa	100	0.0014	720	15	12 (13)
Znamenka	130	0.0003	720	3	2 (3)
Ust-Kamenogorsk	342	0.0012	720	10	8 (10)
Tarkhanka	364	0.0003	720	2.4	2 (3)
Bobrovka	345	0.0003	720	2.4	2 (3)

Village or Town	Distance from Ground Zero, km	Radiation Dose Rates at Location When Measured, R/hr	Time after Explosion When Radiation Dose Rate Measured, hours	Dose at Location, cGy	Public Exposure Dose,[1] cGy
1957					
Abay State Farm	80	0.012	26	2	1.5 (2)
30th Anniversary of Kazakhstan State Farm	90	0.05	8	2	1.5 (2)
1958: Radiation doses off the test site did not exceed 0.5 R					
1959-1960: Nuclear testing moratorium					
1961: Radiation doses off the test site did not exceed 0.5 R					
1962					
Kurchatov	70	0.0005-0.0010	12	3.8	1.5
Topolka	75	0.004	31.5	1.5	1.2
Uglovskoye	178	—	—	1.4	1.2
No testing in 1963					
Only underground nonexcavating tests performed in 1964					
1965: Underground nuclear excavating test in Shaft 1004					
Sarapan	15	0.1	24	5.8	1.6[3]
Beysen	—	—	—	2.8	0.7[3]
Iirbala	—	—	—	6.7	1.7[3]
Shcherbakovka	53	0.003	24	2.6	0.7
Znamenka	44	0.003	24	2.4	0.7
Musa	38	0.010	24	1.3	0.4
Isa	35	0.005	24	0.9	0.3

Notes:

1. Under assumed public exposure conditions.
2. Parenthesized values include dose during plume formation period.
3. Calculation of public exposure dose accounted for evacuation of residents and used measured radiation dose rates as of the time of departure. One hundred ninety-one persons remained in Kara-Aul when the cloud passed; their exposure doses during evacuation to a safe area ranged from 10 to 40 cSv.

In 1949, the γ dose rate was measured near Dolon, 173 hours (a little over seven days) after an explosion. The value was 33 μR/s (0.12 R/hr).

Later, the area underwent an automobile ground γ survey (using an RA-69 instrument), and soil samples were collected layer by layer to a depth of 50 cm to determine concentrations of biologically hazardous radionuclides.[96]

The following principles were considered in estimating outdoor exposure doses:

- the critical population segment—shepherds, field workers, etc., that is, those who spent up to 16 hours a day outdoors—was selected;
- certain γ shielding factors (coefficients of attenuation) for local buildings and structures (wooden, adobe, or brick) were used; these values were 3-5 during plume formation and 13-15 in the resulting plume from the explosion cloud;
- the time of the radioactive contamination front's arrival in the given village or town and the time the people returned after pre-evacuation (Sarzhal, Kara-Aul, Sarapan, etc.) were taken into account;
- the fact that a large part of the outdoor exposure dose was received during the first day (up to 60%) and over 90% of the dose was received during the first week before complete decay of explosion products was taken into account.

Indoor Radiation Exposure Doses

There are many numerical methods of estimating indoor exposure doses. Analysis and systematization of most of these enabled selection of the most acceptable ones for calculations of indoor exposure doses for people living near the test site.

Several important principles were also used in calculating indoor exposure doses:

- characteristics of the biological availability of various radionuclides comprising the radioactive products of nuclear explosions. For example, gastric juice washed only 2% of the ^{90}Sr and ^{137}Cs radioactivities out of fused particles that fell out in the 1949, 1951, and 1953 explosion plumes, and up to 30-60% in the plume from the underground excavating explosion on January 15, 1965. In the far zone, the biological availability of iodine radionuclides in radioactive fallout from the ground nuclear explosion detonated August 7, 1962 was up to 70% of the amount retained by pasture motley grass. The same holds for the bioavailability of iodine in fallout after underground nuclear excavating explosions. The bioavailability of tritium was 100%;

- aspects of the vertical migration of radionuclides in the soil. The highest soil penetration of radionuclides, 50-70 cm, was observed in pine-forest sands near Dolon. The lowest penetration was on steppe loams and chestnut soils for example, around Sarzhal;
- the practical absence of variation in the density of soil contamination due to horizontal migration of radioactive particles from the plume zone (but wind-borne transport of fine aerosols did occur);
- empirical relations between radioactive contamination of vegetation and other environmental systems and the ground γ dose rate.

Samples of soil, vegetation, and other environmental systems, food products, and water were analyzed using radiochemical methods, and later by spectrometric methods as well.

The use of dosimetric measurements, biomedical research, and public examinations permitted an objective estimate of the exposure doses of people living near the test site.

Table 20 gives data describing the maximum possible indoor exposure doses of residents of several villages and towns located in the area affected by operation of the Semipalatinsk Test Site.

The data show the relatively low values of indoor exposure doses (under 30% of the outdoor exposure doses). This is due to the low washability of biologically hazardous radionuclides from fused radioactive fallout particles after ground nuclear explosions in the near zone of the resulting local plumes.

A reliable method of verifying techniques designed for retrospective estimation of indoor exposure doses, and for monitoring the level of public indoor exposure, was *in vivo* determination of the concentration of biologically hazardous radionuclides in the human body and in the body's daily excretions (stool, urine). Some data on the contamination of environmental systems and the human body are presented in Table 21.

These data, which are based on analysis of the archives of comprehensive medical examinations of the public by special teams of physicians from the USSR Ministry of Health, show that the main effect on public health could have come from outdoor γ exposure and irradiation of the integument, the indoor exposure being only a secondary factor. We should note that these examinations of residents of villages and towns located near the test site detected no cases of acute or chronic radiation sickness; this is confirmed by analysis of the archives.

Table 20. Maximum Possible Indoor Exposure Doses of Residents of Certain Villages and Towns Located Near the Semipalatinsk Test Site (Based on Precise Measurements of Basic Parameters of Radiation Levels)[93,102]

Village or Town	Absorbed Radiation Dose, cGy			
	Thyroid		Bone Tissue	Lower GI Tract
	Adults	Children		
Dolon	14-17	200-220	104	4
Cherëmushka	8-17	140-220	—	—
Kanoperka	5	70	—	—
Topolnoye	25	340	—	—
Naumovka	1-25	4-340	—	—
Veseloyarsk	8-13	120-170	—	—
Kaynar	20	300	5	1
Sarzhal	—	—	112	38
Ust-Kamenogorsk	4	55	—	—
Sarapan	10	53	—	—

Table 21. Levels of Soil Contamination and Concentrations of Biologically Hazardous Radionuclides in the Bodies of Residents of Certain Villages and Towns As of One Year after Contamination[93]

Year of Contamination	Village or Town	Density of Soil Contamination in Top 5 cm, Bq/cm^2 (mCi/km^2)		Radionuclide Concentration in Body Tissues of Adult Human		
				^{90}Sr in Bone Tissue, Bq/kg	^{137}Cs in Soft Tissue According to Dietary Features, Bq/body	
		^{90}Sr	^{137}Cs		Russians	Kazakhs
1949	Dolon	1.26 (340)	1.33 (360)	10.4	670	—
1951	Kaynar	0.37 (100)	—	14.4	—	2000

Year of Contamination	Village or Town	Density of Soil Contamination in Top 5 cm, Bq/cm^2 (mCi/km^2)		Radionuclide Concentration in Body Tissues of Adult Human		
				^{90}Sr in Bone Tissue, Bq/kg	^{137}Cs in Soft Tissue According to Dietary Features, Bq/body	
		^{90}Sr	^{137}Cs		Russians	Kazakhs
1962	Controls: Novo-Bazhenovo, Shadrinsk	—	—	3.0-4.4	520-1150	1150

The principal measures of the extent of the effects of nuclear testing on public health are the effective exposure doses, which should be estimated using data on outdoor and indoor exposure doses of certain critical organs and the human body as a whole. Effective dose values are also used to determine the need for rehabilitation measures, and also to resolve questions relating to the justification of various benefits and compensation. The results of a retrospective assessment of indoor and outdoor exposure doses of residents of villages and towns located in the area affected by the operation of the Semipalatinsk Test Site allow us to estimate effective exposure doses of residents of these villages and towns, both during the nuclear testing period and at present.

Principal Objectives of Environmental Radiological Inspection of the Grounds after Cessation of Nuclear Testing

During the period of nuclear testing from 1949-1989 at the Semipalatinsk Test Site, no systematic studies of environmental radiation levels on its grounds were performed.[103] The principal aim of radiation monitoring during the testing period was to characterize each radioactive plume, and primarily to determine the outdoor exposure doses of people living near the test site.

After the cessation of nuclear weapon testing, but especially after the closure of the Semipalatinsk Test Site on August 29, 1991, the question of more precisely measuring the scale and extent of environmental radioactive contamination due to the test site's operation, as well as the damage done to public health by the operation, was raised. Developing scientifically valid programs aimed at cleaning up after the nuclear tests required data on radiation levels during and after the test period and on outdoor and indoor exposure doses of residents of villages and towns whose territories were contaminated by radioactive fallout, as well as the results of medical examinations that objectively described the short- and long-term effects of public exposure.

We should note that the archives of the USSR Ministry of Health contained sufficient source data for an objective assessment of the indoor and outdoor exposure doses of people living in radioactive contamination areas during the nuclear testing period. All these data have been analyzed, interpreted, and fully published.[12,103,104,etc.]

For a comprehensive assessment of the extent of the radiation impact of underground nuclear testing on public health and environmental radiation levels in the Semipalatinsk region, the USSR Supreme Soviet promulgated Resolution 289 on October 27, 1989 entitled, "On Urgent Steps for the Nation's Environmental Recovery," and based on it, the USSR Council of Ministers adopted Resolution 189 on February 14, 1990 directing the USSR Ministry of Atomic Energy and the USSR Ministry of Defense, together with the nation's public health institutions, to carry out this important job. In addition, it ordered the research results to be made available promptly to the general public and the mass media.

It is appropriate at this point to note that specialists from the USSR Ministry of Health's Third Main Directorate and various units of Union ministries and departments have disagreed fairly often with Kazakhstani scientists on assessing the effects of nuclear testing at the Semipalatinsk Test Site. These disagreements began back in 1958-1960 in a discussion of the results of the work of the USSR Ministry of Health's comprehensive medical expeditions, whose specialists examined residents of villages and towns located in areas of radioactive contamination from 1956 to 1960. As we have already noted, the examinations employed laboratory methods of studying the condition of the blood, bodily excretions, etc. We should note that no cases of acute or chronic radiation sickness were detected in the many years of monitoring the health of people living in contaminated areas.[12] Even so, G. I. Knyazev[33] cites the data of Kazakhstani scientist Ivan Chasnikov, who asserts that 1.7 million people have been exposed in Kazakhstan, 67,000 of them supposedly having exposure doses exceeding 100 rems (1 Sv). It is obvious that Mr. Chasnikov is repeating data presented by the former Chief Physician of Clinic No. 4 (Semipalatinsk) B. I. Gusev to the UN Mission, which worked in Kazakhstan in June 1998.

To implement the USSR Supreme Soviet Resolution of October 27, 1989, a special comprehensive program was developed to research the environmental radiation levels in the area affected by the operation of the Semipalatinsk Test Site. The program was initiated in 1990 under the supervision of the Khlopin Radium Institute in Leningrad (now St. Petersburg), under the conventional name “Region-1.”

The Kazakh SSR Supreme Soviet’s message of November 14, 1989 to the Government of the Soviet Union and USSR People’s Deputies implied that Kazakhstani Party and Soviet agencies had received numerous messages from citizens, labor collectives, and public organizations demanding a total cessation of nuclear testing at the Semipalatinsk Test Site. To this end, they had begun forming various public organizations and foundations. And that’s when the Semipalatinsk-Nevada public movement began.

In order to begin work on the Region-1 comprehensive program, a coordinating conference of those involved was held at the Radium Institute on November 26-29, 1990, during which the basic technical mission was refined and a plan was drawn up for research to assess radiation and health conditions on the test site grounds and nearby.

The basic provisions of the plan amounted to the following:

- assess the overall status of the natural environment on the grounds of the Semipalatinsk Test Site and adjacent districts in accordance with the requirements set forth in the USSR State Program for Environmental Protection and Efficient Use of Natural Resources for 1991-1995 and for the Future through 2005;
- ensure the monitoring of underground nuclear tests and begin preparing to conduct such tests as will not disturb the physical, mental, or social welfare of the region’s population;
- develop recommendations for providing information on the test site’s operation and its effect on the environment;
- conduct scientific research for a comprehensive assessment of sanitation, safety, and environmental radiation levels, as well as examinations of the public in order to gather data for development of proposals to establish benefits to persons diagnosed with diseases related to the conduct of nuclear testing;
- ensure the performance of regular monitoring of the background level of environmental contamination with long-lived radionuclides and chemicals harmful to the health. The

results obtained must be discussed with representatives of the Kazakh SSR and USSR State Committees for Nature Conservation [*Goskompriroda*] and with other regional entities for coordination;

- develop proposals for the objective and reliable elucidation of environmental radiation levels in the region based on source data on the actual state of environmental radioactive contamination as a result of nuclear testing conducted during the entire operating life of the Semipalatinsk Test Site. Data from aerial γ-spectrometric surveys of the test site grounds and adjacent districts must be fundamental.

Of all the scheduled measures in the plans of the Region-1 comprehensive research program, the important work of aerial γ-spectrometric inspection of the test site grounds and the villages and towns located along its perimeter were carried out before the test site's closure pursuant to Republic of Kazakhstan President Nursultan A. Nazarbayev's Decree 409 of August 29, 1991 and before the breakup of the USSR in December 1991.

RESULTS OF RADIATION INSPECTIONS OF THE GROUNDS IN 1991-1992

The processing of information from the aerial γ-spectrometric survey of the Semipalatinsk Test Site grounds and adjacent districts determined the γ exposure dose rates one meter above the Earth's surface, the density of ground contamination by ^{137}Cs, as well as surface soil concentrations of uranium, thorium, and ^{40}K.[106]

Radiation on the Grounds and Surrounding Areas in the Early 1990s

In 1990 and 1991, an aerial survey on the test site grounds was performed jointly by specialists from the Moscow Engineering Physics Institute (*MIFI*), the Comprehensive Aerial Survey Expedition of Aerogeologiya Production Geologic Association (*PGO Aerogeologiya*), and the Kazakhstani Aeromagnetic Survey Party of Altyngeo Joint-Stock Company (*AO Altyngeo*).

The aerial γ-spectrometry system consisted of a γ recording unit based on a semiconductor detector and a modular recording unit based on a scintillation detector with a total volume of about 36 liters, and a data storage, processing, and display device using a Nokia LP-4900B multichannel analyzer. The measurement system was mounted on an Mi-8T helicopter.

The work methodology was governed by instructions[107,108] that required a flight level of 25-80 meters and equipment calibrated to standard models in natural calibration areas and on the contaminated grounds of the Semipalatinsk Test Site (for ^{137}Cs).

The survey of the test site's entire grounds, an area of 18,500 km^2, was done at 1:300,000 scale with a spacing between survey profiles of 3 km and a detector registration field width of about 300 meters. In the Test Field, whose area was 120 km^2, the survey was done at 1:25,000 scale with a profile spacing of 250 meters. The area around the Kara-Zhara Coal Field, 115 km^2, was surveyed at 1:10,000 scale.

Natural radionuclides such as ^{40}K and radionuclides of the ^{232}Th and ^{238}U family are known to emit broad-spectrum γ-rays and thereby create a natural radiation background. Assessing the contribution of artificial (manmade) radionuclides to the total dose rate requires information on the concentrations of all γ-emitting radionuclides. This is the only way the contribution of ^{137}Cs to the total dose rate and the density of ground contamination by this long-lived artificial radionuclide can be estimated.

Over most of the test site grounds, the density of ^{137}Cs contamination ranged from the global fallout level (0.05 Ci/km^2) to 0.5 Ci/km^2, as indicated by the data presented in Figure 30. The figure shows that two parcels were observed with contamination densities elevated to 1 Ci/km^2 or more. One of these parcels, with a linear shape to the southeast, was the radioactive plume of the most powerful ground thermonuclear explosion, detonated on August 12, 1953. This was an explosion of a 400-kiloton physics package. On the eastern margin of this plume, where the density of contamination was about 0.3 Ci/km^2, is Sarzhal. The plume broke up, not "reaching" Kara-Aul 15 km away.

Another radioactively contaminated parcel extended to the south. While its outlines are fairly unclear, we can say that this parcel consisted of three spots, each with contamination densities of over 0.3 Ci/km^2. Kaynar is located in one of these spots.[109]

A comparison of the positions of radioactively contaminated areas on the test site grounds and surrounding areas as of the end of 1956 (Figure 28) and as of 1990-1991 (Figure 30) show fairly good agreement. It also shows that these areas are the results of radioactive plumes formed by

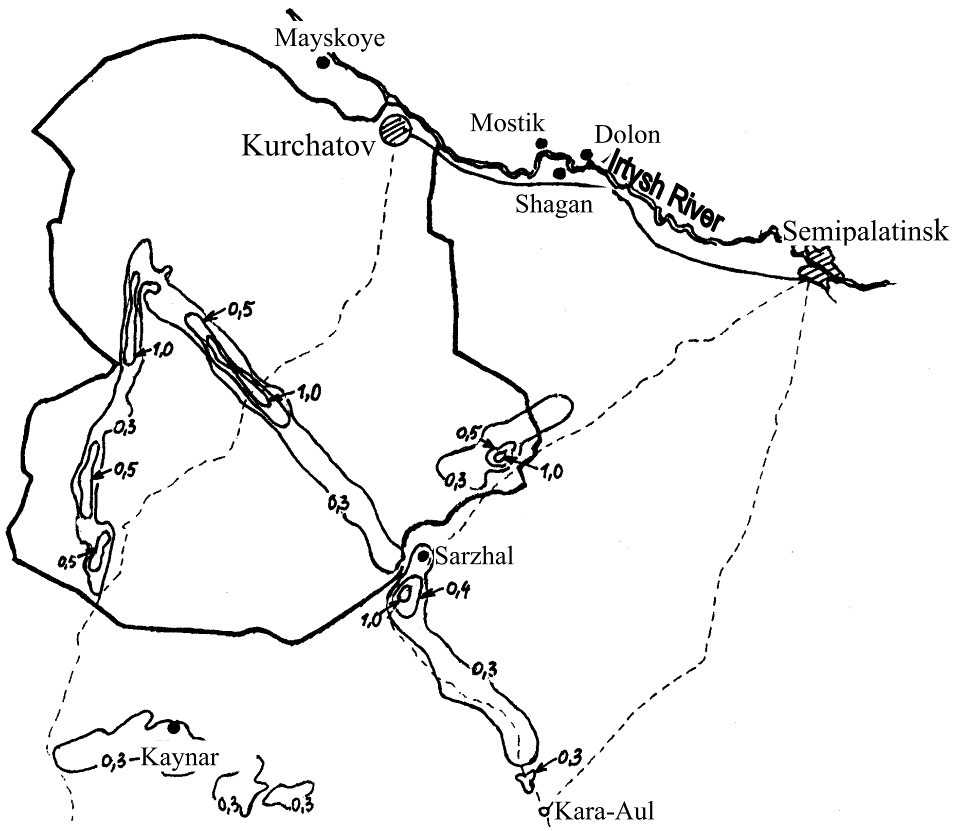


Figure 30. Density contours of ^{137}Cs ground contamination on the grounds of Semipalatinsk Test Site and adjacent districts, in Ci/km^2 (as of December 1992).

ground nuclear explosions at the test site during the period of atmospheric nuclear testing.

Densities of ^{137}Cs contamination exceeding 1 Ci/km^2 were recorded only in the test areas of the Test Field and in very small parcels of the radioactive plume formed after the explosion of August 12, 1953.

Experts who performed a detailed analysis of all radiation events that took place at the Semipalatinsk Test Site over 40 years ago have concluded that the radiological state of the surface layer of soil is defined mostly by such long-lived products as ^{90}Sr and ^{137}Cs and their daughter radionuclides, as well as plutonium isotopes.[10] The defining role of these radionuclides was due to their relatively high production in nuclear explosions, the large gap in time since the explosions, and their high biological action; the activity of shorter-lived radionuclides has declined through natural decay.

During the time that has passed since the explosions, ^{90}Sr and ^{137}Cs activity has declined, but the α activity of plutonium has remained practically unchanged, so the absolute values of $^{90}Sr+^{137}Cs$ and Pu activities have become roughly equal. Since the radiotoxicity of plutonium is nearly double that of ^{90}Sr and ^{137}Cs, the problem of radioactive contamination of the test site grounds is a problem of plutonium contamination.

Radiation in the Most Contaminated Inhabited Areas

The results obtained in 1990 and 1991 during inspections of the test site grounds and adjacent districts have been used to draw a schematic map of the contour lines of γ dose rates, which is given in Figure 31. The data shown in the figure indicate that the dose rates range from 10 to 50 μR/hr, averaging about 20-30 μR/hr. But if we subtract natural radiation from the total dose rate, the maximum dose rate increase due to the manmade component in the southeastern plume (cf. Figure 30) equals 10-15 μR/hr. In the towns of Sarzhal, Kara-Aul, and Kaynar, dose rates from artificial radionuclides do not exceed 5 μR/hr. Some parameters of radiation levels in these villages and towns, obtained by aerial γ survey, are given in Table 22.

The data indicate that the soil concentrations of ^{40}K and ^{232}Th are considerably higher in Kaynar than in Sarzhal and Kara-Aul, while the densities of ^{137}Cs contamination are practically the same in the three towns.

We should note that the area around Kaynar is in the foothills and differs from areas on the steppe plateau in its elevated concentration of natural radionuclides. In the villages and towns in steppe areas, the volumetric concentration of radon in residences did not depend on the building materials used, but in Kaynar, adobe brick homes had an average volumetric radon concentration about 2-3 times higher than in brick or concrete homes.

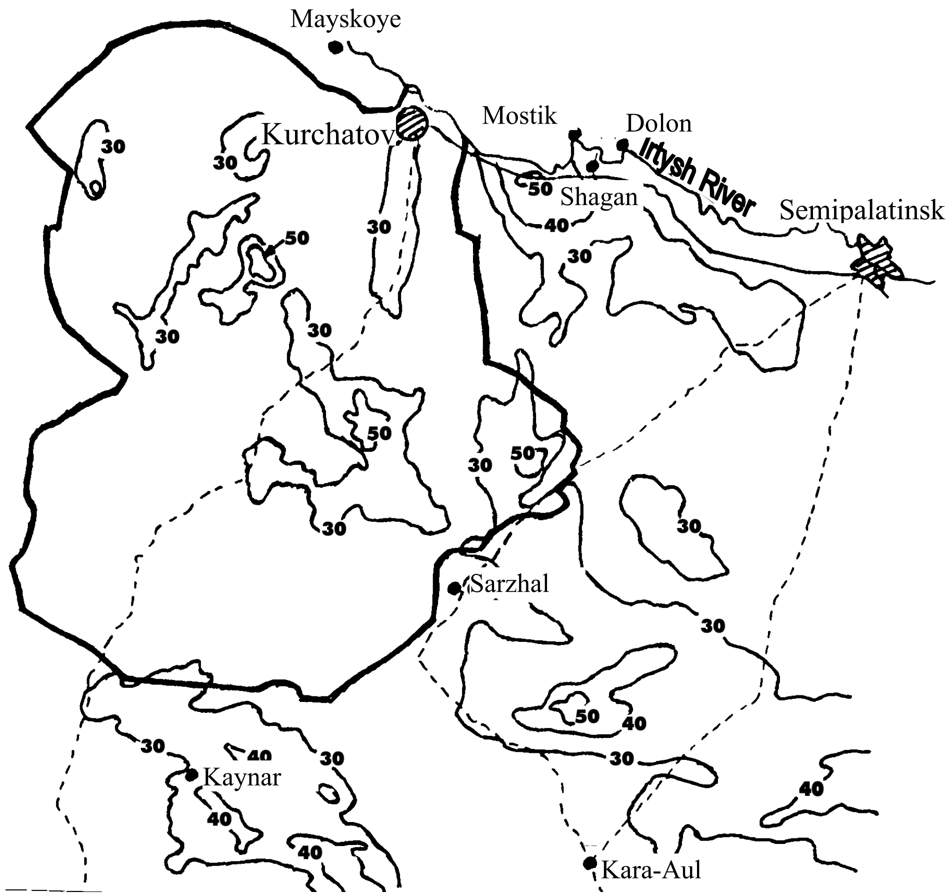


Figure 31. Exposure dose rates on the grounds of Semipalatinsk Test Site and adjacent districts, in µR/hr (as of December 1992).

Table 22. Principal Radiation Characteristics of the Most Contaminated Villages and Towns Located Near the Semipalatinsk Test Site As of 1990-1991[37,38]

Village or Town	Exposure Dose Rate, µR/hr	Density of ^{137}Cs Contamination, mCi/km^2	Soil Concentration of Natural Radioactive Elements, % by weight		
			^{40}K	^{232}Th	^{238}U
Kaynar	35	300	3.5	0.0014	0.0004
Kara-Aul	25	200	2.5	0.0010	0.0002
Sarzhal	15	300	1.5-2.0	0.0005	0.0003

Under the Region-1 research program, in addition to aerial γ surveys, employees of the Radium Institute and other entities performed detailed inspections of the territories of villages and towns with measurement of ground radiation levels (exposure dose rate, Russian *MED*) and collection of soil, vegetation, and water samples. The samples were analyzed at the Radium Institute (St. Petersburg) and at the All-Union (now All-Russian) Scientific Research Institute of Experimental Physics in Sarov (*VNIIEF*).

Figure 32 shows the location of villages and towns near the test site whose territories were most heavily contaminated by radioactive fallout during the period of nuclear testing. These are the towns of Kaynar, Sarzhal, Kara-Aul (Abay), Dolon and the nearby town of Mostik, etc. It shows where soil samples were collected along the perimeter of the Semipalatinsk Test Site, as well as the placement of filtration units and drinking water sampling locations.

Data describing radiation levels in these most contaminated villages and towns in 1991 and 1992 are presented below.

The Dolon and Mostik Area. The towns of Dolon and Mostik are located on the right bank of the Irtysh River 95-118 km from the center of the Test Field at the STS. The area containing these towns has been exposed to radioactive contamination several times: in 1949, 1954, 1955, 1956, 1958, 1961, 1962, and 1965.

The heaviest radioactive contamination in this area occurred after the first nuclear test on August 29, 1949. The plume axis passed within 1.5 km of the northern edge of Dolon, where 1228 people of various ages lived. The inspection of Dolon from 1991 to 1993 and collection of environmental samples are diagrammed in Figure 33.

Consolidated data on the nature of radiation levels in Dolon are given in Table 23.

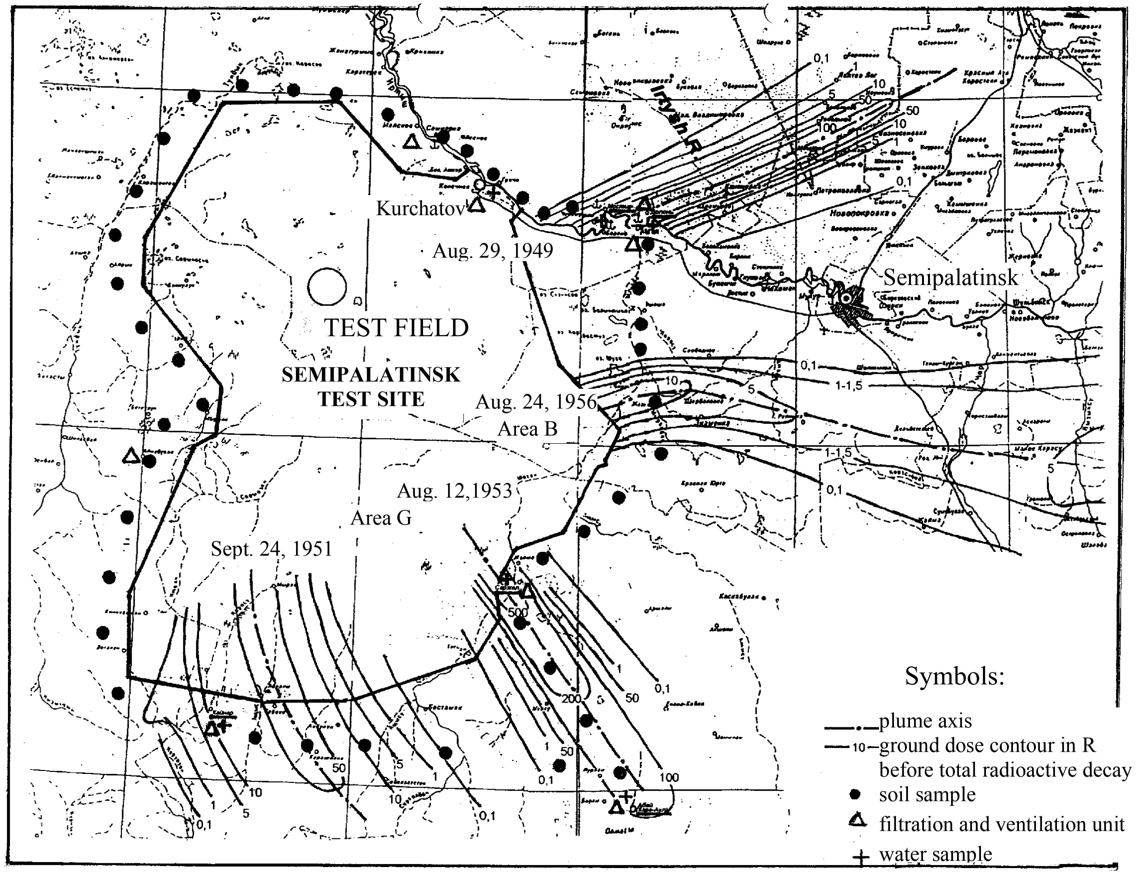


Figure 32. Radiation conditions in areas containing Dolon, Kaynar, Sarzhal, and other populated places in Semipalatinsk Region that were exposed to maximum radioactive contamination

Table 23. Density of Soil Contamination by Biologically Hazardous Radionuclides in Dolon As of December 1992[39-41]

Radionuclide	Number of Sample and Measurement Points	Density of Soil Contamination, mCi/km^2		
		Maximum	Minimum	Mean (Std. Dev.)
^{137}Cs	38	290	20	120 (80)
^{90}Sr	26	300	14	48 (68)
Pu	28	300	1	93 (100)
Gamma Back-ground, μR/hr	38	21	10	16 (2)

Dose rates were measured at soil and vegetation sampling locations. The mean dose rate in Dolon was 16 μR/hr.

Soil samples were collected from the entire territory of the town. Analysis of these samples indicated the spotty nature of soil contamination around the town. Relatively high concentrations of ^{137}Cs and plutonium were noted in soil samples collected in the northern part of the town, which was close to the plume axis formed in 1949 after the first nuclear explosion. However, the soil contamination densities presented in Table 23, which exceed global backgrounds by a factor of two or three, are not hazardous to the public.

The town's soil contains the very biologically important radionuclide ^{239,240}Pu in two principal aggregate states. The first, the main state, is particles of fused soil up to 100 μm in size, from which the plutonium, according to laboratory analyses, cannot be extracted by weak hydrochloric acid. The second is a finely dispersed state that permits the transport of plutonium from the soil into weak acid solutions, that is, a migration-capable form of plutonium. Since plutonium is distributed in the soil layer down to a depth of 20 cm, its concentration in the surface layer of air is below the allowable radionuclide concentration for Group B population (Russian DK_B), 30 aCi/l.[110]

Calculations showed that the additional manmade exposure dose of Dolon residents cannot exceed 1 mSv/yr, and the plutonium concentration in air does not exceed the DK_B level, since it was mostly confined to an insoluble matrix.

The Mostik Area (700 residents, including 211 children) was inspected using the same methods as for Dolon. The exposure dose level on the territory of Mostik ranged from 12 to 18 μR/hr, with a mean of 14 μR/hr.[111] The density of ^{137}Cs contamination, approximately 50 mCi/km^2, did not exceed global contamination levels. The same can be said of the density of ^{90}Sr and $^{239,240}Pu$ ground contamination.

At present, ^{137}Cs occurs primarily in the top 10 cm of soil; its concentration in vegetation is substantially lower than that of ^{40}K (a natural radionuclide), amounting to about 0.1 Bq/g of ash.

The results of the cited inspections confirmed that the radioactive plume from the explosion of August 29, 1949 was located between Dolon and Mostik, which are 12 km apart. In this area, the maximum exposure dose level in 1993 was 20 μR/hr, and the ground contamination density was 500 mCi/km^2.

Laboratory analyses of soil samples established that only 1-3% of the plutonium is in a mobile easily dissolved form and is biologically available (is leached by a 2N hydrochloric acid solution).

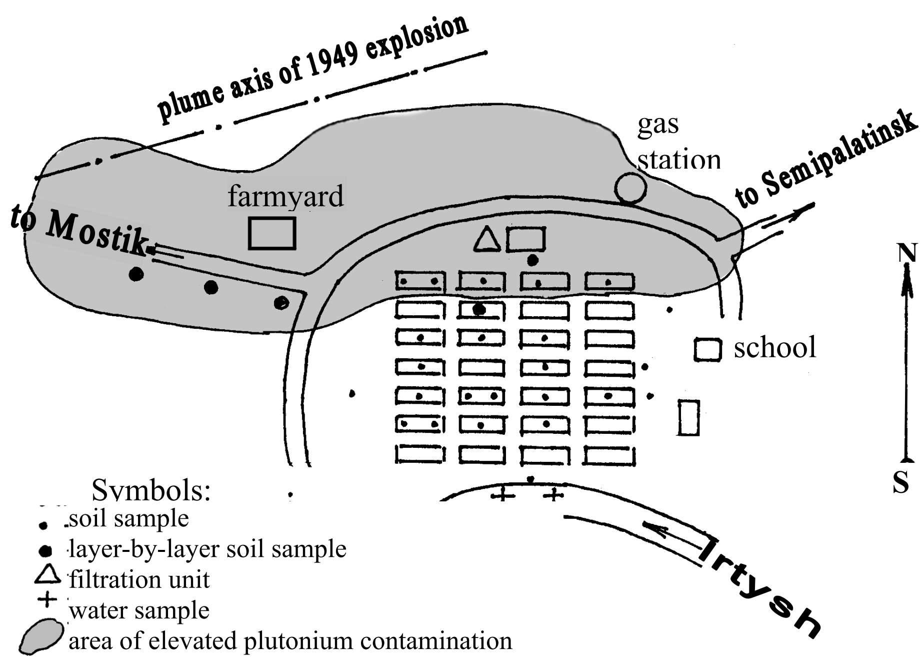


Figure 33. Diagram of environmental sample collection near the town of Dolon in 1991-1992.

The Kaynar Area. The town of Kaynar is located in the radioactive plume from the explosion of September 24, 1951. The inspection of this town is diagrammed in Figure 34.

Nearly two years of monitoring of radiation levels in this town established that the concentration of radionuclides in the drinking water and air is 500-1000 times lower than allowable levels. The main α emitter in aerosol samples collected in the surface layer of air was ^{210}Po, whose concentration after filter cineration averaged 2.2 μBq/m^3.

It is also important to note that in Kaynar, unlike the other inspected villages and towns near the test site, the highest level of volumetric radon activity was observed in the homes: in adobe brick homes it was 133 ± 20 Bq/m^3; in brick homes it was 80 ± 18 Bq/m^3. This can be explained by the elevated ^{232}Th levels in the soil and by Kaynar's location in the foothills. The elevated radon concentration in the residential air may have had an adverse effect on the health of the local population.

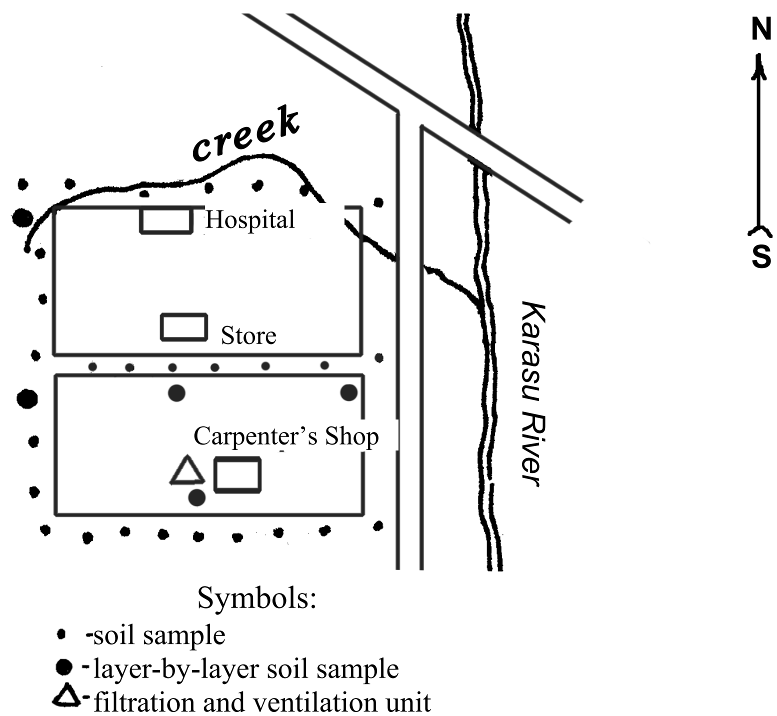


Figure 34. Diagram of outdoor environmental sample collection near the town of Kaynar in 1991-1992.

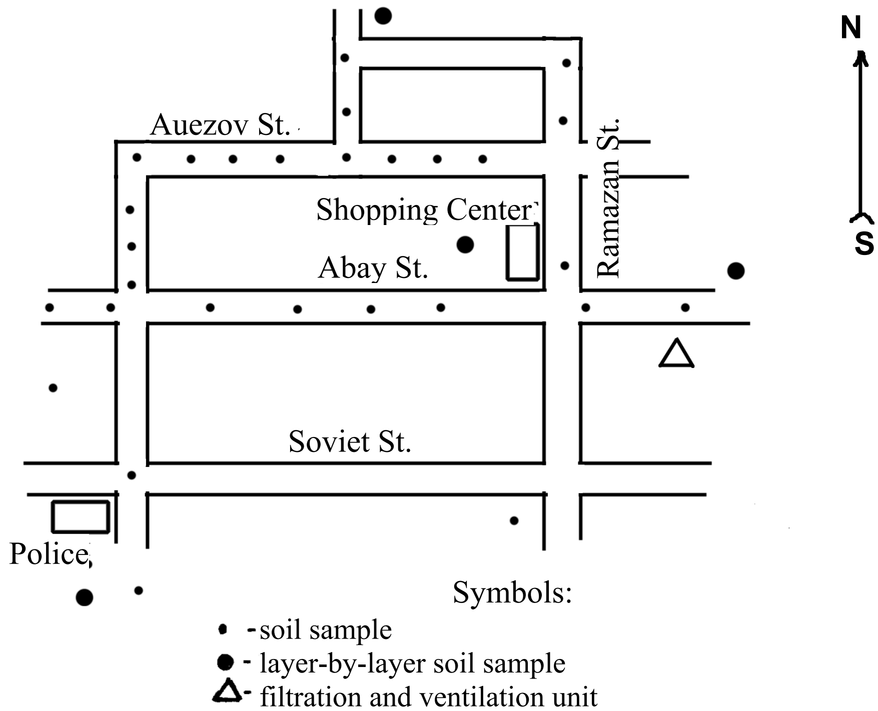


Figure 35. Diagram of outdoor environmental sample collection near the town of Kara-Aul (Abay) in 1991-1992.

The Kara-Aul (Abay) Area. The town of Kara-Aul is located about 200 km southeast of the site's Test Field, where all atmospheric nuclear weapon tests were carried out. Most of the radioactive contamination of this town is related to the August 12, 1953 ground explosion of the first thermonuclear physics package. This town's inspection is diagrammed in Figure 35.

By the time the comprehensive inspection of Kara-Aul was conducted in 1991 and 1992, the town's population was 7000, including 3300 children under 18 (in 1953 the town had 2200 residents).

The inspections established that the density of ^{137}Cs and ^{90}Sr ground contamination was about double the global average. The level of contamination of drinking water samples from wells (11 samples), and of ambient air around the town was considerably lower than public health standards. Consolidated data on the nature of radiation levels in Kara-Aul are presented in Table 24. The data show that in 1991 and 1992, radiation levels in Kara-Aul were practically normal, that is, their characteristics were indistinguishable from global background levels.

Table 24. Density of Soil Contamination by Biologically Hazardous Radionuclides in Kara-Aul (Abay) as of December 1992[112]

Radionuclide	Density of Soil Contamination, mCi/km^2		
	Maximum	Minimum	Mean (Std. Dev.)
^{137}Cs	370	8	82 (70)
^{90}Sr	190	2	60 (47)
$^{239,240}Pu$	32	0.6	8.5 (9)
Gamma Background, μR/hr	18	10	14 (2)

The Sarzhal Area. The town of Sarzhal is also located in the radioactive plume produced by the explosion of a thermonuclear physics package on August 12, 1953, but closer to the test site than Kara-Aul. All residents of Sarzhal, who numbered about 2600, were evacuated before the explosion. Archives preserve reports that soon after their return to the town, some were examined by the site's military doctors, who found no signs typical of acute radiation sickness.[113,114]

The inspection of the town of Sarzhal in 1991 and 1992 was conducted practically according to the scheme used in other villages and towns located near the Semipalatinsk Test Site. The inspection of Sarzhal is diagrammed in Figure 36.

The inspections showed the uneven contamination of the soil by manmade radionuclides typical of all lands contaminated by radioactive fallout. The average density of soil contamination in and around Sarzhal was below critical values, as shown by the data in Table 25.

Based on these data, we can conclude that the mean density of ground contamination by manmade radionuclides is about two or three times higher than the global level; this is not hazardous to human health. The annual exposure dose of residents of Sarzhal does not exceed limits allowable under health regulations.

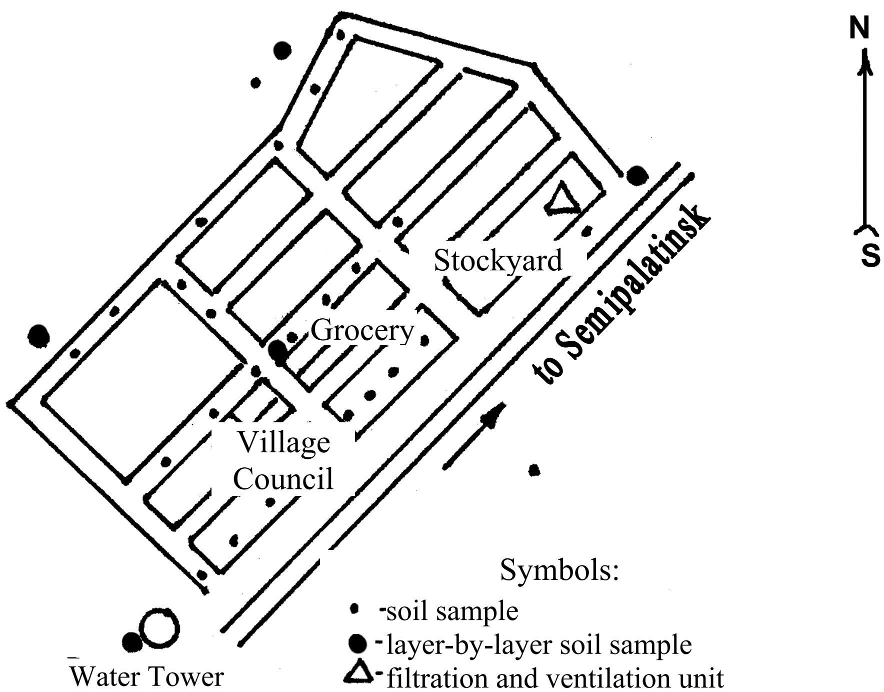


Figure 36. Diagram of outdoor environmental sample collection near the town of Sarzhal in 1991-1992.

From June 1991 through September 1992, the extent of contamination of the surface layer of air in the town was monitored using a fan and filter unit placed on the grounds of the electrical substation. The results showed that the plutonium concentration in air during that period was between 0.046 and 0.8 aCi/l, 1/40th to 1/600th the allowable concentration.[109]

Analysis of drinking water samples from 12 wells in Sarzhal indicated a practically total absence of artificial radionuclides.

Table 25. Density of Soil Contamination by Biologically Hazardous Radionuclides in the Sarzhal Area As of December 1992

Radionuclide	Density of Soil Contamination, mCi/km^2		
	Maximum	Minimum	Mean (Std. Dev.)
^{137}Cs	300	50	120 (50)
^{90}Sr	260	40	70 (40)
^{239,240}Pu	28	0.5	10 (11)

Radionuclide	Density of Soil Contamination, mCi/km^2		
	Maximum	Minimum	Mean (Std. Dev.)
Gamma Background, μR/hr	20	13	16 (3)

As we have already noted, in 1991 and 1992 both the territories of these most contaminated villages and towns, and the territories along the perimeter of the Semipalatinsk Test Site including the villages and towns located there, such as Kurchatov, Mayskoye, Yegendy-Bulak, Shagan, etc. were inspected. The inspections involved measurements of ground γ levels and the sampling of soil, vegetation, air, and water. In each village or town, at least 35-50 soil samples were collected, and at six or seven points, the ground was sampled layer by layer to a depth of 20 cm. The water sample volume was 100 liters. Aerosol samples were collected in the surface air layer using a fan and filter unit. The airborne radon concentration in living and work areas was measured using passive integral track dosimeters.

A large number of water samples from the Irtysh River near the villages and towns of Belogorye, Kurchatov, Dolon, etc., as well as tap water in Kurchatov, were collected and analyzed. The results of the analyses are presented in Table 26.

We should note that these levels of radioactive contamination for water in the region near the Semipalatinsk Test Site are practically the same as the values for concentration of manmade radionuclides in open bodies of water in the European part of the former USSR.

Table 26. Radionuclide Concentration in the Waters of the Irtysh River and in Tap Water in Kurchatov As of December 1992[109]

Water Sample Collection Point	Radionuclide Concentration in Water, pCi/l	
	^{90}Sr	^{137}Cs
Irtysh River near		
• Kurchatov	0.30	4.0
• Dolon	0.24	2.7
• Belogorye	0.44	2.3
Tap Water in Kurchatov	0.21	4.6

Radiation levels in Kurchatov may be of some interest.

Radiation and Possible Exposure Doses of Residents of Kurchatov

During the period of nuclear testing at the Semipalatinsk Test Site in the atmosphere (until 1962) and underground (in emplacement holes), radioactive contamination of the territory of Kurchatov was a relatively rare phenomenon and was characterized by small exposure doses for the people of the city.

According to the collection edited by V. A. Logachev,[12] radioactive clouds from 17 ground, atmospheric, and underground nuclear explosions (with ground excavation and partial exposure of the chamber) could have spread toward Kurchatov, i.e., in the sector from 35° to 65°. Basic information about these explosions is presented in Table 27.

Table 27. Characteristics of Nuclear Explosions Whose Radioactive Clouds Could Have Spread toward Kurchatov

Explosion Date	Description of Explosion		Distance to Which Radiation Survey Data Are Available, km	Gamma Dose on Territory of City before Complete Decay of Explosion Products, cGy	
	Yield, kilotons	Type, Altitude or Depth in meters			
9/10/53	4.9	Atmospheric	60	0.010	
10/23/54	62	Atmospheric	250	0.015	
11/22/55	1600	Atmospheric	465	0.060	
3/16/56	14	0.4	402	0.040	0.320
9/10/56	38	Atmospheric	125	0.160	
4/3/57	42	Atmospheric	90	0.025	
3/18/58	0.16	Atmospheric	320	0.010	
November 4, 1958 to August 1, 1961: nuclear testing moratorium					
9/9/61	0.38	0	130		0.270
9/13/61	0.001-20	Atmospheric	—		
10/4/61	13	Atmospheric	—		

<table>
<tr><th rowspan="2">Explosion Date</th><th colspan="2">Description of Explosion</th><th rowspan="2">Distance to Which Radiation Survey Data Are Available, km</th><th rowspan="2" colspan="2">Gamma Dose on Territory of City before Complete Decay of Explosion Products, cGy</th></tr>
<tr><th>Yield, kilotons</th><th>Type, Altitude or Depth in meters</th></tr>
<tr><td>8/1/62</td><td>2.4</td><td>Atmospheric</td><td>—</td><td></td><td rowspan="5">1.200</td></tr>
<tr><td>8/7/62</td><td>9.9</td><td>0</td><td>750</td><td></td></tr>
<tr><td>8/23/62</td><td>2.5</td><td>Atmospheric</td><td>—</td><td></td></tr>
<tr><td>8/25/62</td><td>0.001-20</td><td>Atmospheric</td><td>—</td><td></td></tr>
<tr><td>11/3/62</td><td>4.7</td><td>Atmospheric</td><td>250</td><td></td></tr>
<tr><td>10/14/65</td><td>1.1</td><td>Underground (1003)</td><td>200</td><td>0.500</td><td rowspan="2">0.510</td></tr>
<tr><td>11/4/70</td><td>0.001-20</td><td>Underground (125</td><td>150</td><td>0.010</td></tr>
<tr><td colspan="5" align="right">Total</td><td>2.300</td></tr>
</table>

The first slight radioactive contamination of the territory of Kurchatov with a ground γ dose of about 0.01 cGy occurred after a low-yield atmospheric explosion on September 9, 1953. This was the eighth nuclear test in the site's Test Field. However, the explosion occurred over Area Sh and the city of Kurchatov.

According to data from the test site's radiation safety service, the territory of Kurchatov was contaminated before the nuclear testing moratorium was declared on November 4, 1958, by radioactive fallout mainly after seven atmospheric explosions, with the exposure dose possibly totaling 0.32 cGy.

When atmospheric testing was resumed after the end of the moratorium, the territory of Kurchatov was contaminated by three tests in 1961 and five in 1962. The most significant radioactive contamination of the city occurred after an unplanned (accidental) 9.9-kiloton ground nuclear explosion on August 7, 1962. The contamination was caused when the missile warhead contacted the ground at the point of an intended atmospheric nuclear explosion. During the formation of the radioactive plume, winds were unstable, ranging from calm to light with occasional gusts. In Kurchatov, 60 km away from the Test Field (Area P-5), ground radiation levels were 500-1000 μGy/hr when the radioactive contamination front arrived, but 24 hours after the explosion, they were 50 μGy/hr.[115] The γ doses from the explosion could have been about one cGy.

According to Yu. S. Stepanov *et al.*,[99] 15 radioactive clouds from nuclear explosions passed over Kurchatov, the first a cloud formed by an atmospheric explosion with a yield of 1-20 kilotons on September 3, 1953, and the last after an underground excavating explosion on October 14, 1965. The maximum exposure dose of city residents is linked to the "accidental" ground explosion of August 7, 1962.

According to data presented by V. M. Loborev *et al.*,[45] the effective exposure dose of residents of Kurchatov after all nuclear tests conducted at the Semipalatinsk Test Site could have been 5.8 cSv. The same study presents the results of an estimate of effective exposure doses for residents of other cities in the area affected by nuclear tests at the site, specifically:

- Semipalatinsk 0.43 cSv;
- Ust-Kamenogorsk 1.8-6.5 cSv (average 3.6 cSv);
- Shagan 22.8 cSv.

However, there is also another opinion on the total exposure dose of residents of Kurchatov. Logachev[12] estimates the effective exposure dose for residents of that city after all nuclear tests at the Semipalatinsk Test Site at 2.0 cSv. The true value of the dose may be somewhere between 2.0 and 5.8 cSv.

During partial camouflet underground explosions, or in cases of nonstandard radiation situations, radioactive noble gases and certain vapor-phase radionuclides escaped. However, such situations produced practically no exposure for residents of Kurchatov, since measured exposure doses were under 10 μR. Analysis of archived documents shows that during the conduct of other underground nuclear tests, no exposure of the population of Kurchatov was recorded.

The results of radiometric analysis of soil samples collected on the territory of Kurchatov at various times have shown that when passage of the radioactive contamination front increased the γ background, the natural activity of the surface soil layer rose by nearly an order of magnitude. It was also noted that the increase in the extent of soil contamination was less related to local radioactive precipitation than to wind-borne transport of radioactive substances from the grounds of the Test Field and to global fallout.

A large volume of work using the most modern spectrometric and radiochemical research methods has established that the present level of radioactive contamination of environmental systems outside the grounds of the test site is practically indistinguishable from the global background and presents no danger to the public. Effective exposure doses for residents of inspected villages and towns due to manmade contamination do not exceed 1 mSv/yr, while the concentrations of artificial long-lived radionuclides in water, air, and food do not exceed health standards.

PART 3. CONVERSION AND FEATURES OF THE MOST RECENT PHASE OF ACTIVITY AT THE TEST SITE

The last phase of operation of the Semipalatinsk Test Site (STS) was the period from 1989 to 1991. The final series of explosions, consisting of seven underground nuclear tests, was detonated in 1989, and on August 29, 1991, Kazakh SSR President Nursultan A. Nazarbayev’s Decree 409 closed the test site. The same decree recommended that the Semipalatinsk Nuclear Test Site be converted to a scientific research center. After the breakup of the USSR in late 1991, the STS became the property of a newly independent state, the Republic of Kazakhstan. Military Unit 52605, which had been the test site’s main unit throughout its life, formally existed until 1993, when it was replaced by the Republic of Kazakhstan National Nuclear Center (RK NNC) formed that year. The period from 1992 through 1994 can be called a transition from the dismantling of all the test site’s structures to the creation of a research center on its grounds around the RK NNC. With the center's creation at the test site, new, very difficult problems began to be addressed, having to do with the assessment of the consequences of the site's operation and the search for possible civilian uses of its grounds.

The Semipalatinsk Test Site had ceased to exist, but the elaborate infrastructure remaining on its grounds (emplacement holes, special installations, test areas, etc.), which had functioned for many years for the conduct of nuclear explosions and various nuclear physics experiments (hydrodynamic, hydronuclear, irradiation, and other tests), had to be dismantled in accordance with international treaties. For these purposes, the Governments of the Russian Federation and the Republic of Kazakhstan signed an Agreement in 1997 declaring 2001 the last year of dismantling of the nuclear testing infrastructure and mothballing of special installations at the former test site.

NUCLEAR TESTING AT THE SITE IN 1989 IN THE CONTEXT OF SOCIOPOLITICAL EVENTS IN THE USSR

In 1989, the Soviet Union performed underground nuclear tests only at the Semipalatinsk Test Site; the Novaya Zemlya Test Site was "silent." In a series of seven tests in adits in Delegen Area and in shafts in Balapan Area, 11 physics packages were detonated, with yields according to official catalog data[1] ranging from 0.001 to 150 kilotons. Table 28 presents data describing the underground nuclear tests conducted at the STS in 1989.

Table 28. Basic Characteristics of Nuclear Explosions at the STS in 1989, Its Last Year of Operation

Nuclear Test Number per Catalog[1] and Date	Test Location	Yield, kilotons	Remarks
708, 1/22/1989	Balapan, Shaft 1328	0.001-20 20-150	

Nuclear Test Number per Catalog[1] and Date	Test Location	Yield, kilotons	Remarks
709, 2/12/1989	Balapan, Shaft 1366	20-150	Radiation from the “plume” of radioactive gases was recorded in the towns of Shagan and Komsomolsky. This provoked a negative reaction among the public of the Semipalatinsk region.
710, 2/17/1989	Delegen, Adit 139	0.001-20	This test caused an even stronger negative attitude toward nuclear testing at the STS.
711, 7/8/1989	Balapan, Shaft 1352	20-150	The test was attended by members of the Nevada-Semipalatinsk antinuclear movement and the press.
712, 9/2/1989	Balapan, Shaft 1410	0.001-20 0.001-20	Members of the Nevada-Semipalatinsk movement were upset by the conduct of the test, calling it a “gift” to schoolchildren returning to their desks after summer vacation.
713, 10/4/1989	Delegen, Adit 169/2	0.001-20	The USSR Ministry of Defense held a press conference in Moscow with domestic and foreign journalists about the test.
714, 10/19/1989	Balapan, Shaft 1365	20-150 0.001-20 0.001-20	TASS reported this test, with a yield of 20 to 75 kilotons, as the last at the STS in 1989. This test was in fact the last in the entire history of the STS.

After a series of underground nuclear tests at the STS in 1989, the Kazakh writer K. B. Kabdrakhmanov wrote in his book, *“... All Kazakhstan has been turned into a single test site where both weapons and the nation’s patience are being tested. That’s how the shepherds put the* *question, directly, and we cannot answer them. Test site workers say the underground tests are harmless, but we will never see the harm with our naked eyes. Tests affect the people's health and standard of living."*[18]

The sociopolitical situation had come to a head, and ultimately forced the closure of the STS. The following is a chronicle of events that played out over the Semipalatinsk Test Site in the late 1980s and early 1990s. The documents, statements, and citations from printed publications are given in italics, uncut and without correction.

On **February 12, 1989,** after a nuclear test in Shaft 1366, the television program *Vremya* ("Time") reported that *"at the STS, another underground nuclear explosion has been set off…"*

This nuclear explosion was detonated under the usual rules, and with the expected (based on the radiation forecast) leakage of radioactive noble gases (RNGs) into the atmosphere. In addition, a "plume" of gases passed over the town of Shagan, where a strategic air division was deployed at the time; the division's dosimetric service recorded a radiation background rise to 3 μR/hr. The division commander, Maj. General of Aviation P. G. Bredikin, did not attempt to "conceal" the measurement results from the leaders of Semipalatinsk Region, who were dissatisfied with the report of the site director, Lt. General A. D. Ilyenko, to Moscow saying that the *"item fired normally and the radiation background showed no deviations."*[17]

In the opinion of the First Secretary of the Semipalatinsk Regional Committee of the Communist Party of Kazakhstan, Keshrim B. Boztayev, the site director's message created a psychological shock in most people, and undermined their belief in the "absolute" safety of underground nuclear testing. Moreover, a second test, conducted according to plan five days later, fanned the flames of public dissatisfaction: *"the public demanded an open study of the situation at the test site."*

In his book three years later,[17] Keshrim B. Boztayev commented on the situation that arose in the society after the two explosions: *"The February 1989 tests exhausted its patience. Worry and anger boiled to the surface. The situation spurred people to strong action. The region's leaders found themselves in an extremely delicate position—what should they attempt in order to avoid making mistakes and losing momentum by choosing the wrong policy?"*

On February 20, 1989, Keshrim B. Boztayev, after meeting with members of the regional party committee office and consulting with Nursultan A. Nazarbayev, the Chairman of the Kazakh SSR Council of Ministers at the time, sent the following telegram to Moscow:

> *"CPSU Central Committee. On the Nuclear Test Site Near Semipalatinsk.*
>
> *"The Semipalatinsk Regional Committee of the Communist Party of Kazakhstan hereby informs the CPSU Central Committee that since 1949, nuclear tests have been conducted at a test site near the City of Semipalatinsk, with a population of 340,000. Initially, they were conducted in the atmosphere, but since 1963, they have been conducted underground.*
>
> *"Now, 40 years later, the conditions surrounding the test site have changed: the population has tripled, and livestock herds have increased manyfold. The site is now in a densely populated area. However, none of this is being taken into account in the site's operation. Every year, 14-18 nuclear explosions are detonated, accompanied by seismic effects on buildings and utility lines and destroying hundreds of wells that supply water to inhabited village, towns, and animals.*
>
> *"The city was built without regard for seismicity. Moreover, the Earth's crust has been deformed on the test site grounds during the 25 years of underground explosions, and in a third of the cases, radioactive gases are leaking to the surface, which is practically impossible to prevent. In 1987, such a gas plume passed through Semipalatinsk with radioactivity of 350-450 μR/hr, and in the test of this past February 12, radioactivity levels of up to 4000 μR/hr were recorded outside the test site, which were only prevented from reaching the regional capital by a change in the wind direction. However, they did spread to the city of Semipalatinsk-21, to Shagan, and to many other villages and towns.*
>
> *"The nuclear tests naturally evoke various interpretations by the public, are creating a tense moral and psychological atmosphere among the public, and are being linked groundlessly to their state of health and possible disorders.*

> *"The region's party committees are working hard on public relations.*
>
> *"The Regional Party Committee, concerned over the emerging situation, requests that the CPSU Central Committee direct the appropriate ministries and departments to temporarily suspend or sharply reduce the frequency and yield of explosions, and to move future nuclear tests to another, more acceptable location."* [emphasis added]

Later, in his memoirs, Keshrim B. Boztayev noted: *"... This telegram sounded a loud alarm of pain and worry; it was the voice of an injured steppe. And soon we heard Olzhas Suleymenov's call for an organized movement to halt nuclear testing at the Semipalatinsk Test Site. I am referring to the poet's famous speech of February 28, 1989 on Kazakh television."*[17]

The telegram was essentially the first official document demanding the cessation of nuclear testing at the Semipalatinsk Test Site.

Keshrim B. Boztayev testifies, *"... The telegram was shown to members of the CPSU Central Committee Politburo, and it struck the Military-Industrial Commission (VPK) like a bolt from the blue. Two days later, I received a call from Gennady Vasilyevich Kolbin, the First Secretary of the Central Committee of the Communist Party of Kazakhstan, who said, 'your telegram reached Mikhail Sergeyevich. Gorbachëv had a conversation with Minister of Defense [Dmitry Timofeyevich] Yazov, who said, 'Boztayev is blowing things out of proportion, the test site is clean—there is no cause for concern.' That's when the unofficial pressure on me began. Later, N. M. Safronov, First Secretary of the Kurchatov Municipal Party Committee (Kurchatov was the center of the STS) and Ye. V. Chaykovsky, Chairman of the Kurchatov Municipal Executive Committee, told me that people in the VPK offices had been calling me 'the first man to rebel against the generals,' 'a dangerous man,' and so forth."*

On **February 28, 1989,** a Government Commission from Moscow came to Kurchatov. Its members included: A. V. Bukatov, Deputy Chairman of the USSR Council of Ministers' Military-Industrial Commission (chairman); Viktor N. Mikhaylov, Deputy Minister of Atomic Energy and Industry; Col. General V. N. Gerasimov, head of the USSR Ministry of Defense's 12th Main Directorate; A. S. Dadayan, Deputy Chairman of the USSR State Committee for Nature Conservation

(*Goskompriroda*); V. P. Strekhnin, an important worker in the CPSU Central Committee's Defense Industry Section, Ye. B. Shulzhenko, head of the USSR Ministry of Health's Third Main Directorate; and Lev Aleksandrovich Buldakov, Academician of the USSR Academy of Medicine.

And on the same day in Alma-Ata, Olzhas Suleymenov, a noted Kazakhstani poet, speaking to a rally of the Kazakh people, and two days earlier on Kazakhstani television, passionately urged a halt to nuclear testing. This day can be called the birthday of the antinuclear movement in Kazakhstan, which soon became the international antinuclear movement later called "Nevada-Semipalatinsk."[128]

THE "FIVE MINUS ONE" FORMULA

On **February 26, 1989,** People's Deputy of the USSR Supreme Soviet and poet Olzhas Suleymenov made an open appeal to the people on Kazakhstani television. His speech focused mainly on the two underground nuclear explosions just conducted at the STS, namely those of February 12 and 17, 1989, which *"... released radioactive gases into the atmosphere and correspondingly increased radiation levels in the city of Shagan."*

Appealing to the people, Suleymenov said: *"... A panic has broken out. As a Deputy to the Supreme Soviet, I have written a, inquiry. A commission has been formed, but no one knows anything about the results of its work. Then I spoke on Kazakhstani television and mentioned the release for the first time on the open airwaves. I understood the position of the Chairman of the Kazakhstan State Television and Radio Broadcasting Committee, who clutched his chest. And I understood the people who didn't know the truth, but should have known. I called the people to a rally February 28 at the Writers' Union…"*

On **February 28, 1989,** a public rally was held in Alma-Ata, and the attendees formed an antinuclear movement chaired by Olzhas Suleymenov.

During the month of **March 1989,** the movement collected signatures of support and charitable contributions in the Kazakh SSR. Over a million signatures were collected, along with thousands of letters and telegrams of solidarity.

The aim of the antinuclear movement was formulated thus: the cessation of nuclear testing at the STS, followed by its closure, as the first of five test sites operated by nuclear powers. The slogan for closing the site was: "Five Minus One."

On **March 3, 1989,** the bureau of the Semipalatinsk Regional Party Committee met with the participation of members of the Government Commission who had worked at the site under V. A. Bukatov.

Below are fragments of a transcript from the speech by the commission chairman and members of the regional party committee bureau as presented in Keshrim B. Boztayev's book.[17]

V. A. Bukatov: *"... Our commission has come at the direction of the General Secretary of the CPSU Central Committee and in response to a telegram from the regional party committee to study the problems on site. Our principal objective and aim at this phase is to improve the workup of nuclear weapon tests and the entire set of related problems. Specialists in these fields have looked at everything. On issues of safety and radiation levels, and based on the results of the commission's work, proposals and recommendations will be made to the regional party committee and the leaders of the CPSU Central Committee and the Government.*

"For each test and for each year, the CPSU Central Committee and the Soviet Government adopt resolutions to conduct tests. Only a resolution can authorize Site Director A. D. Ilyenko, the head of the USSR Ministry of Defense's 12th Main Directorate, V. N. Gerasimov, and USSR Deputy Minister of Medium Machine-Building Viktor N. Mikhaylov to sanction the conduct of tests. There is a resolution for each test.

"Judging strictly by these documents, Ilyenko has not committed a single violation. Nor was there one on February 12.

"Now, the main direction is to minimize the frequency and yield of tests. We will review issues of safety and improvement of the environment and necessary organizational and technical steps to prevent unfavorable events. We will make a series of changes and corrections to instructions and regulations. Then Ilyenko will operate differently.

"We must review the question of setting allowable radiation standards for the Semipalatinsk region as Category B (limited part of the population)."

Keshrim B. Boztayev: *"...But Semipalatinsk Region was not placed in Category B, the region doesn't have the benefits or compensations set for Group B. And it hasn't had them for the whole 40 years. Now that there's* *been a tragedy, we suddenly remember? Do you mean to say there has been a release, the radiation background has exceeded standards by a thousandfold (?!), but nobody's at fault. That's impossible. There are guilty parties, and they must be held accountable."*

M. Zh. Chayzhunusov: *"... I head the ideology section of the regional party committee. This matter cannot be considered only from the angle of loyalty, of understanding what defense needs. The regional committee is doing everything to explain it to the public. I am one of those sitting here who has seen nuclear explosions, back when I was a student in November 1955 and in the fall of 1956. The circumstances created since February 12, are beyond the realm of discussion. I ask the commission members to understand one thing. The land of Abay, where the site is located, is for us Kazakhs what Yasnaya Polyana is for the Russians. It upsets us. This land has been made inaccessible to the people…"*

Here I must digress a little from the transcript fragments to explain what "radiation hazard" is and how much public health can be affected by the plume of radioactive noble gases that can reach the surface within a relatively short time after an underground nuclear explosion. The passage of the plume raises the γ background, but is not accompanied by indoor exposure of the human body.[12] Whenever the radioactive plume passed over inhabited villages and towns outside the test site, the exposure doses of their residents never exceeded the allowable value of 0.5 rem (5 mSv) per year. Under NRB-76/87, this was the exposure dose limit for the Category B population.[126] According to data from Clinic No. 4, the maximum annual exposure dose of Semipalatinsk residents in 1982 was 0.18 rem (1.8 mSv), which is considerably lower than the allowable exposure dose.

Now let's return to the transcript of the Semipalatinsk Regional Party Committee bureau meeting on March 3, 1989.

Keshrim B. Boztayev: *"... We informed the central Government truthfully. We asked the Union Government to resolve the compensation issue and to furnish documents from Clinic No. 4 to permit assessment of the scale of damage from the nuclear explosions. We raised the problem calmly. Our position, as set forth in our telegram to the CPSU Central Committee, is based on principle. It is the position of our people. We stand by it."*

Keshrim B. Boztayev's overall reaction to the event was as follows:[17]

> *"… The commission has not assumed responsibility for February 12. The commission left without saying anything definite. Later, we were informed of its conclusions:*
>
> *"• take additional safety steps;*
>
> *"• increase physics package emplacement depths;*
>
> *"• continue underground tests.*
>
> *"The gases released on February 12 are inert noble gases and do not affect human health.*
>
> *"A conflict has begun, which has lasted for over two and a half years, a conflict between <u>the criminal legacy of the past and the industry obstinacy of the present</u>, on the one hand, and <u>the thoroughly objective and lawful demand of the people to cease the explosions immediately</u> on the other.*
>
> *"Site Director Lt. General A. D. Ilyenko was forced to appear on local television, radio, in the regional newspapers, at meetings with labor collectives… However, no one heard the truth from the general… He convincingly and hotly defended the story of "noble and inert gases," their absolute harmlessness. The cessation of nuclear testing, A. D. Ilyenko said, meant the destruction of the country. This was the official position of the all-powerful Military-Industrial Complex."*

On **<u>March 11, 1989,</u>** the foreign press reported the creation of the first Soviet antinuclear movement in Kazakhstan, which enjoys popular support.

During **<u>April 1989,</u>** a CPSU Central Committee resolution on the Semipalatinsk Test Site was in preparation. The draft resolution was endorsed by Gennady V. Kolbin, the First Secretary of the Kazakh SSR Communist Party Central Committee, but Nursultan A. Nazarbayev, the Chairman of the republic's Council of Ministers, refused to endorse it, and demanded that CPSU Central Committee Secretary Oleg Dmitriyevich Baklanov insert a special paragraph ordering examination of the "injured" population, and then, based on the results, conduct of an interregional scientific and legal conference in Semipalatinsk. The paragraph was added to the draft resolution.

In the opinion of Keshrim B. Boztayev,[139] the resolution was drafted without regard for the opinion of the Semipalatinsk Regional Party Committee, because its representatives did not work on the draft.

On behalf of the test site, Anatoly M. Matushchenko participated in the preparation of source data for the draft CPSU Central Committee resolution. He noted that several attempts had been made on behalf of the test site to prepare joint proposals for the document coordinated with the leaders of Semipalatinsk Region. However, one condition was constantly dictated on behalf of the region's leaders: "Compensation yes, testing no."

On **April 14, 1989,** USSR [Council] of Ministers Deputy Chairman I. S. Belousov ordered several of the country's ministries and departments, together with the Kazakh SSR Council of Ministers, to organize comprehensive examinations of the public and inspections of the environment in Semipalatinsk Region within two weeks and to discuss the results of these investigations at a conference in Semipalatinsk, enlisting specialists and members of the public to participate.

On March 5, 1989, implementing the directive, USSR First Deputy Minister of Health Gennady V. Sergeyev promulgated Order 14-K, "On the Sending of a Comprehensive Commission to Semipalatinsk," and placed Professor Anatoly F. Tsyb, Director of the USSR Academy of Medicine's Scientific Research Institute for Medical Radiology, in charge.

On **April 26, 1989,** the Military-Industrial Commission held a conference, where it discussed a plan to conduct tests at the site. It decided to reduce the number of underground tests in 1989 from 18 to 9, and also to lower test yields to 75 kilotons. Protocol No. 78/11 of that meeting was approved on April 27, 1989 by I. S. Belousov.

In **April and May 1989,** US Ambassador Jack F. Matlock, Jr. visited Alma-Ata to get acquainted with the leaders of the Nevada-Semipalatinsk movement. The US ambassador was given the movement's first documents.

Then a representative of the American antinuclear organization Total Revolution, Yeshua Moser, made an unofficial visit to Kazakhstan.

At the same time, the Nevada-Semipalatinsk movement formed a Coordinating Council and adopted its Program and Charter.

On **May 3, 1989,** a comprehensive commission under Anatoly F. Tsyb began work at the Semipalatinsk Test Site. It consisted of the country's leading Union- and republic-level specialists. Employees of practical public health agencies of the Kazakh SSR and Semipalatinsk Region, as well as members of the Nevada-Semipalatinsk International Antinuclear Movement, were enlisted to participate in the commission's work.

All of the test site's available archive documents containing data on radiation levels, reports with the results of public examinations, and information on environmental radiation levels in the region were placed at the commission's disposal (see Appendix). Based on analysis of these materials, as well as the results of measurements performed by the commission, the commission estimated the public exposure dose during the period of atmospheric and underground nuclear testing at the Semipalatinsk Test Site.[92]

The commission's results were written up in a detailed report that was then submitted for open discussion at a scientific and practical conference in Semipalatinsk in July 1989.

A large number of specialists and members of the public of Kazakhstan participated in the commission's measurements on the ground: R. A. Aytmagambetov, Chief Radiologist of the Kazakh SSR Ministry of Health; Galdet A. Batyrbekov, Deputy Director of the Kazakh SSR Academy of Sciences' Institute of Nuclear Physics (*IYaF*); G. I. Zhukov, V. S. Dobrovolsky, Ye. S. Bekmukhambetov, I. V. Kazachevsky, and V. V. Voronin, specialists from IYaF; S. L. Turapin, a specialist from the Kazakh SSR Ministry of Health's Institute of Oncology and Marginal Pathology; B. S. Chegedekov and M. Kh. Kagan, specialists from the Public Health Stations of the City of Semipalatinsk and Semipalatinsk Region; V. T. Kobrin, a specialist from the Semipalatinsk chapter of the Soviet Committee for the Defense of Peace (*SKZM*); V. N. Krylov, representative of the residents of Shagan; Yu. S. Kalinin, employee of the Pavlodar Region Public Health Station; M. Kh. Yeleumzov, representative of the Nevada-Semipalatinsk Society and Deputy Director of the Kazakh SSR Design-Engineering and Scientific Research Institute of Water Management Construction (*Kazgiprovodkhoz*); V. I. Deriglazov, authorized representative of the USSR Ministry of Health; and K. S. Belyaninov, correspondent for the newspaper *Komsomolskaya pravda* ("Communist Youth League Truth").

On **May 26, 1989,** the Military-Industrial Commission in Moscow adopted Decision 194, "On the Conduct of Research into the Seismic Action of Underground Nuclear Explosions in the Semipalatinsk Region."

On **June 9, 1989,** the CPSU Central Committee issued Resolution P160/63, approving proposals by the Government Commission that had worked at the Semipalatinsk Test Site under the supervision of V. A. Bukatov regarding the problems in the region since the February 12 and 17, 1989 regular underground nuclear tests (cf. data from March 3, 1989).

On **July 8, 1989,** after a five-month hiatus, the regular underground nuclear test was conducted, attended by members of the Nevada-Semipalatinsk movement and the mass media. The test site continued work to carry out the State Program for the Conduct of Underground Nuclear Explosions.

On **July 13, 1989,** General of the Army Dmitry T. Yazov, USSR Minister of Defense, and Gury Ivanovich Marchuk, President of the USSR Academy of Sciences, sent the Secretariat of the USSR Congress of People's Deputies a response to an inquiry by Deputies Ivan Mikhaylovich Aksënov, I. A. Merkulov, and D. S. Mironova on the conduct of nuclear testing at the Semipalatinsk Test Site. Anatoly M. Matushchenko of the USSR Ministry of Defense participated in drafting the response.

At the same time, USSR People's Deputy Olzhas Suleymenov, who was also president of the Nevada-Semipalatinsk Antinuclear Movement, addressed the first USSR Congress of Deputies regarding the movement's aims and demands. Simultaneously, his assistant, Mukhtar Omarkhanovich Auezov, was sent to the US to establish contacts with American activists in antinuclear groups and organizations. The trip produced in a joint action program.

Suleymenov's first visit to the Semipalatinsk Test Site soon followed. The weakening of secrecy restrictions enabled the appearance of various information on the test site and the consequences of nuclear testing there in the mass media, in particular in the magazine *Ogonëk* ("Little Flame").

July 17-19, 1989, the Scientific and Practical Conference, "Public Health and Environmental Conditions in Semipalatinsk Region," was held in Semipalatinsk. Representatives of Union authorities, who faced Kazakhstan's leaders and public as "defendants" for the "harmful" activities of the Semipalatinsk Nuclear Test Site, attended the conference. The conference's verdict: shut down the Semipalatinsk Test Site immediately (Appendix A.6). The site administration and its representatives came in for harsh obstruction and persistent criticism, and the site director was inundated with insults…

At the same time, the leaders of the Nevada-Semipalatinsk movement held a whole series of rallies in Semipalatinsk, at the test site, and in many villages and towns in Semipalatinsk and Pavlodar Regions to protest the nuclear tests.

On **September 1, 1989,** participants in the antinuclear movement organized massive "peace lessons" in the republic's schools. September 1989 was marked by very active rallying in the republic aimed at shutting down the Semipalatinsk Test Site.

On **September 9, 1989,** the leaders of the Nevada-Semipalatinsk movement conducted the First Republic Conference of the Antinuclear Movement in Alma-Ata, which organized the movement. Divisions of the antinuclear movement were established in Yakutia and Chukotka. A delegation of Yakut scientists headed by USSR People's Deputy M. Yakovlev came to Alma-Ata to develop joint documents and coordinate actions.

On **September 23, 1989,** the First Secretary of the Semipalatinsk Regional Party Committee, Keshrim B. Boztayev, sent a personal letter to Mikhail S. Gorbachëv that read as follows:[17]

> *"Comrade Mikhail Sergeyevich Gorbachëv, CPSU Central Committee.*
>
> *"Dear Mr. Gorbachëv,*
>
> *"I consider it my duty to inform the CPSU Central Committee of the state of affairs in Semipalatinsk Region, Kazakh SSR, in connection with the nuclear testing that is continuing on its territory.*
>
> *"As you know, a nuclear test site has been operating near Semipalatinsk for over 40 years. For all these years, the region has provided necessary assistance and made its contribution to the improvement of nuclear weapons and the strengthening of the nation's defense capability.*

"The test site issue has not been raised until now for several well-known reasons.

"Now, the situation has changed. We have become more open with the people, calling things by their true names.

"In accordance with a CPSU Central Committee Resolution, a scientific and practical conference was held on July 17-18 of this year to discuss the issue, 'Public Health and Environmental Conditions in Semipalatinsk Region, Kazakh SSR.'

"The conference revealed many situations previously unknown to the people and local agencies.

"In the 14 years of active ground and atmospheric nuclear testing from 1949 to 1963 and in 1965, hundreds of explosions were carried out, and the people of adjacent districts were exposed to the effects of ionizing radiation, which has considerably injured their health.

"The irradiated people have already borne a second generation of children, who are subject to morbidity due to decreased immunity.

"In the region as a whole, especially in areas adjacent to the test site, the rise in morbidity and pediatric, maternal, and total mortality is continuing. Mortality, congenital deformations, and retardation are on the rise.

"The underground nuclear explosions that official departments consider harmless are causing an exacerbation of chronic diseases and stress. Within a few days after an explosion, people complain of headaches, palpitations, insomnia, lethargy, and irritability, and visits to medical institutions increase sharply.

"We are especially worried by the growing public psychosis over the underground nuclear explosions. Obviously, we cannot ignore it. Mental health is the basis for the growth and development of healthy children.

"The test site is located on land that has given the Kazakh people great minds and become a national holy place.

"Depending on the yields of the physics packages, nuclear tests cause underground shocks as strong as 3, 4, or 5 points [on the Modified Mercalli Scale] *in Semipalatinsk, which was built without regard for seismicity. Every underground explo-*

sion does damage to utility lines and causes cracks in residences and losses of water in hundreds of wells supplying villages and livestock. The appropriate ministries and departments know all about it. But in actively developing the operation of the nuclear test site, they have not concerned themselves in the slightest about aiding the populace. In 40 years, they have not built a single social facility for the people. There has been no compensation for the damage done to people's health and the region's economy.

"All this produces a feeling of national insult.

"This year, the regional party committee has received over 3,000 letters, telegrams, and messages from people demanding closure of the test site.

"The participants in a regional scientific and practical conference of Semipalatinsk, East Kazakhstan, Pavlodar, and Karaganda Regions, the City of Alma-Ata, Kazakh SSR, and Altai Territory, Russian Federation have also spoken out unanimously for its immediate closure.

"All this is provoking an explosion of social protest from the people.

"However, the government departments are not heeding the voice of the people. They are continuing their old approach to the test site as a military facility. But it has long since become an acute national problem.

"The officials' explanations—"clean test site," "inert gases," "radiation safety is assured"—all serve to protect departmental interests. The test site has never been clean and is not likely to become so.

"The 27 years of underground explosions have considerably deformed the Earth's crust. The question of the need to move the test area due to an increase in fracturing of the massif and the complexity of selecting new areas was raised by a design institute back in 1986.

"Unfortunately, the corresponding sections of the CPSU Central Committee are supporting the departments' positions and preparing information for the party leadership without the participation or consideration of the region's suggestions. We have learned that a resolution aimed essentially at continuing

> *the nuclear explosions the Semipalatinsk Test Site has been drafted without our participation.*
>
> *"The regional party committee considers the demands of the public, which has learned the bitter truth about its alarming neighbor, justified. Necessary steps must be taken to rectify the situation in Semipalatinsk Region and restore the people's faith in their future and in social justice.*
>
> *"The people request compensation for the damage done in the 40 years of active operation of the test site. This would be deeply fair and humane, and would help reduce social tensions.*
>
> *"The region has suggestions on this score, and they should be taken into account in the resolution.*
>
> *"Dear Mr. Gorbachëv, in presenting the situation in Semipalatinsk Region to you, we rely upon your wisdom and understanding."*

On **September 28, 1989,** Mikhail S. Gorbachëv's resolution, "Comrade [Lev Nikolayevich] Zaykov, comrade [Dmitry T.] Yazov, comrade [Oleg D.] Baklanov. Please return to the problem again. Gorbachëv," was attached to Keshrim B. Boztayev's note.

On **October 4, 1989,** the USSR Council of Ministers passed Resolution 1159, "On Measures to Accelerate the Economic and Social Development of Semipalatinsk Region, Kazakh SSR," based on which the region was given major allocations for the development of sociocultural and lifestyle facilities.

On the same day, TASS reported the regular nuclear test at the Semipalatinsk Test Site, aimed at studying the harmful action of radiation factors from a nuclear explosion and ionizing radiation on various models of military equipment and materiel. Figure 37 shows a photograph of the physical installation for the experiment in Adit 169/2, which was designed to remove radiation from the nuclear explosion to the test area.

On **October 9-10, 1989,** representatives of the Nevada-Semipalatinsk antinuclear movement participated in the IX International Congress of International Physicians for the Prevention of Nuclear War, where they condemned the nuclear tests being conducted at the Semipalatinsk Test Site.

Figure 37. External view of the physical plant extending out of Adit 196/2 at Delegen Test Area.

On the same days, the USSR Ministry of Health promulgated Order 566, which specified the performance of measures to conduct a comprehensive examination of the inhabitants of Semipalatinsk Region, to strengthen the infrastructure of its public health institutions and reinforce oversight of radiation, sanitary and hygienic, and epidemiological conditions in the region. Considerable funds were allocated for these purposes.

On **October 19, 1989,** the last nuclear test, at which three "special items" were detonated simultaneously, was conducted at the test site in Shaft 1365.

In response, protest rallies were held on October 21-23 in the cities of Alma-Ata, Semipalatinsk, Pavlodar, Karaganda, in the town of Kara-Aul—and in Moscow, too! Activists in the Nevada-Semipalatinsk movement adopted an appeal to the Government of the Kazakh SSR demanding that the question of closing the Semipalatinsk Nuclear Test Site be submitted to the USSR Supreme Soviet for consideration.

On **October 27, 1989,** the USSR Supreme Soviet passed Resolution 289, "On Urgent Measures for the Country's Environmental Recovery," requiring the USSR Ministry of Defense and the USSR Ministry of the Atomic Energy Industry to draft a USSR Council of Ministers resolution, "On Measures Related to the Conduct of Underground Nuclear Tests." This draft specified a 75% reduction in the number of nuclear tests at the Semipalatinsk Test Site and an 85% lowering of explosion yields in 1991 and 1992, and cessation of testing at the site effective January 1993. In addition, it noted that beginning in 1993, nuclear testing in the USSR would be conducted only at the Northern Test Site (Novaya Zemlya). However, the draft resolution was not approved by the Defense Council of the USSR Supreme Soviet's Presidium until a year later, on October 30, 1990.

On **October 30, 1989,** a decision adopted by the USSR Council of Ministers' State Commission for Military-Industrial Affairs specified that in view of the situation around the Semipalatinsk Test Site, it would be advisable to cease conducting nuclear tests there effective October 1989.

On **November 14, 1989,** a session of the Kazakh SSR Supreme Soviet adopted a resolution asking the People's Deputies of the USSR Supreme Soviet to immediately halt nuclear explosions at the Semipalatinsk Test Site.

All of the above indicates a continuous rise in sociopolitical tension over the Semipalatinsk Test Site situation.

On **November 16, 1989,** I. S. Belousov, the head of the Military-Industrial Commission, had a discussion with the nuclear weapon developers Academician Yury B. Khariton and USSR Academy of Sciences Corresponding Member Yury A. Trutnev. The leading scientists expressed the opinion that a unilateral cessation of nuclear testing would lead to a loss of parity in this important area and make the USSR a second-rate power.

From **November 27 to December 6, 1989,** a parliamentary delegation of the Kazakh SSR headed by Olzhas Suleymenov visited the US. It met in New York, Washington, and Boston with US Congressmen, representatives of charities, leaders of the UN, and journalists. It negotiated with Dr. Bernard Lown, President of International Physicians for the Prevention of Nuclear War, and Dr. Jeremy J. Stone, President of the Federation of American Scientists, to conduct an International Congress in support of antinuclear movements from May 24 to 26, 1990 in Alma-Ata.

The Second Republic Conference of the Nevada-Semipalatinsk movement approved the message about the International Congress.

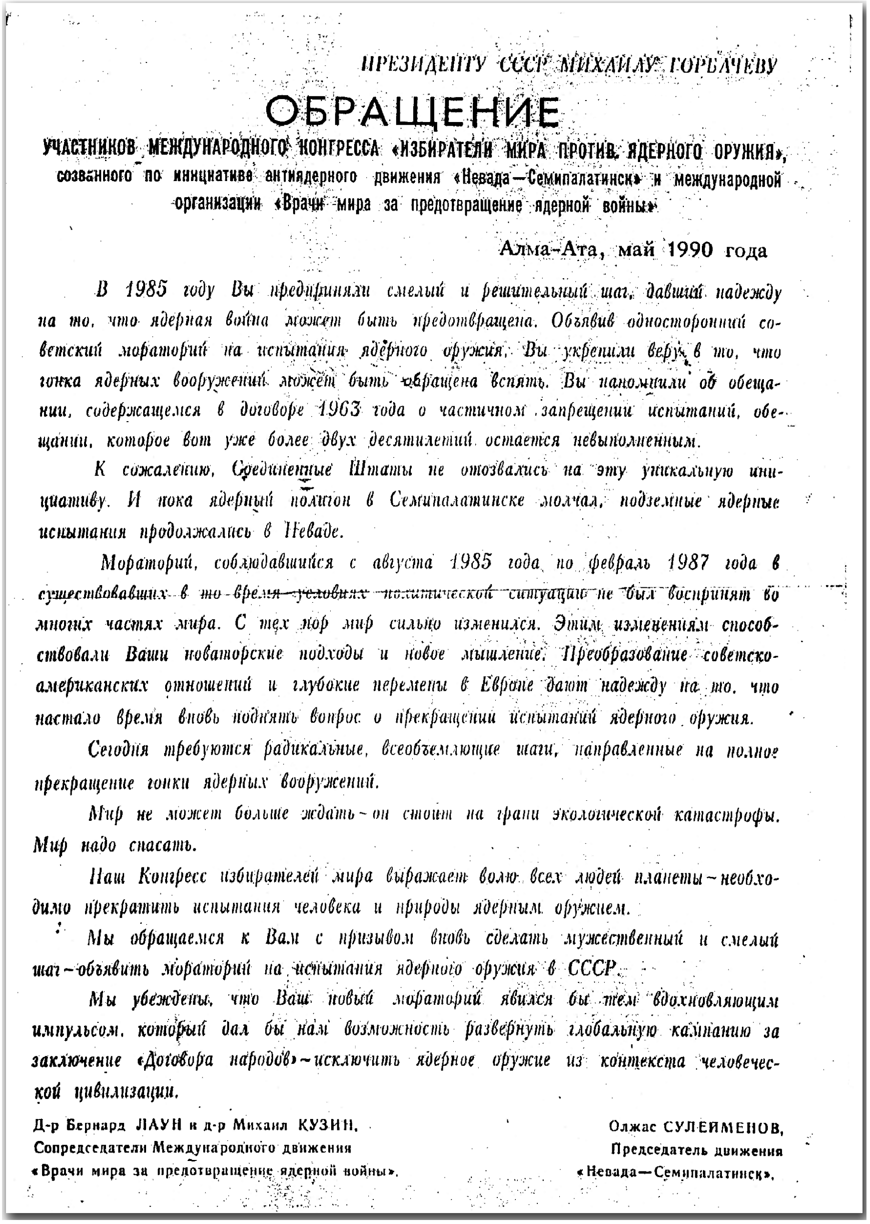
On December 19, 1989, a joint session of the Coordinating Council of the Nevada-Semipalatinsk movement, the regional Committee for the Defense of Peace, and the Regional Trade Union Council took place in Semipalatinsk. The meeting turned into a public trial of the activities of the Semipalatinsk Test Site.

1989, a year of contradictory events and rising political passions, was ending, yielding to 1990, an equally complex and difficult year.

THE EVENTS OF 1990

On **January 3,** and then on **January 19, 1990,** scientists and specialists from the All-Union (now All-Russian) Scientific Research Institute of Experimental Physics in Arzamas-16 (*VNIIEF*) appealed to the country's leaders, justifying the need for the Soviet Union to continue nuclear weapon tests and offering to hold a public discussion of the problem of their unilateral cessation. The letter was signed by 48 of the nuclear center's most noted scientists and specialists. VNIIEF representatives who had taken part in meetings of the relevant committees of the USSR Supreme Soviet to discuss the immediate shutdown of the Semipalatinsk Test Site opposed, justifying their positions with qualifications.

January 1990 was marked by an increase in the activity of the Nevada-Semipalatinsk antinuclear movement. Theaters in the republic and throughout the Soviet Union started showing horror films about the STS: *Amanat*, *Nevada-Semipalatinsk*, *Nevada-Kazakhstan*. *Balkhash Saga* was filmed. Representatives of the antinuclear movement met with the First Secretary of the Kazakh SSR Communist Party Central Committee, Nursultan A. Nazarbayev, and asked for his help in resolving the issue of halting nuclear testing at the STS. The first issue of the movement's newsletter, *Izbiratel* ("Voter"), was prepared. The Alma-Ata–Volgograd–



ПРЕЗИДЕНТУ СССР МИХАИЛУ ГОРБАЧЕВУ

ОБРАЩЕНИЕ

УЧАСТНИКОВ МЕЖДУНАРОДНОГО КОНГРЕССА «ИЗБИРАТЕЛИ МИРА ПРОТИВ ЯДЕРНОГО ОРУЖИЯ», созванного по инициативе антиядерного движения «Невада—Семипалатинск» и международной организации «Врачи мира за предотвращение ядерной войны»

Алма-Ата, май 1990 года

В 1985 году Вы предприняли смелый и решительный шаг, давший надежду на то, что ядерная война может быть предотвращена. Объявив односторонний советский мораторий на испытания ядерного оружия, Вы укрепили веру в то, что гонка ядерных вооружений может быть обращена вспять. Вы напомнили об обещании, содержащемся в договоре 1963 года о частичном запрещении испытаний, обещании, которое вот уже более двух десятилетий остается невыполненным.

К сожалению, Соединенные Штаты не отозвались на эту уникальную инициативу. И пока ядерный полигон в Семипалатинске молчал, подземные ядерные испытания продолжались в Неваде.

Мораторий, соблюдавшийся с августа 1985 года по февраль 1987 года в существовавших в то время условиях политической ситуации не был воспринят во многих частях мира. С тех пор мир сильно изменился. Этим изменениям способствовали Ваши новаторские подходы и новое мышление. Преобразование советско-американских отношений и глубокие перемены в Европе дают надежду на то, что настало время вновь поднять вопрос о прекращении испытаний ядерного оружия.

Сегодня требуются радикальные, всеобъемлющие шаги, направленные на полное прекращение гонки ядерных вооружений.

Мир не может больше ждать – он стоит на грани экологической катастрофы. Мир надо спасать.

Наш Конгресс избирателей мира выражает волю всех людей планеты – необходимо прекратить испытания человека и природы ядерным оружием.

Мы обращаемся к Вам с призывом вновь сделать мужественный и смелый шаг – объявить мораторий на испытания ядерного оружия в СССР.

Мы убеждены, что Ваш новый мораторий явился бы тем вдохновляющим импульсом, который дал бы нам возможность развернуть глобальную кампанию за заключение «Договора народов» – исключить ядерное оружие из контекста человеческой цивилизации.

Д-р Бернард ЛАУН и д-р Михаил КУЗИН,
Сопредседатели Международного движения
«Врачи мира за предотвращение ядерной войны».

Олжас СУЛЕЙМЕНОВ,
Председатель движения
«Невада—Семипалатинск».

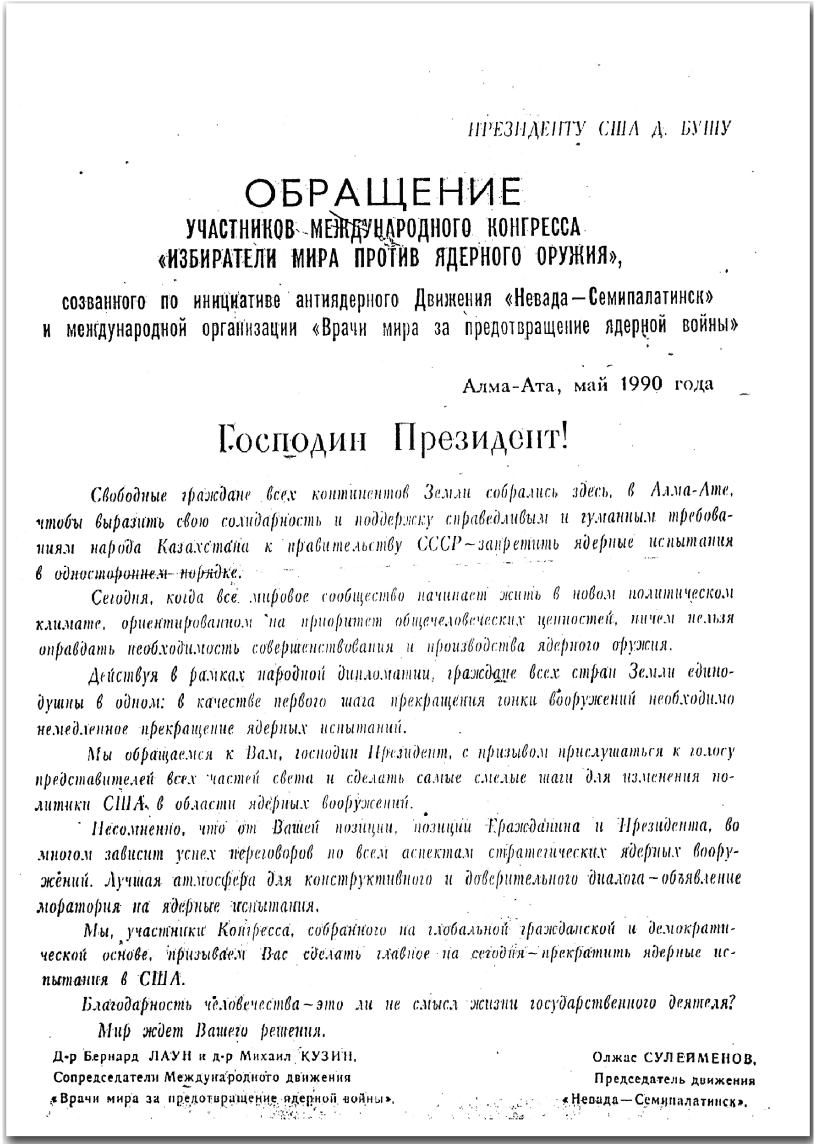
Figure 38. Appeal to Mikhail S. Gorbachëv by the leaders of the Nevada-Semipalatinsk antinuclear movement, May 1990.

Moscow–Riga television bridge, dedicated to the problems of the Semipalatinsk Test Site, was broadcast.

On **February 14, 1990,** the USSR Council of Ministers issued Resolution 189, "On Ensuring Performance of the USSR Supreme Soviet resolution, 'On Urgent Measures for the Country's Environmental Recovery' " (cf. information for October 27, 1989). Paragraph 13 of the resolution proposed to consider the cessation of nuclear testing at the Semipalatinsk Test Site, and to address a whole series of issues relating to the conduct of underground tests at the Northern Test Site and the assessment of their possible effect on the environment in areas of the Far North.

On **February 16, 1990,** USSR Ministry of Health Order 74 specified activities on priority steps in the area of comprehensive examination of the inhabitants of areas adjacent to the Semipalatinsk Test Site. In turn, the USSR Ministry of the Atomic Energy Industry and the USSR Ministry of Defense adopted a decision to implement the Region-1 and Region-2 Special Comprehensive Research Program, "Assessment of the Consequences of the Operation of the Semipalatinsk Test Site and the Northern Test Site on Novaya Zemlya," respectively. The program specified research in several areas: Physical and Chemical Factors; Health and Environmental Factors; Social, Economic, and Cultural Factors; and General Environmental Information System.

In the Russian Federation, work to implement the program continues to this day. Specialists from over 20 scientific organizations from various regions of the RF and the Republic of Kazakhstan are involved. Implementation of the program has included analysis of a large volume of archival information and performance of radioecological research on the grounds of the Semipalatinsk Test Site, the territories of adjacent districts, and Altai Territory (the Semipalatinsk Test Site–Altai program), Altai Republic, etc.[12] The results have been used to implement international projects such as RADTEST ("Radioactivity from Nuclear Test Explosions"), RADLEG ("Radiation Legacy of the Former Soviet Union"), and others.



ПРЕЗИДЕНТУ США Д. БУШУ

ОБРАЩЕНИЕ
УЧАСТНИКОВ МЕЖДУНАРОДНОГО КОНГРЕССА
«ИЗБИРАТЕЛИ МИРА ПРОТИВ ЯДЕРНОГО ОРУЖИЯ»,

созванного по инициативе антиядерного Движения «Невада—Семипалатинск»
и международной организации «Врачи мира за предотвращение ядерной войны»

Алма-Ата, май 1990 года

Господин Президент!

Свободные граждане всех континентов Земли собрались здесь, в Алма-Ате, чтобы выразить свою солидарность и поддержку справедливым и гуманным требованиям народа Казахстана к правительству СССР—запретить ядерные испытания в одностороннем порядке.

Сегодня, когда все мировое сообщество начинает жить в новом политическом климате, ориентированном на приоритет общечеловеческих ценностей, ничем нельзя оправдать необходимость совершенствования и производства ядерного оружия.

Действуя в рамках народной дипломатии, граждане всех стран Земли единодушны в одном: в качестве первого шага прекращения гонки вооружений необходимо немедленное прекращение ядерных испытаний.

Мы обращаемся к Вам, господин Президент, с призывом прислушаться к голосу представителей всех частей света и сделать самые смелые шаги для изменения политики США в области ядерных вооружений.

Несомненно, что от Вашей позиции, позиции Гражданина и Президента, во многом зависит успех переговоров по всем аспектам стратегических ядерных вооружений. Лучшая атмосфера для конструктивного и доверительного диалога—объявление моратория на ядерные испытания.

Мы, участники Конгресса, собранного на глобальной гражданской и демократической основе, призываем Вас сделать главное на сегодня—прекратить ядерные испытания в США.

Благодарность человечества—это ли не смысл жизни государственного деятеля?

Мир ждет Вашего решения.

Д-р Бернард ЛАУН и д-р Михаил КУЗИН,
Сопредседатели Международного движения
«Врачи мира за предотвращение ядерной войны».

Олжас СУЛЕЙМЕНОВ,
Председатель движения
«Невада—Семипалатинск».

Figure 39. Appeal to US President George Bush by the leaders of the Nevada-Semipalatinsk antinuclear movement, May 1990.

On **March 12, 1990,** scientists and doctors in public health practice in Semipalatinsk Region (G. S. Arkhipov, S. O. Talbergenov, M. B. Zhangeldova, etc.) sent a letter to USSR Minister of Defense Dmitry T. Yazov protesting the conduct of nuclear tests at the STS, which in their opinion had had a deleterious effect on human health… (cf. Appendix A.2).

Discussion of the issue of closing the Semipalatinsk Test Site continued at various levels. It would still be 18 months before the site was officially closed.

On **April 2, 1990,** the CPSU Central Committee sent the Defense Section of the CPSU Central Committee (comrade Oleg Sergeyevich Belyakov) a permit to cease nuclear testing at the Semipalatinsk Test Site. This was in response to the numerous messages to the CPSU Central Committee from the Kazakh SSR Supreme Soviet, the Semipalatinsk Regional and Municipal Party Committees, the leaders of the Nevada-Semipalatinsk antinuclear movement, etc. (Figures 38, 39).

On **April 10, 1990,** I. S. Belousov of the USSR Council of Ministers received the leaders of the Kazakh SSR (Uzakbay Karamanovich Karamanov, Yerik Magzutovich Asanbayev, and others) and Semipalatinsk Region (Keshrim B. Boztayev, A. S. Yeremenko) to discuss the dates of cessation of underground nuclear testing at the site. As they say in such cases, the parties reached an agreement.

Also, on **April 28, 1990,** USSR President Mikhail S. Gorbachëv received a letter signed by Lev N. Zaykov, Aleksandr Nikolayevich Yakovlev, Eduard Amvrosiyevich Shevardnadze, and Dmitry T. Yazov justifying the need for nuclear tests at the Semipalatinsk Test Site until late 1992. But they also noted the need to reduce the yields and number of explosions and the mandatory attendance of leaders of the Kazakh SSR.

The proposal was supported by participants at an industry conference on scientific methodology **May 15-17, 1990** at the Khlopin Radium Institute. The conference involved representatives of the USSR Ministry of the Atomic Energy Industry, the USSR Ministry of Defense, and the USSR Ministry of Health. Most of the attention at the meeting was devoted to issues of radiation safety assurance during underground nuclear tests. The solutions were based on compliance with stricter environmental requirements.

In **June 1990,** Minister of Atomic Energy and Industry Vitaly Fëdorovich Konovalov discussed the issue of nuclear testing at the Semipalatinsk Test Site several times with Kazakh SSR President Nursultan A. Nazarbayev. The discussion centered around the following issues:

- cessation of nuclear testing at the site effective January 1, 1992, but detonation of three explosions with yields of up to 20 kilotons in 1991;
- retention of the capability to perform nuclear physics experiments with yields of up to 0.5 kilotons in later years;
- submission of the issues raised to a session of the Kazakh SSR Supreme Soviet.

In addition, Kazakhstani leaders proposed allocating 3.5 billion rubles from the Union budget to pay compensation to the public and 1.6 billion rubles in capital investments (a total of 5.1 billion rubles) for 1992-1995.

On **July 10, 1990,** as a result of numerous inquiries by people's deputies from the Kazakh SSR, the USSR Council of Ministers issued Directive 1082-R, which approved additional steps to "improve public medical services and construct treatment facilities" in Semipalatinsk Region. It increased market funds for foodstuffs, and allocated additional equipment, machinery and materials for the region's needs. It proposed conducting examinations of the people, as well as working to study the sanitation, safety conditions, and radiation levels on the territories of districts near the test site. When the residents were found to have diseases related to the conduct of nuclear testing, proposals to determine and establish certain benefits for such people had to be submitted. Inspections were to be performed by the personnel of practical public health institutions in Semipalatinsk Region, the Medical Institute in Semipalatinsk, and the USSR Ministry of Health's Clinic No. 4.

On **September 5, 1990,** the USSR Council of Ministers' State Committee adopted an important decision: no nuclear testing at the Semipalatinsk Test Site until mid-1991.

On **October 25, 1990,** the Kazakh SSR Supreme Soviet adopted a Declaration of State Sovereignty.

On **November 30, 1990,** the Kazakh SSR Supreme Soviet adopted a resolution prohibiting nuclear tests at the test site in Semipalatinsk Region. This decided the fate of the Semipalatinsk Test Site, one of the defense facilities of the former Soviet Union.

In **December 1990,** the journal *Radiatsionnaya meditsina* ("Radiation Medicine"), No. 12, published an article entitled, "Around the Semipalatinsk Test Site: Environmental Radiation Levels and Public Exposure Doses in Semipalatinsk Region,"[103] prepared by a group of authors under Anatoly F. Tsyb using information in the interdepartmental commission report.

We should point out one of the most important recommendations of the article's authors:

> *"... We must declassify all information on radiation levels outside the grounds of the test site, beginning with the first nuclear explosion in 1949, and publish a picture of all radioactive plumes formed outside the test site, showing their dates of occurrence and basic parameters of their radiation levels."*[103]

However, this work, begun by specialists from several of the country's scientific institutions (K. I. Gordeyev and V. A. Logachev of the USSR and RF Ministry of Health's Institute of Biophysics; Vladimir M. Loborev of the USSR and RF Ministry of Defense's Central Physical-Technical Institute (*TsFTI*); Yury A. Izrael of the USSR Academy of Sciences' Institute of Global Climate and Ecology (*IGKE*); Anatoly M. Matushchenko of the USSR Ministry of Defense's Quality Certification System Scientific Research Center (*NITs SSK*); Yury V. Dubasov of the Khlopin Radium Institute, etc.), proved rather complicated. From 1991 to 2000, very difficult problems had to be solved. The search for answers to many questions entailed complex discussions, defense of methodological approaches, and conflicts of opinions, and even personalities. All this became very obvious during the International Conference, "Radioactivity in Nuclear Explosions and Accidents," held in Moscow in April 2000.[129]

THE NUCLEAR LEGACY OF THE REPUBLIC OF KAZAKHSTAN

In **May 1991**, following a previously accepted plan for nuclear tests, a thermonuclear device with a superlow yield (equivalent to 0.3 kilotons of TNT), developed at the All-Union (now All-Russian) Scientific Research

Institute of Technical Physics (*VNIITF*) in Snezhinsk-on-Ural was installed at the Semipalatinsk Test Site, in the end box of Adit 108-K in Delegen Test Area. Setup of the physics experiment to investigate the radiation hardness of models of military equipment and materiel proceeded. Along the entire length of the adit and beyond, an installation containing the items to be irradiated, was installed. The mine working for complete localization of the radioactive explosion products was plugged with thick concrete stemming "plugs."

The setup of the test was completed by July 1991, but permission to conduct it was not given.[130] During this period, relations between the Republic of Kazakhstan and the Russian Federation were developing in the context of sovereign nation-building processes in both countries (cf. October 25, 1990).

On **July 4, 1991,** a draft decision of the USSR Council of Ministers' State Commission for Military-Industrial Affairs to conduct comprehensive scientific research in the Semipalatinsk region under the Region program was sent to the Kazakh SSR Cabinet of Ministers for endorsement (Ref. No. KP-11/1989 of July 4, 1991). However, by the end of 1991 no answer had been received from the leaders of the Kazakh SSR. Moreover, it was impossible to enlist Kazakhstani scientific organizations to perform work under the RADTEST international project, developed under the aegis of SCOPE (Scientific Committee on Problems of the Environment) and NATO. The drastic changes in the country's geopolitics made it difficult to resolve these issues in the USSR framework.

Soon a new USSR Council of Ministers Resolution was drafted, "On the Cessation of Nuclear Weapon Tests at the Semipalatinsk Test Site." This resolution provided for the conduct of two tests with yields under 20 kilotons and one with a yield under 1 kiloton in 1991, and the cessation of testing at the site effective January 1, 1992. The first two tests were to be conducted under the observation of US specialists in accordance with the 1974 Treaty on the Limitation of Underground Nuclear Weapon Tests.

The draft resolution proposed to convert the Semipalatinsk Test Site to a Union-republic scientific research center for the safe testing (in the radiation and seismic sense) of weapons and military equipment using installations that simulated various types of effects, for performing physics experiments with yields under 0.5 kiloton, for solving problems related to the assurance of safe operation of nuclear power enterprises, and for performing various basic and applied research with the participation of the

Kazakh SSR Academy of Sciences. It was in the framework of this work that the nuclear physics test in Adit 108-K was planned.

> In 1990, the nuclear powers conducted 18 nuclear weapon tests, including eight by the US, six by France, one by Great Britain, two by China, and one by the USSR (the October 24, 1990 test at the Novaya Zemlya Test Site).
>
> In 1991, 14 tests were conducted at test sites around the world, including seven by the US, six by France, and one by Great Britain. The USSR and China conducted no nuclear tests in 1991. We should note that no more tests were conducted after 1990 on the territory of the former USSR.
>
> In the opinion of scientists and specialists from Russian nuclear centers (VNIIEF and VNIITF), the prolonged and unilateral hiatus in nuclear testing had an extremely adverse effect on the conduct of domestic nuclear programs, that is, programs to develop and to maintain the battle readiness, reliability and safe storage of nuclear weapons.—The authors]

On **August 29, 1991,** Kazakh SSR President Nursultan A. Nazarbayev's Decree 409 closed the Semipalatinsk Test Site. Thus, precisely 42 years after the former USSR's first nuclear explosion on August 29, 1949, nuclear tests at this site were halted forever. The Nevada-Semipalatinsk movement's slogan "five minus one" had become a reality.

We must note that the Russians tried to negotiate with Alma-Ata for the possible return of part of the test site's facilities to Russian ownership, but the leaders of the Republic of Kazakhstan refused. All facilities of the former Semipalatinsk Test Site were conveyed to the Republic of Kazakhstan National Nuclear Center (RK NNC) organized in 1993 based on the test site. By June 1994, the last former Soviet troops (after 1991, Russian troops) on the grounds of the test site left Kazakhstan.

But the unresolved and very serious problem of the low-yield nuclear explosive device located in the end box of Adit 108-K since May 1991 remained. A search for a solution began….[131]

In **September 1991,** Adit 108-K, with the nuclear device emplaced in it, was placed under the protection of an armed guard of the Russian Federation Ministry of Internal Affairs.

In **October 1991,** the Nevada-Semipalatinsk movement, along with activists of the Global Antinuclear Alliance proclaimed the slogan, "Five Minus Five." However, they did not succeed in shutting down all nuclear test sites throughout in the world. But by then the number of powers that had chosen the path of acquiring nuclear weapons had increased. India and Pakistan had conducted their own underground nuclear tests.

On **December 16, 1991,** Kazakhstan declared itself an independent state.

On **December 21, 1991,** in Alma-Ata, the CIS nations adopted their Declaration of Consent to Retain Unified Command of Nuclear Forces. In addition, Belarus, Kazakhstan, Ukraine and the Russian Federation signed an Agreement on Joint Steps in the Area of Nuclear Weapons, affirming these states' adherence to nuclear nonproliferation.[132]

Article 5 of the Agreement specified:

> *"• Belarus and Ukraine intend to join the 1968 Nuclear Arms Nonproliferation Treaty (NPT-1968) as nonnuclear states and execute corresponding guarantee agreements with the IAEA;"*

[The Republic of Kazakhstan is not named in this Treaty. This is because a nuclear device was "concealed" in Adit 108-K. The problem of its destruction required a solution that accounted for existing nuclear agreements and accords.—The authors]

Article 5 of the Agreement continued:

> *"• the nations signatory to this Agreement assume the obligation not to transfer to anyone nuclear arms or other nuclear explosive devices and their technology, or control over them either directly or indirectly, and also not to assist anyone, not to encourage or force any nation not possessing nuclear arms to produce nuclear arms or other nuclear explosives or to establish control over them;*
>
> *"• the provisions of Paragraph 2 of this article shall not apply to the transfer of nuclear arms from Belarus, Kazakhstan, or Ukraine to the territory of the Russian Federation for the purpose of their destruction."*

Under Article 6 of the agreement, Belarus, Kazakhstan and Ukraine committed themselves to guarantee the withdrawal of tactical nuclear weapons by July 1, 1992 to central pre-factory bases for purposes of destruction under joint control.[133]

On **December 25, 1991,** USSR President Mikhail S. Gorbachëv formally retired, transferring the nuclear arms release codes to Russian Federation President Boris N. Yeltsin.

The rapidly changing situation called into question the essence and practice of provisions regarding the "unified command of nuclear forces" as codified on **December 30, 1991,** in the Strategic Forces Agreement signed in Minsk.

In this complex situation, Republic of Kazakhstan President Nursultan A. Nazarbayev acted in the eastern way, logically, following the principle "Let's not hurry." Therefore, Kazakhstan only supported the rather vague preamble to the Agreement of December 21, 1991, in which the four states declared their support for the NPT.

February-April 1992 was the period when the Republic of Kazakhstan defined its nuclear policy. Many specialists and politicians agree that American diplomacy played a major role in Kazakhstan's adoption of the nonnuclear choice. US Secretary of State James A. Baker III, who visited Alma-Ata twice in this period, and met personally with President Nursultan A. Nazarbayev, made a special contribution to Kazakhstan's choice. Both Baker and other American politicians took pains to emphasize that Kazakhstan's security could be more reliably assured not with nuclear arms, but by economic development and integration into the world economic system.[134]

Naturally, we should not underestimate the strength of the antinuclear mood among the people. The general public support for the Nevada-Semipalatinsk movement and other antinuclear organizations, whose actions successfully culminated with the closure of the Semipalatinsk Test Site, is instructive in this respect.

Observers note that the public statements and actions of RK President Nursultan A. Nazarbayev relating to the Semipalatinsk Test Site indicate his receptiveness to the voters' antinuclear mood. In this case, these actions were reinforced by public attitudes toward nuclear testing and its possible effect on human health and by radiophobic sentiments that deepened after the accident at Chernobyl Nuclear Power Plant.

On **March 3, 1992,** the Republic of Kazakhstan was accepted into the UN. This gave Kazakhstan's leaders an opportunity to place the question of liability of the members of the "nuclear club" for the radiological consequences of nuclear arms tests before the UN. The nation that had been the first to close its nuclear test site decided to be first to raise the issue of nations' ratification of UN Declaration RIO-92 by 2001, so that the world could enter the new millennium with a civilized environmental doctrine.

In the first half of 1992, the policy of the leaders of the Republic of Kazakhstan regarding the possession of nuclear arms was still not fully defined. It largely leaned toward remaining a nuclear state. In an interview for the Tokyo television company NHK on **May 1, 1992,** RK President Nursultan A. Nazarbayev addressed the issue: *"Kazakhstan must retain its nuclear forces for at least 15 years, since Russia is financially and technically unprepared to accept Kazakhstani warheads."*

But on **May 16, 1992,** in a statement published in *Kazakhstanskaya pravda* ("Kazakhstan Truth"), "Strategy for the Formation and Development of Kazakhstan As a Sovereign Nation," Nursultan A. Nazarbayev had noted that the Republic was striving *"to gain the status of a non-nuclear nation…"* A day earlier, on **May 15, 1992,** President Nazarbayev signed a Decree, "On the Republic of Kazakhstan National Nuclear Center and Atomic Energy Agency," which prescribed the creation of the RK NNC based on the complex at the former Semipalatinsk Test Site and the corresponding research organizations and facilities on Kazakhstani territory.

On **May 23, 1992,** the leaders of Kazakhstan signed the Lisbon Protocol to the SALT-1 Treaty and promised to join the NPT as a nonnuclear state *"as soon as possible."*[135] However, the Republic of Kazakhstan did not ratify the NPT Protocol until February 15, 1994.

On **May 25, 1992,** the Russian-Kazakhstani Friendship, Cooperation, and Mutual Assistance Treaty was signed, forming the basis of Kazakhstani military doctrine. Both parties to the treaty committed themselves to participate in one another's defense if one of the parties was a victim of aggression. The treaty reaffirmed Kazakhstan's commitment to join the NPT as a nonnuclear state.

In the **first half of 1992,** the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Experimental Physics (*VNIIEF*) performed the important job of drafting proposals for joint Russian-Kazakhstani-American research to assess the radioecological consequences of the nuclear testing performed by the former USSR on the grounds of the Semipalatinsk Test Site. These proposals were supported by Russian Federation Minister of Atomic Energy Viktor N. Mikhaylov, and in **June 1992,** a preliminary discussion of them took place in Washington involving A. K. Chernyshev, head of VNIIEF's theoretical section, and Don A. Linger, head of the Test Directorate, US Defense Nuclear Agency.

In **early January 1993,** the Russian embassy in Alma-Ata began active operation. The Russian Federation's first Ambassador to the Republic of Kazakhstan was Valery Dmitriyevich Nikolayenko.[135]

On **January 22, 1993,** the Republic of Kazakhstan and the Russian Federation signed an Agreement on the Procedure for Use of the Former USSR Test Sites Left on Kazakhstani Territory. The list of test sites included in the agreement noted that the "Second State Semipalatinsk Test Site" was considered converted to the RK NNC.

On **January 25, 1993,** the results of research conducted under the first phase of the Region-1 comprehensive research program headed by Yury V. Dubasov were discussed at the Khlopin Radium Institute. The research, which was funded by the Russian Ministry of Atomic Energy, cost 8.1 million rubles in 1992 prices.

The Region-1 program included examinations of people living near the Semipalatinsk Test Site. The examinations revealed a fairly high frequency of various diseases. However, no links were established between the development of the diseases and exposure to radiation factors.

On **February 7, 1993,** the headquarters of the Republic of Kazakhstan President and Cabinet of Ministers formed a working commission to perform an expert assessment of information on the number of nuclear and nonnuclear explosions carried out at the Semipalatinsk Test Site.

On **February 28, 1993,** the commission's report was endorsed by the commander of Military Unit 52605, Yu. V. Konovalov, and by the Senior

Figure 40. Remains of a missile launch silo destroyed by a conventional explosive charge.

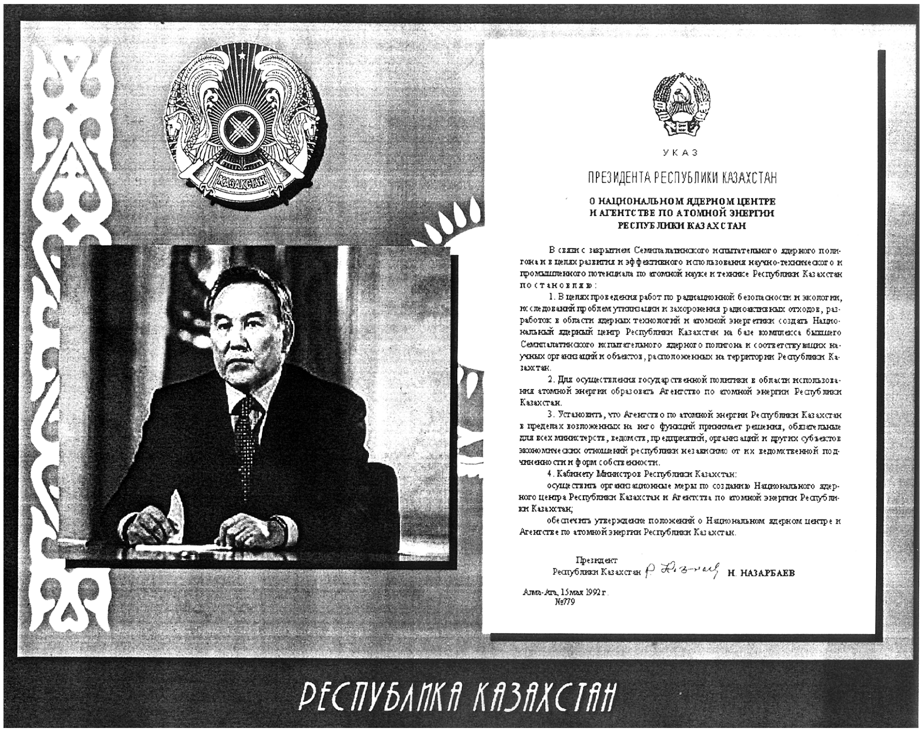
Reviewer of the headquarters of the Government of the Republic of Kazakhstan, Zh. K. Kozhasbayev. The report stated that *"… from an analysis of archival documents of Military Unit 52605 (the command of the former Semipalatinsk Test Site), the commis-sion is convinced of the accuracy of data on the number and types of nuclear explosions carried out."*

Thus began the declassification of information on the test site's operation, access to which members of the "Nevada-Semipalatinsk" antinuclear movement had tried especially hard to gain.

On **March 28, 1993,** an agreement on nuclear arms in Kazakhstan was reached at a Russian-Kazakhstani summit in Moscow. Exactly one month later, on April 28, 1993, the newspaper *Segodnya* ("Today") reported that all nuclear warheads from Kazakhstan were to be removed to Russia within 14 months, and all intercontinental ballistic missile launch silos were to be destroyed within three years. Figure 40 shows a photograph of the crater after demolition of one missile silo located on the grounds of the Semipalatinsk Test Site using a powerful conventional explosive charge.

At the March 28, 1993 meeting, the Government of the Russian Federation and the Government of the Republic of Kazakhstan signed an Agreement to dismantle the nuclear device emplaced in the end box of Adit 108-K even before closure of the Semipalatinsk Test Site.[136]

THE REPUBLIC OF KAZAKHSTAN NATIONAL NUCLEAR CENTER AND THE MAJOR ACTIVITIES OF ITS CONSTITUENT INSTITUTES



The Republic of Kazakhstan National Nuclear Center (RK NNC) was created by the Republic of Kazakhstan President's Decree of May 15, 1992 based on the complex at the former Semipalatinsk Nuclear Test Site and other research organizations located on Kazakhstani territory (Figure 41 and Appendix A.8). The aims of its creation were to perform studies in radiation safety and ecology, to study the problem of radioactive waste recycling and disposal, and to conduct research on the development of nuclear technologies and nuclear power. Galdet A. Batyrbekov was appointed General Director of the RK NNC, but was soon replaced by Yury S. Cherepnin, during whose five years as General Director the center acquired international notoriety. Since October 13, 2000, Shamil T. Tukhvatulin has been the General Director.

Expanding on the President's Decree, the Republic of Kazakhstan Cabinet of Ministers adopted a series of resolutions defining the RK NNC's organizational structure and the principal areas of activity of its constituent institutes (Appendices A.8, A.9). Figure 42 gives an organization chart of the RK NNC. Each institute comprising the Center has been assigned certain objectives, whose natures are determined by the specific institution's characteristic areas of study.

The incorporation of each specific institution into the RK NNC was guided by its principal areas of activity (Appendix A.9).

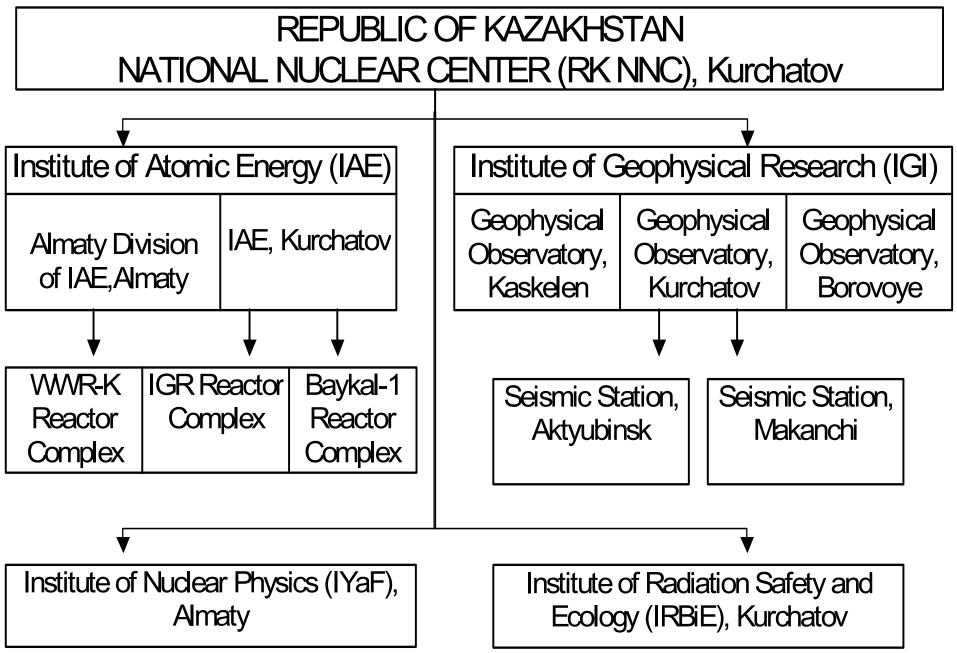


Figure 42. Organization Chart of the Republic of Kazakhstan National Nuclear Center

The Institute of Atomic Energy (*IAE*) was formed out of the Unified Expedition of the Ray Scientific Production Association (*NPO Luch*), which consisted of the IGR and Baykal-1 reactor complexes, located in Kurchatov. Additionally, the institute was given the WWR-K reactor belonging to the Institute of Atomic Energy, which is in Almaty. The IAE's principal area of activity is the development of concepts and programs for the development of nuclear power in the Republic of Kazakhstan. In addition, it is charged with studying such matters as nuclear power safety, space-based nuclear power plants, solid-state radiation physics, and reactor materials science.

The Institute of Nuclear Physics (*IYaF*), created in 1957, is located in Almaty. Its principal fields of activity are basic and applied research in nuclear and solid-state physics.

The Institute of Geophysical Research (*IGI*) was given the geophysical observatories in the cities of Borovoye and Kaskelen, as well as seismic stations in the cities of Aktyubinsk, Borovoye, Kurchatov, and Makanchi that previously belonged to the USSR Ministry of Defense. IGI's principal area of activity is participating in studies having to do with monitoring the conduct of nuclear tests in the framework of the International Monitoring System, which is one of the points of compliance with the Comprehensive Nuclear Test Ban Treaty (CTBT). In addition, IGI is assigned tasks such as developing methods of assessing the consequences of underground nuclear tests, monitoring the geologic structures of former nuclear test sites, selecting sites for construction of nuclear and thermal power plants and radioactive waste storage and disposal sites, recording earthquakes and developing methods of forecasting earthquakes, and prospecting and exploration of minerals.

The Institute of Radiation Safety and Ecology (*IRBiE*) was formed from the scientific research units of the former Semipalatinsk Test Site in accordance with RK Cabinet of Ministers Resolution 1082 of October 29, 1993 and based on the RK NNC General Director's Order 40 of November 8, 1993. Doctor of Biological Sciences A. T. Seysebayev, who interned at the Institute of Biophysics in 1965-1969 in the laboratory of USSR Academy of Sciences Corresponding Member Aleksandr Mikhaylovich Kuzin, was appointed IRBiE's first Director by Order 44 of November 12, 1993. From May 3, 1995 until May 5, 1997, IRBiE was headed by Candidate of Engineering Samat K. Smagulov, a veteran of the Semipalatinsk Test Site and the former head of the test site's radiation safety service. The institute's current Director is Murat A. Akhmetov.

In accordance with the organization chart approved December 8, 1993 by its General Director, IRBiE consists of the following sections:

- Radiation Ecology and Monitoring;
- Radiobiological Research;
- Radioactive Waste Handling;
- Radiation Safety;
- Chief Engineer.

In the first months after IRBiE's organization, all its sections were housed at Building 27 on the grounds of the former experimental research part of the test site (Figure 43). Since completion of repairs on several specialized laboratory buildings in the test site's experimental research area, they have been placed at the disposal of institute units. The photo in Figure 44 shows the building that currently houses IRBiE's administration, its domestic and auxiliary services, and a historical museum of the former Semipalatinsk Test Site.

IRBiE's principal areas of activity are: assessing the biomedical and radioecological consequences of exposure to radiation factors after nuclear tests, radiation monitoring of test sites and other radiation-hazardous facilities, studying the condition of cavities from underground nuclear explosions and mothballing them, revegetating lands contaminated by radioactive substances, and collecting, transporting, disposing of, and reprocessing radioactive wastes.[137]

We should note that a major role in the conduct of radioecological research on the grounds of the Semipalatinsk Test Site and adjacent districts belongs to the specialists of the Institute of Radiation Safety and Ecology, whose supervisors have recruited many specialists from other countries to assist in the performance of the Institute's assigned tasks.

COLLABORATION OF THE IAEA MISSION AND THE RK NNC IN 1993-1994

At the international forum in Vienna in May 1993 under the aegis of the IAEA and UNDP, "Strengthening of Radiation and Nuclear Safety Infrastructure in the Countries of the Former USSR," representatives of Kazakhstan voiced concern over environmental radiation levels on the territories of Semipalatinsk Region and western Kazakhstan. After the forum, the Government of the Republic of Kazakhstan appealed to the IAEA for assistance in studying and improving the environment on the territories of these regions.

Figure 43. Building 27 on the grounds of the former STS Research Center in Kurchatov. This building originally housed the RN NNC's Institute of Radiation Safety and Ecology (IRBiE).

Figure 44. Building 23 on the grounds of the former STS Research Center in Kurchatov. This building houses the IRBiE's administration and the STS History Museum.

IAEA General Director Hans Blix supported the request and decided to help Kazakhstan implement a series of measures on these territories under the existing International Technical Cooperation Program.

In **November, 1993,** the first IAEA mission in Kazakhstan began work. Its aims were:

- to organize work to assess the radioecological situation in the Republic of Kazakhstan;
- to assist in the development of domestic infrastructure in the area of radiation safety, paying special attention to the organization of environmental monitoring.

Peter Stegnar supervised the mission, which also included Murat A. Akhmetov, R. D. Hopper, Edwin L. Sensintaffer, and Friedrich Steinhäusler.[138] The mission operated in many areas, such as:

- determining the most likely areas of radioactive contamination at the Semipalatinsk Test Site and on adjacent lands;
- performing measurements of ground radiation levels and collecting samples from environmental systems;
- visiting laboratories of the RK NNC's institutes for purposes of future collaboration and inspection of available data on radiation levels;
- acquainting specialists from the RK NNC's institutes with the latest instruments that should be used for measurements of radiation parameters.

The summary report of the first mission's work on Kazakhstani territory noted that the mission specialists "did not discover anything indicating significant radiation hazard on the territories surrounding the test site. High levels of radioactive contamination were found only at locations of nuclear explosions. Much lower radiation levels were recorded in certain villages and towns outside the test site."[139]

In **July 1994,** the second IAEA mission worked in Kazakhstan. Its members were representatives of the Republic of Kazakhstan, the Russian Federation, the US, France, and Great Britain, including Murat A. Akhmetov, Igor Kuleshov, Anatoly M. Matushchenko, Christian Chenal, Adam R. Hutter, Jerry LaRosa, Daniel Robeau, Peter Shebell, Peter Shaw, and Anthony Wrixon. The aim of this mission, which was supervised by Peter Stegnar, was:

- to assess environmental radiation levels in areas adjacent to the test site, accounting for available dosimetric information;
- to determine possible exposure doses of residents of Semipalatinsk Region.

The summary report on the mission's work noted that:[138]

> *"In most areas, γ dose rates and environmental contamination levels were very close to normal global levels. In certain areas, we noted a certain elevation, but it was slight from the standpoint of exposure of the local population. The town of Dolon has a higher plutonium level than other villages and towns. However, the approximate annual dose remains low (0.13 mSv/yr), and further investigation does not seem justified… The mission unexpectedly encountered considerable concern over the test site's operation among local village residents. This is a consequence of the shortage of precise information regarding the true radiological hazard and general distrust of the authorities…*
>
> *"The only clear exceptions are areas around the test areas and Lake Balapan, which have radioactive contamination.*
>
> *"Measurements performed by the IAEA missions, together with the voluminous research conducted by various organizations of Kazakhstan and the former Soviet Union, corroborate one another…"*

IAEA General Secretary Hans Blix personally verified the results of both missions. Thus, on July 27, 1994 he visited the epicenter of the first ground nuclear explosion, where he was given appropriate explanations by Anatoly M. Matushchenko and Samat K. Smagulov. Standing at this historic place for the former USSR, which unfortunately is not marked by any memorials (which cannot be said of the first explosion in the US, where a stone slab marks its location), Blix remarked, *"Nuclear tests are a fact of mankind's biography. Good or bad? We must regard them with understanding."* His conclusion about the work of the IAEA mission on Kazakhstani territory was unambiguous: the results of their work should be presented to the scientific community at the Second International Workshop on the RADTEST Project. The workshop took place in September 1994 on Russian Federation territory at Barnaul, the capital of Altai Territory.

Other important events were also occurring in Kazakhstan at the same time as the IAEA mission.

BEGINNING OF DEMILITARIZATION OF THE SEMIPALATINSK TEST SITE

On **September 24, 1993,** pursuant to the content of the joint Protocol of Intent of the US Government and the Government of the Republic of Kazakhstan, the countries formed a team of specialists to perform a preliminary study of the damage done to the people and economy of Kazakhstan by the nuclear tests at the former Semipalatinsk Test Site. A team of specialists from the US headed by Don A. Linger came to Kurchatov, where the general offices of the RK NNC are located, on **November 9, 1993.** Linger expressed a wish that Russian specialists also participate in the work (Appendix A). His proposal was accepted. A team of specialists from Russia, including the experts Yury V. Dubasov, V. A. Logachev, Anatoly M. Matushchenko, A. K. Chernyshev, and other specialists who had participated in nuclear tests at the site, was headed by Academician of the Russian Academy of Sciences Yury A. Trutnev from the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Experimental Physics (*VNIIEF*).

A trilateral meeting at the RK NNC heard reports and statements from former employees of the Semipalatinsk Test Site, as well as experts from Russia, Kazakhstan, and the US. The meeting was the beginning of future cooperation among the three parties on a whole range of issues relating to the operation of the Semipalatinsk Nuclear Test Site, including its demilitarization and the destruction or erasure of so-called "sensitive information."

By the end of 1993, Kazakhstan and the US signed a framework agreement and five executive agreements relating to threat reduction. According to these agreements the US committed to grant $85 million to Kazakhstan for nuclear disarmament aid.[133] And on December 17, 1993, Russian Defense Minister Pavel Sergeyevich Grachëv signed Directive No. 314/4/01363 on, disbanding the military units that had comprised the former Semipalatinsk Test Site.

Negotiations over the demilitarization of the test site also continued at the level of the Governments of the two nations, the Republic of Kazakhstan and the Russian Federation.

Figure 45. Don Linger with Vladimir Shkolnik, Minister of Energy and Mineral Resources of the Republic of Kazakhstan.

On **December 25, 1993,** Russian Federation President Viktor Stepanovich Chernomyrdin and Republic of Kazakhstan Prime Minister Sergey Aleksandrovich Tereshchenko had a meeting in Alma-Ata, where they agreed to discuss issues relating to the problem of *"... cleanup after nuclear arms tests at the Semipalatinsk Test Site"* in January and February 1994 and devise solutions to it.

To this end, under Russian Federation Government Instruction ASh-P8-00315 of January 18, 1994, the leaders of the RF Ministry of Defense were to negotiate with the leaders of the Republic of Kazakhstan on matters defining the specific participation of both Russia and Kazakhstan in the implementation of the Program to Assess the Consequences of Nuclear Tests at the Semipalatinsk Test Site.

The Russian Federation made its own proposal for resolving these issues, the essence of which was:

- full coordination of the actions of Russian ministries and departments in negotiations over this problem should be assigned to the Ministry of Cooperation [with the CIS Countries] and the RF Ministry of Foreign Affairs;

- the concept of negotiations had to be to exclude possible future claims by the Kazakhstani side regarding bias in approaches to assessing the consequences of nuclear testing, and to account for the fact that funding of the Work Program must come primarily from the Kazakhstani side;
- the Work Program had to be signed by both parties at the intergovernmental level and contain a provision regarding the need to solve the important problem of the dismantling or destruction of the nuclear device that had been in the end box of Adit 108-K since 1991. Work to solve this problem had to be financed by Russia.

We should note that both sides were extremely interested in successful implementation of the Program.

On **March 9, 1994,** Republic of Kazakhstan Deputy Minister of Foreign Affairs V. Gazzatov presented the Russian Ministry of Foreign Affairs the working group roster for negotiations to be held during Republic of Kazakhstan President Nursultan A. Nazarbayev's first official visit to the Russian Federation:

M. Bayadilov, First Deputy General Director of the RK Atomic Energy Agency;

Galdet A. Batyrbekov, General Director of the RK NNC;

Shamil T. Tukhvatulin, First Deputy General Director of the RK NNC;

Atlant Anatolyevich Vasilyev, section head in the Science and Scientific and Technical Policy Section of the Headquarters of the RK President and the RK Cabinet of Ministers;

V. Shadrin, consultant to the CIS Affairs Section of the Headquarters of the RK President and the RK Cabinet of Ministers;

Valeriyan Aleksandrovich Shemansky, Vice President of KTEP Corporation;

T. Kaliyev, Second Secretary of the RK Ministry of Foreign Affairs;

A. Demin, consultant to the RK Ministry of Justice;

Timyr Mitah-Uly (Russian *Timur Miftakhovich*) Zhantikin, section head in the RK Atomic Energy Agency.

The RF Ministry of Foreign Affairs also presented the RK Ministry of Foreign Affairs the roster of the working group for the Russian side.

On **March 28, 1994,** the Government of the Republic of Kazakhstan and the Government of the Russian Federation reached an agreement in Moscow to dismantle the nuclear device in Adit 108-K, which was signed by the heads of state, Sergey A. Tereshchenko and Viktor S. Chernomyrdin.

DESTRUCTION OF THE NUCLEAR DEVICE IN ADIT 108-K

In Delegen Test Area, a whole series of jobs began and continued to excavate Adit 108-K and drive a bypass tunnel to the end box, where the special nuclear device had been for a long time under unregulated and complex conditions.[130]

The closure of the test site and the disbanding of military units disrupted the traditional scheme of setup, support and conduct of laborious expedition work at the site. For this reason, a special expedition was formed to carry out all the tasks related to the dismantling of the nuclear device in 108-K. This expedition was made up of specialists from the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Technical Physics (*VNIITF*), who would have to act independently, drawing support from the RK NNC and its major units such as the Institute of Atomic Energy (Director Yury S. Cherepnin) and the Institute of Radiation Safety and Ecology (Director Samat K. Smagulov). The heaviest digging was done with the participation of specialists from the Delegen Small Industrial Enterprise (Director A. M. Klimov).

Gennady Petrovich Zyryanov was appointed head of the expedition, and B. A. Andrusenko was named work supervisor. Both were from VNIITF.

A plan entitled, “Exposure and Destruction of the Object” was quickly developed by specialists from the All-Russian Scientific Research and Design Engineering Institute of Industrial Technology (*VNIPIPromtekhnologiya*) under the supervision of Ye. P. Kozlov. The plan called for breaking up the thick stemming in the adit, dismantling the complex vacuum-sealed physical installation, and drilling a bypass tunnel to penetrate the end box and reach the nuclear device. Since the special device’s warranty service life, according to its specifications, was short, and it had already been exposed to a variety of nonstandard complex factors for nearly four years, including flooding of the end box with water, the device's destruction naturally had to be done with great caution.

The RF Ministry of Atomic Energy submitted the completed plan for destruction of the special device to Kazakhstani environmental organizations for an expert assessment of its long-term radioecological safety. In addition, the Interdepartmental Expert Commission for Assessment of the Radiation and Environmental Safety of Nonnuclear Experiments (*MVEK-NE*), offered their finding—a positive one—on the plan. This commission included independent experts from the RF Ministry of Atomic Energy, the RF Ministry of Health, the RF State Environmental Protection Committee (*Goskomekologiya*), the RF Federal Service for Hydrology, Meteorology, and Environmental Monitoring, and the RF Ministry of Defense. The respective commission cochairmen from each of these departments were Anatoly M. Matushchenko, V. A. Logachev, A. B. Ivanov, and G. A. Krasilov.

A Coordinating Group was formed to coordinate the destuction of the nuclear device, whose members included specialists from various organizations and departments of the Russian Federation and the Republic of Kazakhstan.

A. N. Shcherbin, of the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Technical Physics (*VNIITF*) was approved as Chairman of the Coordinating Group (CG). The Russian Federation's members of the CG were Gennady P. Zyryanov, Anatoly M. Matushchenko and K. V. Kharitonov (RF Ministry of Atomic Energy), O. V. Komkov (RF Ministry of Defense), V. N. Fëdorov (RF Ministry of Foreign Affairs), V. V. Kuznetsov (RF Ministry of Internal Affairs) and V. D. Fomichev (RF Nuclear and Radiation Safety Federal Oversight Committee, *GAN*); the Republic of Kazakhstan's members were Timyr M. Zhantikin and Sergey Vasilyevich Krechetov (Atomic Energy Agency), Samat K. Smagulov and Shamil T. Tukhvatulin (RK NNC), Yu. N. Leontyev (RK Ministry of Defense), Yu. R. Abdukadyrov and B. B. Sadykov (RK Ministry of Internal Affairs), V. I. Pichulsky (RK Mining Safety Oversight Committee, *Gosgortekhnadzor*), S. P. Shevtsov (RK Ministry of Ecology and Bioresources), and M. A. Tuleshev (Main Customs Directorate of the RK Ministry of Finance). V. G. Smirnov was appointed Executive Secretary of the CG. Highly qualified experts such as Yu. I. Vashchinkin, A. A. Grigoryan, S. V. Demyanovsky, Yu. I. Kuznetsov, V.

N. Khlopunov, N. S. Shcherbatyuk, V. V. Ganzha, R. A. Aytmaganbekov, A. M. Klimov, and others made a major contribution to the CG's work.[135]

During the conduct of work specified by the Plan, the CG held seven meetings, at which it adopted important decisions on matters of the destruction of the nuclear device in Adit 108-K and the coordination of interactions at the intergovernmental and local levels.

We must note in this connection that during the preparations for the intergovernmental agreement in 1992-1994, the Russians warned several times, and frankly, about the possible destruction of the nuclear explosive device that had been lying in the end box for some four years at a humidity of over 80% if there were the slightest doubts of the safety of its dismantling. In that case, the agreement specified the device's destruction by detonation of an additional chemical explosive, with complete prevention of a nuclear energy release, which would have naturally been carried out under appropriate controls.

Among the first to begin work on Adit 108-K were the mine tunnelers. While they were drilling the bypass through the granite to reach the end box, VNIITF specialists in Snezhinsk were determining the possible condition of the nuclear device's units and assemblies, which had lain for a long time without monitoring and which were designed to study the effects of penetrating radiation on samples of military and space equipment. By the time the work was begun, they already knew that the adit had been flooded by ground water, possibly more than once, during the waiting period. The results of numerical, analytical, and experimental studies to determine the condition of the radioactive materials and explosives in the nuclear device suggested several risk factors that could manifest themselves when the nuclear device was dismantled.[140]

After discussing all possible options for solving the problem, VNIITF's Science and Technology Council clearly favored the device's destruction in place. A commission of specialists appointed by order of Russian Federation Minister of Atomic Energy Viktor N. Mikhaylov, headed by the director of that nuclear center, Professor V. Z. Nechay, after inspecting the end box and the container holding the nuclear device, finally decided to destroy the nuclear explosive device without exposing it and removing its container from the physical installation.

On **May 31, 1995,** the nuclear device was destroyed in the end box using a special additional chemical explosive charge without nuclear energy release.[136]

The device's destruction was recorded by three independent remote monitoring methods. The design firing parameters, the time, and the completeness of detonation of the explosive in the system were fixed unambiguously.

For reliable confinement of toxic and radioactive products in the destruction zone, the stemming system used new technologies developed by specialists from the Russian Ministry of Atomic Energy's All-Russian Scientific Research and Design Engineering Institute of Industrial Technology (*VNIPIPromtekhnologiya*) based on the use of cement-bentonite slurries.

The results of radiation monitoring performed for the first five days after destruction of the nuclear device established that the observed radiation parameters, both inside the adit and at the entrance, were at natural background levels.

All work in Adit 108-K was carried out in full compliance with the Russian Federation's obligations under the nuclear test moratorium and the Republic of Kazakhstan's obligations when it joined the Nuclear Arms Nonproliferation Treaty. The collaboration by two countries that had formerly belonged to the unified USSR to destroy the nuclear explosive device attracted great international interest, as demonstrated by the fact that the US and Japanese Ambassadors to the Republic of Kazakhstan visited Adit 108-K on the day after VNIITF expedition left the site and personally verified, with their own dosimeters, the total environmental cleanliness of the work.

The practice of efficiently solving problems that arose during performance of the intergovernmental agreement through the Coordinating Group consisting of specialists from various ministries and departments involved in carrying out the "Exposure and Destruction of the Object" proved very useful. In addition, a model of interaction and cooperation between nations to solve a complex scientific and technical problem was tested during the work to dismantle the nuclear device in Adit 108-K, a model that was later used to solve other existing problems.

For their successful performance of the intergovernmental agreement, the team of specialists from the Russian Federation and the Republic of Kazakhstan received the Russian Federation Government's 1995 Prize in Science and Technology. They included: B. A. Andrusenko, A. M. Klimov, Yu. I. Kuznetsov, A. Muzyrya, Yu. Polovinkin, B. Rybin, V. G. Smirnov, Kh. Suleymanov, V. Filin, and A. N. Shcherbin from the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Experimental Physics (*VNIIEF*); A. A. Grigoryan and Ye. P. Kozlov from the All-Russian Scientific Research and Design Engineering Institute of Industrial Technology (*VNIPIPromtekhnologiya*); K. V. Kharitonov from the Russian Ministry of Atomic Energy; Samat K. Smagulov from the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*); and Timyr M. Zhantikin from the RK Atomic Energy Agency. In addition, Gennady P. Zyryanov and Anatoly M. Matushchenko received Certificates of Merit from RK President Nursultan A. Nazarbayev.

We should note that the successful solution of the problems related to implementation of the Agreement to Dismantle the Nuclear Device in Adit 108-K was aided by Russian Federation Government Resolution 39 of January 24, 1994, "On the Exemption of Goods Carried across the Customs Border in Accordance with International Disarmament Agreements from Customs Duty." This was an example of the specific and constructive actions of the two parties on the territory of a nonnuclear nation where there had previously been a nuclear test site and where all the terms and conditions of nonproliferation of "sensitive information" had to be strictly observed.

SEARCHING FOR AGREEMENT ON THE RADIATION LEGACY

From **May 22 to 29, 1994,** a team of Russian and Kazakhstani scientists worked in the US capital of Washington at the invitation of Test Director Don A. Linger. They included Yury V. Dubasov, V. A. Logachev, Anatoly M. Matushchenko, A. K. Chernyshev, V. A. Azarov, V. R. Burmistrov, G. S. Shuklin, and A. V. Yushkov. The visit's main purpose was to discuss the contents of preliminary reports on the consequences of nuclear testing at the Semipalatinsk Test Site, prepared under contracts between VNIIEF's Physics and Technology Center and the US Defense Nuclear Agency (DNA).

The Technical Assignment for the Russian specialists' work during their stay in Washington identified the following objectives:

> *"• Take part, with the status of scientific and technical experts on behalf of the Russian Ministry of Atomic Energy, in the discussion of issues of the assessment of environmental radiation levels at the former Semipalatinsk Test Site together with experts from Kazakhstan and the US, which is related to the need to develop a draft Agreement between the Governments of the Russian Federation and the Republic of*

Kazakhstan to clean up after the nuclear arms tests on the territory of the Republic of Kazakhstan (pursuant to Instructions VCh-P8-09805 of April 13, 1994 and ASh-P8-12091 of April 30, 1994);

"• discuss matters of the radioactive contamination of the test site grounds and establish the status of its separate areas from the viewpoint of approaches to revegetation;

"• discuss critical approaches to the meaning of agreement language in its technical aspects and priority areas of necessary research based on archive information and new measurements and sample analyses;

"• discuss possible cooperation between scientific groups and their priorities in the framework of the planned work program, funding sources and redistribution of costs among the interested parties, and intellectual property issues relating to research materials, reporting, and the provision of information by various entities, including in the framework of projects at the international level (RADTEST, RADLEG), as well as contracts with the DNA (Defense Nuclear Agency);

"• study US experience on this problem, paying special attention to practical aspects of the adequate use of new scientific advances in the US and expansion of cooperation on terms mutually acceptable to Russia;

"• coordinate approaches to criteria for social protection of people exposed to radiation outside the test site."

The following concluding provisions were adopted at a meeting devoted to the radioactive contamination of the test site grounds and the establishment of status for its separate areas from the standpoint of revegetation:

"• the selection of sampling control points for comparison with the results of measurements involving DNA or DOE experts does not require an additional aerial γ survey of the test site grounds, an extremely expensive operation, since the use of information available to Russian and Kazakhstani experts is quite adequate;

"• the assessment of the degree of radioactive contamination of selected local parcels identified as possible health protection zones requires identification of the quan-

> *titative makeup of soil in the samples, primarily ^{239}Pu and ^{241}Am, as well as ^{90}Sr and ^{137}Cs, with a determination of their ratios (available ratios for the conditions of the Nevada Test Site are not acceptable for the conditions of the Semipalatinsk Test Site).”*

The Washington meeting took place on the eve of the second RADTEST workshop, which was planned for the fall of that same year in Barnaul, the capital of Altai Territory.

The meeting in the US worked out a system of transparent[3] and adequate representation of information on nuclear tests sufficient to describe the operation of test sites in the US and the former USSR. Later, Russia released a series of collections in the *USSR Nuclear Testing* series.[1,141, etc.] Work to create this series of collections continues to this day.[12,47, etc.]

From **July 20 to 30, 1994,** interesting and very important radio-ecological studies were conducted at the Semipalatinsk Test Site. Under an accord previously reached in Washington, experts from Kazakhstan (RK NNC), Russia (the Khlopin Radium Institute Scientific Production Association) and the US (LANL), organized into three national teams, performed radiological measurements on the territories of 10 pre-selected control areas: the “Test Field,” the radioactive fallout plumes from ground nuclear tests, the earthen embankment of the manmade Lake Shagan, and 10 km from Kurchatov. The team of specialists from Russia and the US recorded γ spectra using field instruments, while the Kazakhstani team and part of the team of Russian specialists collected environmental samples for laboratory radiochemical analysis.

Within methodological error, the results of the radiological measurements performed as part of these studies corroborated the data from measurements made under the Region-1 comprehensive research program, whose principal investigator was the Khlopin Radium Institute Scientific Production Association, in accordance with USSR Supreme Soviet Resolution 289 of November 27, 1989 and USSR Council of Ministers Resolution 189 of February 14, 1990.

Moreover, the circumstances of the 1994 investigation were a model of specific and effective activity by specialists from different nations at the

[3]—“Transparency”: provision of effective monitoring of compliance with existing accords.

former Semipalatinsk Test Site. While the politicians were resolving their own difficult problems, the scientists were working, supporting the accords that had been codified in friendship agreements. The First Deputy Minister of Ecology and Bioresources Maydan Iskendirovich Zharkenov and Republic of Kazakhstan Chief State Inspector for Environmental Protection V. Slavgorodsky wrote in the newspaper *Nauka Kazakhstana* ("Kazakhstan Science"):[142]

> *"Within the boundaries of the test site itself, we have established that 88% of its grounds exhibit radiation levels within limits that do not exceed sanitary standards, and 12% require temporary condemnation pending decontamination.*
>
> *"We have certified areas from one-time nuclear explosions (25 areas, 32 explosions) ... After the study is complete, a decision will be adopted on a number of areas, whether to take them out of circulation or impose certain restrictions…*
>
> *"Over an area of 570,000 km^2 within the Semipalatinsk environmental disaster area, and within the boundaries of West Kazakhstan and Atyrau Regions, we have studied radiation levels from the air. We have established local parcels of radioactive contamination, whose substantive makeup points to the possible environmental effects of the Chernobyl accident, global fallout, and especially in East Kazakhstan Region, manmade processes.*
>
> *"Over an area of 250,000 km^2, we have completed a radiological, hydrological, lithologic, and chemical survey. Within the boundaries of East Kazakhstan, Pavlodar and Kökshetau Regions, the survey allowed us to identify nine putatively anomalous zones with ^{137}Cs reserves exceeding 0.07 Ci/km^2… In Semipalatinsk and Taldy-Kurgan Regions, we have identified large foci of surface water contamination by selenium, mercury, and fluorine, which is due to natural factors…*
>
> *"The Ministry of Ecology and Bioresources is prepared to consider any business proposals that could improve radiation levels in the republic, but exclude the authors' careerist, populist, or selfish interests. Objective, competent statements by the mass media, which we are counting on, would greatly assist the advancement of business proposals…."*[142]

During this period, both the Kazakhstani and the Russian mass media continued their intense discussion of the fate of the Semipalatinsk Test Site and the consequences of nuclear testing there. For example, the Russian *Nezavisimaya gazeta* ("Independent") for August 19, 1994 contained an article by A. Vaganov, which read in part:

> *"... It is no secret, however, that the attitudes of Kazakhstani environmental organizations toward the Semipalatinsk Test Site are very critical. We hear constant demands for the allocation of colossal sums to remediate the adverse environmental consequences resulting from its operation. The IAEA mission set the determination of the actual status of the environment as of today as one of its main objectives. But at any rate, it would be more efficient—from the environmental and the economic standpoints too—not to destroy the test site as such, but to turn it into a museum. Moreover, the implementation of this approach could generate serious income. In the Western press, for example, sporadic reports have already appeared to the effect that the US might add the Alamogordo nuclear complex to its National Registry of Historic Places…*
>
> *"Now the US intends to try to include the Alamogordo complex in the International Convention on the Protection of the World's Legacy. In addition to prestige (as a 'major scientific historical achievement'), this will also bring real economic gains."*

On **September 5, 1994,** the Russian Federation Government's instruction A3-P9-27921 ordered several industry-specific ministries headed by the Russian Ministry of Emergency Situations (Sergey Kuzhugetovich Shoygu) to jointly review the Resolution, "On the Procedure for the Granting of Compensation and Benefits to Russian Federation Citizens Who Resided from 1949 to 1962 outside the Russian Federation and Were Exposed to Radiation Due to Nuclear Testing at the Semipalatinsk Test Site" and submit a draft decision to the Government. This Resolution was drafted in implementation of the Russian Federation President's Decree of December 20, 1993 "On the Social Protection of Citizens Exposed to Radiation…," Paragraph 3 of which provided:

> *"... the RF Ministry for Cooperation with CIS Member States, together with relevant ministries and departments, is*

> *hereby directed to prepare and duly submit by January 1, 1995 a draft intergovernmental agreement with the Republic of Kazakhstan on a uniform approach to the assessment of radiation levels prevailing since the conduct of nuclear tests at the Semipalatinsk Test Site during the period from 1949 to 1963 and to the determination of total (aggregate) effective exposure doses received by citizens residing in the zone affected by the Semipalatinsk Test Site during said period."*

We should note that the Russian Ministry of Emergency Situations (*MChS*) lobbied to some extent for the interests of Altai Territory, which was reflected in its Resolution 1263 of November 17, 1994, "On the Procedure for the Granting of Compensation and Benefits to Russian Federation Citizens Who Resided from 1949 to 1963 outside the Russian Federation and Were Exposed to Radiation Due to Nuclear Testing at the Semipalatinsk Test Site."

Unfortunately, ministries such as the RF Ministry for Cooperation and the RF Ministry of Atomic Energy did not participate in the drafting of this Resolution.

On **September 5-10, 1994,** the Second International Workshop on the RADTEST project, titled "Long-Term Consequences of Nuclear Testing for the Environment and Public Health," took place in Barnaul, the capital of Altai Territory. The workshop was a component of the "Comprehensive State Program to Assess the Consequences of Radiation Exposure of the Population of Altai Territory from Nuclear Testing at the Semipalatinsk Test Site," which came to be called "Semipalatinsk Test Site–Altai." The program's research supervisor was Professor Yakov Nakhmanovich Shoykhet, the President of Barnaul Medical Institute, who later became a Deputy to the Council of the Federation.

Russian specialists presented a series of fundamental reports at the workshop containing information on the consequences of nuclear testing at the former Semipalatinsk Test Site:

- "Chronology of Atmospheric Nuclear Tests at the Semipalatinsk Test Site and Their Radiation Characteristics," by Anatoly M. Matushchenko, A. K. Chernyshev, and Georgy A. Tsyrkov (RF Ministry of Atomic Energy), Sergey Aleksandrovich Zelentsov (RF Ministry of Defense), V. A. Logachev (RF Ministry of Health), G. A. Krasilov and Yury Sarkisovich Tsaturov (RF Federal Service for Hydrology, Meteorology, and Environmental Monitoring), and Samat K. Smagulov (RK NNC);

- "Contemporary Interpretation of Data from Aerial and Ground Radiation Reconnaissance of the Plume from the USSR's First Nuclear Test in 1949," by V. A. Logachev, L. A. Mikhalikhina, and Yu. S. Stepanov (RF Ministry of Health), Anatoly M. Matushchenko, I. A. Andryushin, and A. K. Chernyshev (RF Ministry of Atomic Energy), and G. A. Krasilov (RF Federal Service for Hydrology, Meteorology, and Environmental Monitoring);
- "On the Question of Estimating Public Exposure Doses Due to the Conduct of Nuclear Tests at the Semipalatinsk Test Site," by V. A. Logachev, L. A. Mikhalikhina, N. G. Darenskaya, Yu. S. Stepanov, and O. I. Shamov (RF Ministry of Health), Anatoly M. Matushchenko and A. K. Chernyshev (RF Ministry of Atomic Energy), and G. A. Krasilov (RF Federal Service for Hydrology, Meteorology, and Environmental Monitoring);
- "Characteristics of Source Data on the Radiation Status of the Epicentral Zone of the Shagan Facility, an Excavating Underground Nuclear Explosion to Create an Artificial Reservoir: On the Question of Revegetating the Earthen Embankment and the Internal Body of Water," by Anatoly M. Matushchenko, Yury V. Dubasov, Anatoly A. Iskra, and A. K. Chernyshev (RF Ministry of Atomic Energy), V. A. Logachev and Yu. S. Stepanov (RF Ministry of Health), A. L. Maltsev (RF Ministry of Defense), Murat A. Akhmetov, E. M. Bayadilov, and Samat K. Smagulov (RK NNC), P. V. Boyarsky (Russian Scientific Research Institute of Cultural and Natural Legacy), and V. M. Zavyalov (Chernobyl-Invest Business Partnership Association). This report was published in its entirety in late 1994 in the Proceedings of the RK National Academy of Sciences [*Izvestiya natsionalnoy akademii nauk RK*], which shows the rather high assessment of the information contained in it.[143]

The contents of each of the reports named above were based on real (actual) data that were obtained during the period of testing and that were important in the drafting of the bilateral Russian-Kazakhstani Agreement to Clean up after Nuclear Arms Tests at the Semipalatinsk Test Site.

The foreign specialists at the workshop presented three reports:

- "American Tests in the Pacific Ocean," by Mark Morelli (US Department of Energy);
- "Review of the British Nuclear Testing Program," by Ken Johnston (Great Britain);
- "Some Data on Nuclear Arms Tests for UNSCEAR," by Lars-Erik De Geer (National Defense Research Establishment [*FOA*], Sweden).

The data presented in these reports can be used to create a database of nuclear tests carried out at other test sites around the world.

Unfortunately, however, we must state that the representatives of nuclear powers such as France and China did not present their reports to the workshop, that is, they did not follow the "principle of openness" that Russia and the US had demonstrated.

The populist speech of RK NNC representative Musin S. Zholdybayev was somewhat disappointing. His approach to assessing the consequences of nuclear testing, like that of the Nevada-Semipalatinsk movement's representatives, was distinguished by a lack of objectivity. The report noted that nuclear testing at the STS had done irreparable harm to Kazakhstan, and had created "environmental disaster areas." In addition, the report attempted to disavow the results produced by the two IAEA missions in 1993-1994, their conclusions on the nature of the radiation situation, the levels of environmental contamination, and the extent of the nuclear tests' effect on local public health. Zholdybayev's speech found no support among his colleagues, and he was soon forced to leave his job at the Institute of Radiation Safety and Ecology (*IRBiE*). Galdet A. Batyrbekov, one of the most active participants in the Nevada-Semipalatinsk International Antinuclear Movement, also left the post of General Director of the RK NNC.

The American specialists at the Barnaul workshop, despite the position of the French and Chinese representatives on the characteristics of the nuclear tests, proposed to expand the list of information on testing, specifically:

- specify the numbers of group underground nuclear tests, with information on the detonation of each separate physics package. Russia and the US have furnished this information;[35,144]

- include ^{131}I, which is largely responsible for the dose burden on the human thyroid gland, especially in children, in data on the quantity of radionuclides injected into the atmosphere by atmospheric nuclear explosions.

However, due to the special position of the representatives of several nuclear powers, primarily France and China, the latter proposal has not been implemented.

During the workshop, V. A. Logachev's report, "Modern Interpretation of Data from Aerial and Ground Radiation Surveys of the Plume of the USSR's First Nuclear Test in 1949,"[145] prepared using primary data from radiation reconnaissance after the explosion,[39] drew special interest. The information presented in the report was critical in the implementation of the Semipalatinsk Test Site–Altai program, because for the two years preceding the workshop, data on the position of the plume formed after the USSR's first nuclear explosion were based on the results of probabilistic calculations and simulations conducted by specialists from the Semipalatinsk Test Site[146,147] and the RF Ministry of Defense's Central Physical-Technical Institute (*TsFTI*) under the supervision of Barrikad Vyacheslavovich Zamyshlyayev and Vladimir M. Loborev.[148-150]

The *Methodological Instructions MU 2.6.1.015-93* for forecasting radiation levels by mathematical modeling, developed at TsFTI, remarked on the assessment of radiation levels in the plume from the USSR's first nuclear test (page 53): *"In view of the impossibility of unambiguous assessment of the position of the plume from the explosion of August 29, 1949, a probabilistic estimate is made."*

It is important to note that until a report containing the results of radiation reconnaissance of the plume produced by the first nuclear explosion was found in the archives of the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Experimental Physics (*VNIIEF*) in Sarov,[39] employees of the test site and the Central Physical-Technical Institute had no data on the ground location of the plume, which

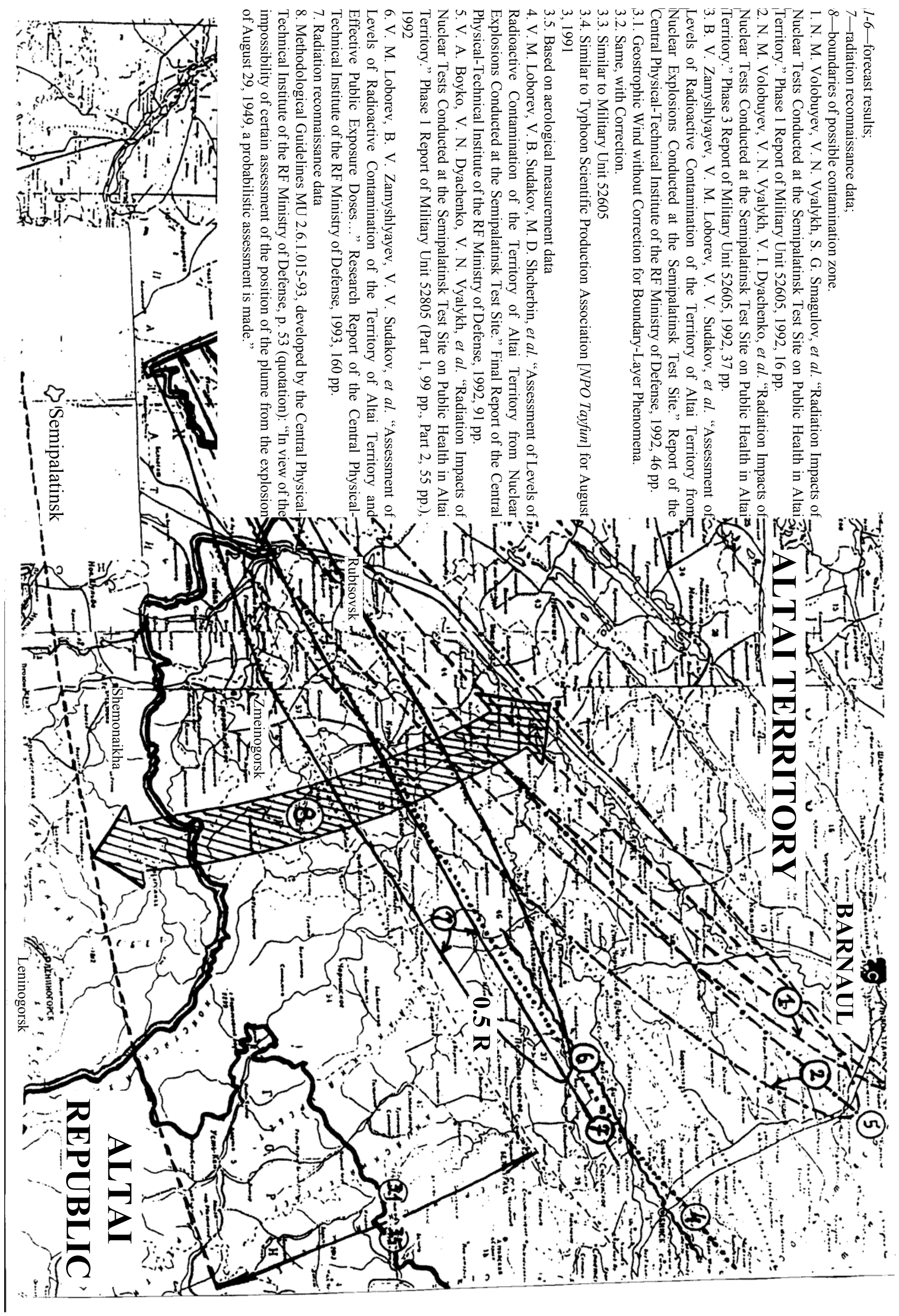


Figure 46. Alternative positions of the radioactive plume after the nuclear explosion of August 29, 1949.

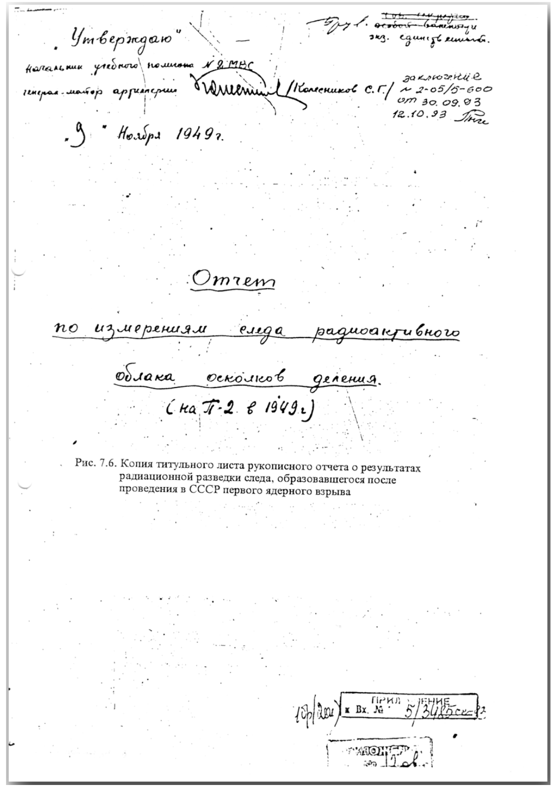
was very important for assessing public exposure doses. For a long time, due to the lack of factual data from radiation reconnaissance, they reconstructed the position of the first radioactive plume using mathematical modeling methods,[146-150] which naturally produced a significant exaggeration of public exposure doses and an increase in the sizes of the possible contamination zones. Figure 46 graphs various options for estimating the position of the radioactive plume produced on August 29, 1949 after the USSR's first nuclear test. The figure shows that mathematical modeling placed the plume axis with various probabilities in a sector from the direction of Barnaul to the direction of Gorno-Altaysk (Altai Republic), but the actual plume occupies only a small part of the territory within the boundaries of the radioactive contamination sector (in the figure, this plume is shown as number 7).

Participants in the RADTEST workshop remarked on the fact that most of the reports submitted by investigators in the Semipalatinsk Test Site–Altai program[151,152, etc.] had discrepancies between actual dose values and the medical consequences of nuclear tests. Biomedically oriented reports were marked by incorrect statistical processing of results, and in several cases by finagling results to support the conclusion that radiation was the main cause of degradation of the health of residents of the areas affected by nuclear tests. We should note that foreign workshop participants could not conceal their negative attitudes toward the contents of these reports by expressing them very delicately. For example, workshop secretary P. Kantrei [spelling not verified], summing up the results of the workshop in his concluding remarks, observed (quoting from the transcript):

- *"... I haven't seen a large and significant workup of the dose reconstruction model"*;
- *"... I'm confused about what is fact and what is fiction in the medical results presented"*;
- *"... now it would be better to give some range of values rather than precise figures..."*;
- *"... the conflicts I heard point to a lack of scientific control of the program."*

Such statements indicate that the foreign specialists, who had a scientific grounding in the issues under discussion, and in particular knew the intricacies of the effects of radiation factors on human health, were difficult to confuse.

Upon completion of the workshop, a copy of a fax containing data on the radiation reconnaissance of the radioactive plume produced by the first nuclear test in the former USSR was deposited in the library of the RADTEST project. Experts from the RF Ministry of Defense's Central Physical-Technical Institute (*TsFTI*) had examined this document, or rather, the only manuscript copy of the 1949 report (whose title page is shown in Figure 47), back in late 1993, gaining an opportunity to verify the location of the plume axis when forecasting radiation levels using mathematical modeling methods. Moreover, this report had been used in 1959 in the system of the USSR Ministry of Health's Third Main Directorate to map radioactive plumes outside the grounds of the Semipalatinsk Test Site.[12] We can call this a case of the "new" being the long-forgotten old.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„9" Ноября 1949 г.

экз. единственный.
заключение № 2-05/5-600 от 30.09.93
12.10.93

Отчет
по измерениям следа радиоактивного облака осколков деления.
(на П-2 в 1949 г.)

Рис. 7.6. Копия титульного листа рукописного отчета о результатах радиационной разведки следа, образовавшегося после проведения в СССР первого ядерного взрыва

Figure 47. Title page of the manuscript report on the results of radiation reconnaissance of the plume produced by the USSR's first nuclear explosion.

From **October 6 to 14, 1994,** the Russian experts A. K. Chernyshev and V. M. Gorbachёv (Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Experimental Physics, *VNIIEF*), Yury V. Dubasov (Radium Institute Scientific Production Association) and A. A. Spivak (Institute of Geosphere Dynamics, Russian Academy of Sciences) worked at the US Defense Nuclear Agency (DNA) in Washington, DC.

The DNA's chief attorney informed the Russian experts that in the opinion of the Americans, all matters relating to the radioecology of the STS should, in the interests of confidentiality, be discussed very delicately in the open press and always coordinated with the Russian Ministry of Defense and Ministry of Atomic Energy. While at the DNA, the Russian experts discussed the results of an assessment of environmental radiation levels at the former Semipalatinsk Test Site. Thus, Yury V. Dubasov presented the results of expedition work in the site's Test Field. The Russian experts were shown the results of field work performed by specialists from the Republic of Kazakhstan. The discussion of the radio-ecological problem resolved all issues of "distrust" of the results obtained by specialists from the various parties.

On **November 17, 1994,** the Russian Federation Government issued Resolution 1263, "On the Procedure for the Granting of Compensation and Benefits to Russian Federation Citizens Who Resided from 1949 to 1963 outside the Russian Federation and Were Exposed to Radiation Due to Nuclear Testing at the Semipalatinsk Test Site," with the Russian Ministry of Emergency Situations (*MChS*) taking a leading role.

Paragraph 3 of the Resolution directed the Russian Ministry of Emergency Situations, together with the Russian Ministry of Defense, the Ministry of Health and the Medical Industry (*Minzdravmedprom*), and the State Sanitary and Epidemiological Oversight Committee (*Goskomsanepidnadzor*), based on information available in the Russian Federation from retrospective assessment of radiation levels on the territory of the former Kazakh SSR, to prepare a list of villages and towns in that republic exposed to the effects of radiation from 1949 to 1963 as a result of nuclear tests at the Semipalatinsk Test Site and submit it to the RF Government for approval within two months. A list of such villages and towns in the former Kazakh SSR that had been exposed to the effects of radiation after the nuclear tests at the STS on August 29, 1949 and August 7, 1962 was soon approved.

In **December 1994,** in connection with the need to correct RK Cabinet of Ministers Resolution 1103 of December 31, 1992, "On Urgent Steps to Improve Radiation Levels in the Republic of Kazakhstan," Republic of Kazakhstan Minister of Bioresources Svyatoslav A. Medvedev described the scale of work related to an assessment of environmental radiation levels prevailing in the republic after the nuclear tests at the Semipalatinsk Test Site:

> *"The study of radiation levels is being conducted by aerial γ spectrometric and radiological, hydrological, lithologic, and chemical surveys. In 1993 and 1994, 916,000 km^2 of the republic's territory was surveyed from the air and 517,000 km^2 was surveyed from the ground at 1:1,000,000 scale. This concerns mainly the Semipalatinsk environmental disaster area and adjacent lands and the region of West Kazakhstan…"*

At the same time, work was continuing on the draft Agreement to Clean up after Nuclear Arms Testing at the Semipalatinsk Test Site.

On **<u>December 30, 1994,</u>** Russian Federation Minister of Atomic Energy Viktor N. Mikhaylov informed RF Minister of Defense Pavel S. Grachëv and other RF Government agencies that the legislation of two republics of the former USSR, namely the Russian Federation and the Republic of Kazakhstan, took different approaches to the mechanism of providing benefits and compensation to people "exposed to the effects of radiation on the territory of Kazakhstan." Mikhaylov was concerned about this, and also about the fact that the RK was actively engaged in issuing certificates confirming the right to benefits and compensation. According to available data, the Republic of Kazakhstan had issued such certificates (Figure 48) to about two million citizens of the republic, including some living on Russian Federation territory.

Утверждено постановлением
Кабинета Министров Республики
Казахстан от 26 мая 1993 г. № 431

РЕСПУБЛИКА КАЗАХСТАН
УДОСТОВЕРЕНИЕ

подтверждающее право на льготы пострадавшему (-ей) вследствие ядерных испытаний на Семипалатинском испытательном полигоне.

Серия СП №

Фамилия

Имя

Отчество

Дата рождения

с января 1949 г. по 1973 г. проживал (-а) в г. Семипалатинске, расположенном в зоне повышенного радиационного риска, а с 19 г. по 19 г. в

расположенном в зоне

риска

Комитет по ликвидации последствий ядерных испытаний на Семипалатинском полигоне

(учреждение, выдавшее удостоверение)

09. 1994 г. м. п. Роспись

Удостоверение бессрочно и действительно на всей территории Республики Казахстан.

Краткие сведения
о льготах гражданам, пострадавшим вследствие ядерных испытаний (из Закона Республики Казахстан от 18 декабря 1992 г. «О социальной защите граждан, пострадавших вследствие ядерных испытаний на Семипалатинском испытательном ядерном полигоне»).

Гражданам, проживавшим и проживающим в зонах указанных в статьях 5, 6, 7, 8, 9, гарантируется дифференцированная единовременная денежная компенсация.

Кроме того, эти граждане имеют право в установленных Законом рамках на:

пенсию на льготных условиях;
льготы по исчислению стажа;
ежегодное лечебное пособие для инвалидов, у которых инвалидность появилась вследствие ядерных испытаний;
дополнительную оплату труда, выплату пенсий, стипендий и пособий;
ежегодный дополнительный оплачиваемый отпуск

Дети и подростки до 18 лет, проживающие на территориях, пострадавших от ядерных испытаний, имеют право на бесплатное оздоровление (по медицинским показаниям) в санаторно-оздоровительных учреждениях.

Выплата единовременной денежной компенсации в сумме не произведена 5.09.1994 г.

(наименование организации, дата, печать и роспись произведшего компенсацию).

Личная подпись получателя

Figure 48. Certificate entitling the holder to benefits and compensation (name and date of birth concealed).

All this shows that in the framework of the Agreement being developed, a unified approach to the assessment of radiation levels on the territories of Kazakhstan and Russia and to the use of its results in addressing social protection problems was needed.

If the Agreement to Clean up after Nuclear Arms Testing at the Semipalatinsk Test Site were signed, the lead contractor for the work for the Russian Federation would be the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Experimental Physics (*VNIIEF*). The retrospective assessment of radiation levels on the territories of the RF and the RK, as well as exposure doses of residents of various villages and towns was to be done using the *Methodological Instructions, "Assessment of Public Exposure Doses in the Area of Local Fallout of Radioactive Products of a Nuclear Explosion"* (MU 2.6.1.015-93), developed at the RF Ministry of Defense's Central Physical-Technical Institute (*TsFTI*), which should have been sent to VNIIEF. These instructions should have become the basis for a unified approach to the assessment of public exposure doses.

However, events developed along a different path. The leaders of TsFTI decided to use this methodology in the performance of the regional Semipalatinsk Test Site–Altai program, for which the main contractor was the Barnaul Scientific Research Institute of Regional Medical and Environmental Problems (*NIIRMEP*) (program research supervisor Yakov N. Shoykhet, institute Director V. I. Kiselëv). The research study approved for implementation under this program was titled, "Development of a List of Villages and Towns Exposed to Radiation Effects as a Results of Nuclear Tests at the Semipalatinsk Test Site from 1949 to 1963 in Doses Exceeding 5 cSv." This area of work was supervised by V. A. Vladimirov of the Russian Ministry of Emergency Situations (*MChS*).

[Not until February 1998, in response to Russian Deputy Minister of Emergency Situations Sergey Valentinovich Khetagurov's Inquiry No. 33-339-6 of February 9, 1998, sent to the supervisors of the Semipalatinsk Test Site–Altai program, were the results of the research under this program sent for review to the Russian National Commission on Radiation Protection (*RNKRZ*).

In the Republic of Kazakhstan during this period, existing "Dose Passports" for 711 villages and towns, which had been drawn up earlier rather hurriedly by specialists from Military

Unit 52605 at the demand of the RK Ministry of Ecology and Bioresources, were used for reference.

By March 1998, based on the results of performance and editing of “Development of a List of Villages and Towns…” under the Semipalatinsk Test Site–Altai program, Samat K. Smagulov, a leading expert who had been involved in developing the “Dose Passports,” proposed to exclude the possible use of these doses for resolving practical issues, since the “passport doses” were about 10 times too high.—The authors]

RF Minister of Atomic Energy Viktor N. Mikhaylov’s proposal to carry out the Federal special research study, “Assessment of Radiation Levels on the Territory of the former Kazakh SSR as a Result of Nuclear Tests at the Semipalatinsk Test Site and Determination of the Extent of Its Effects on the Public” (Appendix A) was rejected by the leaders of the Russian Federation Ministry of Health’s Institute of Biophysics, but they did support performance of the regional Semipalatinsk Test Site–Altai program, assigning Professor K. I. Gordeyev from the Institute of Biophysics to head the study to assess public exposure doses resulting from nuclear testing at the Semipalatinsk Test Site.

Unfortunately, the results of the research study under this program revealed a characteristic feature of the performance of regional programs to assess public exposure doses, the calculated values from which formed the basis for decisions on the allocation of benefits and compensation in connection with radiation exposure during the period of nuclear testing. Specifically, they showed an elevation of exposure doses compared to their optimal values. The reasons for this vary, but the main one is the influence of the regional programs’ research supervisors, who are naturally interested in exaggerating exposure doses. These supervisors select the appropriate investigators, fund the development of “advantageous” methodological approaches, contractually set the level of payment to performers of “research studies,” and finally, dismiss “uncooperative” and principled specialists.

Thus—and this is especially noteworthy—Kazakhstan “was out of the loop” with respect to all events relating to the assessment of public exposure doses, since representatives of the Russian Ministry of Emergency Situations did not try to maintain contacts with the RK NNC. Specialists from the Russian Ministry of Atomic Energy were also practically eliminated from the work; like the Kazakhstani specialists, they were interested in obtaining objective data on radiation levels in the areas affected by the operation of the Semipalatinsk Test Site and on public exposure doses in the radioactive contamination plumes.

The complicated year of 1994, which was characterized by disparate approaches by various entities to the assessment of radiation levels prevailing after nuclear testing at the Semipalatinsk Test Site, culminated in a **December 14, 1994,** message from Dr. Charles S. Shapiro, Chairman of the Executive Committee of the SCOPE (RADTEST) project, and Dr. Sir Frederick E. Warner, Chairman of the project's Scientific Consultative Committee, inviting Russian and Kazakhstani specialists to take part in the preparation and conduct of a Third Workshop on the SCOPE (RADTEST) Project in Belgium in March 1995. At this workshop, they planned to discuss issues relating to the assessment of radiation levels after the conduct of nuclear tests at various sites around the world, and thereby complete a database on conditions and regimes of nuclear testing, that is, collect data necessary for the conduct of biomedical research and adequate assessments of dose burdens. The world community tried to join forces in solving the problems of assessing the consequences of nuclear testing.

NUCLEAR ARMS NONPROLIFERATION ISSUES AND DISMANTLING OF THE TESTING INFRASTRUCTURE

The breakup of the Soviet Union was a unique event in the history of international relations in general and nuclear arms nonproliferation in particular. The circumstances that emerged after this extraordinary event, both in the country and in the world, were complex and characterized by several factors, in particular:

- the post-Soviet states had no real force conflicts, either in relations with one another or in relations with other nations of the world, that demanded the use of military force, so nuclear arms lost their importance as tools for maintaining stability in international relations;
- the developed industrial nations participated actively in the division of the "Soviet nuclear legacy," which concerned both the fate of the nuclear arms themselves and the technologies accumulated in the nuclear arms complex;

- there was a continuous negotiating process over the legal status of the nuclear infrastructure, equipment, and various facilities outside the Russian Federation.

We should note that from 1992 to 1994, the risk of wide proliferation of nuclear arms due to disintegration processes occurring in the former USSR continuously existed and even increased. This risk did not begin to decline until late 1994 and early 1995. This was promoted largely by the establishment of national nuclear export control systems in Kazakhstan, Ukraine, and Belarus, as well as the acceptance of IAEA guarantees by these countries.

Nuclear Weapons after the Breakup of the USSR

Even before the breakup of the USSR, the Soviet military had concentrated its main tactical nuclear warheads on the territories of Russia, Ukraine, and Belarus, permitting considerable reduction of the threat of nuclear proliferation. However, all did not go smoothly: certain political forces tried to forcibly impede the nuclear arms nonproliferation process. For example, in 1990, the removal of nuclear warheads from the territory of Azerbayjan after the well-known events in Baku was greatly complicated by an attempt by certain forces related to the Popular Front of Azerbayjan to impede the process. A runway at one military airfield was blocked by a group of people trying to prevent airplanes from taking off. The situation was so tense that the crew was forced to use weapons. Fortunately, the shots dispersed the crowd, there were no casualties, and the planes were able to take off.

However, the main problem was the presence of the former USSR's strategic nuclear arsenal on the territories of newly formed sovereign nations such as Russia, Belarus, Kazakhstan, and Ukraine. The fate of these arms was at the center of politicians' attention throughout the world, especially the US and Russia. A slew of varied issues arose. Some of them include:

- how to safeguard the nuclear arms;
- how to effect continuity of nuclear materials control and accounting in compliance with world standards;
- how to prevent the expansion of the "nuclear club" and assure that Kazakhstan, Ukraine, and Belarus would join the Nuclear Arms Nonproliferation Treaty (NPT);

- how to prevent leakage of "sensitive information" related to nuclear arms out of the nuclear nations;
- how to ensure the complete and unconditional succession of the former USSR's obligations in the area of nonproliferation of weapons of mass destruction (WMD), and in particular, nuclear arms;
- how to ensure the application of IAEA guarantees to nuclear facilities located on CIS territory.

On **July 6, 1992,** nine of the CIS nations (Armenia, Belarus, Kazakhstan, Kyrgyzia, Moldova, Tajikistan, Türkmenia, Uzbekistan and Ukraine) officially declared their support for Russia's participation in the NPT as a nation possessing nuclear arms, and their willingness to sign the Treaty as nonnuclear nations. Thus, the issue of succession was "legally" resolved. The Russian Federation became the USSR's full-fledged successor with respect to the ownership of nuclear weapons.

But how many nuclear arms were there on Kazakhstani territory? Documents indicate that by December 1991, when the Republic of Kazakhstan declared its independence, there were 1,410 strategic nuclear warheads on various vehicles on its territory, including 104 RS-20 silo-based missiles (in American nomenclature, "SS-18s"), located at missile bases in Zhangiz-Tübe and Derzhavinsk.[153,154] In addition, there was a group of Tu-95 strategic bombers equipped with nuclear cruise missiles in the town of Shagan.

On **February 24, 1994,** the Republic of Kazakhstan became a full-fledged member of the NPT with nonnuclear status. The safe operation of all facilities of the civilian nuclear infrastructure, including nuclear reactors and other civilian facilities, was guaranteed by the IAEA.

By **April 1995,** the last nuclear warhead had been removed from Kazakhstan to Russian territory.

On **September 5, 1996,** the Russian Strategic Missile Forces (*RVSN*) completely left the territory of the Republic of Kazakhstan.

We should note that the nuclear arms nonproliferation steps taken by the leaders of the Republic of Kazakhstan practically completely excluded the threat that the uncontrolled breakup of the powerful Soviet nuclear weapons complex at some later date could create for the system of international relations.

DISMANTLING OF THE NUCLEAR TESTING INFRASTRUCTURE

Naturally, informative impressions and "sensitive" information, the study of which could produce information on experimental technology and certain parameters of nuclear explosive devices, still remained on the grounds of the former Semipalatinsk Test Site as a result of atmospheric nuclear explosions and nuclear physics experiments in special working areas of the Test Field, in adits and tunnels in Delegen Massif, and in shafts in Balapan Area.

At present, the work being done to destroy mine workings at the test site has increased the likelihood of access to such information, and this could lead to a violation of several provisions of the NPT. The work is being performed under the supervision of the RK NNC as part of the implementation of the "Agreement between the US and the RK Regarding Destruction of ICBM Launch Silos, Cleanup after Accidents, and Prevention of Nuclear Arms Proliferation" of December 13, 1993, as well as the "Agreement between the US Department of Defense and the RK Ministry of Science and New Technologies on Reducing Nuclear Infrastructure" of October 3, 1995, as amended June 10, 1996.[155,156] Of course certain measures are required to prevent dissemination of "sensitive" information. The most important measure is the dismantling of the nuclear testing infrastructure.

On **April 2, 1996,** the demonstration closure of the first adit (No. 192) in Delegen Work Area was carried out. The event was attended by members of the Government of the Republic of Kazakhstan, the Semipalatinsk Region Council (*akim*), the US Ambassador to the RK, and highly placed employees of the US Department of Defense.

In all, 181 adits were prepared in Delegen Massif. Between 1996 and 2000, they were all closed, using methods such as the installation of a cement plug, drilling of blast holes from within, the drilling of blast holes from without, and the detonation of additional charges.[157] The adits had cross sections from 9 to 25 m^2 and lengths of 1000 meters or more. In 163 of 181 adits, 212 nuclear tests were carried out, involving the detonation of 307 special items, with 18 adits remaining unused.[12] Figure 49 shows photographs of several adits in Delegen Work Area before and after their closure, that is, after their entrances were buried with “clean” earth.

The adits were closed by a Kazakhstani enterprise, Delegen LLC (Director Vladimir V. Kovalëv). All the work was funded by the Defense Special Weapons Agency (DSWA) of the US Department of Defense, whose representatives (technical managers) were authorized to monitor the quality of the work done and provide technical assistance on the principle of noninterference. Visits to adits for the purpose of selecting the optimal method of closure and performing radioecological measurements had to be limited to a depth of 50 meters from the entrance. All adit closure work was done according to special designs.

Besides adits, 128 shafts were used for underground tests during the operation of the Semipalatinsk Test Site.[12] We should note that no especially laborious work was done in the environmental cleanup of the caps of used shafts, unlike for used adits. Special attention was paid to the closure of unused shafts, and to preparations for the destruction of intercontinental ballistic missile (ICBM) launch silos located in Balapan Work Area.

After its closure, the test site still had 13 unused shafts, Nos. 1071-bis, 1074, 1311, 1327, 1330, 1343, 1349, 1381, 1383, 1386, 1389, 1409 and 1419. These were all located mainly in an area 30×12 km across in the southwestern part of Balapan Area.[156] These shafts were drilled in various years of the test site’s operation, to various depths and under various geological and hydrological conditions. The deepest of them (down to 630 meters) was deviated from the vertical.[158]

The baseline method of closing shafts consisted of filling the shaft with earth to a depth of up to 11 meters and then installing a concrete plug. After this was done, the area around the mouth of the shaft was graded to conform to the natural topography.

Twelve missile silos (Nos. 373, 374, 375, 376, 377, 395, 401, 402, 403, 407 and 408), located in two local parcels of the northern part of Balapan Area, were slated for destruction. Each consisted of a shaft up to 40 meters deep and a system of underground bunkers. The main shaft was lined with steel structures. The bunkers and shafts communicated through underground tunnels, each of which was up to 100 meters long. Chemical explosives were used to destroy the missile silos.

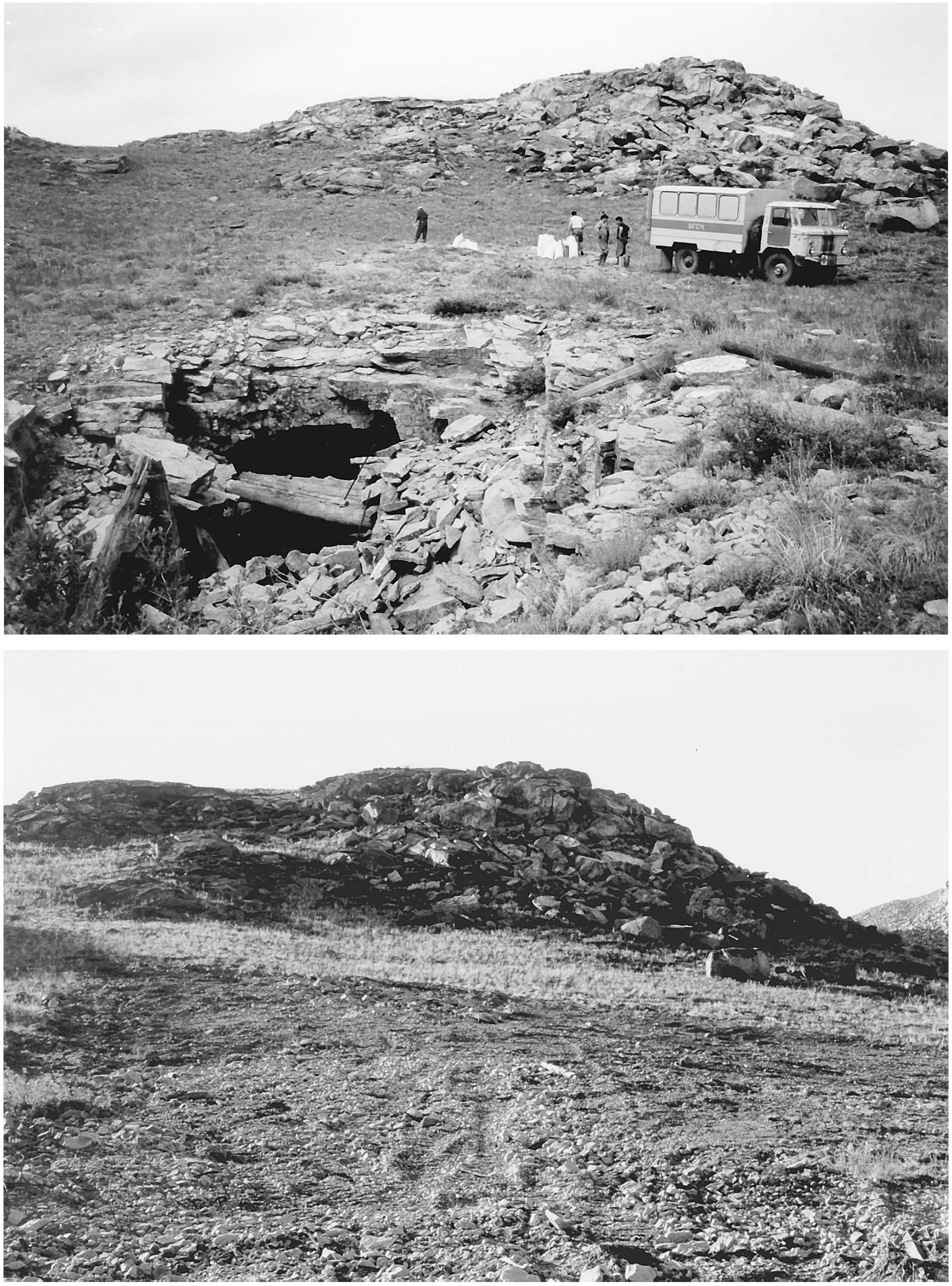


Figure 49. Adits in the Delegen Massif before closure and after backfilling to restore the natural topography.

On **March 28, 1997,** the "Agreement on Flask Containers and Special Technological Equipment Located on the Grounds of the former Semipalatinsk Test Site" was signed between the Government of the Russian Federation and the Government of the Republic of Kazakhstan, aimed at dismantling the nuclear testing infrastructure and improving environmental conditions on the grounds of the test site.[159] The supervising and monitoring agency for implementation of the agreement was the Coordinating Group (CG), consisting of authorized representatives of the relevant ministries of both countries. The CG was co-chaired from the Kazakhstani side by Shamil T. Tukhvatulin, Deputy General Director (now General Director) of the RK NNC, and from the Russian side by A. N. Shcherbin, a section head at the Russian Federal Nuclear Center/All-Russian Scientific Research Institute of Technical Physics (*VNIITF*).

The people implementing the Intergovernmental Agreement faced the following tasks:

- perform joint radiation measurements and monitoring of the site's test areas;
- complete the long-term and reliable disposal of agreed facilities and equipment;
- organize environmental cleanup and revegetation of the grounds of test areas;
- dismantle and destroy selected equipment in accordance with design solutions;
- set up and carry out joint experiments and research.

The principles of interaction between the Parties in carrying out the agreement were also defined, specifically:

- parity in safeguarding the interests of both Parties;
- transparency, that is, the provision of effective monitoring of compliance with existing accords when performing all work and operations.

One of the main jobs defined by this Agreement was the job of mothballing and superlong-term disposal of so-called flask containers. During the testing period, these containers were used to transport especially hazardous cargo, including nuclear warheads, with a guarantee that all radioactive products of an unauthorized explosion with a maximum yield of up to 200 kg of TNT would be completely localized in the sealed interiors of these containers.[160] These "super-containers" had the following parameters: weight not over 30 metric tons, length 9.5 meters, diameter 2.7 meters. Figure 50 shows a photograph of a flask container mounted on a special carriage. Of the six containers left at the test site after its closure, five had been used during the testing period, so they contained radioactive substances. However, they presented hardly any radiation hazard as a source of outdoor exposure. One container, which had not been used during the testing period, was "clean," i.e., it contained no radioactive substances. The plan for disposing of the containers for the long term included the use of their unique strength qualities and prevention of unauthorized access to them, which required concrete encasement. Environmental requirements applicable to this design solution consisted mainly of preventing the entry of radioactive substances into the environment. These requirements corresponded to the principles of safety and the technical criteria for underground disposal of high-level radioactive waste (IAEA standards, series 99, 1990).

The resulting working plans for disposal of flask containers were

Figure 50. Exterior view of a flask container, mounted on a special carriage.

approved by the Interregional Inspectorate of the Republic of Kazakhstan Committee for Emergency Situations. From 1997 to 1998, Kazakhstani and Russian specialists using these plans carried out the disposal of all flask containers: one in a bunker near the mouth of Adit K-85, three in Adit 200-ASM, and two in a bunker at facility RB, Area Sh-2.

In **1998-2000,** as part of the implementation of the Russian-Kazakhstani intergovernmental Agreement, the special technological equipment used in nuclear physics experiments performed in the Aktan-Berli and No. 7 test areas north of the Delegen Massif was dismantled and destroyed. In addition, the grounds of these areas underwent environmental cleanup and revegetation to remove dispersed radioactive materials. Figure 51 presents a photograph recording the dismantling of technological gear of nuclear physics experiments performed in the Aktan-Berli Test Area.

The twelfth meeting of the Coordinating Group in Kurchatov from November 25-30, 2000, summarized the major results of joint Russian-Kazakhstani and Kazakhstani-Russian-American work from 1997 to 2000

Figure 51. Dismantling and destruction of special technological equipment at Aktan-Berli Area.

to dismantle the nuclear testing infrastructure as part of the implementation of the "Agreement on Flask Containers and Special Technological Equipment…" It also discussed other issues of interest to the two Parties, such as the organization and performance of joint work under the International Science and Technology Center's Project K-414, "Creation of an Extensive STS Database," based on available information, the consequences of testing of military radioactive materials in Areas 4 and 4A, and the drafting of a monograph on nuclear testing and peaceful nuclear explosions on Kazakhstani territory, etc.

At the same meeting of the Coordinating Group (Figure 52 shows a photograph of the participants), the CG members and experts noted positive results in achieving optimal solutions on all nuclear nonproliferation issues.

The year 2001 will mark the tenth anniversary of the closure of the Semipalatinsk Nuclear Test Site and the beginning of work to demilitarize it. In addition, 2001 should be the final year in the solution of the important problem of dismantling and disposing of the most important part of the technological equipment, namely the infrastructure of nuclear testing and nuclear physics experiments conducted at one time for the purpose of creating the Soviet Union's nuclear shield. However, we must admit that a very big part of the test site's technological equipment, specifically the part prepared but not used for nuclear tests in emplacement holes, has been put to work for so-called calibration experiments needed to support the operation of the world nuclear explosion monitoring system.

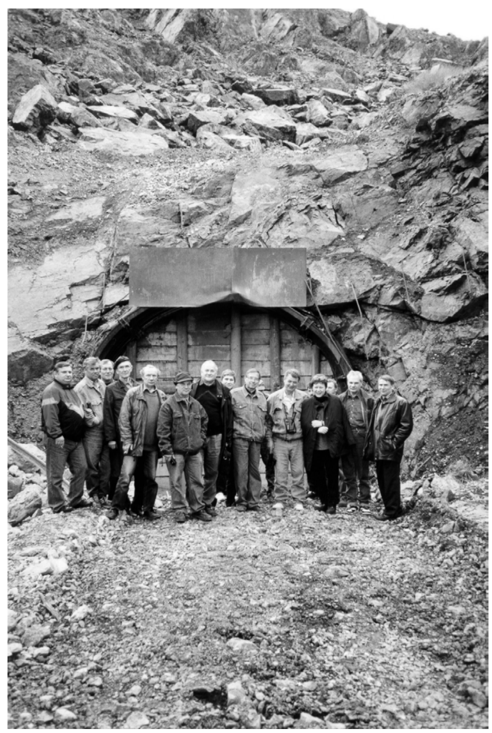


Figure 52. Participants in the Coordinating Group's twelfth meeting, November 25-30, 2000.

Experimental and Calibration Explosions Using "Conventional" Explosives

In 1997 and 1998, in accordance with the plan for experimental closure of several shafts in Balapan Test Area, specialists from the RK NNC's Institute of Geophysical Research (*IGI*) and the Kazakh State Scientific Production Center of Explosives (*KGTsVR*) worked long and hard to close the first four shafts (Nos. 1311, 1349, 1381, and 1071). To this end, they used environmentally safe explosives with yields of 50-100 kg at depths of 50 to 580 meters.[158] Shafts 1381 and 1311 were closed by two explosions at various depths.

We must note that all geophysical explosions were carried out in order to study the effect of geologic structures on seismic wave propagation patterns, and for field testing of the operability of explosives and charge shaping conditions for successful conduct of future work. To record seismic signals in Balapan Area, a network of temporary seismic stations was set up at locations chosen by American specialists.

Figure 53. View of the head of Shaft 1389 before detonation.

In this area, six calibration explosions with 50- to 100-kg charges at depths of 50 to 580 meters and eight explosions with 2-ton charges at depths of less than 10 meters were detonated.[161] The charges for these geophysical explosions weighing up to 100 kg were lowered to the design depth on a cable in metal containers 0.3 meter in diameter and 1.5-2 meters long, made of sheet metal 1 mm thick. A polyethylene bag containing the primer (the detonators) with two pieces of detonating cord was placed in the container, which was then filled with the design amount of granulated TNT explosive.

Shaft 1389 was selected for a five-ton experimental calibration explosion. The shaft's head before the explosion is shown in Figure 53. The experiment, carried out on July 13, 1997 at 3:11 PM local time, confirmed the possibility of detonating granulated TNT at a depth of 600 meters in a shaft filled with water. The firing of the five-ton explosive charge produced a seismic signal, but the casings of Shaft 1389 were lifted 10 meters above the ground surface. Figure 54 shows the casings lifted by the explosion.

The explosion produced an outburst of gas, water, and concrete from the shaft, and was recorded by all temporary seismic stations located in Balapan Area.

Figure 54. Casing lifted from Shaft 1389 after detonation.

The results of the geophysical and experimental explosions were used to determine the technology for explosions with yields of 25 tons or more. Such explosions were detonated at various depths on August 3, 1997 in Shaft 1311, on August 31, 1997 in Shaft 1381, and on September 28, 1997 in Shaft 1349. The seismic waves from these explo-sions were also recorded by all temporary stations, and by the seismic stations and observatories of the RK NNC's Institute of Geo-physical Research (*IGI*). With the aid of these explosions, the unused shafts were reliably destroyed. The resulting craters were filled with earth and regraded to their natural level using graders and bulldozers.

On September 17, 1998, a 25-ton experimental calibration explosion was detonated to close the last Shaft 1071 in Balapan Test Area.

During 1998-2000, in addition to experimental calibration explosions in shafts in Balapan Area, calibration tests were carried out in adits in Delegen Area. On August 22, 1998, a 100-ton explosion, called "Omega-1," was detonated in the "clean" Adit 214. The purpose of the experiment was to calibrate seis-mographs on the regional scale and improve calib-ration technologies in the interests of supporting the Comprehensive Test Ban Treaty (CTBT) using the International Seismic Network. The end [box] of Adit 214, which was 600 meters long, was a detonation chamber in the shape of a 5.5-meter ribbed cube. To create conditions for the maximum coupling of the explosive energy with the rock, a strong stemming system was used. The thickness of the rock hanging over the detonation chamber along the line of least resistance was 100 meters. Similar calibration explosions were detonated on September 25, 1999 ("Omega-2") and July 29, 2000 ("Omega-3").

ASPECTS OF THE PERFORMANCE OF THE LAST SEISMIC CALIBRATION TEST, "OMEGA-3"

The first two calibration experiments at the former Semipalatinsk Test Site to test the seismic equipment of the international system of observation of the nuclear arms nonproliferation regime, code named "Omega-1" and "Omega-2," were performed in adits in 1998 and 1999.[190] The last similar test, "Omega-3," was carried out on July 29, 2000 in Adit 160/160-S.

The working design for the "Omega-3" test was prepared on the basis of Directive 05-5/295 of the Chairman of the Republic of Kazakhstan Interdepartmental Commission for the Implementation of the Agreement signed by Kazakhstan's Ministry of Science and New Technologies and the US Department of Defense to dismantle the nuclear arms testing infrastructure at the former Semipalatinsk Test Site, as well as the Supplemental Agreement DSWA 0016/1/D-4 (modification 00008) of November 9, 1999 under Contract DSWA 0016/1 of December 8, 1997 to perform a 100-ton calibration test in Adit 160/160-S. The work defined by the plan was carried out in compliance with the "Unified Blasting Safety Rules" and other documents, and accounted for the results of many years' experience producing large-scale mine explosions in Kazakhstan and Russia.[192]

The seismic experiment was performed using Adit 160, which was cut into a basaltic ridge in the western part of the Delegen Massif. In this adit, no nuclear tests had been performed, so there was no radioactive contamination.

The plan called for tunneling an additional adit above the existing Adit 160, installing a ribbed cubical detonation chamber about 5 meters in size whose center was 20 meters above Adit 160, placing 100 metric tons of chemical explosives (granulated TNT), and installing a stemming system. After the experiment, Adit 160 was to be mothballed by the installation of a concrete plug.

For this experiment, the method of firing using electric detonators and detonating cord was adopted as before, ensuring the safe detonation of a charge with a total mass of 100 metric tons.

The dimensions of the safety zone were calculated:

- for human seismic exposure: 550 meters;
- for the size of clods of earth from the ejection crater: 1100 meters;
- for the harmful effects of the aerial shock wave: 650 meters;
- for the toxic effects of explosive gases: up to 2500 meters.

The firing post was placed in a reliable shelter 1100 meters from the detonation point, and the observation area was placed at 2500 meters. Security posts located at least 1500 meters away could use mobile shelters. Electric power and lighting for the facility were provided from an AD-100 diesel generator.

The explosion at a depth of 39.5 meters produced a surface crater 70-80 meters across with a volume of about 75,000 m^3 along the line of least resistance.

Thus, the detonation of a powerful chemical explosive charge destroyed the last Adit 160 in the hills of Delegen Test Area on July 29, 2000. The explosion served simultaneously as an experiment for the purposes of calibrating seismic equipment installed in the system of monitoring and observation of the nuclear arms nonproliferation regime. The closure of the last adit at the former test site was an important milestone in the history of the Republic of Kazakhstan.

To assess environmental radiation levels after the explosion, a detailed inspection of the additional adit and Adit 160 was conducted, including precise localization of the distribution of earthen embankments and the position of fractures.

Radiation inspections and monitoring of environmental radioactivity was assigned to the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*), whose employees performed all of their assigned tasks in full. Tasks relating to the performance of the seismic calibration test in Adit 160 were also accomplished in full.

We must note that calibration explosions in support of the CTBT have been performed throughout the world for over 10 years now. For example, in 1989, the Nevada Nuclear Test Site in the US and the still-operational Semipalatinsk Test Site in the USSR detonated underground nuclear calibration explosions. Later, seismic stations were calibrated using chemical explosions. For example, in 1993, the Nevada Test Site in the US detonated a 1200-ton calibration explosion in an adit. In 1996, Spain detonated a 300-ton explosion. In 1998, the Nevada Test site in the US detonated a 2-kiloton physics package. In 1996-1998, Australia detonated a series of calibration explosions with yields of up to 300 tons each, and in 2000, Israel detonated a 300-ton explosion. Thus, the calibration explosions at the former Semipalatinsk Test Site were part of the work done worldwide in support of this important international treaty.

The information obtained from calibration explosions has helped and will continue to help the international community to detect and more precisely identify nuclear explosions and to distinguish them from earthquakes and conventional explosions, thereby ensuring effective monitoring of compliance with the CTBT. In addition, this information will permit the establishment of the kind of monitoring systems that will make it impossible to perform nuclear tests anywhere on the globe without the knowledge of the world community.

One of the last important events of 1998 was the implementation of UN General Assembly Resolution 52/169M on *"international cooperation and coordination of activities for the purposes of rehabilitating the people and environment and the economic development of the Semipalatinsk region in Kazakhstan."*[4] This was the aim of organizing the UN Development Program (UNDP)'s mission.

[4]—"The Semipalatinsk region," as used by the UN mission and the RK NNC, is a term encompassing areas whose territories were radioactively contaminated during the period of nuclear testing at the site.

WORK OF THE UN DEVELOPMENT PROGRAM'S MISSION

Republic of Kazakhstan Minister of Science and Higher Education Vladimir Sergeyevich Shkolnik, in his letter No. 32-10-1/2-89 of February 3, 1999 to Republic of Kazakhstan Prime Minister Nurlan Utebovich Balgimbayev, wrote:

> *"International cooperation on the grounds of the former Semipalatinsk Test Site (the STS) in the framework of various projects and programs has its own peculiarities. These peculiarities lie primarily in the presence of places and facilities containing 'sensitive' information. Issues of its nonproliferation are monitored by the joint Kazakhstani-Russian Coordinating Group (CG) formed in accordance with the Agreement of March 28, 1997 between the Governments of Kazakhstan and Russia, 'On Flask Containers and Special Technological Equipment Located on the Grounds of the STS.' When international projects are performed on the grounds of the STS, the CG coordinates the time, place, and nature of the work. All international programs carried out at the STS (including the Delegen Adit Mothballing Program jointly with the US, the destruction of Balapan shafts jointly with the US, the setup and conduct of calibration tests jointly with the US and the Comprehensive Test Ban Treaty Organization, etc.), are coordinated with the CG and monitored by an interdepartmental commission formed under our Ministry.*
>
> *"Since the work to destroy 'sensitive' information at the STS is incomplete, UN plans on the STS must be duly coordinated in the Coordinating Group framework…*
>
> *"In this connection, the UN's design proposals regarding the grounds of the STS must be 'linked' with the RK NNC's activities to clean up after nuclear testing."*

During the UNDP mission's work period from June 15 to 30, 1998, all these requirements were met in full. The mission included experts from the US, Canada, Great Britain, Sudan, Kazakhstan, Russia, Belarus, Ukraine, and UNESCO. A total of 25 people, including interpreters, worked on the mission. The Russian Federation's experts, at the initiative of the United Nations Permanent Representative to the Republic of Kazakhstan, supported by the RK Ministry of Foreign Affairs and RF Ministry of Foreign Affairs, were V. A. Logachev and Anatoly M. Matushchenko, participants in nuclear testing at the Semipalatinsk Test Site and authors of the monograph, *The Semipalatinsk Test Site: Assurance of the General and Radiation Safety of Nuclear Tests*.[12]

The principal objective of the UNDP mission's work *"was to assess the impact of nuclear tests on problems and needs of the inhabitants of the Semipalatinsk region in four respects: environment, health, economic recovery, and humanitarian assistance."* The mission worked in the cities of Semipalatinsk, Kurchatov and Almaty successively. The four points identified in the mission's objectives also defined the objectives of its teams. Thus, issues of "Radiation and Human Health" were addressed under the supervision of Armin Weinberg, an expert from the US; the team of experts for the problems of "Environment and Agriculture" was headed by UNESCO representative Vefa Moustafaev (France); the team of experts for the problems of "Humanitarian Assistance" was headed by Sudanese expert A. Elton [spelling not verified]; and the "Economic Problems" team was headed by British expert P. Grey [spelling not verified].

The discussions that took place in the "Radiation and Human Health" team, which included experts from Kazakhstan, Russia, and the US, were marked by a special temperament. This was because the data submitted for discussion by one of the Kazakhstani representatives, B. I. Gusev, on the scale of environmental radioactive contamination as a result of nuclear testing at the STS and on possible public exposure doses were significantly exaggerated, drawing sharp criticism from experts from the US and Russia. In this context, the provision to the mission of the anthology *USSR Nuclear Tests: Hydronuclear Experiments. Inventorying Plutonium Losses*,[11] prepared by specialists from the Russian Ministry of Atomic Energy, and a monograph on the Semipalatinsk Test Site,[12] which consolidated data from information available in archives with the results of radiation surveys and calculations of public dose rates, was especially timely. These two books, which also provided information on peaceful nuclear explosions carried out on the territory of western Kazakhstan, were of some help in the success of the UNDP mission.

Russian experts held numerous consultations on issues such as modern and maximally objective assessments of the radioecological and medical consequences of nuclear testing at the Semipalatinsk Test Site. These assessments were based on the results of research performed between 1991 and 1998, that is, after closure of the test site, by Kazakhstani and Russian specialists in the framework of the Region-1 program.[10,112]

The results of the international experts' work were discussed together with Kazakhstan's domestic experts and representatives of nongovernmental organizations (Nevada-Semipalatinsk, Test Site 29, etc.) at a workshop in Almaty June 29-30, 1998, and were also used to write a report to the UN Secretary General.[163] The report interpreted all *"the mission's observations regarding the needs of the Semipalatinsk region, and set out specific proposals for actions that could be undertaken to solve the most urgent problems."* It went on to note that a special *"conference of donor nations with the participation of UN agencies to mobilize necessary support for the actions proposed in the report"* must take place.

The main result of the UNDP mission's work on the territory of the so-called Semipalatinsk Region should be considered *"assistance to the Government of the Republic of Kazakhstan in creating an adequate mechanism of coordination for planning and carrying out future and on-going assistance."* In addition, the results of the work were used to prepare RK legislation aimed at social protection of its citizens.[164]

PART 4. ENVIRONMENTAL RADIATION SINCE CLOSURE AND PROBLEMS OF CIVILIAN USE OF THE STS GROUNDS

The radioecological inspections of the grounds of the Semipalatinsk Test Site and the territories of adjacent districts begun after its closure and continuing to this day enable us to obtain data that characterize the scope and nature of the damage inflicted on the environment and public health by the test site's operation during the period of nuclear testing.

The Institute of Radiation Safety and Ecology (*IRBiE*), created in 1993 under the RK NNC, has assumed all obligations to study and interpret data on radiation levels and to develop recommendations on the possible civilian use of the test site grounds.

Both employees of the RK NNC's constituent institutes and employees of the Kazakh SSR Ministry of Health's Institute of Radiation Medicine and Ecology (*IRMiE*), created by Kazakh SSR Cabinet of Ministers Resolution 130 of February 25, 1991 based on Clinic No. 4 in Semipalatinsk, as well as foreign specialists, have participated and continue to participate in inspections of contaminated lands.

Major Areas of Research and Results of Analysis of Information on Radiation at the Test Site

Based on the content of its scientific research, the IRBiE can be regarded as the successor to the former Semipalatinsk Test Site's Radiation Safety Service. Moreover, one of the institute's first directors was Samat K. Smagulov, the last supervisor of that service.

In accordance with IRBiE's formal mission statement, its principal fields of activity are:[170]

- investigation of radiation levels on the territory of Kazakhstan;
- development of recommendations to clean up after nuclear testing and radioactive contamination of the environment;
- radiobiological studies of the consequences of nuclear testing.

The institute's specialists perform continuous monitoring in the site's former test areas: Test Field, Delegen, Balapan, etc., as well as sequential radioecological inspections of the entire territory of the test site and its surroundings.

Before providing information on the research methods used to study environmental radiation levels during inspections of the grounds of the former Semipalatinsk Test Site after its closure, we should briefly discuss the data describing the radiation levels on the test site grounds by the time those inspections began.

We cannot deny that nuclear testing at the Semipalatinsk Test Site over a 40-year period has injected a considerable amount of radioactive ^{137}Cs and other long-lived radionuclides into the natural environment. The tests caused radioactive contamination beyond the grounds of the test site, unfortunately affecting the territories of adjacent districts as well. However, the degree of this contamination varied, and depended on the nuclear explosion type and yield and the distance from ground zero. Also, we should acknowledge that secondary effects of the contamination of the test area grounds, especially Delegen Area, are now being felt due to the accumulation of fission products produced by underground nuclear explosions and their transport to the surface by meltwater and storm water. In assessing the environmental consequences of nuclear testing, we must account for the entire amount of radioactive substances concentrated on the surface and underground.

Ground and excavating (underground) nuclear explosions made a major contribution to the radioactive contamination of the test site grounds. Thirty ground nuclear explosions were carried out in the Test Field and four excavating nuclear explosions in Balapan Test Area at the Semipalatinsk Test Site. The activation of a large quantity of earth particles, the transport of these particles by air currents, and their gradual deposition that occurred in ground nuclear explosions helped form radioactive fallout plumes. However, we should state that only four ground nuclear explosions could have caused the relatively high radioactive contamination of the territories outside the test site's exclusion zone.

Based on the results of the first inspections of the test site grounds, the unevenness of ground radioactive contamination was established. These were extensive plumes produced by air and ground explosions, or local spots varying in area and contamination level. In addition, it has been noted that the regional background within the test site is somewhat higher than the average global background on the territory of Kazakhstan.

The main radioactive plumes after nuclear explosions formed to the southeast and southwest of the Test Field, with a small plume to the northeast. The southeasterly plume (based on the 0.5 Ci/km^2 contamination level) is currently about 100 km long and 4-5 km wide, and the southwesterly plume is 80 km long and 4-5 km wide. The north-easterly plume is about 600 km^2 in area, with an average contamination density not over 0.3 Ci/km^2.[171]

The grounds of the Test Field Area have been and remain the most contaminated, at the epicenters of ground and atmospheric nuclear explosions.[171] We should note that parcels with high ground contamination levels occupy only a small part of the Test Field grounds. Thus, the territory where the ^{137}Cs contamination density is 5 Ci/km^2 and above occupies an area of 10-12 km^2, which is no more than 3% of the total area of the Test Field Area. The distribution of radioactivity within these parcels is uneven, with the density of contamination rising from the periphery to the center, where it can be 15-20 Ci/km^2 or more. At the boundaries of these areas, contamination levels can decline to 2-3 Ci/km^2, and outside the Test Field to the south and southeast within the test site grounds, they do not exceed 1-2 Ci/km^2.

The maximum density of ground contamination within the Test Field, approximately 50 Ci/km^2, has been observed on the grounds of Area P-1. Also, three spots with contamination densities of 40 Ci/km^2 were noted in Test Area P-5, and high levels of ^{137}Cs ground contamination were recorded in Areas P-3 and P-7, equal to 10 Ci/km^2 and 20 Ci/km^2, respectively. Exposure dose rates in the epicentral zones were 5-10 mR/hr.[172]

In the eastern part of the test site, near the manmade "Atom Lake," produced after the USSR's first industrial excavating nuclear explosion on January 15, 1965, the maximum density of ground contamination was 100 Ci/km^2. Within half a kilometer of this lake, the contamination density fell to within background values (0.15 Ci/km^2). In the northeastern part of the test site grounds, the density of ground contamination was only slightly above background, at 0.2-0.3 Ci/km^2.

In Balapan Test Area, where underground nuclear explosions had been detonated in shafts, 103 shafts were inspected. In the epicentral zones of most of these, the dose rate was within background values, at 12-20 μR/hr. Only in the epicentral zones of nine shafts were elevated radiation levels of 0.1-5 mR/hr noted.[8]

The areas of contaminated zones in Balapan Area were no more than 0.2 km^2. Exposure dose rates 200 meters away from the shaft entrances were at background levels.

The main cause of contamination of the epicenters of underground nuclear explosions in Balapan Area was the early escape of gaseous fission products and aerosols to the ground surface.

The following factors must be taken into account when assessing the possible consequences of underground nuclear tests in shafts:[172]

- Seismic sensing performed by the RK NNC's Institute of Geophysical Research (*IGI*) near shafts has shown that underground nuclear explosions cause rock disintegration, which increases the likelihood of migration of fission products from shafts;
- In several shafts, spontaneous combustion and burning of the shafts has occurred; several shafts have exploded many years after nuclear tests in them. It is assumed that methane is

accumulating in the shafts due to breakdown of shaly rocks passing simultaneously through the shafts and the operational Kara-Zhira Coal Field also located there. Naturally, these phenomena require more detailed study.

In the southern part of test site grounds, near Delegen Massif, was Delegen Test Area, where nuclear tests were conducted in adits. The radiation levels in this area were characterized mainly by two irregularly shaped spots, whose dimensions within the 0.4 Ci/km^2 contour line were 24 and 12 km^2. The maximum contamination density within these spots was under 2 Ci/km^2.

Inspections of Delegen Massif in 1992 recorded water leaks in 27 adits and found 24 entrance areas contaminated by radioactive substances to varying degrees. Exposure dose rates near these adits were 1-5 mR/hr. Migration of radioactive substances with water and subsequent absorption by ground and vegetation were observed. We should acknowledge that the radiation levels in Delegen Test Area have not stabilized; they are still changing somewhat. The mothballing of adits will help reduce direct leakage of radioactive water to the surface in the adit area, but the disintegration of rocks as a result of the explosions could increase the underground migration of radioactivity, so continuous monitoring of radiation levels near the adits will be needed. Additionally, aerial ground γ surveys near Delegen Massif will have to be performed after the adits are mothballed.

We must note that by the beginning of work at the test site, the Institute of Radiation Safety and Ecology (*IRBiE*) had fully studied the degree of contamination of the test site grounds by γ-emitting radionuclides, in particular, ^{137}Cs. In the early 1990s, the entire grounds of the test site, a total of 18,500 km^2, were covered by a 1:300,000 aerial ground γ survey (the survey was performed with a profile spacing of 3 km and a detector registration field width of about 300 meters). However, the results of this aerial γ survey did not give a complete picture of the degree of radioactive contamination of the test site grounds or permit certain decisions on whether to return certain parcels to commercial and agricultural use.

The automobile γ survey method (with a spacing of 500 meters) between routes and a registration field width of about 10 meters) was also used to inspect a small part of the test site grounds to the southeast and in the area of the Test Field. The length of the automobile γ survey route was

1731 km, and the total area covered was 858 km^2, or 4.6% of the total area of the test site grounds.

Ground inspections using the sampling method were performed on a very small part of the test site grounds.

Abraly District on the grounds of the Semipalatinsk Test Site has been inspected in the most detail by aerial and automobile γ survey methods, as well as sampling. However, the inspection results support only a preliminary estimate of the ^{137}Cs contamination of this area. The area of the land whose ^{137}Cs contamination is under 0.3 Ci/km^2 is about 11% of the total area of the test site grounds, while the area of the most contaminated ground, which is between 5 and 100 Ci/km^2, comprises only 0.08% of the total area of the test site grounds.[171]

Since the inspections on most of the test site grounds were not full-scale, but transitory in nature, it seems impossible to get a complete picture of the test site's real contamination.

The level of contamination of the test site grounds by β-emitting radionuclides, plutonium, and americium has been poorly studied. The results of measurements performed in 1994 during a joint expedition of Kazakhstani, American, and Russian specialists on ten control areas 180×240 meters [590×790 feet] in size, as well as data obtained by specialists from the IAEA mission, the Republic of Kazakhstan Main Directorate for Hydrology and Meteorology (now Kazgidromet State Enterprise), and the RF Radium Institute during the inspection of Abraly District, and by Japanese specialists in 1995, do not support valid conclusions regarding the level of contamination of the test site grounds by α-emitting isotopes, primarily ^{239}Pu.[172] If we consider that plutonium is also a highly toxic substance, and its maximum allowable concentrations are very small, the problem of studying its concentration and distribution in soil and other biosphere systems on the test site grounds takes on a special significance and urgency. The successful solution of this problem will require further development, improvement, and implementation of more productive, more precise, and less expensive methods of determining ^{239}Pu concentration and form in the soil on the test site grounds.

The data presented above on the radiation levels that prevailed on the grounds of the Semipalatinsk Test Site after its closure, that is, in the early 1990s, indicate that the radioecological inspection of the test site grounds will require considerable effort and financial outlays for successful completion.

We should admit that even today, many years after the end of nuclear testing, certain parts of the test site grounds cannot be used commercially, since their surface and subsurface contain large quantities of biologically hazardous substances that could potentially spread radioactive contamination to relatively clean parcels of the test site grounds and beyond through the actions of natural and anthropogenic factors. These factors, whose ability to alter the radiation levels on the test site grounds requires study, include:

- wind erosion of soil layers;
- transport of radioactivity by meltwaters, storm waters, and ground waters depending on the substances' solubility in water;
- conduct of nonnuclear experiments at the test site and other work involving disturbance of the soil and the geologic structure of the rocks and changes in the state and motions of surface and ground waters;
- nonstandard situations during operation of nuclear physics installations of the RK NNC.

Due to the small amount of materials containing information on the radiation levels on the test site grounds before it was closed, it is hard to trace the dynamics of change of those levels versus the impact of the aforementioned natural and anthropogenic factors over the period since the closure of the test site. Although even the available fragmentary information shows practically no influence of natural factors on the broad-scale migration of radionuclides on the test site grounds. This is also aided by favorable natural factors such as the silicate makeup of the rocks, the shortage of water sources, the highly seasonable climate, the low speed of ground water movements, etc.

The results of an investigation of radionuclide migration with ground water showed that this factor had practically no influence on radiation levels on the test site grounds. The hydrology of the region as a whole is favorable for containment of radioactive products. Within tectonic blocks, the ground water percolation rate is extremely low—hundredths of millimeters per day—so the minimum time required for ground water to reach the bottomlands of the Irtysh River could be some 200 years. In that time, the principal fission products ^{137}Cs and ^{90}Sr will decay practically to nothing.

However, the redistribution of radioactivity in certain parts of the test site grounds is still incomplete, as confirmed by the results of an inspection of the Delegen Massif and a study of the radioactive contamination of the manmade "Atom Lake," created by an excavating nuclear explosion.[172]

All the data presented above show that certain areas of the grounds of the former Semipalatinsk nuclear test site contain large quantities of radioactive substances (^{137}Cs content ~ 9×10^{16} Bq), so these parcels can still present a hazard to people residing on the land. Therefore, it is especially important today to zone the test site grounds by level of radiation hazard and strictly regulate people's activities in these areas. The following must be done:[172]

- total long-term condemnation of the grounds of test areas and "old" plumes with contamination levels of 0.3 Ci/km^2 or more;
- restriction of human productive activities on the remainder of the test site grounds; mandatory preliminary radioecological examination of plans to be implemented at the test site; assurance of strict radiation inspections and safe work practices;
- long-term radiation monitoring throughout the test site grounds and beyond.

Such steps, based on a detailed study of the level of radioactive contamination of natural systems, will considerably reduce the hazardousness of the test site to the public.

To complete the whole set of tasks aimed at studying the radiation levels and monitoring the test site grounds and adjacent areas, specialists from the Institute of Radiation Safety and Ecology (*IRBiE*) have done much to improve existing methodological approaches and research equipment and to develop new ones.

SCIENTIFIC METHODOLOGICAL FOUNDATIONS OF THE STUDY OF ENVIRONMENTAL RADIATION AT THE TEST SITE

During the operating life of the Semipalatinsk Test Site, state of the art scientific and methodological approaches, as well as various types of measuring equipment, were developed and used to perform research on radiation levels on its grounds. From the standpoint of hardware, we can identify three major phases in the performance of this research: the first, from 1949 to 1956, when measurements were made using instruments that mainly recorded γ-ray intensity (Geiger counters); the second, from 1957 to 1967, when the first spectrometric studies using NaI(Tl) scintillation crystals began; and the third, beginning in the early 1970s, when high-resolution semiconductor γ spectrometers began to be used. Today, the specialists from the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*), whose laboratory is equipped with the latest modern measuring and computing equipment and procedural innovations, have the ability to perform all types of radioecological studies at the very highest level. This enables them to obtain reliable results.[181]

During the work to assess the consequences of nuclear testing at the test site, employees of the Institute of Radiation Safety and Ecology developed and certified with the Republic of Kazakhstan State Standardization Committee [*Gosstandart*] over 20 methodologies to support the full cycle of radioecological research. In addition, the Semipalatinsk State Standardization Committee certified the radiological, γ spectrometric, and radiochemical research laboratories and issued appropriate certificates.[173-175]

Field and laboratory measurements were performed using modern instruments and measuring devices that underwent state calibration annually at the Republic of Kazakhstan's Alma-Ata Center for Standardization, Metrology, and Certification. It is also important to note that during analyses of various samples collected in the field, the laboratories of the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*) drew upon the experience earned over decades by laboratories in the research sections of the former Semipalatinsk Test Site, as well as the experience of foreign specialists participating in joint studies with IRBiE associates.

To determine the concentrations of individual photon-emitting radionuclides, the institute's laboratories used semiconductor detectors with high energy resolution based on multichannel pulse analyzers. Gamma spectra were processed—radionuclide content identified and quantified—using specialized programs running on personal computers. All spectrometers were calibrated to standard spectrometric γ sources for various measurement geometries. In particular, the use of spectroscopic methods permitted determination of fairly low radionuclide concentrations (4-6 Bq/kg with a total error of $\pm$20% at 95% confidence). The radiochemical research laboratory worked to determine the $^{239,240}Pu$, ^{90}Sr and T concentration with isolation of these radionuclides in a radiochemically pure state and subsequent α spectroscopy and β radiometry.

At present, field measurements are made using a mobile radiology laboratory obtained from the US based on four all-terrain vehicles complete with modern field γ spectrometers, various dosimetric equipment, and satellite navigation aids. Figure 56 shows one of the mobile laboratories.

In addition, we should note that the use of modern instruments and measuring devices in radioecological research has produced fairly reliable data on the concentrations of biologically significant radionuclides in various environmental systems.

A complete overview of the principal methods used to perform field and laboratory measurements is presented in Appendix C. Improvements in methods of collecting environmental samples and making preparations for measurements have been emphasized.

Figure 55. Mobile radiological laboratories complete with modern field γ-spectrometers, dosimetry equipment, and satellite navigation aids.

PROGRAMS FOR STUDYING ENVIRONMENTAL RADIATION SINCE CLOSURE OF THE TEST SITE, AND PRINCIPAL RESULTS OF THEIR IMPLEMENTATION

When the RK NNC developed programs for radioecological research on the test site grounds after its closure, it had to account for the features of the test site grounds. Among these were its area, which was over 18,000 km^2, the long period of nuclear testing and nuclear physical experimentation, the presence of active nuclear installations at the test site that were being used to solve various military and scientific problems, including the testing of nuclear space engines and power plants, as well as many others. However, due to incomplete information on the nature of the radiation levels, both throughout the test site grounds and in its individual test areas, the researchers actually needed to begin the radioecological inspections of the test site grounds almost from scratch. They understood that without specific, fairly extensive research, they would be unable to formulate a conclusion about either the possibility or the advisability of commercial use of the entire test site grounds or individual parts of it.

The researchers also had to consider that three research nuclear reactors are continuing to operate on the grounds of the former test site, which is currently under the administration of the RK NNC, and it also has nuclear fuel and radioactive waste storage facilities, including “Baykal-1,” a republic-level repository for spent ampule sources of ionizing radiation.[173]

The problem of the test site’s contamination by biologically hazardous plutonium radionuclides has required and still requires special attention in implementing the radioecological research program.

We should note that the results of analysis of available information on radiation levels on the test site grounds have been used to distinguish three groups of parcels according to the extent of their ground radioactive contamination, namely:

- Parcels with significant and reliably known levels of ground radioactive contamination that cannot be used commercially for a relatively long time. This category includes the actual sites of nuclear explosions in Test Field, Balapan, P-7, and other test areas, as well as the Baykal technological areas and the secure areas of the RK NNC’s facilities: Baykal-1, Area Sh, “RBSh,” and Area 5;

- Contaminated parcels whose return to commercial use will require further radioecological studies. The results obtained for certain parcels show that they will require revegetation or decontamination work. These parcels include parts of the lands of the aforementioned areas and adjacent areas contaminated by radioactive fallout during the passage of radioactive clouds during the period of ground nuclear testing;
- Parcels whose levels of radioactive contamination were slight according to preliminary data. After control inspections, these parcels can be returned to commercial use. Even so, the existence of local "spots" of ground radioactive contamination in these parcels, which includes the remainder of the test site, must also be taken into account.

We should note that rapid progress in the radioecological inspection of the test site grounds began after the Government of Kazakhstan appealed to the world community for assistance in improving the situation at the former Semipalatinsk Test Site and the IAEA, the US, Japan, and other countries provided assistance.

On **September 24, 1993,** the Governments of the RK and US signed a Joint Agreement of Intent, which formed the basis of a contract for joint work at the former Semipalatinsk Test Site by employees of the RK NNC and the US Defense Nuclear Agency.

On **November 11-14, 1993,** a team of experts from the US visited the RK to perform a preliminary assessment of the extent of the effects of nuclear arms tests at the Semipalatinsk Test Site on the environment and public health.

The US experts visited Kurchatov and Almaty, where they conducted negotiations and discussions with specialists from Kazakhstan and Russia, which led to a decision to draft a contract for joint work at the test site. In addition, the American specialists obtained permission during the visit to perform field measurements directly on the grounds of the Semipalatinsk Test Site in July 1994, so that they could report the results to the Government of the Republic of Kazakhstan in October 1994. These results were to aid the RK NNC in assessing environmental radiation levels on the grounds of the former Semipalatinsk nuclear test site in the interests of the Republic of Kazakhstan.

In **March 1994,** US experts visited the Republic of Kazakhstan and signed Contract DNA 001-94-C-0031.

In **May and June 1994,** a 1:50,000 automobile γ spectrometric survey (route spacing 500 meters) was done in five parcels of the Semipalatinsk Test Site.[180] The total area of these parcels was 858 km^2, with a total route length of 1731 km.

The results of the contract work permitted a preliminary assessment of the scale and extent of radioactive contamination of the test site grounds, determination of the qualitative and quantitative makeup of the principal contaminant radionuclides, and establishment of basic guidelines for further research.[181]

In November 1993 a team of experts from the IAEA performed an inspection of the territories of villages and towns adjacent to the Semipalatinsk Test Site, as well as individual parcels of the test site grounds.[138] The IAEA specialists drew the following main conclusions:

- In most districts, villages, and towns, the γ dose rates and levels of environmental contamination were practically indistinguishable from the global background;[173]
- At present, annual exposure doses for people living outside the test site do not exceed 0.1 mSv (0.01 rem). Actual human exposure doses from radioactive products that have fallen out since the nuclear tests at the site are considerably lower due to shielding of radiation by buildings and structures;
- There is no need for further studies to pin down the radiation levels in villages and towns, including the most contaminated town of Dolon;
- The local public's strong concern over the effect of nuclear testing on human health can be attributed entirely to the shortage of information on the relative level of radiological risk and the general distrust of representatives and leaders of various levels of government.

Thus, the IAEA mission's main conclusion was that there were no problems with radioactive contamination of the environment outside the former Semipalatinsk Test Site's exclusion zone.

The experts also drew conclusions on the status of environmental radiation levels on the test site grounds:

- There is sufficient proof that most of the former test site grounds either were slightly contaminated by radioactive substances or have no residual radioactive contamination at all from the nuclear tests. Only a small part of the test site grounds, which includes the test areas of the Test Field, the area near Lake Shagan and the areas where nuclear physics experiments were conducted, has contamination levels above background;
- The results of measurements performed in areas of the Test Field are quite sufficient to define a contamination model. In particular, they established that ground radioactive contamination is relatively localized;
- At present, villages and towns should not be created on the grounds of the Test Field or on the embankment around Lake Shagan where the effective annual dose may be as high as 140 mSv. It would be advisable to limit settlement of the most contaminated parcels of the Test Field and Lake Shagan, since annual human exposure doses in these parcels may be some 10 mSv;
- There are data on elevated levels of ground contamination in small parcels in areas where excavating nuclear explosions were detonated. These are Telkem and Sary-Uzen Areas. For this reason, limited radioecological inspections are needed to determine precise radiation levels at the locations of excavating explosions and hydronuclear experiments;
- All data on the status of radiation levels on the grounds of the former nuclear test site must be available to residents of local villages and towns.

The IAEA experts' conclusions were supported by most foreign specialists.

It is especially noteworthy that the baseline source of information on the concentration of γ-emitting radionuclides on the test site grounds remains the results of aerial γ spectrometric surveys performed in 1990 and 1991 using scintillation NaI(Tl) crystals with a total detector volume of at least 36 liters. The work procedures were governed by instructions requiring that the height of survey flights be 25-80 meters and equipment be graduated to standard models and on natural graduation areas.

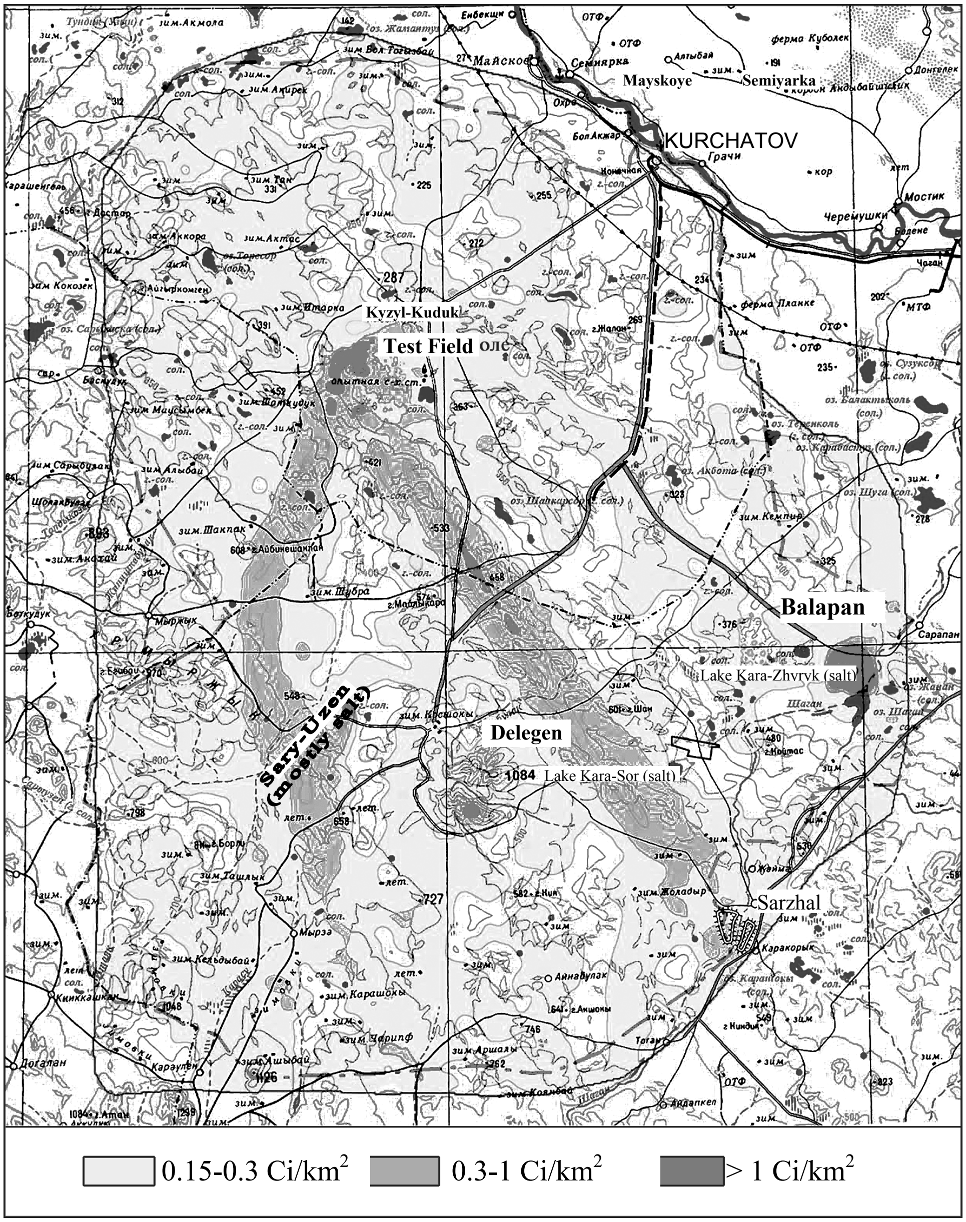


Figure 56. Map of the distribution of ^{137}Cs contamination density on the grounds of the Semipalatinsk Test Site (based on 1990-1991 aerial γ survey data).

The survey was performed at 1:300,000 scale (survey profile spacing 3 km, detector registration field width about 300 meters) throughout the test site grounds (18,500 km^2); at 1:25,000 scale (profile spacing 250 meters) in the Test Field Area (120 km^2), and at 1:10,000 scale in the eastern part of the test site (Anniversary [*Yubileyny*] Parcel, area 115 km^2).

The measurement results were processed using computer systems for data processing and mapping of the ^{137}Cs contamination of the grounds. Figure 57 gives data describing the extent of the test site grounds' contamination by this radionuclide. Analysis of these data shows that the area of radioactive plumes with ground ^{137}Cs contamination densities over 1 Ci/km^2 does not exceed 0.5% of the entire test site grounds. The density of contamination of most of the test site grounds by this biologically hazardous radionuclide is less than 0.3 Ci/km^2.

Research performed by specialists from Military Unit 52605 and the RK NNC established that the complex set of physical chemical processes in the fireball and cloud following a nuclear explosion simultaneously with the transformation of radioactive nuclear explosion products has a substantial effect on the isotopic makeup of the individual particles carrying the radioactivity. In turn, the radioactive particles determine the extent and nature of the radioactive contamination of environmental systems. The Institute of Radiation Safety and Ecology (*IRBiE*) began a study of the physical chemical properties of these particles and their solubility in solutions of various acidities, which will permit determination of the migration characteristics of selected radionuclides.

In addition, since the institute's founding in late 1993, the employees of its laboratories have been collecting samples of environmental systems on the grounds of the Test Field, Delegen, and Balapan Test Areas. The results of analysis of these samples will permit refinement of the parameters of environmental radiation levels on the test site grounds.

Thus, soil samples collected on the grounds of the Test Field Area were found to contain radionuclides produced by fission (^{137}Cs and ^{90}Sr), unreacted nuclear fuel ($^{239,240}Pu$, ^{241}Am), and radionuclides of activation origin (^{60}Co, $^{152\text{-}154}Eu$). The results of a study of the radionuclide contents of soil samples collected ground in various directions from the center of the Test Field established that the most contaminated grounds were those located in the southern and southwestern parts of the test site. These results agree satisfactorily with file data, supporting the identification of the radioactive plume from the thermonuclear explosion of August 12, 1953.[182]

Radioecological inspections of the grounds of Delegen Test Area revealed numerous zones with relatively high α and β contamination levels.

In the inspection of this area, special attention was paid to the study of adit hydrology and the determination of water radionuclide concentrations. The results support the following hypotheses:

- The disruption of the rock structure during the period of nuclear testing, as well as the ongoing formation of new fractures in the massif, have altered the direction of flow of the fracture waters. These waters are carrying radionuclides up to the surface, and will probably be involved for a long time in shaping radiation levels on the territory of the Delegen Massif;
- Adit closure work could cause water buildup, creating conditions for radionuclide escape. This process could also affect the epicentral zones of nuclear explosions and the man-made and natural fracture zones;
- The vegetation of Delegen Massif, which is dominated by motley grass, could accumulate nuclides to a much greater extent than steppe cereals.

The results of radioecological inspection of the grounds of Balapan Test Area and the shaft and missile silo sites in it indicate the mosaic nature of ground radioactive contamination, but the level of contamination does not exceed regulatory levels. The only exception is the area around the so-called "Atom Lake." Inspections of the land near Missile Silos 401 and 406 revealed areas of local contamination (up to 1 km^2) with radionuclides such as $^{152\text{-}154}Eu$ and ^{235}U.

In 1996 and 1997, employees of the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*) performed an areal inspection of the southern part of the test site grounds.[178] In an area covering some 4,500 km^2, they inspected 653 points and collected numerous samples of soil, water, and vegetation. They paid special attention to agricultural lands, pastures, haylands, plowlands, and the territories of residential settlements. The field measurements and laboratory analyses of the environmental samples produced a complete picture of radiation levels on the inspected lands, and permitted identification of the most contaminated places on the grounds of the southern part of the test site: several local spots about 3 km^2 in size.

The beginning of the radioecological inspections of the test site grounds was preceded by extensive preliminary work. Data on radioactive contamination of the test site grounds and adjacent districts were collected and analyzed, permitting better planning of measurement routes and development of sample collection techniques.

The results of the radioecological inspections support the following conclusions regarding the parameters of radiation levels in the southern part of the test site grounds:

- The exposure dose rate on the inspected grounds does not exceed the established standard of 0.33 μGy/hr;
- The surface β contamination does not exceed 55 counts per minute per cm^2, which is below the allowable 200 counts per minute per cm^2;
- The surface α contamination over most of the test site grounds is below 2 counts per minute per cm^2. At locations where this value was exceeded, a more detailed inspection of the grounds was performed to delineate the potentially hazardous zone;
- At certain points, the level of ground ^{137}Cs contamination exceeds the global fallout background, which for mid-latitudes in the northern hemisphere is 100-150 mCi/km^2;
- At several locations on the inspected grounds, the level of ground ^{90}Sr contamination also exceeds the global fallout background of 50-70 mCi/km^2;
- Most samples revealed ^{239}Pu, the most toxic radionuclide. It was found both in samples collected from radioactive plumes and outside those plumes. However, it is too soon to draw any conclusions about the level of ground contamination, because we have very little data at present on its concentration in environmental systems. Since the sample collection spacing exceeds the size of the plutonium contamination spots, a more detailed inspection of the test site grounds is needed.

As previously noted, the program of research into environmental radiation levels on the test site focused its attention on the inspection of both locations of temporary human habitation (winter camps, summer camps, farms, etc.) on its grounds and locations of permanent habitation in areas adjacent to the test site.

ENVIRONMENTAL RADIATION AT SITES OF TEMPORARY HUMAN HABITATION ON THE GROUNDS

The Kazakhstan public, even before RK President Nursultan A. Nazarbayev's decree closing the Semipalatinsk Test Site, demanded convincing proof of the accuracy of data on the level of public risk from the nuclear tests being conducted at the test site.

The emerging situation necessitated the creation of an interdepartmental commission for comprehensive inspection of the environmental conditions and public health in Semipalatinsk Region. Based on USSR First Deputy Minister of Health Gennady V. Sergeyev's Order 14 of March 5, 1989 to perform these inspections, a team of specialists from the USSR Ministry of Health, the USSR Academy of Sciences, the USSR Academy of Medicine, the USSR State Committee for Hydrology, Meteorology, and Environmental Monitoring (*Goskomgidromet*), the USSR State Committee for Nature Conservation (*Goskompriroda*), the USSR State Agroindustrial Committee (*Gosagroprom*), the USSR Ministry of Defense, the USSR Ministry of Medium Machine-Building, and the Kazakh SSR Ministry of Health was organized and sent to Semipalatinsk in May 1989. The comprehensive team of specialists (expedition), chaired by Professor Anatoly F. Tsyb, Director of the USSR Academy of Medicine's Scientific Research Institute of Medical Radiology and a Corresponding Member of the USSR Academy of Medicine,[103] had the following principal objectives:

- perform a comprehensive inspection of the health status of the population and environmental conditions on the territory of Semipalatinsk Region and subsequent discussion of the results of that inspection, involving specialists and the Kazakhstani public;
- develop proposals to improve environmental conditions and medical service to the population of Semipalatinsk Region.

During its work to assess radiation levels, the comprehensive expedition performed measurements of ground γ dose rates, as well as measurement of β and α background levels on the territories of certain villages and towns in Semipalatinsk Region. To determine radionuclide concentrations in environmental systems, it collected soil samples at measurement locations, water samples from several surface sources, and atmospheric aerosol samples along three routes outside the test site grounds.

Later, in 1990, specialists from the Unified Expedition of the Ray Scientific Production Association (*NPO Luch*) estimated $^{134,137}Cs$ levels in the bodies of residents of Zhana-Semey District, Semipalatinsk Region using an SYeG-01T human radiation spectrometer. They examined 64 people, many of whom had lived in the area since 1949. In all, the ^{137}Cs concentration was below the minimum detectable activity, that is, below 13 nCi.[165,172]

After the RK NNC created the Institute of Radiation Safety and Ecology (*IRBiE*), its specialists continued inspecting the test site grounds and several districts in Semipalatinsk Region, focusing on inspecting parcels temporarily inhabited by people on the test site grounds. Thus, IRBiE specialists inspected a large number of such parcels in the southern part of the test site grounds in 1996.

Villages, towns, and temporary human residences (winter and summer camps) on the test site grounds were identified from maps, and also confirmed with the local authorities. A total of 48 locations were inspected. At each village or town, the radius of the inspected territory was 200-250 meters. Within that radius, parameters of radiation levels were measured, soil samples were collected at five points thought to be located in the center of the temporary human residence and along bearings oriented in the direction of the four compass points, and samples of drinking water from wells were collected. In addition, a pedestrian ground γ survey was carried out in search mode. The results of inspections of 48 villages and towns are given in Table 29.[171,172]

Table 29. Results of Field and Laboratory Studies of Temporary Human Residences in the Southern Part of the Semipalatinsk Test Site

Village or Town	Particle Flux from Soil Surface, counts per minute per cm^2		Exposure Dose Rate at Specified Height above Earth's Surface, μR/hr		Concentration of Radionuclide in Soil Samples, mCi/km^2	
	α	β	3-4 cm	1 meter	^{137}Cs	^{90}Sr
Aynashulak winter camp	0.7	11	22	21	143	108
Aytzhan winter camp	1.5	16	24	21	82	68
Akzhal winter camp	1.2	11	20	18	79	34

Village or Town	Particle Flux from Soil Surface, counts per minute per cm^2		Exposure Dose Rate at Specified Height above Earth's Surface, μR/hr		Concentration of Radionuclide in Soil Samples, mCi/km^2	
	α	β	3-4 cm	1 meter	^{137}Cs	^{90}Sr
Aksay winter camp	0.5	9	24	20	155	83
Aktaban winter camp	0.9	9	24	21	115	114
Akshcheke winter camp	0.8	12	21	23	60	72
Arshaly winter camp	0.8	7	20	17	102	42.8
Arshaly 2 winter camp	0.8	5	17	17	128	118
Askarabay winter camp	0.8	10	22	20	91	54
Begalin State Farm	0.7	6	17	17	73	93
Beyseit winter camp	0.7	10	23	22	61	50
Borli	0.8	3	20	19	86	92
Dzhamilya summer camp	0.5	10	14	15	81	68
Yegeubay farm	0.8	9	22	22	122	66
Zhumakan winter camp	0.9	13	20	22	431	148
Kara-Buzhur w. camp	0.7	4	19	16	68	67
Karabulak winter camp	0.7	10	18	18	44	55
Karasu winter camp	1.4	12	22	19	65	25
Karatas winter camp	0.7	10	20	22	31	< 2.7
Kara-Shoky w. camp	0.8	6	18	18	250	209
Kara-Shoky 2 w. camp	0.8	4	18	18	94	49
Kara-Shoky 4 w. camp	0.6	3	16	16	127	63
Kasymbek winter camp	0.8	8	20	20	58	72
Keldybay winter camp	0.8	11	26	24	45	48
Kos-Ay winter camp	0.5	12	20	20	38	58
Kurman-Ali w. camp	0.8	8	18	18	70	55

Village or Town	Particle Flux from Soil Surface, counts per minute per cm^2		Exposure Dose Rate at Specified Height above Earth's Surface, μR/hr		Concentration of Radionuclide in Soil Samples, mCi/km^2	
	α	β	3-4 cm	1 meter	^{137}Cs	^{90}Sr
Kshymaramyk w. camp	0.6	7	24	23	59	38
Maramyk 1 w. camp	0.4	6	21	20	70	74
Maramyk 2 w. camp	0.4	11	24	22	69	26
Myrza summer camp	1	13	20	18	59	514
Olzhay winter camp	0.9	11	25	23	145	86
Omar	0.9	10	17	20	161	131
Ospankul winter camp	0.7	7	24	20	202	137
Samay	0.8	7	19	18	135	102
Sanky winter camp	1.1	9	18	15	82	45
Sarykamys winter camp	0.8	10	22	22	74	64
Serikpay winter camp	0.9	7	20	13	117	49
Sunkar 1 winter camp	0.9	9	19	18	77	77
Sunkar 2 winter camp	0.9	10	20	19	108	98
Taymas winter camp	0.4	6	20	19	79	49
Takybay winter camp	0.7	7	20	18	74	55
Tanbaltas winter camp	0.7	9	21	21	113	115
Tas-Baskan w. camp	1.1	10	21	20	125	55
Tetyk winter camp	1.1	13	18	22	91	52
Tleubek winter camp	0.9	12	22	19	46	46
Tolegen winter camp	0.7	11	21	20	75	32
Utebay winter camp	0.6	8	21	19	47	
Shol-Adyr winter camp	0.9	12	22	21	64	44

The data show that at locations of temporary human habitation on the test site grounds, γ dose rates ranged from 14 to 26 μR/hr, that is, below the allowable limit of 33 μR/hr set by the Radiation Safety Standards (NRB). The α and β flux density from the Earth's surface was below the detection limit. Recall that under NRB-99, the standard for indoor contamination of room surfaces by α-emitting radionuclides, if the rooms are permanently inhabited by humans, is five counts per minute per cm^2, and the standard for beta-emitting radionuclides is 2000 counts per minute per cm^2. Thus, the α- and β-particle flux from the Earth's surface on farming plots was below the established standards.

The results presented in Table 29 from soil sample analyses show that they contain fission products from nuclear explosives: the long-lived radionuclides ^{137}Cs and ^{90}Sr.

For independent reasons, no soil sample analysis was performed to determine $^{239,240}Pu$. At the same time, we should note that the γ spectrometric soil sample analysis, within the limits of the method's sensitivity, detected no ^{241}Am, which is produced by plutonium decay and can serve as an indirect measure of the latter's presence in soils. These data agree well with the results of the α radiometric survey, which did not reveal a high-intensity α particle flux from the Earth's surface.

The results of laboratory analyses of soil samples established that the density of ground surface ^{137}Cs contamination in practically all inspected parcels on the grounds was approximately equal to the global background level at mid-latitudes of the northern hemisphere. The ^{90}Sr soil contamination level ranged from 30 to about 500 mCi/km^2. A comparison of these data with the global fallout level shows that the density of ^{90}Sr soil contamination on the grounds of most inspected parcels is within the background level.

Laboratory analyses of water samples from wells on animal farms located at various points on the test site grounds showed that the concentration of manmade radionuclides did not exceed levels permitted by hygienic standards.[183] This is confirmed by the data presented in Table 30 on radionuclide concentrations in water wells and springs in villages, towns, and animal farms located in the southern part of the test site grounds.[171]

The data show that the radionuclide concentration of water is considerably lower than the health standards. For example, NRB-96 sets the allowable ^{137}Cs concentration in drinking water at 97 Bq/l. In terms of radiation parameters, the water can be considered practically pure, and its consumption for drinking and household needs presents no danger.

We should note that data characterizing the radiation levels in those locations of temporary human habitation that are in the southern part of the test site grounds fully agree with the data obtained by inspection of the villages and towns most contaminated during atmospheric nuclear testing, which are located near the boundaries of the test site's exclusion zone. The parameters of radiation levels on these lands indicate an absence of any danger to human habitation.

The inspected parcels in the southern part of the grounds of the former Semipalatinsk Test Site are safe for traditional farming operations by local livestock herders.[171]

Table 30. Relative ^{137}Cs Concentration and Total α and β Activity in Water Samples from Wells and Springs Located in the Southern Part of the Test Site

<table>
<tr><th rowspan="2">Village or Town</th><th colspan="3">Relative Radionuclide Concentration in Drinking Water, Bq/l</th></tr>
<tr><th>^{137}Cs</th><th>α Emitters</th><th>β Emitters</th></tr>
<tr><td>Samay (spring)</td><td>5 ± 3</td><td rowspan="4">< 0.5</td><td>7.7</td></tr>
<tr><td>Samay (well)</td><td>3 ± 2</td><td>2.0</td></tr>
<tr><td>Kara-Buzhur</td><td rowspan="16">< 2</td><td>< 2.0</td></tr>
<tr><td>Omar</td><td>4.2</td></tr>
<tr><td>Sarzhal</td><td>1.09</td><td>1.5</td></tr>
<tr><td>Yegeubay</td><td rowspan="10">< 0.5</td><td rowspan="11">< 2</td></tr>
<tr><td>Sarykamys</td></tr>
<tr><td>Askarabay</td></tr>
<tr><td>Aytzhan</td></tr>
<tr><td>Olzhay</td></tr>
<tr><td>Keldybay</td></tr>
<tr><td>Maramyk</td></tr>
<tr><td>Aynashulak</td></tr>
<tr><td>Beyseit</td></tr>
<tr><td>Kos-Ay</td></tr>
<tr><td>Sanky</td><td>1.2</td></tr>
<tr><td>Tetyk</td><td rowspan="2">< 0.5</td><td>4.1</td></tr>
<tr><td>Takybay</td><td>0.7</td></tr>
</table>

RESULTS OF ROUTE INSPECTION OF THE MOST CONTAMINATED SOUTHERN PART OF THE GROUNDS

We should note that the selection of the southern part of the test site grounds for studies of radiation levels was due, first of all, to the fact that this part of the condemned land had undergone the most significant radioactive contamination during ground nuclear tests in the site's Test Field from 1949 to 1956 and the underground excavating nuclear explosion to create the manmade lake in 1965. Second, state agencies, the general public, and the public and business community of the Republic of Kazakhstan are showing the greatest interest in this part of the test site grounds due to the prospects for commercial use of its underground minerals. In particular, the radiation safety of coal mining in Kara-Zhira Field, located near the area where underground shaft tests were conducted, must be assured. There are also ideas of putting other areas in this part of the test site grounds into commercial production.

The current radiation levels in the southern part of the test site grounds arose mainly after ground nuclear explosions in the Test Field, during which the high-temperature fireball contacted the surface of the Earth, activating a huge number of soil particles. These particles, lifted upward, were transported by air currents, and gradually fell out onto the ground to produce a plume of radioactive contamination that can be described in three levels for convenience: heavy, moderate, and light contamination. The criterion for classifying the radioactive plume as one or another contamination level is the ground γ-ray dose.

Heavy ground radioactive contamination on the test site grounds occurred mainly after four ground explosions, detonated at the test site August 29, 1949, September 24, 1951, August 12, 1953 and August 24, 1956; moderate contamination followed the explosions of October 5, 1954, October 30, 1954, September 21, 1955 and August 7, 1962; and the remaining ground explosions produced light radioactive contamination.[184]

In 1997 and later years, employees of the Institute of Radiation Safety and Ecology (*IRBiE*) performed studies to assess environmental radiation levels in the area around the Test Field Area. This work involved a comprehensive inspection of the area's grounds, with collection of environmental samples and subsequent laboratory analysis to determine their concentrations of the most significant manmade radionuclides.

The inspection routes began near ground zero for the ground explosions (Area P-1), and diverged along the major dose-forming plumes. In developing the routes, the researchers accounted for the contributions of radioactive substances to the local contamination of environmental systems. We should note that the ground explosions made a larger contribution to the local ground contamination than did the atmospheric explosions.

Before these studies were begun, information on the level of radioactive contamination of the Test Field Area was limited to a few data on the contamination of its grounds by radionuclides such as ^{137}Cs and ^{90}Sr.

From 1994 through 1999, 701 soil samples and 510 vegetation samples were collected and analyzed during ground inspections of radioactive plumes from ground nuclear explosions. In addition, field measurements of radiation levels such as exposure dose rates and α- and β-particle fluxes from soil were performed at the soil sample locations.

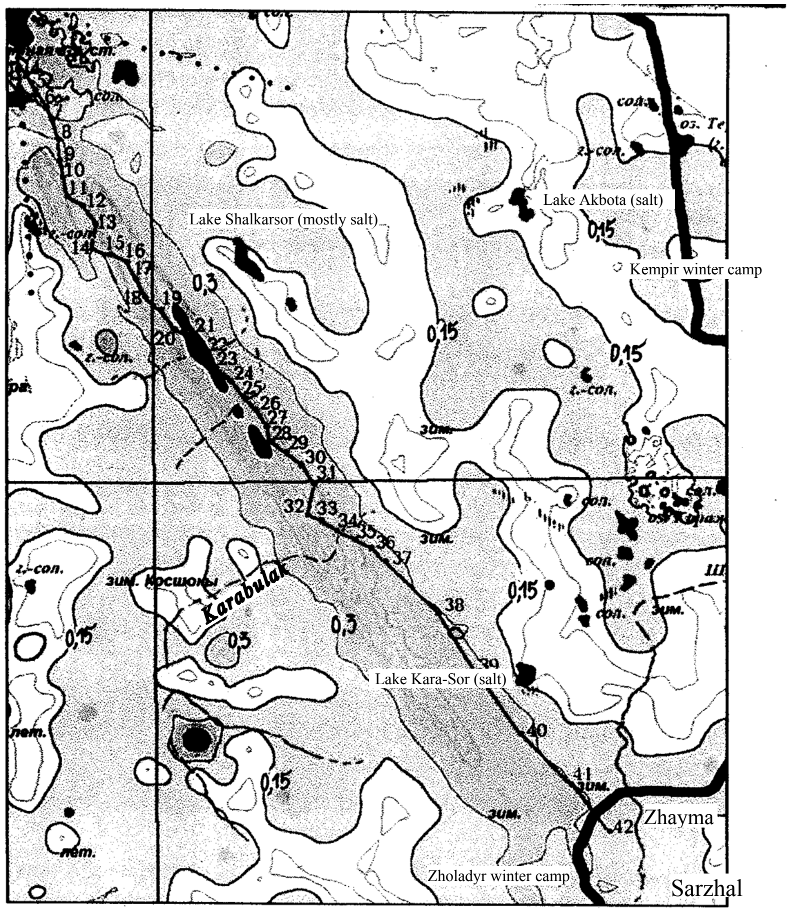
Inspections of the southern part of the test site grounds were conducted in various directions from the Test Field Area.

The Southeasterly Direction

The route used to inspect the southern part of the test site grounds to the southeast passed close to the axis of the plume produced by the August 12, 1951 test of the first thermonuclear physics package with a yield equivalent to 400 kilotons of TNT.

The inspection of the southern part of the test site grounds to the southeast is diagrammed in Figure 58. In this direction, the highest levels of ground contamination within the former Semipalatinsk Test Site were observed. The plume with ground contamination levels from 0.15 to 1 Ci/km^2 is over 120 km long within the test site, and part of the plume goes beyond its boundaries. Figure 57 also shows the isolines of ^{137}Cs ground contamination density. The ground inspection was performed along the plume axis, following profiles various distances from ground zero (Test Area P1). This inspection was 120 km long. Within 70 km of ground zero, the profiles were spaced 2 km apart; beyond that range, they were 10 km apart.

The studies showed that the soil samples contained the following radionuclides: ^{137}Cs, ^{90}Sr, $^{239,240}Pu$, ^{241}Am and ^{152}Eu. The concentrations of fission products such as ^{137}Cs and ^{90}Sr were 0.06-1.26 Ci/km^2 and 0.05-



< 0.15 Ci/km^2 0.15-0.3 Ci/km^2 0.3-1 Ci/km^2 > 1 Ci/km^2

Figure 57. Map of ^{137}Cs ground contamination density contour lines.

1.12 Ci/km^2, respectively, and those of unreacted nuclear fuel (^{239,240}Pu) ranged from 0.05 to 5.62 Ci/km^2.[171] At certain points, radionuclides with induced activity such as ^{152}Eu were detected.

Figure 59 plots the laboratory analysis of soil samples collected in the ground in the southeasterly direction as the radionuclide concentration versus distance to ground zero.

The experimental data were used to calculate the ratio of ^{137}Cs to ^{90}Sr, which was 1.7-1.9 over most of the southeasterly plume, which roughly matches the ratio in global fallout.

With time, the radionuclides that fell out after ground and atmospheric explosions have migrated deep into the soil, forming a layer of radioactively contaminated soil over a relatively wide area of land by now. Analysis of samples of this soil has shown that most of the radionuclides are concentrated in the top 10 centimeters.

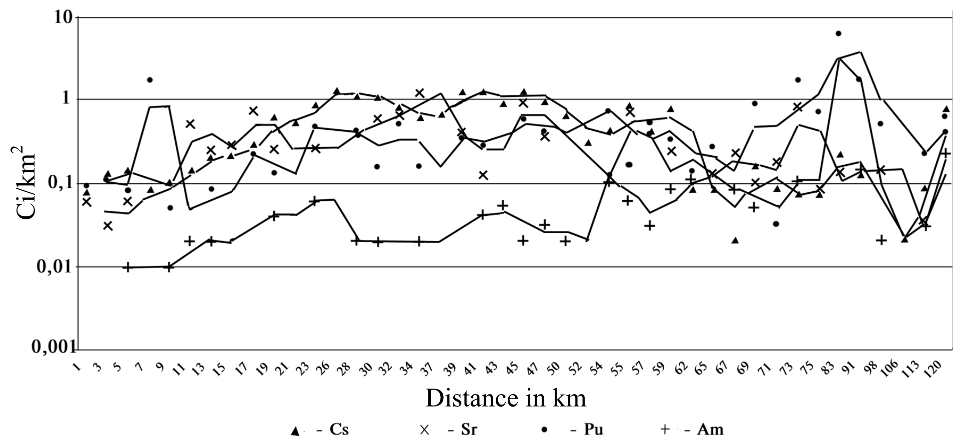


Figure 58. Distribution of ground contamination densities
for various radionuclides along the axis of the southeasterly plume.

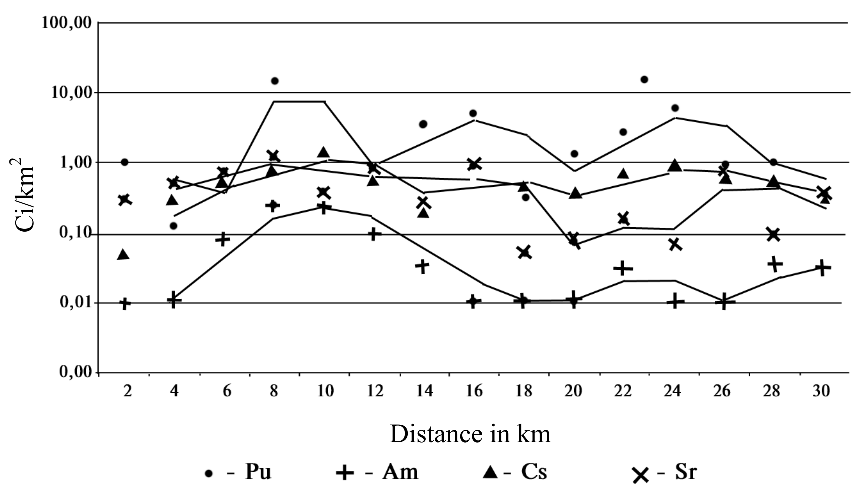


Figure 59. Distribution of ground contamination densities
for various radionuclides along the axis of the southwesterly plume.

The Southwesterly Direction

The route used to inspect the southwesterly direction follows the axis of the plume produced by the September 24, 1951 ground test of a physics package with a yield equivalent to 38 kilotons of TNT. The plume from that explosion was one of the main dose-producing plumes on the test site grounds. The inspection of radiation levels was performed along its axis on four profiles at various distances from ground zero. The route was 30 km long.

During the inspection of the grounds to the southwest, the field measurements of parameters of the radiation levels were supplemented by collection of soil samples for later laboratory analysis. Using γ spectrometric and radiochemical study methods, researchers determined the radionuclide makeup of 20 soil samples.

The laboratory analyses of the soil samples, which are plotted in Figure 60, indicated that the soil contained fission products (^{137}Cs, ^{90}Sr), induced-activity products ($^{152,154}Eu$), and unreacted nuclear fuel products ($^{239,240}Pu$ and ^{241}Am). The radionuclide concentrations varied over wide ranges: ^{137}Cs from 0.05 to 1.31 Ci/km^2; ^{90}Sr from 0.05 to 1.17 Ci/km^2; $^{239,240}Pu$ from 0.13 to 14.5 Ci/km^2; and ^{241}Am from 0.05 to 0.24 Ci/km^2.

The greatest ground concentrations in the soil in this direction was observed at a point 10 km from ground zero for ^{137}Cs, and at a point 8 km from ground zero for ^{90}Sr and $^{239,240}Pu$. Later analysis showed results similar to those for the southeasterly direction.

Figure 60 clearly shows the general pattern of distribution of all radionuclides along the southwesterly plume, which is that the greatest ground contamination densities were 8-10 from ground zero for the explosion of September 24, 1951. A comparison of the graphs in Figures 59 and 60, which portray the distribution of radioactive substances on the ground to the southwest and southeast, shows that the southeasterly plume, produced by the first thermonuclear explosion, is more complex.

We should note that reconstructing, and even estimating, radiation parameters on “old plumes” is very difficult, since the very same grounds were contaminated by radioactive fallout after several tests and at various times. Moreover, global radioactive fallout, products of the accident at Chernobyl Nuclear Power Plant, and so forth also fell on these grounds. Therefore the radiation parameters can be assessed only by making a whole series of various assumptions.

Naturally, the data presented are far from exhaustive information on the nature of the ground contamination on the "old" plumes produced on the grounds of the southern part of the test site to the southeast and southwest. However, these data are quite sufficient for a radioecological characterization of the parcels with the highest contamination levels on the test site grounds. These characterizations will enable an assessment of the level of radiation hazard of lands before they are returned to commercial use.

The Southerly Direction

Between the southeasterly and southwesterly directions, environmental radiation levels were studied on lands located to the south. Near the Test Field, the route passed over the territories of the main radioactive plumes, which are located in the two directions discussed above.

The results of the inspection of grounds to the south were similar to those obtained by the inspection of radioactive plumes to the southeast and southwest. The maximum density of ground contamination was also located at a distance of 8-12 from the center of the test area.

All data on radiation levels obtained by inspections in various directions in the southern part of the test site grounds are of great scientific and practical importance for the economy of Kazakhstan, since promising deposits of various minerals have been discovered on these grounds and further geologic exploration is underway.

Results of "Areal" Inspection of the Southern Part of the Grounds

In 1996 and 1997, some 4,500 km^2 of the southern test site grounds was inspected. The inspection was preceded by much preliminary work. For example, information was analyzed from studies performed in various years by specialists from various departments. The results of this analysis were used to prepare a valid inspection program. The sizes of the inspection grids, that is, the spacings of radiation parameter measurement points on the ground, varied from parcel to parcel and depended on the volume of information available on radiation levels in the specific parcel and its commercial value.

On the grounds of the southern part of the test site, measurements of radiation parameters by the methods described above were made at 701 points. The environmental samples collected at these points were analyzed

Table 31. ^{137}Cs Measurement Results by Type of Survey and Laboratory Study

Sampling Area	^{137}Cs Activity, Ci/km^2					
	By Survey Type from 1990 to 1994			Mean Based on Sampling Results		
	Auto-mobile γ Survey	1:25,000 Aerial Survey	1:200,000 Aerial Survey	Lab Analyses	Field Measure-ments	Lab Analyses & Semicon-ductor Detector Field Measure-ments
Area 1			0.2 (23%)	0.24	0.28	0.26
Area 2	0.35*	0.3 (15%)	0.4 (5%)	0.38	0.46	0.42
Area 3	0.8 (49%)	0.5 (19%)	1.5 (5%)	1.44	1.7	1.57
Area 4	1 (17%)	2 (27%)	2.5 (107%)	0.66	1.76	1.21
Area 5	0.6 (20%)	2.5 (107%)	1.5 (100%)	0.65	0.85	0.75
Area 6	0.4 (14%)		0.4 (14%)	0.27	0.43	0.35
Area 7	1.1 (32%)		2 (23%)	1.44	1.8	1.62
Area 8			7	18.2	1.7	17.6
Area 9			0.3 (150%)	0.14	0.11	0.12
Area 10			0.1 (11%)		0.09	0.09

Notes:

1. Parentheses enclose the difference between measurement results (from aerial and automobile surveys) from the mean results from laboratory analyses and field measurements by semiconductor detector.
2. *—By calibration.
3. Areas 1-4 are located in the Test Field, Area 5 is in the plume from the ground test of September 24, 1951, Areas 6 and 7 are in the plume from the ground test of August 12, 1953, Areas 8 and 7 are near “Atom Lake,” and Area 10 is on the laboratory grounds of Kurchatov.

in the laboratory: 701 samples for γ-emitting radionuclides, 584 samples for ^{90}Sr concentration, and 44 samples for $^{239,240}Pu$ concentration.[171]

The data obtained using the various study methods and the results of their comparison gave a picture of the scale and level of radioactive contamination of the environmental systems.

The following information was used for a comparative assessment of the ^{137}Cs measurements by various methods:

- data from laboratory analyses and measurements by field semiconductor detectors over the inspection areas;
- results of automobile survey measurements, presented as isolines on maps, computer files, and digital arrays of ^{137}Cs values over survey areas;
- maps of isolines from aerial surveys (based on data from a 1:300,000 aerial survey) at 1:200,000 scale over the entire test site grounds and at 1:25,000 scale over the Test Field Area;
- map of isolines and array of digital data from 1:10,000 aerial survey in Anniversary Area.

Table 31 presents the results of determination of ^{137}Cs concentration by various methods in 10 areas. The table takes the results of measurements by remote methods in each area from maps of isolines of the surveys corresponding to the scales. It presents the test results as averages over each area, and separates data from laboratory analyses of mixed samples and measurements by semiconductor detectors at sampling points, as well as their aggregate measures.

Figure 61 shows the distribution of the density of ^{137}Cs surface contamination on the southern part of the former test site grounds, and Figure 62 shows that of ^{90}Sr.[171] Analysis of the data presented in Table 31 and Figure 61 shows that the results obtained both by the sampling method and by field detector measurement agree well for all areas but Area 4. The reason for the significant discrepancy is probably due to the highly irregular distribution of ^{137}Cs in Area 4, since soil samples with a total area of about 1000 cm^2 cannot be representative of an area of some 1000 m^2 integrated by a field detector. The agreement between the results of measurements of the same sample's ^{137}Cs concentration in various laboratories is within 10-15%.

The discrepancy between the automobile γ survey results and the ^{137}Cs measurement data from ground inspections in areas with concentrations of that radionuclide below 0.6 Ci/km^2 does not exceed 25% on average.

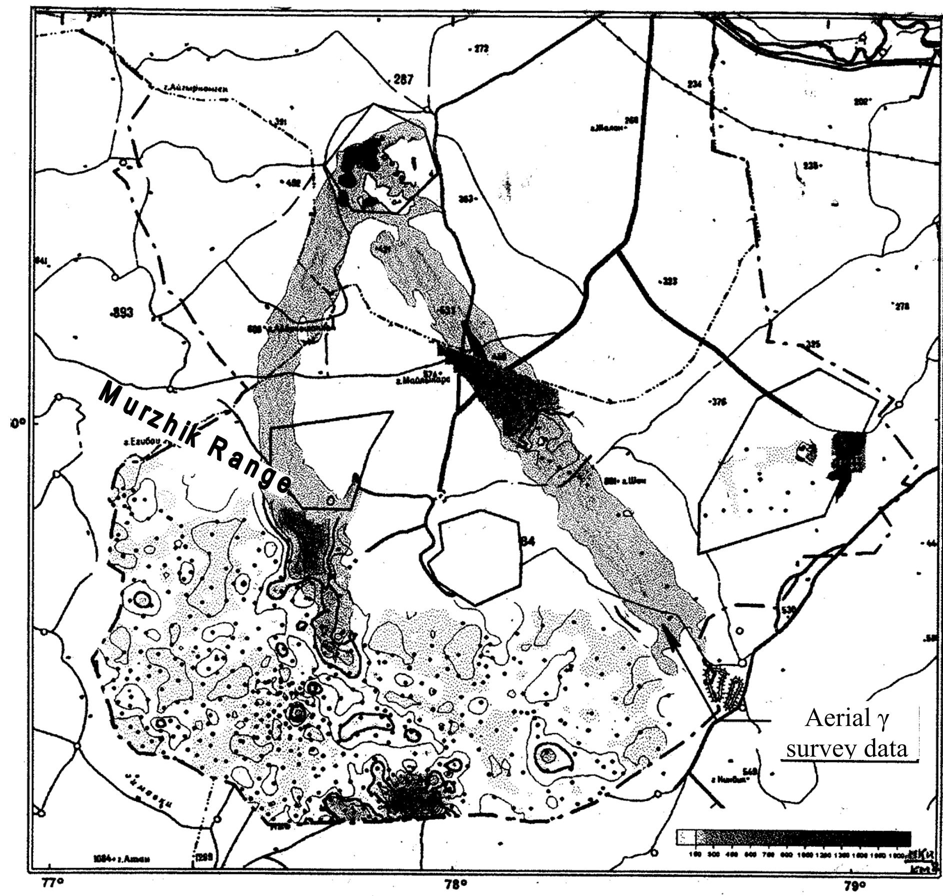


Figure 60. ^{137}Cs surface contamination density distribution in the southern part of the grounds of the former Semipalatinsk Test Site (as of January 1, 2000).

Moreover, the readings of automobile γ survey measurements of ^{137}Cs tended to be lower than the data of sampling areas in contrasting (anomalous) fields with cesium contamination levels above 0.6 Ci/km^2. We should also note that when the automobile γ survey data were processed, the measurements were normed to an area 500×200 meters in size, which is larger than the sampling areas.

For a 1:25,000 aerial survey containing only four sampling areas, we can give only a tentative description of the skewing of the measurement results, with a tendency to read up to 30% high compared to Areas 1, 2, and 3. Within the 1:10,000 areal survey, there were no ground sampling

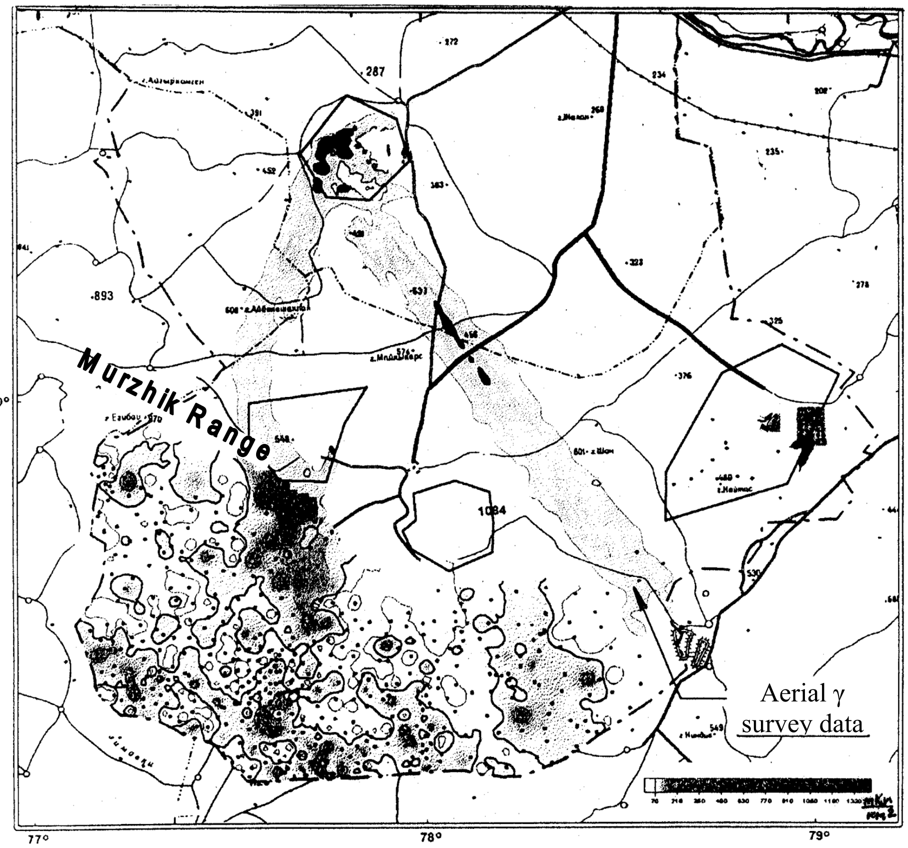


Figure 61. ^{90}Sr surface contamination density distribution in the southern part of the grounds of the former Semipalatinsk Test Site (as of January 1, 2000).

areas, and the ^{137}Cs background measurement corresponded to fine-scale (1:300,000) aerial survey measurements.

Thus, a comparison of the results of ^{137}Cs measurements by aerial and automobile γ spectrometric surveys with sampling area data shows that the measurements in weakly contrasting fields with low background levels of ^{137}Cs contamination are comparable within 30% by all methods.

When comparing the summary map of the surface ^{137}Cs contamination of the test site grounds, the results of aerial γ surveys and automobile γ spectrometry and their tentative characteristics obtained by comparison with sampling areas should be used.

Available experimental data on the soil concentrations of plutonium and strontium on the test site grounds are very limited and do not permit reliable conclusions on its areal contamination. Since no studies have been done to determine contamination of the epicenters and simulated test zones, that is, the zones where underground tests without nuclear energy release were conducted, we can suppose that the highest levels of soil contamination by these radionuclides could be in the epicentral zones of the ground nuclear explosions, and the highest levels of soil contamination by plutonium could be in the simulated test zones. Thus, Area P-2G (the Test Field) could have total dispersed plutonium activity of 800-900 Ci. The total area of the test site grounds with plutonium contamination exceeding 0.1 $\mu Ci/m^2$ could be about 440 km^2. Areas P-2 and P-7 could contain some 1000 Ci of dispersed plutonium.

Evidently, it would be desirable to perform a second determination of plutonium and strontium since 1994 in Areas 1-8, which will permit, albeit in the future, an assessment of the dynamics of ground contamination by these radionuclides. The labor intensity of radiochemical studies creates well-known difficulties from the standpoint of inspection of large areas. This will require a search for methods that make such studies possible.

BALAPAN TEST AREA AND KARA-ZHIRA COAL FIELD

Balapan Test Area is characterized by the largest volume of testing and research performed at the former Semipalatinsk Test Site. This area was designed primarily for nuclear weapons tests with maximum threshold yields under 150 kilotons in shafts (vertical mine workings). It was also the site of a large volume of work using both nuclear and chemical explosions aimed at solving a series of applied military problems in mechanics, combustion physics, earthquake modeling and measurement of the earthquake resistance of buildings and special defense structures, development of methods of killing gas blowouts, etc.

Kara-Zhira Coal Field is located near Balapan Test Area. In addition, the Baykal-1 reactor test facility, where the IVG-1 and RA nuclear rocket motor prototypes were fired, was 15 km south of the field. The operation of these reactors as designed entailed the exhaust of heat transfer medium (coolant) into the atmosphere.

Naturally, the assessment of environmental radiation levels in the areas of Balapan Test Area and Kara-Zhira Coal Field is important to the local residents, to personnel working in the coal mine, and to consumers of the coal produced.

Balapan Test Area

Figure 62. Exterior view of a shaft ready for an underground nuclear test.

The first nuclear explosion in Balapan Area was on January 15, 1965, in Shaft 1004 near the confluence of the Shagan and Ashchi-Su Rivers. It was the former Soviet Union's first industrial nuclear explosion, carried out to create the manmade Lake Shagan in an arid part of Kazakhstan (or, as it was popularly called, "Atom Lake"[5]).

From 1965 to 1989, 108 underground nuclear tests in which 167 nuclear explosive devices were detonated were carried out in Balapan Area. The largest numbers of tests (10 per year) were conducted in 1979 and 1984.[35] A maximum of no more than three nuclear explosive devices were detonated in shafts per test.

The closure of the test site in Balapan Area left 13 shafts up to 500-600 meters deep ready for tests.[185] Figure 63 shows the exterior of one of these shafts.

Usually, the physics package to be tested was lowered to the bottom of the shaft on a special running string[6] consisting of pipes of various diameter. At the same time, an instrument hanger was run into the shaft, carrying sensors to measure the explosion parameters. These sensors were connected to recording equipment by cable lines. Monitoring and measuring equipment was located on the surface in mobile rigs at a safe distance from the vertical emplacement hole.

After the physics package had been run, the shaft was stemmed for its entire height. The design of the stemming system consisted of a

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[5]—Russian *Atomnoye ozero*, Kazakh *Atomkul*.—*Trans.*

[6]—The term is borrowed from the oil industry. Russian also uses the oilfield term *skvazhina*, 'well, hole' to refer to the vertical shaft. Readers familiar with oil drilling will recognize other similarities.—*Trans.*

combination of strong and technological components: cement plugs and sections of rubble fill.

Figure 64 diagrams the locations of shafts and other facilities in Balapan Test Area. It shows that the field seismic complex, whose grounds contained 12 intercontinental ballistic missile launch silos, was approximately in the center of this area. Figure 65 diagrams the arrangement of the missile silos. In the northwestern part of the area was

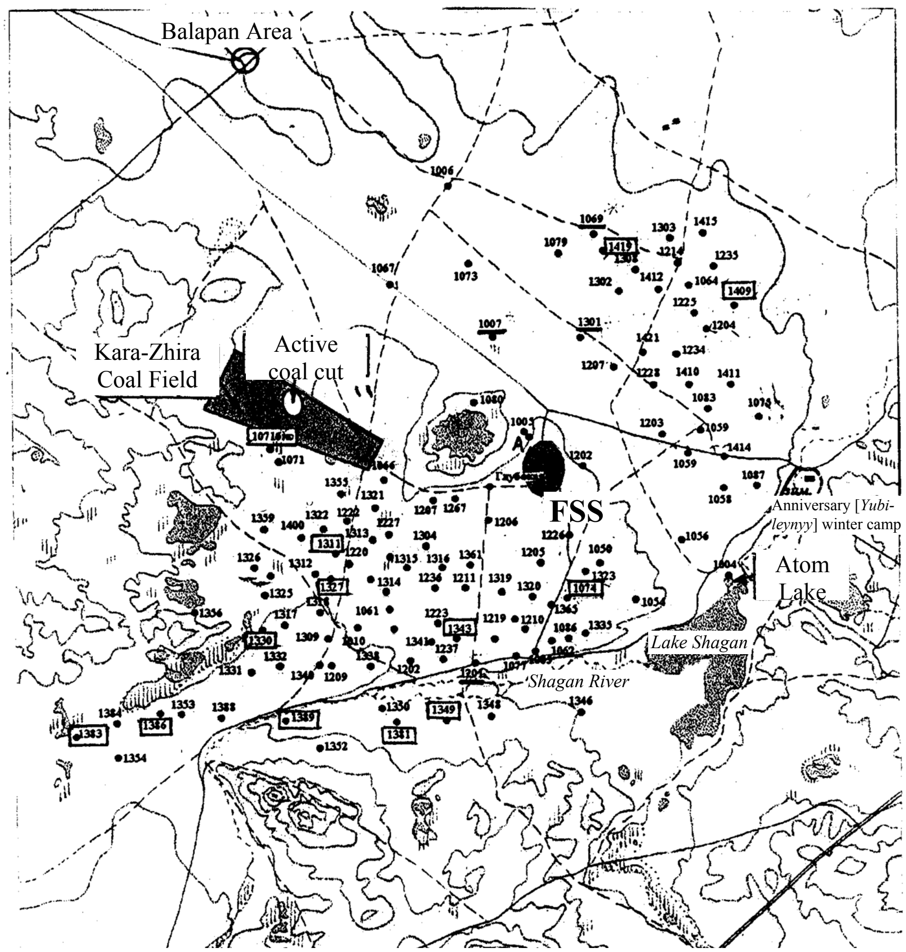

Figure 63. Map of the locations of shafts and other facilities in Balapan Test Area. Underlined—four shafts in which nonstandard radiation situations arose during testing. Framed—13 unused shafts. FSS—Field Seismic Station, whose grounds contained 12 missile launch silos.

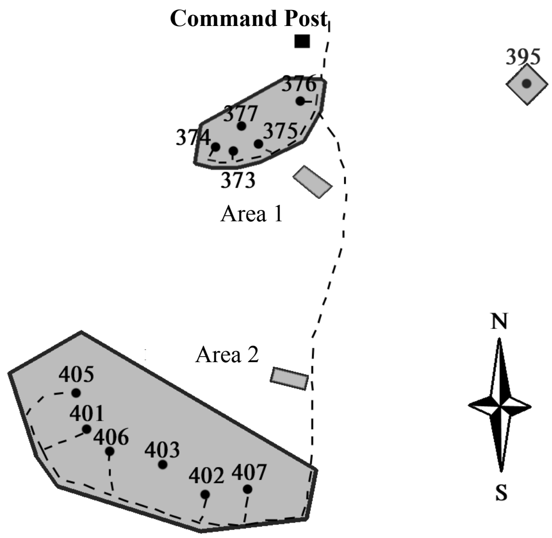

Figure 64. Diagram of the launch silo arrangement.

Kara-Zhira Coal Field, with today's operational surface coal mine. In the southeastern part of the area, nearly at the boundary of the test site, was manmade reservoir Lake Shagan, which consisted of an inner reservoir (in the explosion crater) and an outer one.

In 1996, specialists from the RK NNC's Institute of Radiation Safety and Ecology (*IRBiE*) began inspecting shafts and other facilities located in Balapan Area, to make decisions on their closure.

Inspection of 103 shafts revealed parcels on which exposure dose rates were 0.1-8 mR/hr, and the areas of the contaminated zones did not exceed 0.2 km^2. The main cause of contamination of these parcels was the early escape of nuclear explosion products to the surface.

During shaft testing in Balapan Area, there were four instances of nonstandard radiation situations (incidents). These occurred in Shafts 1007, 1204, 1069 and 1301, after tests involving substantial radioactive contamination of the surface near the opening.

The most significant ground contamination resulting from rapid dynamic leakage of gaseous products in the epicentral zone, including their combustion, occurred after the explosion in Shaft 1301.[12] Soon after the accident, ground radiation levels surpassed 10 R/hr. A 1999 inspection of Shaft 1301 established that radiation levels were between 0.02 and 0.9 mR/hr. The length of the radioactive plume with an exposure dose rate of 33 μR/hr was approximately 1 km, as indicated by the data in Figure 66.

The explosion in Shaft 1069 ejected the entire stemming system, including casing pipe 900-1200 mm in diameter. The parameters of the radiation levels were the same as after the nonstandard situation produced by the explosion in Shaft 1301.

Because the depths of test shafts were generally over 500 meters, we can assume that if there were any failures in the system used to isolate the nuclear explosion cavities from the environment, products could escape into the ground water. Inspection of shafts in which nuclear explosions were not conducted revealed a tritium concentration in the water of Shaft 1419 exceeding 1000 kBq/l. This supports the supposition that some cavities produced by nuclear explosions are in communication with the ground water, and radionuclides have migrated from these cavities for considerable distances (over 1 km).

In all the epicentral zones of 13 unused shafts, radiometric field measurements of exposure dose rate, density of surface α and β-emitter contamination were performed and soil and water samples were collected. Laboratory analyses of the samples were used to determine the radionuclide makeup of the soil and water contamination. For example, radiochemical analysis revealed tritium and ^{90}Sr in eight water samples.

Field radiometry, as well as γ spectrometric and radiochemical analysis of soil and water samples collected near shaft openings indicated no radioactive contamination of the ground and water at the inspected points. The exception was Shaft 1419, where the water was found to contain tritium.

In 1998, a radioecological inspection was performed on bodies of water and shore vegetation in the most contaminated part of Balapan Area, near Lake Shagan (“Atom Lake”). The results of this inspection are described below.

Inspection of Kara-Zhira Commercial Coal Field

The radiation levels in the area of Kara-Zhira Coal Field were due to the field’s location on the grounds of the former Semipalatinsk Test Site, specifically, in the “neighborhood” of the Balapan Test Area, where about a third of all underground nuclear explosions at the test site were conducted, and to the Baykal-1 reactor test facility, whose operation as designed entailed the release of heat-transfer medium (coolant) into the atmosphere. Although we must note that the small number of fissions in the cores of these reactors (compared to nuclear explosions) could not produce a noticeable long-term contamination of the grounds. The present reactor operating program rules out the possibility of direct release of radioactive products into the atmosphere.

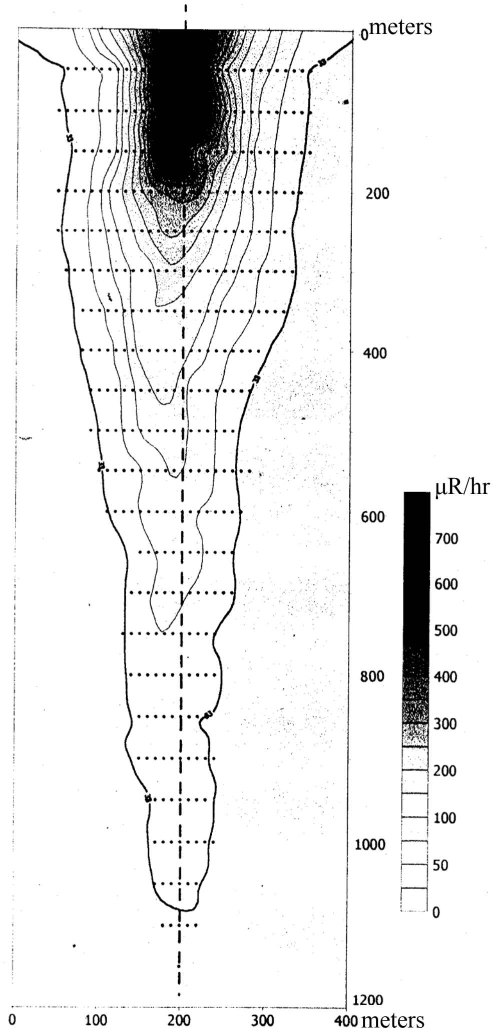

Figure 65. Radiation levels on the plume of radioactive contamination after a nonstandard radiation situation occurred when an explosion was detonated in Shaft 1301 (as of 1999).

The field of shafts in which nuclear explosions were detonated could present a potential hazard to workers in the field, but even the closest of them is beyond the boundary of the coal-bearing structure (cf. Figure 64).

Inspections of environmental radiation levels in the pit indicate that the values of radiation parameters that can affect the health of personnel do not exceed allowable levels set by Republic of Kazakhstan radiation safety standards.

However, many types of crude minerals, including coal, naturally contain elevated concentrations of natural radionuclides from the uranium and thorium families. So during the mining of raw materials with elevated natural radioactivity, personnel may be exposed through inhalation of radionuclides with the production dust, external γ-rays, swallowing of dust particles, and inhalation of radon (thoron) with its daughter decay products.

Usually, the assessment of the level of inhaled uptake of radionuclides into the bodies of personnel with production dust is made by the annual radionuclide uptake and the maximum annual average dust content, which are compared to the annual uptake limit (*PGP*) and the concentration of dust in the workplace air. Since the workers at the Kara-Zhira Experimental Mine are not classified as working with manmade sources or exposed to their effects in the course of their work, the annual uptake limit for them is taken as equal to the values for the general public: 130 Bq/yr for uranium compounds and 24 Bq/yr for thorium compounds.

Specialists from the Institute of Radiation Safety and Ecology (*IRBiE*), as part of the tasks set by the program of inspections of contaminated lands, performed additional studies in the workplace at Kara-Zhira Coal Field, specifically:

- determination of specific activities of dust-producing products;
- measurement of radiation parameters;
- determination of yearly average dust content of workplace air;
- assessment of the radiation-safety significance of the natural radioactive background by the annual uptake and average annual dust concentration limit corresponding to the annual uptake limit.

The collection of dust samples from workplace air was performed using RAMON-01 and EPRAM devices.

In order to increase the information value of dust monitoring data and use them for hygienic assessment of the efficacy of introducing dust-suppression measures, and also to analyze measures of worker morbidity, air dust content was defined both by peak one-time and monthly average concentrations. The time required to collect samples for concentration data was 30 minutes. Operational data on monthly average dust concentrations were the results of analyses of five one-time samples collected during the most typical work operations over five shifts. To determine the dust content of air entering the mine, measurements were made 10 meters from the pit rim on the windward side.

The dust-radiation factor was assessed pursuant to Radiation Safety Standard NRB-96 and the methodological recommendations *Assessment of the Dust-Radiation Factor in Beneficiation of Non-Uranium Crude Minerals* (Kazakh SSR Ministry of Health, Alma-Ata, 1987) insofar as it did not contradict the standard.

Comparison of the data with the standards showed that even at the maximum dust content recorded in one of the workplaces and the resulting specific activity of the dust-forming products (rock and coal), these data were well within the standards. This in turn indicated that as a whole, the existing level of specific activity of production dust in workplaces of the pilot-production mine did not present a hazard to personnel attending mine haulage equipment in the coal mine. The exposure dose rate at work places and on the grounds of the work area is within the background range and does not exceed 20 μR/hr.

Based on the results of this work, we can conclude that the radiation-safety significance of the dust factor in the workplaces of personnel attending mine haulage equipment in the coal mine does not exceed standard values. However, elevated dust levels were observed on roads along which the coal and spoil was hauled from the mine, especially in calm weather. To reduce dust formation, the roads must be sprinkled more often; moreover, mine water can be used for the purpose.

DEGELEN TEST AREA

According to available data,[12,35] 307 nuclear explosive devices with TNT equivalent yields of up to 50 kilotons were detonated from 1961 through 1989 for military and peaceful purposes in some 200 adits in the Delegen Massif. In several adits, as in the shafts, not only were single explosions conducted, but also group tests involving the detonation of several physics packages. For example, five nuclear explosive devices were detonated nearly simultaneously in Adit 104 on July 27, 1978. A fairly large number of nuclear tests in adits in Delegen Massif involved the simultaneous detonation of three physics packages. In some cases, group nuclear tests were conducted using several mine workings. Several adits were used more than once. Figure 67 diagrams the locations of adits in Delegen Test Area.

We should note that the scale of radioactive contamination of the ground and various environmental systems within this test area is considerably less than in the Test Field, since most of the induced radioactivity in underground nuclear explosions remained in the resulting cavities. After nuclear explosions deep in the massif, there was practically no ground radioactive contamination outside the condemned test site grounds.

However, in certain cases of nuclear explosions in adits, nonstandard radiation situations arose where, for a number of reasons, the explosion was followed by early and often pressurized leakage of vapor-gas mixtures of radioactive products into the atmosphere. In Delegen Test Area, such situations occurred from 1964 through 1980 after six tests in Adits A-8Sh, A-6Sh, 11P, 810, 608P and 204PP. Accidental releases after explosions in these adits caused substantial ground radioactive contamination, either in

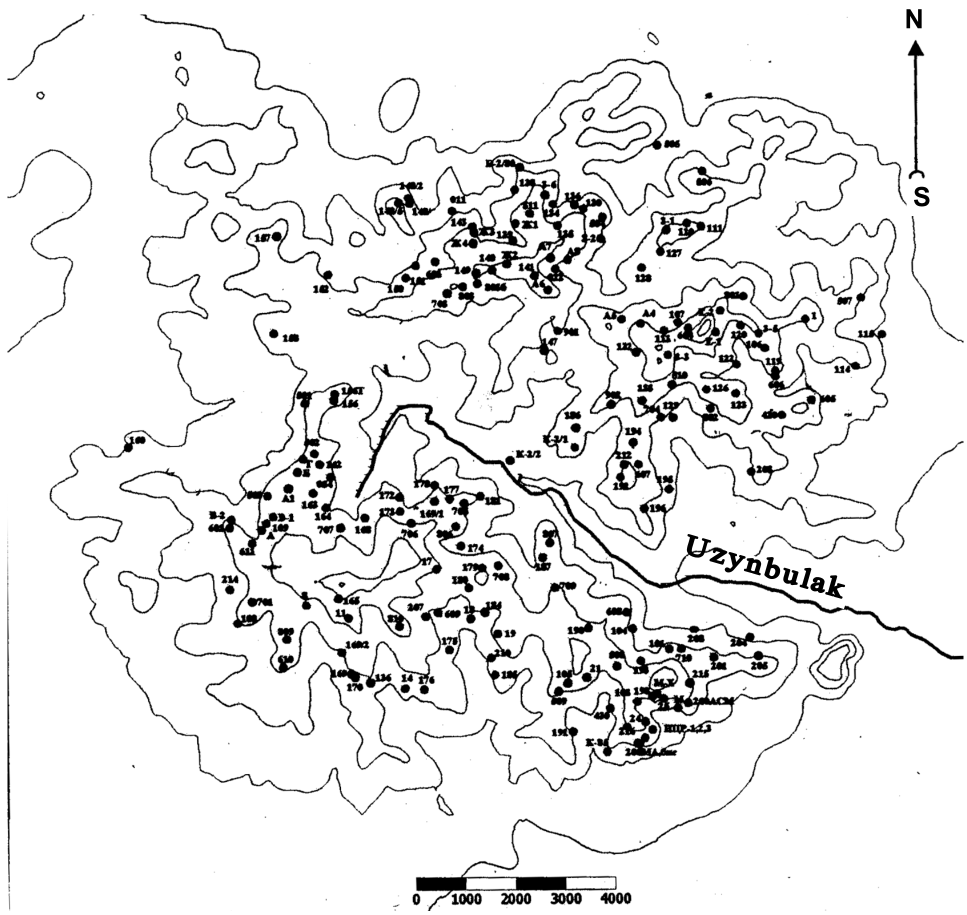

Figure 66. Map of the locations of adits in Delegen Massif
(dots mark end chambers for physics packages).

the area around the entrance, or in the epicentral zone, where the explosion products escaped.

Even though relatively low-yield explosions were detonated in Delegen Area, the rock structure was severely damaged. Manmade rock caving often occurred from rock slopes 300-500 meters high right up to adit entrances. Significant changes underground in the massif also resulted from destruction of the domes of mine workings and the formation of cavities that could be hundreds of meters long.

The hydrology was especially important in shaping radiation levels on the territory of the Delegen Massif, since the ground water became the principal carrier of radioactivity from the explosion cavities after the

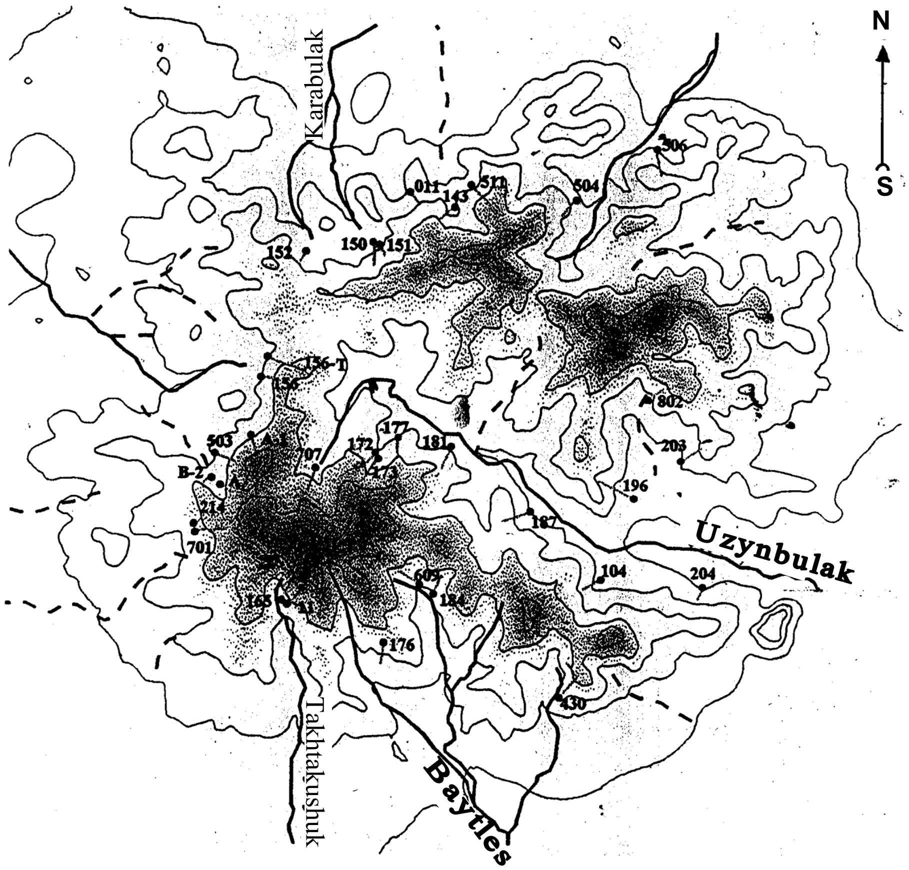

Figure 67. Hydrologic map of the Delegen Massif.
Symbols: • —adits with water shows; - - - - —seasonal streams.

gaseous radionuclide migration phase was over. The contaminated water, seeping through the crushing zones and numerous fractures, produced flows that reached the surface.

In several researchers' opinions,[171,181, etc.] there are two principal mechanisms of radioactive contamination of the massif's water system:

- entry of radionuclides into the water horizon from nuclear explosion cavities;
- "movement" of radionuclides due to washout from rock slopes by precipitation and storm waters.

Hydrologically, the Delegen Massif is a fairly well-developed water system, including a network of creeks and streams from adits. Figure 68 diagrams this water system. Surface water systems originate in the

Delegen Hills: Uzynbulak, Karabulak, Baytles, and Takhtakushuk Creeks, which flow radially and receive water from many adits. So the radionuclides carried out by adit flows can be transported to great distances. Thus, one of the critical ecosystems in Delegen Massif is the river system, which receives radioactive waters from adits over many years. These flows bring radioactivity to the surface, thereby producing ground radioactive contamination in the basin of the water system.

The data in Figure 68 show that eight aquiferous adits are located along the north slope of the massif. Water flowing from these adits to Karabulak Creek, whose volume is about 1000 l/min, is carried to a distance of over 30 km.[171] In the central and eastern parts of the massif are nine adits, whose flows at 3000 l/min empty into Uzynbulak Creek. The flows from four adits in the southern Delegen Massif empty 400 l/min into Baytles and Takhtakushuk Creeks and are transported to a distance of about 8 km. Four more adits with water showing are located on the western slopes of the massif. Their waters, at 600 l/min, flow for 8 km along the channels of intermittent streams and are then lost in the sands.

It is important to note that the rate of atmospheric precipitation is relevant to the process of ground radioactive contamination. The action of this factor can produce seasonal streams. For example, in 1998, which can be described as a wet year, seasonal streams were discovered in those adits where water had not been seen. Numerous temporary springs also cropped up. The total water flow in May 1998 was 9700 l/min.

Laboratory studies of environmental samples have shown that the principal γ-emitting radionuclide near the adit openings is ^{137}Cs. In some areas, spotty soil contamination by $^{239,240}Pu$ and ^{90}Sr has been discovered, with a surface contamination density of over 100 Ci/km^2. Such high levels of these radionuclides have been noted in samples collected from the cinders of cribbing, whose origin can be explained by the incineration of cable recovered from adits.

Consequences of Shaft Demolition in Balapan Test Area

The extent of the effect of shaft closings on environmental radiation levels was assessed using the results of an inspection of the area. Inspections were performed before and after facilities demolition, and the methods and techniques used were identical.

Radiation monitoring of the areas around shaft openings before and after closure was carried out as diagrammed in Figure 69.[171] A com-

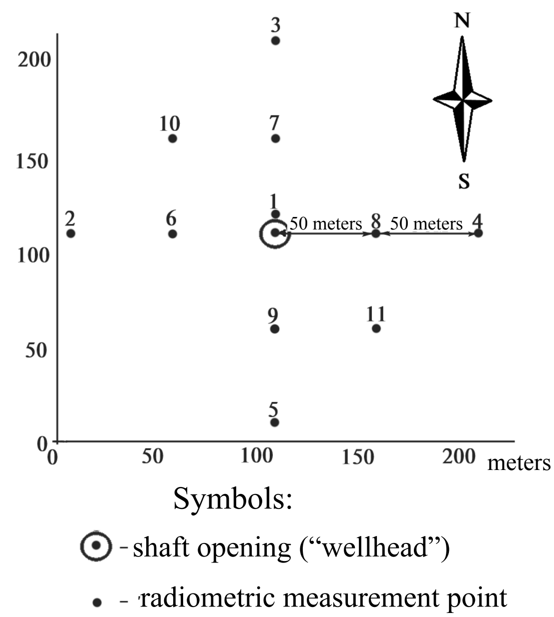

Figure 68. Diagram of the inspection of areas around shaft openings at Balapan Test Area.

parison of the results of the two monitorings revealed that the rad-iation levels in Balapan Test Area after shaft demolition were practically unchanged. Radiation parameters in the areas around the openings, both before and after shaft closings, mostly did not exceed background values. This is expected, since no nuclear tests had been conducted in the shafts to be demolished with chemical explosive charges. The demolition of such shafts and the later performance of regrading to the natural topography certainly had a positive effect on the environment near the test area. Thirteen unused shafts and 12 missile silos were destroyed by detonating chemical explosive charges.

Specialists from the Institute of Radiation Safety and Ecology (*IRBiE*) believe the greatest potential hazard has to do with vertical emplacement holes, that is, with the shafts where nuclear explosions were detonated.[172] Balapan Area had considerably more of these shafts than unused ones. Of course, the radiation hazard could be tied most of all to the presence of a "chimney" in the ground at a certain depth, containing radioactive products from a nuclear explosion. We should note that the RK NNC has no archive data on the presence or size of any chimneys.

However, back in 1990, test site employees doing a ground inspection of the area around 103 vertical emplacement holes established that exposure dose rates near most shafts did not exceed established standards. The exceptions were some 10 shafts near which they discovered small contaminated parcels no more than 0.2 km^2 in area.

An inspection of the ground around vertical emplacement holes in 1999 showed that elevated levels of radioactive contamination on the ground surface were observed mostly near the heads of shafts. The results of this inspection are presented in Table 32.

Table 32. Radiation Levels Near the Heads of Some of the Most Contaminated Vertical Emplacement Holes (As of the End of 1999 [189]

Vertical Emplacement Hole No.	Maximum Exposure Dose Rate, μR/hr	Alpha Particle Flux Density, counts per minute per cm^2	Beta Particle Flux Density, counts per minute per cm^2	^{137}Cs Surface Contaminatio n Density, Ci/km^2
1007	1100	2	900	200
1061	200	—	—	18
1080	8000	1.0	5000	1100
1267	450	97	1200	180
1304	846	—	1000	190
1071	800	0.8	280	—

The ground contamination near the heads of shafts was characterized by high-gradient zones, so a slight sideways movement significantly reduced both exposure dose rates and soil contamination densities. The radiometer readings could vary by more than a factor of 100 over a distance of several meters.

Near the heads of most used shafts, the nuclear explosions had produced annular deformations of the Earth's crust. In the epicentral zones of many shafts, the explosions had produced craters 10-30 meters across and several meters deep. Usually these craters had turned into small lakes overgrown with reeds.

In several of the most contaminated heads of vertical emplacement holes, decontamination work was done. This involved detonating explosive charges, followed by filling with clean soil. The result of this work was a considerable reduction in ground radioactive contamination.

The safety of human presence on the grounds of Balapan Area depends on the solution of the pressing problem of the stability of the chimneys. These cavities are prone to spontaneous collapse due to the fracturing of the rock by the explosion. Sometimes, chimneys can collapse immediately after the explosion; other times they remain intact underground for many years. There have been cases of "cave shafts" reaching the Earth's surface, producing subsidence craters up to 200 meters across and up to 25 meters deep.

The unprovoked collapse of a chimney can have catastrophic consequences. For example, on April 16, 1992, the epicentral zone of Deep (*Glubokaya*) Shaft collapsed. This cave-in was accompanied by a practically instantaneous subsidence of the ground surface near the head of the shaft. The ground collapse was accompanied by a powerful gas release, an explosion that was heard several dozen kilometers away, and then a two-hour fire. The collapse produced a crater about 80 meters across and 18 meters deep. The crater continued to subside for the next two years: by late 1994 its diameter had reached 115 meters and its depth had reached 30 meters.

Thus, the presence of intact chimneys and their proneness to sudden cave-ins necessitates special geophysical studies of the conditions and predictions of their stability. Moreover, safety zones 500 meters across must be established and maintained around all vertical emplacement holes and all work in these zones must be prohibited.

To ensure the safe conduct of all work in Balapan Test Area, comprehensive monitoring must be set up.[190]

An inspection of Balapan Area in 2000 showed that the destruction of shafts and missile silos on its grounds had altered the radiation levels, which were characterized by a decline in ground contamination levels. At the locations of shafts and the field seismic complex, a whole series of sanitary and safety measures was performed to help considerably improve the overall conditions on the grounds of this area. For example:

- dumps were eliminated and all construction waste was removed;
- the mouths of destroyed shafts and missile silos were filled with dirt and then graded to the natural topography;
- local foci of radioactive contamination were decontaminated.

The result of all these measures was a reduction in the exposure dose rate to the regulatory level of 0.6 μGy/hr that had been adopted in the Republic of Kazakhstan based on NRB-96. The concentration of radionuclides in the ground declined significantly.

We should mention that in areas near the Murzhik Hills (Sary-Uzen Area, etc.), 22 underground nuclear tests were conducted in shafts. So this land also needs radioecological inspections to gather information on the scale and extent of ground radioactive contamination.[138]

CONSEQUENCES OF ADIT MOTHBALLING IN DEGELEN TEST AREA

Adits were mothballed using various methods, since the conditions of adit entrances and nearby areas varied. In several adits, certain structural members had deteriorated to the point that entering them was hazardous. In choosing methods of mothballing adits, workers considered the condition of each and the features of their location in the area. Taking these and other features into account, they used one of the following methods:

Figure 69. View of Adit 22 before and after closure.

1. Caving of rock overlying the adit using mudcap (unconfined) explosive charges on the surface. This method was used to close 25 adits.
2. Caving of overlying rock by detonating vertical explosive charges in blast holes from the surface. This method was used to mothball 60 adits.

3. Caving of overlying rock by detonating vertical hole charges installed on the inner surface of the adit. This method was used to close 48 adits.
4. Installation of a concrete plug at the adit entrance. This method was used to mothball 45 adits.
5. Caving of overlying rock by detonating horizontal borehole explosive charges from the surface. This method was used to close 11 adits.

After closure of the Semipalatinsk Test Site, 189 adits were closed in Delegen Test Area by these methods. About 10 adits were closed while the test site was still active. Figure 70 presents photographs showing the exterior of the entrance to Adit 22 before and after its closure.

We should note that the method of caving the overburden using industrial explosives has caused surface damage to the integrity of the rocks and produced subsidence. Fractures and slumps have become channels for rainwater, which has helped to increase the washout of radionuclides from the adit to the surface.

The areas around the adit entrances were inspected after mothballing as shown in Figure 71.

Unfortunately, once adits had been mothballed, surface deformation often made it impossible to pin down the previous location of reference points. For this reason, the extent of the effect of adit mothballing on environmental radiation levels on the grounds of a test area was assessed by comparing averaged measures of the radiation levels before and after mothballing.

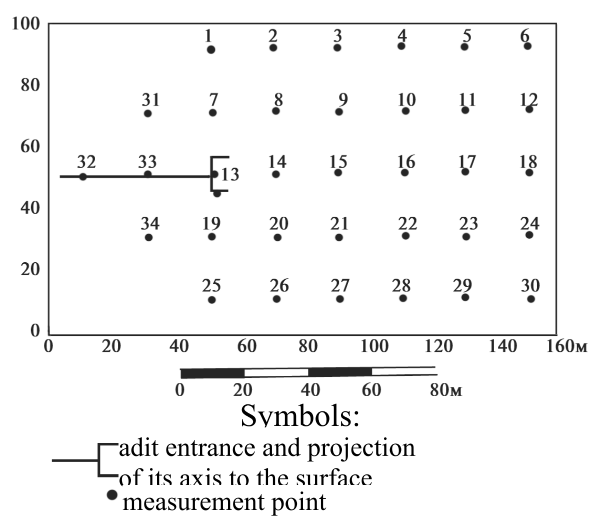

Figure 70. Diagram of the inspection of areas around adit entrances in the Delegen Massif.

As an example, Figure 72 presents a version of the change in radiation levels in the area around the entrance to Adit 504 due to mothballing. By comparing these data, we can see that the mothballing of the adit and burial of its entrance with a layer of "clean" dirt has completely eliminated local foci of radioactive contamination.

The filling of adit entrances with dirt has helped to improve the topography, bringing it closer to the natural landscape. In most cases, the closing of adits with filling of the entrances with "clean" dirt has improved radiation levels near the entrances, that is, it has significantly reduced both the level and the area of radioactive contamination. Since mothballing, radiation levels have improved around the entrances to 100 adits, remained unchanged at the entrances to 69, and unfortunately, worsened around the entrances to 12.

Inspections of adits in Delegen Area in 2000 showed that exposure dose rates at locations containing 90% of the adits do not exceed the standard set by NRB-96, that is, 0.6 μGy/hr. At locations containing 9% of the adits, the exposure dose rate is no more than five times the standard. And only at locations containing 1% of the /hr adits is the exposure dose rate significantly above the standard.[190]

We should note that adit demolition has helped reduce the number of adits containing water. Water flow has been reduced, and consequently, the washout of radioactivity to the surface has also been reduced. By late 2000, visible water with various flow rates was

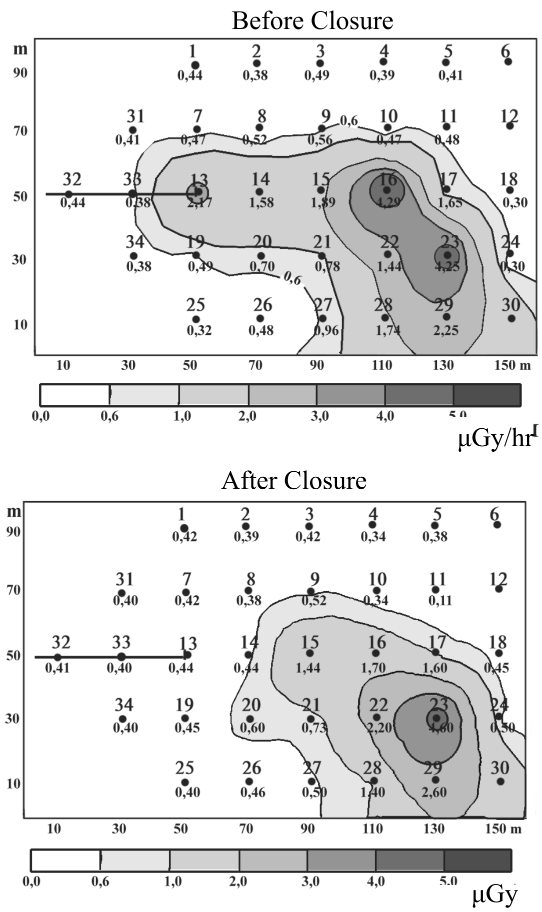

Figure 71. Exposure dose values in the area near the entrance of Adit 504 before and after mothballing.

observed in seven adits, with a total flow of about 1100 l/min. Of course, the water flow varies and depends largely on the season. However, the washout of radioactivity by streams in these seven adits, despite the considerable flow of water, is very small. The reduction has occurred since the installation of gravel filters, which contain finely dispersed material, including clay and silt particles with good sorbent properties, in the path of the water. The radioactivity of the water has been significantly reduced by filtration, as indicated by laboratory analyses of water samples collected in Adit 176.[172] Thus, the specific concentration of ^{137}Cs in the water of this adit was 100 Bq/l before filter installation, and about 70 Bq/l afterward.

Thus, the cleanup and radiation safety measures carried out in Delegen Test Area have certainly improved environmental radiation levels throughout the Delegen Massif. However, it is rather difficult to make a clear assessment of the results of adit mothballing for the future, that is, for a relatively long time interval. It is also important to note that mothballing adits and filling their entrances with "clean" dirt has prevented human access to the explosion cavities, promoting the health of certain especially "inquisitive" individuals.

During the time that has passed since the cessation of nuclear testing in adits, there has been a noticeable growth in the populations of certain animals and birds on the Delegen Massif, as well as an expansion of their habitats. Transitory visual observation has recorded an increase in the numbers of marmots, red-cheeked ground squirrels [*Citellus erythrogenys*], and wild sheep [*Ovis ammon*]. Individuals from seven species of animals previously in the Republic of Kazakhstan's "Red Book" (rare and endangered species list) have been seen: the black-bellied sand grouse [*Pterocles orientalis*], the tawny eagle [*Aquila rapax*], the demoiselle crane [*Anthropoides virgo*], and others. It is quite possible that the numbers of these and other animal and bird species will gradually increase.

We must note that Delegen Test Area has occupied a special place in the realization of various technologies for performing nuclear explosions and nuclear physics experiments. Nuclear devices have been installed in horizontal adits, expanding the range of associated studies and enabling the ionizing radiation to be directed toward physical and biological targets. Some 200 horizontal workings with various cross-sectional areas and lengths have been drilled for testing in the massif, and nuclear devices with various yields have been detonated in them in order to develop military technologies and study the effects of nuclear explosions on underground structures. Testing there has produced considerable changes underground, consisting of vitrification of explosion chambers, destruction of the domes of workings, production of rock disintegration zones, and contamination of fracture waters with radionuclides.

A characteristic feature of the radiation levels, both on the surface and in the rocks underground, has been continual change, which will continue for many decades, and maybe even centuries to come. The radioactivity, which is based on long-lived radionuclides, will be redistributed. They will be washed out of the nuclear explosion cavities and adits to the surface by ground water, enter the river systems, and be carried to great distances. However, the concentrations of these radionuclides in the aquatic systems will be slight, and the exposure doses will not exceed the manmade exposure doses, that is, values that cannot do any harm to human health. Naturally, the redistribution of radioactivity will have to be monitored, and all forms of radiation monitoring must be scientifically grounded.

ASSESSMENT OF THE POSSIBLE CIVILIAN USE OF THE GROUNDS OF THE FORMER SEMIPALATINSK TEST SITE AND ADJACENT AREAS

The prospects for returning the grounds of the former Semipalatinsk Test Site to commercial use, and the related problems, have stood out most clearly since the mid-1990s—they mean the future development of the mining industry. The establishment of this industry is of strategic importance. Over 300 ore deposits, including 30 fields of minerals such as manganese, chromium, copper, lead, tungsten, molybdenum, gold, chemical and ceramic raw materials, and building and finishing stone, have been discovered on the test site grounds and in adjacent districts.[191] In terms of frequency of field discoveries, copper dominates, and in terms of value, gold and rare metals dominate. The Koskuduk and Naymanzhal Gold Fields, whose gold production is predicted to exceed 30 metric tons, are of special interest.

In addressing the difficult problem of assessing the prospects for commercial use of lands radioactively contaminated during the period of atmospheric and underground nuclear testing at the specialized test site, we should rely on data obtained during many years of radioecological studies on its grounds.

In the opinions of many scientists from the Republic of Kazakhstan, the test site grounds should be environmentally zoned, for which they propose to use several methodological foundations of ground radioecological inspection.[139] We must admit that this is a very difficult job, since it will require an assessment of the impact both of the radiation and also of other non-radiation factors, as well as the objective and subjective circumstances that have adversely affected human health.

We should note that an interesting attempt was made in 1999, considering radiation factors alone as consequences of the nuclear tests, and based on data on the concentrations of major dose-producing radionuclides such as ^{137}Cs, ^{90}Sr, and ^{239,240}Pu in environmental samples, to develop recommendations for the agricultural use of some of the test site grounds.[193] In selected parcels of the test site grounds, the authors collected and analyzed soil, vegetation, and water samples. Based on the results of their analyses, they calculated annual radionuclide uptakes into the human body through the soil-plant-animal-human food chain. They determined that milk was one of the main sources of ^{90}Sr uptake into the human body. Given the average human diet established at present, human plutonium uptake exceeding standards is completely impossible. The authors also established that the inhalation route of radionuclide uptake into the body was insignificant.

The calculations made as part of that study showed that the annual uptake of ^{137}Cs, ^{90}Sr, and ^{239,240}Pu into the human body with food products will not exceed the annual radionuclide uptake limit for the general public (Russian $PGP_{nas.}$). In the parcels where the maximum ground contamination density was noted, the annual radionuclide uptake could exceed regulatory levels by severalfold, but since even under these conditions, we are speaking only of small indoor exposure doses, they naturally cannot have an adverse effect on human health.[194]

In accordance with the Republic of Kazakhstan Law, "On the Use of Atomic Energy," working on the grounds of the former Semipalatinsk Test Site requires a license, and the procedure for returning test-site lands to commercial use is set forth in the Statute, "On the Procedure for Confiscation, Protection, and Use of Contaminated and Disturbed Lands," approved by RK Government Resolution 976 of June 16, 1997.

The data presented above regarding a method of assessing the possible use of lands contaminated by radionuclides can help solve this difficult problem. Moreover, in order to resolve such a complex problem as the return of the grounds of the former Semipalatinsk Test Site to commercial use successfully, it will be very important to make a comparison, based on the research results, of large-scale radioecological maps of the test site grounds specifying the densities of ground contamination by the principal biologically significant radionuclides.

Comparison of Large-Scale Environmental Radiation Maps of the Grounds of the Former Semipalatinsk Test Site

From the day the Republic of Kazakhstan National Nuclear Center was formed, specialists from its constituent institutes, and in particular, from its Institute of Radiation Safety and Ecology (*IRBiE*), began working to collect and interpret the results of an assessment of environmental radiation levels on the grounds of the former Semipalatinsk Test Site. As part of this work, they summarized the results of previous inspections, drew a series of 1:200,000 radioecological maps of the entire test site grounds, and submitted recommendations for further plans of study.

During the last several years, researchers at the RK NNC have been performing studies under the topic "Areal," the main result of which has been the drawing of maps at various scales. They have drawn maps showing the scale and extent of the contamination of the test site grounds with radionuclides such as ^{137}Cs, ^{90}Sr, and $^{239,240}Pu$. The most difficult task has been to determine the level of ground contamination by $^{239,240}Pu$, since ground contamination levels, even along obvious radioactive plume axes from ground nuclear explosions, have been difficult to measure and have been highly irregular. Using the IRBiE methodology for inspecting the ground, it is difficult to draw a map that objectively shows the levels of ground contamination of the test site grounds by plutonium isotopes. In addition to the considerable costs, it will take much time.

Maps showing the scale and extent of contamination of the test site grounds by ^{137}Cs and ^{90}Sr are more reliable. Areas marked on these maps as contaminated by these radionuclides practically coincide with aerial and automobile γ survey data. On the maps shown in Figures 73, 74, and 75, locations with elevated ^{137}Cs and ^{90}Sr concentrations coincide with the radioactive plumes produced by the tests of August 29, 1949 (the site's first nuclear explosion), September 24, 1951, and August 12, 1953 (the first thermonuclear explosion).[172]

It would be best to continue the mapping work, and to solve the cartographic problems by trying to use less labor-intensive modern methods. The most complete data on the radioactive contamination of the test site grounds, that is, on a larger scale, will require use of remote γ spectrometric methods and other techniques permitting large-scale mapping by successive approximation to the necessary scale with monitoring of statistical reliability.

It is very important to note that the currently available data on the scale and level of radioactive contamination of the grounds of the former Semipalatinsk Test Site have been systematized and entered into computer

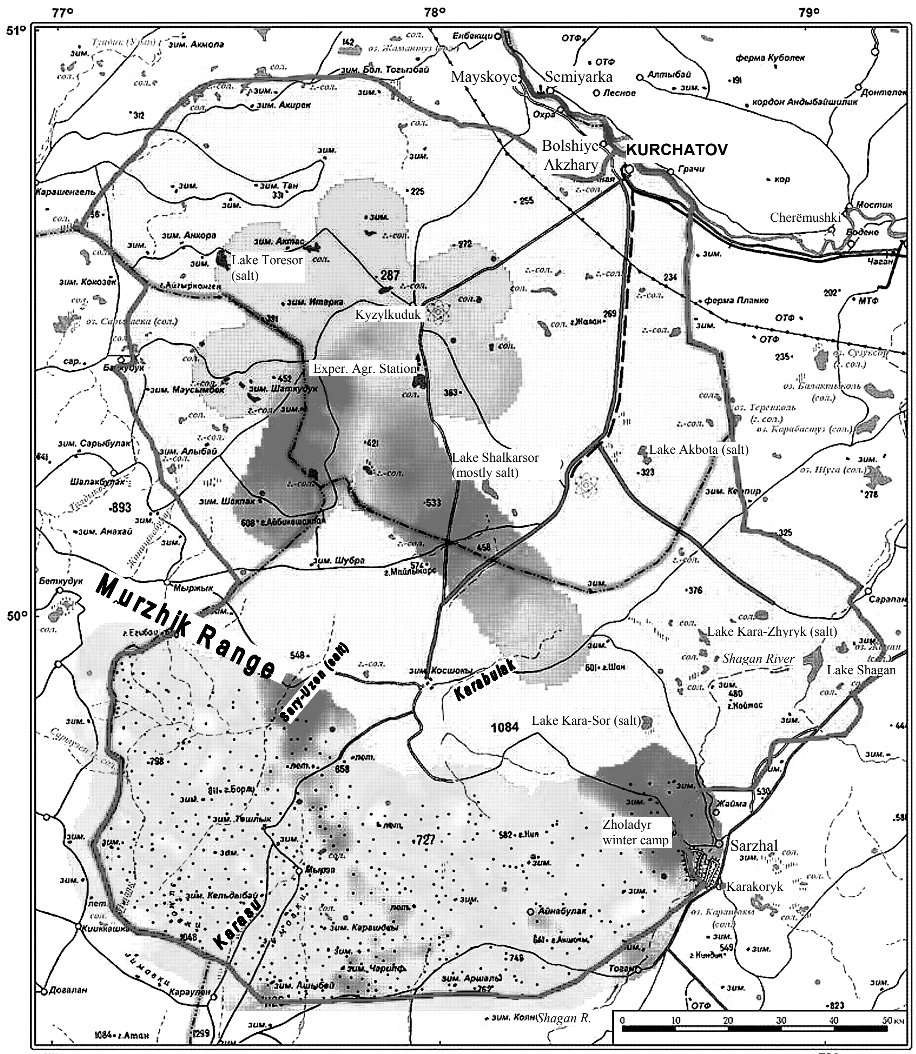

Figure 72. ^{137}Cs contamination map of the grounds of the Semipalatinsk Test Site.

files. These data will become a component of the RK NNC's geographic information system, enabling the plotting of radioecological maps describing radiation levels in various parcels of the extensive test site grounds. It is hard to overvalue the results of this work, since they will be of enormous importance if significant mineral resources are discovered on the test site grounds and the mining industry, one of the most promising directions for commercial use of this land, is developed.[191]

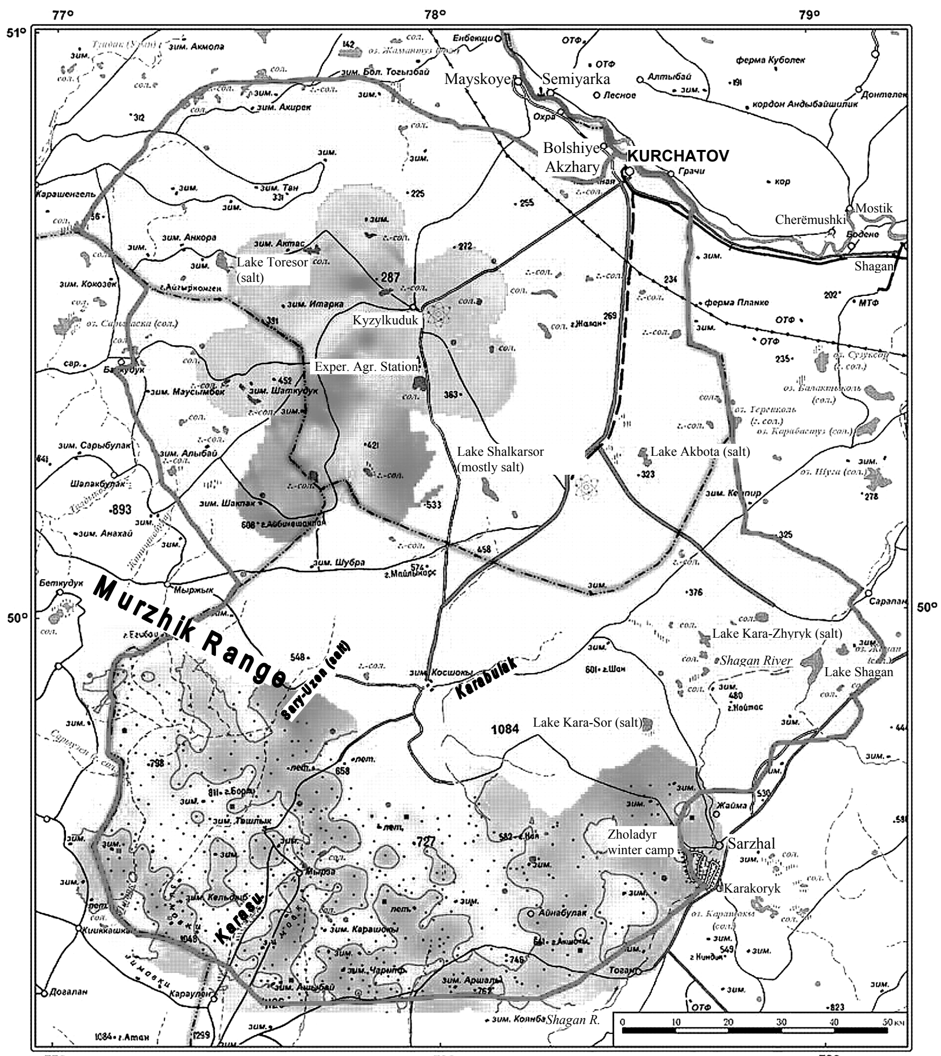

Figure 73. ^{90}Sr contamination map of the grounds of the Semipalatinsk Test Site.

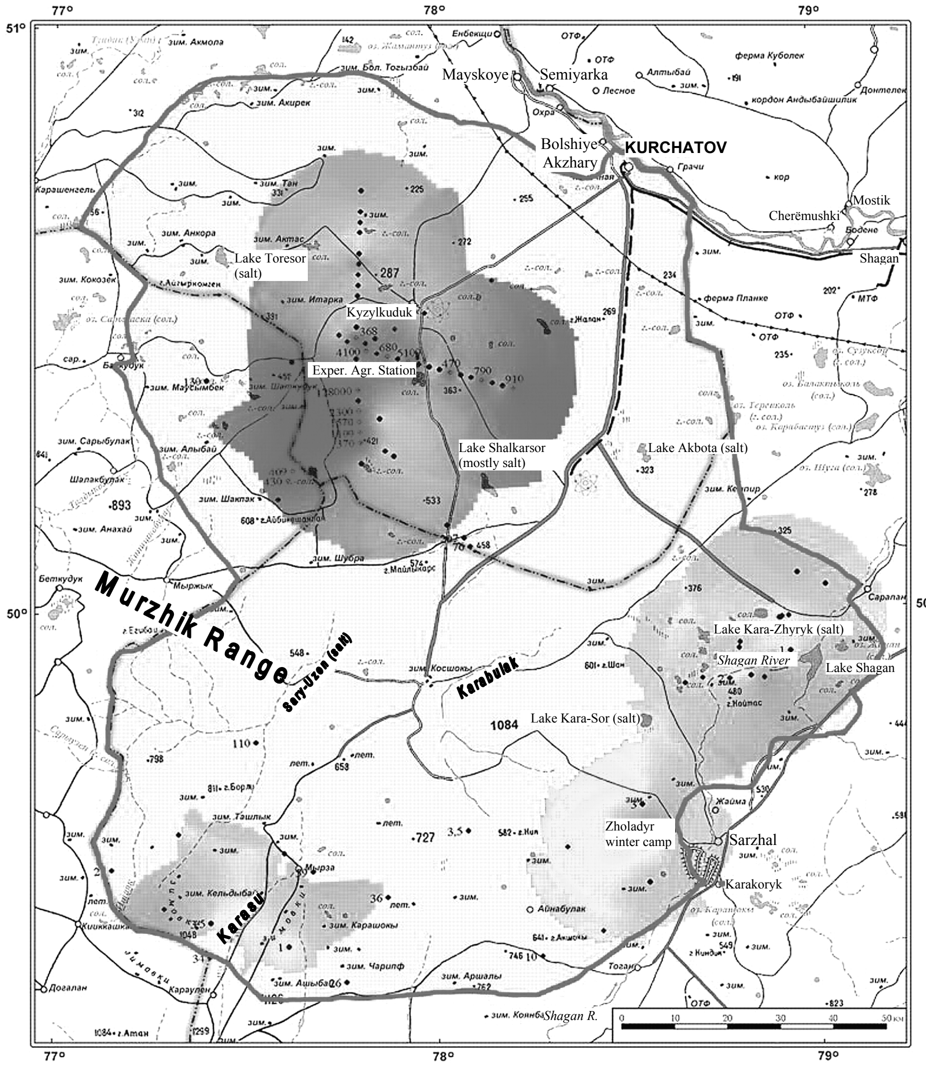

Figure 74. $^{239,240}Pu$ contamination map of the grounds of the Semipalatinsk Test Site.

The creation of such a geographic information system at the RK NNC will help accomplish the following tasks:

- computation and analysis for statistical processing and mathematical modeling of radionuclide migration patterns in natural media on the test site grounds;

- selection and practical implementation of methods calculating individual and collective exposure doses of people and farm animals in various parts of the test site grounds;
- drawing of radioecological maps at various scales, specifying concentrations of biologically significant radionuclides in environmental systems, and based on these data, development of recommendations for the commercial use of the test site grounds.

The RK NNC is currently performing a large volume of various research studies, in particular, studies related to the replenishment of missing information on the nature of radioactive contamination of the ground surface and deep rocks during various types of nuclear explosions, and also on the behavior of biologically significant radionuclides in natural media. The study program is designed for the long term and must be carried out in phases. One of the principal objectives of the first phase, which will soon be completed, is radiation mapping of the test site grounds and establishment of monitoring at locations of the most significant ground radioactive contamination. Issues must also be resolved regarding the classification of certain parts of the test site grounds as protected lands, both with respect to degree of hazardousness of commercial use and as historical landmarks of such a special kind of activity as the use of nuclear explosive technologies for scientific and industrial purposes.

Advisability of Using Part of the Test Grounds as a Natural History Preserve

The grounds of the former Semipalatinsk Test Site have not only seen nuclear arms tests and experimental nuclear explosions for scientific and industrial purposes, but also the development and operation of unique nuclear physics installations and reactor complexes of great scientific and cultural value. So the RK NNC's future research program, which is described in Ptitskaya *et al.*,[172] must, in addition to radioecological issues, also address medical-demographic and social ones, as well as issues related to the classification of certain facilities on the test site grounds as historical monuments of the nation's cultural and natural legacy based on features of their origin, unique characteristics, and other features.

One such facility is the manmade reservoir Lake Shagan, created using nuclear explosive technology.[195] On the earthen embankment thrown up from the explosion crater, relatively high γ-ray levels (up to several mR/hr) are observed at present. In the hypothetical scenario of living at the most contaminated point, that is, on the earthen embankment, the annual exposure dose would not exceed 1-5 mSv, and the short-term dose received by residing at such a point for several days would be absolutely safe. However, we should make special note of the fact that measures of radiation levels outside the embankment correspond to background levels, so there is no need to limit the time people stay on that land or to limit the consumption of milk, meat, or other local products, including water from the most varied sources.[195,196]

There is a proposal to revegetate Lake Shagan, that is, to eliminate the earthen embankment and crater, remove the bottom sediments, and restore the previous channels of the Shagan and Ashchi-Su Rivers, which disappear in the summer. Specialists consider the proposal absurd, short-sighted, and uneconomical. And the very complicated problem of disposing of the excavated sediments should not be overlooked. So it is appropriate to recall a basic tenet of public radiation protection: *"... no step should be taken if the risk of future exposure is less than the risk of taking the step."*[197] Only an economic feasibility study can give a picture of the cost of work to completely revegetate an artificial reservoir. Naturally, these funds would be better spent implementing measures with greater return. For example, partial rehabilitation of this monument to peaceful nuclear explosions by appropriate landscaping of the earthen embankment around the crater.

The manmade reservoir Lake Shagan, created using nuclear explosive technology, is a unique facility that, like the Sedan facility in the US but without creation of a reservoir, possesses a whole series of characteristics that permit its classification as a historical monument of the nation's cultural and natural legacy.[176] The distinguishing feature of Lake Shagan is that it can be developed relatively easily using landscape architecture criteria. Under certain conditions, it could be regarded as a tourist attraction, and in the future it could be used as an alternative treatment site. This subject is addressed in the book, *Monuments of Science and Technology of the Domestic Nuclear Industry* (Moscow, 1999), in which this unusual lake is quite objectively accorded the status of a natural museum-quality monument to nootechnospheric activity in the application of nuclear explosion technologies for industrial purposes.

Opinions have been advanced regarding the creation of an international laboratory for various radioecological studies under RK NNC supervision in some parts of the former Semipalatinsk Test Site.[198-200]

All measures now being carried out on the grounds of the Semipalatinsk Test Site correspond to the content of the "Plan of Measures to Improve Radiation Levels in the Republic of Kazakhstan," approved by RK Cabinet of Ministers Directive 383 of March 30, 1995, and will eventually enable the former nuclear test site grounds to be returned to commercial use.

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APPENDICES

APPENDIX A. COPIES OF ORIGINAL DOCUMENTS

Appendix A.1. Report of B. I. Gusev, Chief Physician of the USSR Ministry of Health's Radiological Clinic, to USSR First Deputy Minister of Health Gennady V. Sergeyev

1990

To: USSR First Deputy
Minister of Health
Gennady V. Sergeyev

REPORT
"Overview of the Health Status of Persons Residing on the Territories of Abay, Beskaragay, and Zhana-Semey Districts, Semipalatinsk Region Previously Exposed to Ionizing Radiation at Various Dose Ranges"

Since August 1949, nuclear weapons tests have been conducted at the test site near Semipalatinsk. Before 1963, these tests were conducted in three media [space, air, and water]. Some of these tests contaminated the territories of three districts of Semipalatinsk Region (Beskaragay, Abay, and Zhana-Semey) with fission products due to local fallout, and exposed people residing in villages and towns in these districts to ionizing radiation in various (small) doses.

In August 1949, the populations of the villages of Dolon, Cherёmushki, Mostik, Kanoperka, and Belokamenka, Beskaragay District, were exposed to ionizing radiation under the real conditions of a nuclear explosion at a dose of 20-150 rems. There was indoor exposure as well. In 1953, the populations of the villages of Sarzhal, Kara-Aul, and Kaynar, Abay District, were exposed to ionizing radiation at doses of up to 27 rems. In the same year, and in 1956 and 1957 as well, the residents of the villages of Znamenka, Zubair, Isa, and Sarapan, Zhana-Semey District, were exposed. The exposure dose was up to 10 rems.

Thus, the medical section of the USSR Ministry of Health's Clinic No. 4 has been observing over 20,000 people since 1961 (8-12 years since the time of exposure), 10,000 of whom had been exposed to ionizing radiation at doses ranging from 10 to 150 rems. The remaining 10,000 subjects were control groups. Before 1971, the medical research was done on an out-patient basis, but since 1971 it has included both out- and in-patient approaches. **I draw your attention especially to the fact that according to information at our disposal, no districts of Semipalatinsk Region other than those named above were exposed to local contamination by fission products, and no residents of those districts were exposed to ionizing radiation.**

Overview of Medical Research Conducted at the Clinic

Most of the clinical research we performed dynamically (over 27 years) did not reveal any substantial differences in the health status of the monitored population that had been exposed to up to 100 rems of radiation compared to the populations of the control groups. Measures such as total morbidity and total mortality over the entire period of study did not differ substantially in the test groups and the controls (Tables 1, 2, 3, 4). We did not detect a single case of acute or chronic radiation sickness. Moreover, clinic-wide methods of examination did not even reliably reveal a probable risk group.

Only a small part of the population that had been exposed to up to 150 rems of radiation revealed disturbances (at the level of physiological variations) for which we could not rule out a cause-effect relationship with ionizing radiation.

Genetic Effects

We studied the condition of the chromosomal machinery and peripheral blood lymphocytes in persons who had been exposed to local radioactive fallout 15-20 years earlier. The age of the examinees ranged from 21 to 60, and their external γ-ray doses ranged from 20 to 150 roentgens. We found (by dynamic observation over 10 years) a reliable increase in the number of chromosomal aberrations in persons in the test groups compared to the controls, but the number of chromosomal aberrations in the test groups did not exhibit a dose dependence. Dynamic observation of persons with chromosomal aberrations in subsequent years revealed no substantial shifts in the quantity or quality of disorders, which confirms, we believe, the one-time nature of the exposure.

Long-Term Non-Cancer Consequences of Exposure

In persons exposed to up to 150 rems, we found an increase in blood vessel viscoelasticity and a disturbance of lipid metabolism. Indices of these disorders in the 41-50 age group were approximately the same as in the 51-60 age group. We regarded the shift in involutional processes as the subclinical period of atherosclerosis.

In this group of persons, we found disturbances of autonomic innervation, analyzer systems, and cerebral hemodynamics reliably more frequently.

An investigation of various immunological reactions in persons exposed to up to 150 rems revealed signs of dysfunctions in the natural immune state. Characteristic manifestations of these changes included a rise in autoallergic reactivity, signs of depression of antimicrobial immunity, and morphofunctional defectiveness of cellular immunity. In general biological terms, we regarded the changes in natural immunity as signs of accelerated aging after the impact of ionizing radiation.

In individuals exposed in early childhood, we found no functional disorders of the thyroid gland. The different thyroid pathology rates noted in the different monitored areas is due to the uneven distribution of marginal thyroid pathology.

Cancer Morbidity and Mortality of the Monitored Population

We analyzed information from long-term observations of a cohort of 6700 persons residing in six populated places in Semipalatinsk Region: the villages of Sarzhal, Kaynar, and Kara-Aul (population exposure doses up to 42 rems), Dolon, Cherëmushki, and Mostik (exposure doses up to 150 rems). The unexposed population of these same villages comprised the control group.

In developing the cancer mortality rate of the population that had been exposed to the impact of ionizing radiation, we found some changes in its levels and structure, which can be regarded with various degrees of confidence as the consequences of radiation exposure. The excess mortality from all malignant neoplasms, including all nosological forms that gave reliable results, was 0.66 case per thousand person-years. The excess cancer mortalities from lung cancer (0.1 case), stomach cancer (0.14 case), esophageal cancer (0.3 case), and liver cancer (0.066 case) were logical and statistically reliable in the observed group. In the entire 27-year observation period, the cancer mortality was 39-40% higher in the test group than in the control group.

With the high spontaneous level from esophageal cancer in this region (five to six times higher than normal), the excess mortality from this tumor disease also proved seven to eight times higher than might have been expected. Carcinogenic effects occurred mainly in the higher age groups and approximately equally between men and women. Excess mortality rates from malignant neoplasms observed in this group, calculated per unit of dose, are also similar to analogous data in the published literature. For all malignant neoplasms taken together, the excess mortality was 0.66 case per million persons per year per rad.

By studying the cancer mortality of the monitored contingents, we found that the excess cancer effect occurred more often in the populations of districts located within 200 km of the explosion epicenters.

Overview of Research on the Health Status of Children Exposed to Low Doses of Ionizing Radiation and Children Born of Exposed Parents

In analyzing the results of research on juvenile contingents, we must note the fairly high percentage of general somatic illnesses, both in children in the test groups and in the controls. A study of the physical development of directly exposed children showed that their weight and height were more often reliably higher than the controls. We found no difference in the health of children exposed to intrauterine radiation versus the control group. The children of the town of Dolon, who received the greatest exposure dose, suffered respiratory diseases more often than the control group.

Developmental and birth defects in the children of the test groups (directly exposed) occurred approximately equally in the test and control groups [*sic*]. We observed the same picture in our examination of first- and second-generation children. In both the test and the control groups, the examined children often exhibited reductions in hemoglobin, white counts, and platelet counts. No radiation-related cancer effects were found among children in the test groups. We found a reliable increase in mortality among children in the test groups (under one year) due to toxic dyspepsia and pneumonia.

Conclusions

1. The health status of people exposed to ionizing radiation in the past in doses up to 100 rems over the entire 30-year observation period does not differ from that of control groups.

2. Poorly marked disturbances of natural immunity, cytogenetic effects, accelerated aging processes, and excess cancer mortality were detected among a small group of the population who had been exposed to ionizing radiation in doses up to 150 rems. The excess cancer mortality of these groups was 6.6 cases per million.

3. The morbidity of children directly exposed to ionizing radiation, and of children born of exposed parents, over all the years of the study, did not differ substantially from the measures of control groups.

4. The mortality of children under one year of age exposed to radiation or born of exposed parents over the 25-year observation period was continuously above the control measures.

[signature]
B. I. Gusev
Chief Physician
Radiological Clinic
USSR Ministry of Health

Table 1. Morbidity of Adult Population of Beskaragay District (Dolon, Cherëmushki, Mostik) Exposed to Ionizing Radiation in Doses up to 150 Rems in 1949 (rate per 1000)

Disease Class	1964		1974		1984	
	Test	Control	Test	Control	Test	Control
Total morbidity	2286.7	2428.6	4753.3	4930.2	5411.9	5692.4
1. Infectious and parasitic diseases	496.3	321.6	1111.9	909.1	1221.6	1008.4
2. Neoplasms	15.3	19.4	62.9	52.2	79.3	60.4
3. Diseases of the endocrine system and nutritional and metabolic disorders	7.2	92.6	11.9	130.4	29.3	192.4
4. Neurological disorders	162.3	181.4	391.6	308	400.4	372.6
5. Ophthalmological disorders	124.5	110.3	349.7	217.4	300.2	221.4
6. Ear, nose, and throat (ENT) diseases	103.2	171.6	216.8	443.5	256.3	456.8
7. Circulatory diseases	534.7	603.9	993.0	1008.7	1276.4	1389.2
8. Respiratory diseases	160.7	192.3	349.7	434.8	374.2	404.3
9. Digestive system diseases	321.9	301.7	545.5	582.6	560.3	601.4
10. Diseases of the kidneys and urinary tract	42.3	72.4	90.9	139.1	134.2	171.6
11. Gynecological diseases	110.4	112.3	195.8	260.9	211.3	292.6
12. Diseases of the skin and subcutaneous tissues	100.3	110.6	223.8	200.0	243.4	203.3
13. Diseases of the musculoskeletal system and connective tissue	93.4	121.2	181.8	217.4	292.6	281.4
14. Miscellaneous	14.2	17.3	28.0	26.1	32.4	36.6

Table 2. Morbidity of Adult Population of Beskaragay District (Kanoperka) Exposed to Ionizing Radiation in Doses up to 20 Rems in 1949 (rate per 1000)

Disease Class	1964		1974		1984	
	Test	Control	Test	Control	Test	Control
Total morbidity	2304.8	2336.4	5139.9	4859.7	5185.0	5035.8
1. Infectious and parasitic diseases	436.7	372.4	1231.4	1121.4	996.5	831.4
2. Neoplasms	17.3	17.9	79.3	49.3	61.3	59.6

Disease Class	1964		1974		1984	
	Test	Control	Test	Control	Test	Control
3. Diseases of the endocrine system and nutritional and metabolic disorders	34.6	41.6	59.6	34.5	43.1	56.4
4. Neurological disorders	19.34	200.4	321.4	296.5	341.6	306.5
5. Ophthalmological disorders	132.6	152.4	376.7	353.5	391.4	367.3
6. Ear, nose, and throat (ENT) diseases	92.3	81.6	261.2	209.4	240.5	256.3
7. Circulatory diseases	627.4	590.4	1221.4	1311.5	1421.9	1479.3
8. Respiratory diseases	132.4	121.6	300.3	261.3	321.6	300.4
9. Digestive system diseases	371.2	337.4	621.3	592.4	631.6	600.3
10. Diseases of the kidneys and urinary tract	72.4	70.4	72.3	69.4	89.3	73.4
11. Gynecological diseases	134.6	111.8	212.3	192.1	273.2	251.6
12. Diseases of the skin and subcutaneous tissues	123.6	141.9	172.1	152.4	142.4	173.5
13. Diseases of the musculoskeletal system and connective tissue	110.4r	82.3	193.2	200.6	217.3	261.4
14. Miscellaneous	17.2	14.3	17.4	15.4	13.3	18.4

Table 3. Morbidity of Adult Population of Abay District (Sarzhal, Kaynar) Exposed to Ionizing Radiation in Doses up to 27 Rems in 1953 (rate per 1000)

Disease Class	1964		1974		1984	
	Test	Control	Test	Control	Test	Control
Total morbidity	2497.4	2413.1	4565.4	4454.5	5135.5	5187.6
1. Infectious and parasitic diseases	321.7	221.4	695.7	571.4	734.5	621.6
2. Neoplasms	26.3	92.5	78.3	142.9	100.3	179.8
3. Diseases of the endocrine system and nutritional and metabolic disorders	39.0	100.8	87.0	155.8	100.2	198.6
4. Hematological disorders	20.8	40.9	34.8	77.9	40.3	89.3
5. Mental disorders	6.3	13.0	0	26.0	13.4	17.8
6. Diseases of the nervous system and sense organs	503.7	362.3	808.7	662.3	902.3	792.4
7. Circulatory diseases	300.2	310.5	565.2	532.5	613.5	592.6
8. Respiratory diseases	492.3	450.2	843.5	831.2	948.5	992.6
9. Digestive system diseases	321.6	375.3	617.4	675.3	713.4	813.5
10. Diseases of the urogenital tract	164.3	171.2	304.3	246.8	346.3	302.1

Disease Class	1964		1974		1984	
	Test	Control	Test	Control	Test	Control
11. Diseases of the skin and subcutaneous tissues	100.3	39.9	191.3	77.8	261.3	134.8
12. Diseases of the musculoskeletal system and connective tissue	158.3	213.6	278.3	415.6	311.2	418.3
13. Congenital anomalies	33.6	17.5	43.5	26.0	50.3	34.2
14. Accidents, poisonings, and injuries	9.0	4.0	17.4	13.0		

Table 4. Morbidity of Adult Population of Zhana-Semey District (Znamenka, Zubair, Sarapan, Isa) Exposed to Ionizing Radiation in Doses up to 10 Rems in 1953 (rate per 1000)

Disease Class	1974		1984	
	Test	Control	Test	Control
Total morbidity	3838.3	3715.8	4525.5	4686.3
1. Infectious and parasitic diseases	679.3	541.4	624.3	531.6
2. Neoplasms	43.4	39.6	51.3	52.4
3. Diseases of the endocrine system and nutritional and metabolic disorders	92.6	73.4	69.3	72.1
4. Neurological disorders	321.6	329.6	412.5	432.6
5. Ophthalmological disorders	291.3	261.4	312.5	298.6
6. Ear, nose, and throat (ENT) diseases	203.7	216.4	267.3	312.8
7. Circulatory diseases	893.0	908.7	1110.4	1289.2
8. Respiratory diseases	296.3	276.4	329.3	313.4
9. Digestive system diseases	513.5	545.5	593.3	608.4
10. Diseases of the kidneys and urinary tract	112.6	90.6	139.6	149.3
11. Gynecological diseases	115.5	156.8	189.3	211.6
12. Diseases of the skin and subcutaneous tissues	98.3	72.3	143.4	111.3
13. Diseases of the musculoskeletal system and connective tissue	161.2	192.4	260.6	280.4
14. Miscellaneous	16.0	11.3	22.4	22.6

Appendix A.2. Letter from 20 concerned scientists to Dmitry T. Yazov, USSR Minister of Defense [excerpt]

March 12, 1990

To: Comrade Dmitry
Timofeyevich Yazov, USSR
Minister of Defense

On the Effect of
Underground Nuclear Tests
on Human Health

[Dear Mr. Minister,]

At present, due to the growing public movement to halt nuclear testing at the Semipalatinsk Test Site, certain scientists and specialists, defending narrow departmental interests, are trying to prove that underground nuclear testing does not affect public health.

We, scientists and physicians in the practice of public health in Semipalatinsk Region, consider such assertions antihuman, and contradictory to the basic principles of safeguarding health.

An interdepartmental commission formed by the USSR Ministry of Health in 1989 under the supervision of [Anatoly] F. Tsyb, Corresponding Member of the Academy of Medicine, disclosed:

The nuclear test site in Semipalatinsk Region is a chronic, psychotraumatic factor that adversely affects the mental health of the region's population.

…

We are firmly convinced that the only solution to this situation is to immediately halt nuclear testing at the test site near Semipalatinsk.

[20 signatures]

Appendix A.3. Letter from Col. Gen. V. Gerasimov, Head of the USSR Ministry of Defense's 12th Main Administration, and Maj. Gen. of Medical Service E. Nechayev, Head of the USSR Ministry of Defense's Central Military Medical Administration, to Col. Gen. B. A. Omelichev, First Deputy Chief of the General Staff [excerpt]

April 2, 1990

To: Col. Gen. B. A. Omelichev,
First Deputy Chief of the
General Staff

[Sir,] we report:

In accordance with your instructions of March 16, 1990, we have reviewed the letter from the physicians of Semipalatinsk public health department expressing concern over the state of public health in the area of the Semipalatinsk Test Site.

…

Based on the above, we have drafted a response to the physicians of Semipalatinsk Region (enclosed) for your review.

[signature]
Col. Gen. V. Gerasimov
Head, 12th Main
Administration
USSR Ministry of Defense

[signature]
Maj. Gen. of Medical Service
E. Nechayev
Head, Central Military
Medical Administration,
USSR Ministry of Defense

Appendix A.4. Letter from Col. Gen. B. A. Omelichev, First Deputy Chief of the General Staff, and Col. Gen. V. Gerasimov, Head of the USSR Ministry of Defense's 12th Main Administration, to Dmitry T. Yazov, USSR Minister of Defense [excerpt]

April 3, 1990

To: Dmitry T. Yazov, USSR
Minister of Defense

[Sir,] we report:

In accordance with your instructions of March 16, 1990, we have reviewed the letter from the physicians of Semipalatinsk public health department expressing concern over the state of public health in the area of the Semipalatinsk Test Site.

…

Based on the above, we have drafted a response to the physicians of Semipalatinsk Region (enclosed) for your signature.

[signature]
Col. Gen. B. A. Omelichev,
First Deputy Chief of the
General Staff

[signature]
Col. Gen. V. Gerasimov
Head, 12th Main
Administration
USSR Ministry of Defense

Appendix A.5. Letter from Dmitry T. Yazov, USSR Minister of Defense, to Semipalatinsk Regional Public Health Department [excerpt]

[coat of arms]
USSR MINISTRY OF DEFENSE

April 4, 1990
No. 448/2603

To: Semipalatinsk Regional
Public Health Department

Dear comrades,

I have reviewed your letter of March 12, 1990.

The USSR Ministry of Defense shares your concern over the state of public health in Semipalatinsk Region.

…

At present, in accordance with the USSR Supreme Soviet Resolution [289] of November 27, 1989, "On Urgent Steps for the Nation's Environmental Recovery," the question of the possible cessation of underground nuclear testing at Semipalatinsk Test Site is being considered.

[signature]
Dmitry T. Yazov

Appendix A.6. Letter from Lt. Gen. A. Ilyenko, Test Site Director, and Maj. Gen. G. Soldatov, Head of the Test Site's Political Section, to V. L. Lapygin and Keshrim B. Boztayev [excerpt]

July 21, 1989

To: V. L. Lapygin
Chairman, USSR Supreme
Soviet Defense and State
Security Committee

Cc: Keshrim B. Boztayev
Deputy to the USSR
Supreme Soviet Defense and
member, USSR Supreme
Soviet Defense and State
Security Committee

Dear comrades,

From July 17 to 19, 1989, the Semipalatinsk Regional Committee of the Communist Party of Kazakhstan and the regional executive committee held a scientific and practical conference, "Public Health and Environmental Conditions in Semipalatinsk Region, Kazakh SSR."

…

Recommendations:

1. Demand that local Party and Soviet agencies take active control of the development and conduct of a system of measures to shape public opinion in accordance with Resolution 160 of the Politburo of the CPSU Central Committee of June 9, 1989. In the light of this document, alter the content of organization and indoctrination work performed by local Party and Soviet agencies and the mass media toward a loyal public attitude toward the site.

Cease threats, persecution, insults, and attacks on the test site, its workers, and all its residents.

Create normal conditions around the test site for the accomplishment of the objectives set by the Party and Government.

2. When considering the question of the future existence of the test site in Semipalatinsk Region, rely on the materials and conclusions of the comprehensive interdepartmental commission. In deciding the question, ignore the assessments and recommendations of the conference, which were dictated by subjective factors.

[signature]
Lt. Gen. A. Ilyenko
Test Site Director

[signature]
Maj. Gen. G.
Soldatov
Head, Test Site
Political Section

Appendix A.7. Letter from Col. Gen. V. Gerasimov, Head of the USSR Ministry of Defense's 12th Main Administration, to Dmitry T. Yazov, USSR Minister of Defense [excerpt]

July 29, 1989

To: Dmitry T. Yazov, USSR
Minister of Defense

[Sir,] we report:

In accordance with Resolution 160 of the CPSU Central Committee of July 9, 1989, a scientific and practical conference, "Public Health and Environmental Conditions in Semipalatinsk Region, Kazakh SSR" was held from July 17 to 19 of this year.

The conference was attended by representatives of Party and Soviet agencies, as well as members of the public from Semipalatinsk, Aktyubinsk, Karaganda, East Kazakhstan, Pavlodar Regions of the Kazakh SSR and Altai Territory of the RSRFR, and members of the Nevada society.

…

Based on its work, the conference adopted recommendations mainly approving the finding of the comprehensive commission and identified environmental problems that need to be solved. However, under public pressure, the conference came out in favor of the need to halt nuclear tests at the Semipalatinsk Test Site.

This report is for your information.

[signature]
Col. Gen. V.
Gerasimov
Head, 12th Main
Administration
USSR Ministry of
Defense

Appendix A.8. RK Cabinet of Ministers Resolution 55 of January 21, 1993, "On Steps in Support of the Operation of the Republic of Kazakhstan National Nuclear Center" [excerpt]

[coat of arms]
RESOLUTION OF THE CABINET OF MINISTERS OF THE REPUBLIC OF KAZAKHSTAN
NO. 55, JANUARY 21, 1993

On Steps in Support of the Operation of the Republic of Kazakhstan National Nuclear Center

In implementation of Republic of Kazakhstan President's Decree 779 of May 15, 1992, "On the Republic of Kazakhstan National Nuclear Center," the Republic of Kazakhstan Cabinet of Ministers resolves:

1. That the Republic of Kazakhstan National Nuclear Center (hereinafter, "the Nuclear Center") shall be an independent republic-level institution within the Republic of Kazakhstan Academy of Sciences, which shall perform scientific supervision and coordination of its work.

…

[signature, seal]
Sergey A. Tereshchenko
Prime Minister of the Republic of Kazakhstan

Appendix A.9. RK Cabinet of Ministers Resolution 1082 of October 29, 1993, "On the Organization of Institutions Comprising the Republic of Kazakhstan National Nuclear Center" [excerpt]

[coat of arms]

RESOLUTION OF THE CABINET OF MINISTERS OF THE REPUBLIC OF KAZAKHSTAN
NO. 1082, OCTOBER 29, 1993

On the Organization of Institutions Comprising the Republic of Kazakhstan National Nuclear Center

The Republic of Kazakhstan Cabinet of Ministers resolves:

1. That the recommendation of the Republic of Kazakhstan National Nuclear Center, endorsed by the National Academy of Sciences, the Ministry of Science and New Technologies, the Ministry of the Economy and the Ministry of Finance, to organize the following institutions under the Center, be and hereby is adopted:

…

Sergey A. Tereshchenko
Prime Minister of the Republic of Kazakhstan

Appendix A.10. Letter from Vladimir S. Shkolnik, General Manager of the Kazakhstan Atomic Energy Agency, to Viktor N. Mikhaylov, Russian Minister of Atomic Energy

[coat of arms]
KAZAKHSTAN ATOMIC ENERGY AGENCY
13 Republic Square, Almaty 480012
Telephone 63-4885, 63-7374
Teletype 251179 INFOR
Faxes: (3272) 63-4885, 63-3386

November 8, 1993

To: Viktor Nikitovich Mikhaylov
Russian Minister of Atomic Energy
Fax (095) 230-2420

Cc: Yury A. Trutnev
VNIIEF
Fax 54565

Dear Mr. Mikhaylov,

On November 9, 1993, a group of U.S. experts led by Dr. Don Linger is scheduled to arrive at Kurchatov for the purpose of studying and certifying the aftermath of the conduct of nuclear tests at the Semipalatinsk Test Site.

Please send the following team of experts from the Atomic Energy Ministry to participate in the negotiations:

A. K. Chernyshev, Yury V. Dubasov, Anatoly M. Matushchenko, V. A. Logachev, F. M. Gudin, V. N. Rubashkin, V. V. Gorin.

[signature]
Vladimir S. Shkolnik
General Manager

[various handwritten notations not translated]

Appendix A.11. Letter from RK President Nursultan A. Nazarbayev to Russian Federation President Boris N. Yeltsin [excerpt]

[coat of arms]
PRESIDENT OF THE REPUBLIC OF KAZAKHSTAN

December 2, 1993
No. N-770

To: Boris Nikolayevich Yeltsin
President of the Russian
Federation

Dear Mr. President,

For 40 years, the Semipalatinsk Test Site was used to study and improve nuclear weapons in the Soviet Union. The tests resulted in serious damage to the health of people and the natural environment.

Some 500 nuclear explosions were detonated on the grounds of the Semipalatinsk Test Site (87 in the air, 25 on the ground, and 360 underground). Some 12 million metric tons of radioactive wastes with a total activity on the order of 13 million curies were produced.

In this context, the problems of studying the condition of the natural environment in the areas where the tests were conducted and of cleaning up and assisting the victims, in our opinion, are a common responsibility of all the countries of the former USSR, primarily the Russian Federation and the Republic of Kazakhstan, and must be solved in the framework of the withdrawal of nuclear weapons from Kazakhstani territory and their transfer to the Russian Federation.

…

Boris Nikolayevich, I hope for your understanding of this complex, common human problem and I am confident of your full support.

Sincerely,
[signature]
Nursultan A.
Nazarbayev

Pr-1858

Appendix A.12. Letter from Viktor N. Mikhaylov to S. K. Shoigu, RF Minister for Civil Defense, Emergencies, and Natural Disaster Relief [excerpts]

December 30, 1994
No. 01-3096

To: Sergey Kuzhugetovich Shoigu
RF Minister for Civil Defense, Emergencies, and Natural Disaster Relief

Re: Agreement between Russian Federation and Republic of Kazakhstan on matters of the Semipalatinsk Test Site

Dear Mr. Minister,

1. Russian Federation Government Directives VCh-P8-09805 of 4/13/94 and VCh-P8-25000 of 8/11/94 specified that the Russian Ministry of Atomic Energy, together with the Russian Ministry of Defense and Ministry of Finance and other involved and interested ministries and departments, were to revise and submit for signature a draft Agreement to Clean up after Nuclear Weapons Testing at the Semipalatinsk Test Site and other nuclear explosions on Republic of Kazakhstan territory. This is specified by the Memorandum on the Results of the Meeting at Almaty on 12/25/93 between the President of the Russian Federation Government, Viktor S. Chernomyrdin, and the Prime Minister of the Republic of Kazakhstan, Sergey A. Tereshchenko and by the Minutes of the Meeting of the Heads of State of the Russian Federation and the Republic of Kazakhstan on 3/28/94.

…

In this context, based on the importance of the problem, we propose that, in support of the implementation of the Agreement, the special research study, “Assessment of Radiation Levels on the Territory of the former Kazakh SSR as a Result of Nuclear Tests at the Semipalatinsk Test

Site and Determination of the Extent of Its Effects on the Public," be carried out on an urgent basis. It should be assigned to the Russian Ministry of Health and the Medical Industry [*Minzdravmedprom*]'s Institute of Biophysics based on Professor V. A. Logachev's laboratory, which in our opinion is prepared for appropriate expert research based on archive documents containing data from radiation surveys on Republic of Kazakhstan territory and the results of comprehensive medical examinations of the population of that republic, which is the purview of the Russian Ministry of Health and the Medical Industry. A financial investment in the funding of this study (with appropriate endorsements) should be considered critical, so that in future relations with the Kazakhstani Party, the Russian Party can, specifically through our departments, objectively note its real contribution to the accomplishment of the objective of guaranteeing performance of Agreement obligations. This is also necessary from the standpoint of optimizing expenses on the part of the Russian Federation.

A draft of the corresponding Technical Assignment for Research may be submitted by the Institute of Biophysics of the Russian Ministry of the Health and Medical Industry (under Professor V. A. Logachev).

Please make a decision.

[signature]
Viktor N. Mikhaylov

Appendix A.13. Letter from I. Mamedbakov, Chief Specialist of the Semipalatinsk Regional Administration's Nuclear Testing Relief Committee to individual citizen

[coat of arms]
Semipalatinsk Regional Administration
Nuclear Testing Relief Committee
8 International Avenue
Semipalatinsk 490037
Tel. 62-3573, 62-3504, 62-2382

____________, 1994
No. _________

To: Citizen

Re: Certificate Series SP, No.
____

STATEMENT

In accordance with the Republic of Kazakhstan Law, "On the Social Protection of Citizens Exposed to Radiation due to the Nuclear Tests at the Semipalatinsk Test Site":

The zone of elevated radiation risk is that part of the territory exposed to radioactive contamination with a lifetime public exposure dose from 7 to 35 rems.

[signature, seal]
I. Mamedbakov
Chief Specialist

APPENDIX B. ENVIRONMENTAL PROBLEMS OF THE SEMIPALATINSK TEST SITE

By Saule T. Ryskulova, Doctor of Biological Sciences, Institute of Zoology, Republic of Kazakhstan

Introduction

We can now state for certain that our society is quite familiar with the word "radiation." However, this term usually has negative, fearful associations. Radiophobia, which has been overdramatized in the mass media since the declassification of the Semipalatinsk Test Site, has gotten into everyone's flesh and blood. Let's go back to 1949, when the first nuclear explosion rumbled across our test site. In those days, the naïve residents of adjacent lands thought, as in the song: "They're exercising."[7] The soldiers themselves didn't know a thing about what was hidden behind the atom bombs, and they recall "falling in love with" the beauty of the mushrooms; the exultation was pervasive (*Komsomolskaya pravda* ["Communist Youth League Truth"], August 18, 1999). Doctors, who had never seen patients with radiation sickness in their clinical practice, took every malady and many medical and biological deviations from the norm for manifestations of the body's reaction to radiation.

All this engendered negative psychological emotions, deepened the sense of helplessness, and helped produce a general radiophobia. In medicine, we know that negative stress is the first cause of immunodeficiency. Pressure on the immune system, in turn, leads to the development of various diseases, and the vicious circle is closed. But in the context of socioeconomic decline, all these phenomena are exacerbated. It was actually the lack of complete information on the impact of radiation on the living body, protective measures, and methods of treatment that produced more than a few deaths, especially in the early years of the test site's operation, when the evil things were detonated on the ground and in the air. But now we understand how harmful the secrecy over the site's operation was.

[7]—The song to which the author refers describes the heroic efforts of a YaK-28 crew with a failed engine, at the expense of their own lives, to crash the plane where it would not kill anyone on the ground. Naturally, the residents had no idea of the situation, and assumed the plane's movements were just another exercise.—*Trans.*

It would seem, with the arrival of openness, and more importantly, the republic's sovereignty, we should promptly fill this gap, teach the public the facts of ionizing radiation, and train our own radiobiologists. But even universities in the republic are still not turning out such specialists. At best, some colleges offer only short courses in radiation biology. Recently, attempts have been made to defend dissertations in this specialty, but such candidates are had pressed to find appropriate opponents, since the majority of radiobiologists have remained in Russia.

Several years ago, when radiophobia was at its height, many districts of Kazakhstan demanded the government allocate supplemental benefits to the supposed victims of the Semipalatinsk explosions and the radioactive wastes left behind on their land. This author was a member of one such commission, formed by directive of the RK Cabinet of Ministers. In analyzing the extensive medical statistics provided for Akmola and Kökshetau Regions, we found the claims of the radiation origin of all existing pathology among the residents of these areas invalid and unproven (except for personnel who actually worked in the uranium mines). It turned out that the medical statistics reflecting the level and nature of morbidity among the adult and juvenile populations of these regions had much in common with those for the entire republic. As a practical matter, public health is poor in all districts of Kazakhstan. The areas under discussion were contaminated by toxic chemical compounds, harmful emissions from numerous boiler rooms and power stations, and naturally released radon gas in various areas.

Unfortunately, with our sluggishness it will still take quite a few years to overcome all the rumors and provide the republic's residents accurate scientific information on ionizing radiation and its harms and its benefits. In this connection, I believe this book, which is intended for a general audience, could benefit from some information on the properties, actions, and role of ionizing radiation in human life and wildlife.

The Concept of Ionizing Radiation

Mankind learned of the existence of X-rays a little over 100 years ago, in 1895. But radiation has always been present on Earth and in space, even before the appearance of life on our planet. Radiation is called "ionizing" when its interaction with matter breaks chemical bonds and ionizes atoms and molecules, thereby causing serious biological damage. In contrast, non-ionizing radiation (visible light, radio waves, electromagnetic fields from televisions, computers, cell phones, etc.) does not cause ionization and the corresponding destruction, although it can have biological effects if the intensity of exposure is high.

Ionizing radiation has various sources. It can occur as rays: X-rays and γ-rays. Their energy is transmitted as waves, like light and heat from the sun. they are similar to one another, differing only in their method of production. Whereas X-rays are produced by the familiar electronic device, γ-rays are emitted by radioactive isotopes. Other types of ionizing radiation consist of long-lived particles of matter. Some of these carry an electric charge (α and β particles), others (neutrons) do not.

As it passes through cells and tissues of the living body, ionizing radiation transfers its energy, which is absorbed unevenly, and depending on the dose, can have serious consequences.

Alpha-rays are most dangerous when they enter the body with food, by inhalation, or through open wounds. However, with their low penetrating ability, they are blocked even by a sheet of paper. Beta-rays reach depths of up to two centimeters. Gamma-rays, like X-rays, travel at the speed of light, have the greatest penetrating ability, and are blocked only by a thick layer of lead or concrete[1,2].

Thus, there are two ways that radiation can affect the body: external and internal. The greatest difficulties come from internal exposure, when radioactive substances can enter the body through the lungs during breathing, along with food, through injuries and openings in the body, and by passing directly through healthy skin. This is why the detonation of ground and atmospheric explosions at the test site from 1949 to 1963 was the most hazardous and produced the most severe consequences. After radioactive matter falls out and settles in the body, its effects will depend on the amount of energy and type of radiation, the shape and weight of the organ, and the physical and biological half-life of the isotope. The "half-life" is the time required for a material to lose half of its radioactivity. The half-life can range from fractions of a minute to thousands of years. The biological half-life is the time required for half of the radioactive material to leave the body, which can be with perspiration, saliva, urine, feces, etc.

The study of the patterns of ionizing radiation's biological action at various levels of organization of living systems, from the individual cell and its contents to a whole organ or body, is a complex scientific discipline called "radiation biology." It is closely related to a whole series of theoretical and applied fields of knowledge, and has several major subfields (Figure 1).

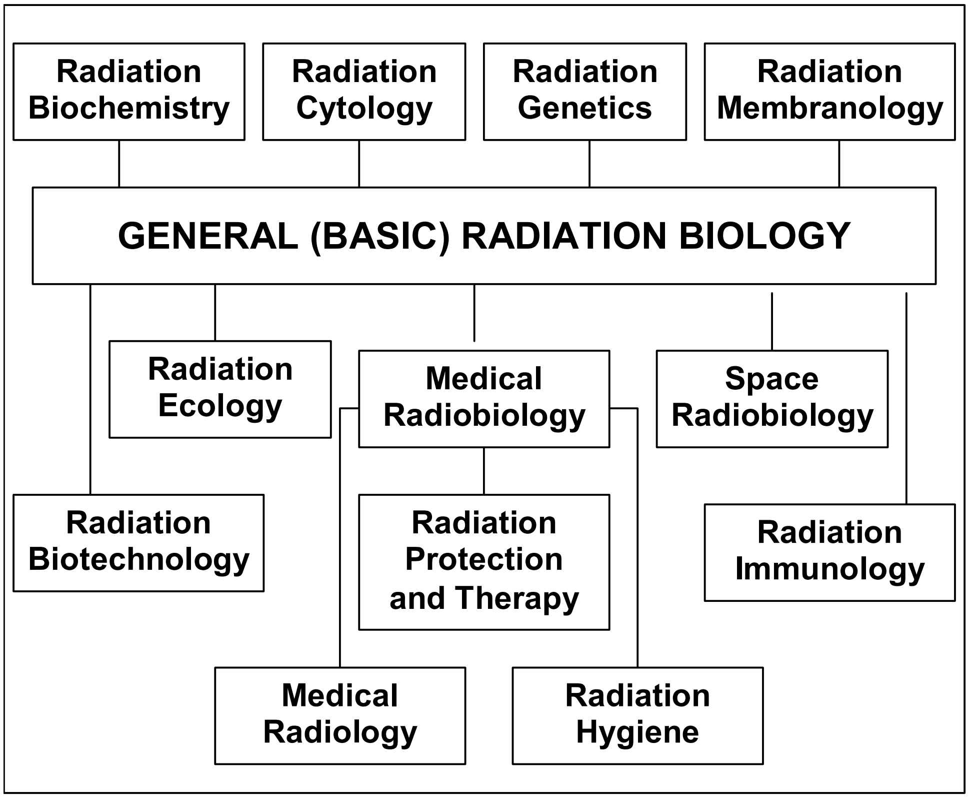

Figure 1. Relationship of the subfields of radiation biology.

The figure shows the complex interrelated system of various radiobiological disciplines, whose advances are used both for the comprehensive study of organisms and communities exposed to radiation, and for using ionizing radiation itself in the treatment of malignant tumors (medical radiology), in various medical diagnostic systems (radioimmunoassay, computer tomography, etc.), in sterilizing medical instruments, certain food products, in radiation biotechnology (irradiation of seeds before planting, destruction of crop pests, and much more), and in nuclear power. All this serves the good of mankind and his surrounding environment.

Historically, radiation biology has devised a wide variety of different physical quantities to denote radiation dose and radioactivity, and named them mostly after scientists. In 1979, the Sixteenth General Conference on Weights and Measures in Paris adopted the International System (Système

Internationale, or SI). This employed such units as the roentgen, rad, curie, and their derivatives. However, here in the republic, as in the former Soviet Union, the old designations remain in use alongside the new ones. This often creates difficulties in the perception of the numerous dose designations. Table 1 below gives reference data for converting the principal radiation quantities to SI units.[3]

Table 1. Basic Physical Quantities Used in Radiation Biology, and Their Units

Physical Quantity	Name and Designation		Conversion Factors	
	Extrasys-temic Unit	SI Unit	Extrasystemic Unit in SI Units	SI Unit in Extrasystemic Units
Activity of a nuclide in a radioactive source	curie (Ci)	becquerel (Bq)	1 Ci = 3.7×10^{10} Bq	1 Bq = 1.7×10^{-11} Ci
Radiation exposure dose	roentgen (R)	coulomb per kilogram (C/kg)	1 R = 2.58×10^{-4} C/kg	1 C/kg = 3876 R
Radiation exposure dose rate	roentgen per second (R/s)	ampere per kilogram (A/kg)	1 R/s = 2.58×10^{-4} A/kg	1 A/kg = 3876 R/s
Absorbed radiation dose	rad (rad)	gray (Gy)	1 rad = 0.01 Gy	1 Gy = 100 rad
Absorbed exposure dose rate	rad per second (rad/s)	gray per second (Gy/s)	1 rad/s = 0.01 Gy/s	1 Gy/s = 100 rad/s
Integrated radiation dose	rad-gram (rad·g)	joule (J)	1 rad·g = 10^{-5} J	1 J = 10^{5} rad·g
Equivalent radiation dose	rem (rem)	sievert (Sv)	1 rem = 0.01 Sv	1 Sv = 100 rem
Equivalent radiation dose rate	rem per second (rem/s)	sievert per second (Sv/s)	1 rem/s = 0.01 Sv/s	1 Sv/s = 100 rem/s

Natural Radiation Sources

Man receives his greatest exposure dose from natural radiation sources. He has always been exposed to the natural radiation background. It is produced by cosmic rays and by radioactive elements contained in the earth's crust and the food we eat (Table 2).

Table 2. Natural Sources of Ionizing Radiation

Source	Mean Annual Dose		Percentage of Dose
	Rems	sieverts	
Space (radiation at sea level)	30	0.30	15.1
Earth (soil, water, building materials)	50-130	0.5-1.3	68.8
Radioactive elements in the human body	30	0.30	15.1

The natural radiation background is relatively constant, but its level varies at different points on the globe, from 120 to 1270 millirems (μrem).[2]

About half of the external exposure received by the public from natural radiation sources is produced by cosmic rays (galactic radiation, the Earth's radiation belts, solar flares). The effects of cosmic rays increase with altitude above sea level, because less and less of the protective atmosphere, which acts as a shield, remains above us. So if we ascend from 4000 meters to 12,000 meters (the altitude of a trans-continental airliner), the level of exposure will rise about 25-fold.[2] Obviously, space flights involve much more intense exposure. The relatively young science of space radiobiology studies issues of radiation safety of short and long space flights, as well as the full panoply of problems of protecting astronauts and providing life support under conditions of exposure to cosmic rays.[4]

Ground sources of radiation include rocks, spring water, and the radioactive gas radon. These comprise five-sixths of the annual effective dose received by the population in the form of internal (incorporated) radiation with food, water, and air. The natural radioactive substances widespread in the Earth's crust emit γ rays. These are concentrated primarily in granitic rocks of mountains, and consist of ^{40}K, ^{87}Rb, and the radioactive families that begin at ^{238}U and ^{232}Th. The half-lives of these long-lived isotopes are in the millions of years.

The effects of natural radioactivity on the human body depend on the part of the Earth and vary widely. We know of quite a few places where the natural radiation background differs by two or three orders of magnitude from the world average. This includes Brazil, where it is 800 times higher, and India, Iran, France, Nigeria, Egypt, and China. Neighboring China has a group of people who live with a natural radiation background three to five times above normal (5×10 Gy/hr), but do not exhibit an increase in the number of cancers and other diseases. In Abkhazia and Dagestan, the prevalence of longevity was high until recently, and some attributed this to the elevated radiation background in the mountains. It would certainly be interesting to know the distribution of natural radiation background in our mountainous areas, but we have no such data.

Internal exposure, which a person receives from natural radiation sources, is caused by radioactive substances that enter the body with water, food, and air. Radioactive thorium, radium, and lead are found in most people, by the exposure dose rate is very low, amounting to less than 0.01 mSv per year. The greatest contribution to exposure through the gastrointestinal tract comes from natural radioactive potassium, which creates 0.02 mSv/yr in the tissues of the gonads, which can cause mutations in humans. Individuals who consume a lot of fish, mollusks, and other seafood can receive relatively high exposure doses through ^{200}Pb and ^{210}Po. Both these radioactive isotopes occur in rather high concentrations in reindeer meet, which accumulates in them by feeding on lichens.[2] There are many similar examples of the presence of radioactivity in food products. The most surprising thing is that people who live from generation to generation under conditions of elevated natural radiation become more radiation tolerant.

Radon

The highly toxic gas radon, which decays to uranium and thorium, occupies a special place in the ranks of natural radiation sources. This gas is colorless, odorless, and tasteless, and is 7.5 times heavier than air, so it flows along the ground wherever it escapes. The concentration of radon in air depends on the permeability of the soil and the depth of occurrence of the radon-bearing beds. It is called the “killer gas.” The danger of dying in your home from radon is thought to be much more realistic than that of natural disasters such as fire or flood. Radon is released from rocks and enters a room with building materials or from the soil on which the building stands. Consequently, a closed room can accumulate fairly high levels of radon, averaging some eight times more than in outdoor air.[2]

An increase in the concentration of radon in inhaled air causes physiological changes in the body by affecting the pituitary and adrenal cortex. During flare-ups in the concentration of radon, some 30% of the population experiences a feeling of alarm, palpitations and hot flashes, migraines, and insomnia. Forecasts of radon flare-ups are related to perturbation of the Earth's magnetic field and with variable compression and extension of rocks, which actively release the gas. For this reason, it is hypothesized that human feelings of well-being are affected less by magnetic storms themselves than by the radon releases they cause.

For a long time, medicine has been unable to answer the question why certain districts have much higher percentages of malignant diseases. Now that the answer has been found, these phenomena have even been found to be predictable. According to American scientists' data, three to four people per thousand living today will die from lung cancer caused by radon. And the mortality risk among smokers is ten times greater due to the synergistic effect (the combined action) of radon and smoking. According to the foreign press, the U.S. records about 20,000 radon-related deaths each year. In Germany, according to 1991 data, of 25,000 people who died of lung cancer, 1,056 were caused by radon. According to data published in the Soviet media (*Meditsinskaya gazeta* ["Medical News"] for March 30, 1990), about 15,000 people died annually from radon-induced cancer. Kazakhstan does not keep such statistics, so we cannot understand the sources of the Union calculation.

Control levels of radon in inhabited houses, both in Russia and in Kazakhstan, should not exceed 200 Bq/m^3, and in new ones they should not exceed 100 Bq/m^3. And if the level of radon in indoor air cannot be reduced, the residents must be moved (we have never heard of such a case here in real life). In the U.S., a concentration of 190 Bq/m^3 is considered sufficient to require protective measures, at 40-190, they are strongly recommended, and below 40 people can live in peace. In many countries, appropriate government programs are in place, and thorough geological studies are performed in areas of future development. In these countries, findings regarding indoor radon concentrations are required not only before construction, but also for sales and rentals. But measures related to radon protection are set out there in special catalogs that also list their effectiveness and cost. Thanks to this strict monitoring, for example, 4,600 homes in Sweden were deemed unfit for habitation (in 1989). In several provinces in France, 40-fold elevations in radiation due to radon were discovered. In 1992, Kazakhstan introduced mandatory radiation checks for all inert building materials (*Ekspress K* ["Kazakhstan Express"], March 24, 1992).

Precautionary and protective measures against radon are now well known. For example, since the greatest hazard is due to radon contained in the steam of baths and showers, the simplest and most effective measure is good ventilation and the installation of air filters in these rooms. Basement ventilation systems are recommended, as well as the finishing of room walls with plastic material, several coats of oil paint, or simply wallpaper, which reduce radon emissions by a third. This is most relevant for the bottom two floors. Because radon from the soil enters indoor spaces through cracks in floors, walls, and poorly fitted paneling, it is considered effective to cover the soil under homes with concrete, that is, to seal the building foundation. Radon is removed from drinking water by simple boiling, or by the use of charcoal filters. It should be kept in mind that the most radon is released in January and July.

The radon problem is very important worldwide. In Kazakhstan, we are also interested in studying these vitally important issues: the government operates the Radon program, and has set up production of its own express radon meter under the name "Rayon." However, we still lack integrated radon measuring equipment capable of determining the average daily, monthly, and yearly radon dose burden, have not established a radon metrological certification system, do not periodically calibrate γ spectrometers, and have not ordered full scientific research.[5] even so, radon issues require urgent solutions, especially since 50% of the republic's territory is contaminated by this poison gas, and a link between radon concentrations and seismic activity has not been ruled out.

Artificial Sources of Radiation

Artificial radioactive sources are all around us. Man has created hundreds of radionuclides, which along with X-rays are used in medicine and industry, to generate power and detect fires, in the manufacture of glowing watch faces and the search for minerals, and finally, for the development of nuclear weapons (Table 3).

Even so, man receives his greatest dose from natural sources of ionizing radiation. This conclusion is generally accepted and has been confirmed by the prestigious United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), created back in 1955 by the

Table 3. Artificial Sources of Radiation (Estimated Mean Annual Doses)

Source	Annual Dose		Percentage of Natural Background (up to 200 rems)
	mrem	mSv	
Medical devices (photofluorography 370 mrem, dental X-ray 3 rems, chest X-ray 2-8 rems)	100-150	1.0-1.5	50-75
Airplane flight (distance 2000 km, altitude 12,000 meters), five times per year	2.5-5	0.02-0.05	1.05-2.5
Television (watching up to four hours per day)	1	0.01	0.5
Nuclear power plant	0.1	0.001	0.05
Coal-fired power plant 20 km away	0.6-6	0.006-0.06	0.3-3
Global fallout from nuclear weapons testing	2.5	0.02	1
Miscellaneous	40	—	—
Total	150-200		

UN General Assembly. For example, D. Arnolt has calculated[6] that in the former GDR, the annual burden from natural exposure averages 3 mSv (300 mrem) per person. Therapeutic exposures add 0.8 mSv (80 mrem). But such low doses cannot be harmful, while radon baths, Arnolt writes, are used successfully for therapeutic purposes. Damaging levels are about 1000 times higher, at doses of 2-8 Sv (200-800 mrem).

During his activities to develop industrial production, chemical technologies, and so forth, man has encountered toxic substances completely unfamiliar to him, unlike radiation. These are the products of burning coal and oil, smoke, pesticides, and chlorinated organic compounds, which have entered practically all areas of our lives. Dioxins alone, produced by combining chlorine with organic matter, are 68,000 times more poisonous than potassium cyanide (*Komsomolskaya pravda*, February 3, 2000). They are dangerous even in microdoses, and are not excreted from the body; they can occur even in unfiltered tap water. Compounds such as chlorobenzene and polyvinylchloride (PVC) occur in paints, finishing materials, many detergents and some soft rubber toys, and in drinks bottled in PVC containers. The buildup of these compounds disrupts the reproductive function and produces birth defects (the hands and feet are most susceptible), with mental retardation. "Greens" (ecologists) throughout the world urge us to refrain from all use of chlorine, before mankind degenerates into mutants.

Unlike the harmful burdens that man didn't used to experience in his natural environment, radiation has always been present. Moreover, biological systems have a wonderful capacity for adaptation to prolonged, centuries-long exposure to ionizing radiation. Living organisms have evolved protective qualities and physiological mechanisms capable of countering radiation if its level is not too high. And it's also important that so far, there is no direct, convincing proof of the development of genetic anomalies, the appearance of various forms of cancer from exposure to X-rays and γ-rays, at least in doses of about 0.01 Gy.[1] This does not mean we have an absolute safety guarantee in such cases. At least the conclusion that a given pathology is radiation-induced requires a great degree of caution, and in the absence of indisputable factual proof, can only be speculative.

Manmade radioactive sources are most widely used in medicine, specifically in nuclear medicine, one of the most modern and rapidly developing fields.[7] Today it is hard to find anyone who has not experienced radiological or radionuclide (radioisotope) methods of diagnosis, since they are used in practically all areas of medicine. Cancer patients are very familiar with radiation therapy, which paradoxically enough is one method of fighting cancer.

In recent years, diagnostic computer tomography has become quite widespread in our republic, permitting the creation of tomographic images of any part of the human body. In the West, this method has been used since its invention in 1972. It has enabled doctors to reduce radiation exposure doses to a few percent of those used with X-ray technology.

Calculations show that the main contribution to the level of human exposure received from manmade sources does come from medical procedures. These doses are obviously highly individual. They range from zero in people who have never had an X-ray to many thousands of times the average annual "natural" dose.[2] Even so, it is hard to find people who have never in their lives undergone a single photofluorograph,[8] which is also an X-ray method. We should also note as an aside that doctors often order such radiation procedures liberally, usually to confirm diagnoses and avoid liability. Oversight of the use of X-ray diagnostics in medicine is

[8]—A technique far more routinely used in the FSU than here in the U.S.—*Trans.*

much weaker than in the nuclear industry. Patients generally do not object and calmly accept the irradiation procedure. But it has been calculated that about a third of all X-rays are unnecessary.[1]

Understanding the lack of justification for requiring mandatory photofluorographs of the public (routine since the days of the former Soviet Union), especially for city dwellers, this author has categorically refused them for 20 years now and has never once had cause to regret it. Our schoolchildren are sometimes submitted to this procedure two or three times a year due to sloppy record-keeping and for other reasons; I can say this as an eyewitness. There is one regular pattern: the lower the doctor's professionalism, the more procedures he prescribes, including radiographic ones. All this goes on in an atmosphere of complete indifference among the doctors, parents, and teachers, side by side with rampant radiophobia in the republic. This confirms the one-sidedness of the information given to our people, who believe that all woes come from the Semipalatinsk Test Site.

The mean effective equivalent dose (adjusted for the radiation sensitivity of various tissues) received from all sources of exposure in medicine is believed to be about one mSv per resident, that is, about half the mean dose from natural sources. Thus, the collective effective equivalent dose (the effective equivalent dose received by a group of people from all sources) for the entire world population is about 1,600,000 man-sieverts per year.[2]

World society is most alarmed by the creation of artificial radiation sources for the proliferation of peaceful and military nuclear technologies. Public organizations of the Group of Seven and Russia are undertaking decisive steps to reduce the risk of nuclear accidents and disasters at nuclear power plants, to solve the problem of handling radioactive waste (radwaste) from the nuclear industry, including spent nuclear fuel, as one of the world's most important problems.[8] In September 1996, the UN General Assembly adopted a treaty banning nuclear testing. However, despite the ban, some nations are ignoring it. For example, in May 1988, India and Pakistan detonated 12 nuclear explosions. This is very alarming.

The first nuclear test in history was conducted more than 50 years ago at the Los Alamos test site. A bomb with a plutonium core was detonated. But mankind first heard of nuclear explosions after the bombings of the Japanese cities of Hiroshima and Nagasaki in 1945, when a plutonium and a uranium bomb were set off. However, more complete information about the awful radioactive fallout that followed accidents and atmospheric explosions did not become available until the declassification begun in 1986. The US Department of Energy provided information about Hanford, which released 40 curies of radioactivity into the atmosphere during nuclear weapons production from 1944 to 1947, that is, five years before the Semipalatinsk Test Site began operations, and Great Britain disclosed information about Windscale, where the effective collective dose produced by a major nuclear accident in 1957 was 1300 man-sieverts.[9] After the detonation of an American atom bomb in Nevada on March 1, 1955, the radioactive fallout arrived 7-18 days later, first in England, then in Greece and Turkey, and later in Eastern Europe. In all, more than 1900 nuclear explosions have been detonated worldwide.

The former Soviet Union conducted 132 tests on Novaya Zemlya alone, releasing a total energy into the atmosphere equivalent to 320 megatons of TNT, equivalent to the production of 15 MCi of ^{137}Cs and 10 MCi of ^{90}Sr. In 1957, an explosion at the Kyshtym (South Urals) nuclear complex for plutonium extraction released 20 MCi of radioactivity from a reservoir. Two thousand TBq of ^{90}Sr and 20 TBq of ^{137}Cs [34,000 and 340 curies, respectively] fell out onto land and water surfaces.[10] In 1967, the same complex in the Urals suffered a cesium emergency that lasted until 1972. In that disaster, the windborne transport of radioactivity from Lake Karachay (a settling pond or dump), contaminated about 1800 km^2 with 60 TBq of ^{90}Sr and 17 TBq of ^{137}Cs [1020 and 289 curies, respectively].[11]

The radioactive plumes from the 1986 Chernobyl tragedy were felt practically worldwide. The disaster released 100 PBq [100,000 curies] of ^{137}Cs and a total of 50 million curies of radioactivity into the environment.[12] The last, third unit of the plant was only just closed on December 15, 2000. Unit 1 had been brought online in 1977. A full halt of operations of Unit 3 will not occur for some time, and will cost 82.5 million rubles in 2001 alone (*Komsomolskaya pravda*, December 15, 2000).

In April 1993, at a radiochemical plant in Tomsk-7, an explosion occurred in a unit containing 500 grams of plutonium, several tons of uranium, and a similar amount of nitric acid and radioactive aerosol that entered the atmosphere (*Moskovskiye novosti* ["Moscow News"], April 18, 1993). According to data from Greenpeace, the radioactive background at several spots in the affected area reached 3000-6000 decays per cm^2 per minute.

Atmospheric nuclear tests are the most dangerous. Underground explosions usually do not involve the production of radioactive fallout.

Radioactive material, which remains in the air for about a month, gradually falls to earth. However, most of it enters the stratosphere (an altitude of 10,000-15,000 meters) and remains there for many months, gradually falling and scattering over the globe. Of the several hundred different radionuclides contained in this fallout, the main contributions to human exposure come from ^{14}C (with a half-life of 5,730 years), ^{137}Cs (33 years), ^{95}Zr (64 days) and ^{90}Sr (28 years).

The Semipalatinsk Test Site is distinguished by the number and duration of testing, the most severe of which lasted from 1949 to 1963, when explosions rumbled through the air and the ground. Over 60% of all the Soviet Union's nuclear tests occurred at Semipalatinsk (*Argumenty i fakty* ["Arguments and Facts"], No. 50, 2000). By 2000, the contribution of ^{137}Cs and ^{90}Sr, the site's principal radionuclides, had been practically exhausted.

All radioactive elements distribute themselves differently in the bodily tissues. They are cleared with the most difficulty from bone, where they are held in a chemically bound state; this is most applicable to strontium, as well as radium, uranium, plutonium, etc. They are cleared fairly quickly from the many tissues where they form highly soluble salts. Cesium is distributed uniformly in animal tissue and leaves the body without difficulty within 100 days, which is its half-life in the body.[13] Under natural conditions, radionuclides with various affinities usually do not exhibit separate actions, but combined ones, which causes more complex links between the living system and the emission.

Nuclear power plants, which were so popular before the Chernobyl accident, have gradually lost their prevalence, and we now see a declining trend in their construction. The main reasons are the economic decline and the strong public opposition. The Americans have generally switched to steam and gas power generating units, which are much cheaper than nuclear power. The proposed construction of our nuclear power plant (with a capacity of 1900 megawatts) on Lake Balkhash has been deferred. The reason is the unfinished design and the need for additional studies of the site's reliability and earthquake resistance. The problem of radioactive waste remains extremely urgent as well.[14] Uranium ore is mined and processed into nuclear fuel in many countries. At all stages of the production cycle, radioactive substances, including long-lived ones, enter the environment. So the reliable disposal of the hazardous byproducts is extremely important. The U.S. plans to cleanse itself of the accumulated radioactive dirt by 2005, for which it has allocated five billion dollars a year (*Radikal*, August 7, 1991). "Burials" of radioactive waste in Russia cost 200 billion rubles in 1993 terms (*Moskovskiye novosti*, May 16, 1993). At Chelyabinsk-65 alone (Mayak Production Association), the accumulated activity is over a billion curies, and the dose rate of Lake Karachay is 600 R/hr. Russia has over 15,000 metric tons of nuclear fuel waste and over 20 metric tons of plutonium residue.

Kazakhstan's sources of hazardous radioactive products are uranium mining and ore processing enterprises, the nuclear power industry, the Semipalatinsk Test Site, and many accidental dumps of worn-out industrial parts and equipment containing emitters. For example, back in 1990, according to *Argumenty i fakty Kazakhstana* ["Kazakhstan Arguments and Facts"], No. 46, 2000, a slag heap leaking radioactivity 100 times above the allowable limit was discovered on the grounds of a rebar mill in the very center of the city of Semipalatinsk. On another of the city's streets, a completely unsecured source turned up consisting of 70 meters of radioactive garbage containing ^{137}Cs leaking at up to 3800 μR/hr. Hundreds of city dwellers have already picked through these dumps and carried off various discarded parts without suspecting they were in mortal danger.

According to 1997 data from the RK Ministry of Ecology and Bioresources,[15] the republic has 101 temporary burial sites where 225 million items of low-grade radioactive waste with a total activity of 57,600 curies are concentrated. Another 100,000 radioisotope sources with a radioactivity of 200,000 curies are in use. The neglected radioactive dumps are also hazardous because natural precipitation acting on the radionuclides leaches them out to migrate into the biosphere, ground, and aquatic ecosystems. The radionuclide migration process is still poorly understood.

Uranium production in Kazakhstan is continually being cut back, and ore administrations are closing. Nevertheless, the waste disposal problem remains extremely pressing. Worldwide, about half of the uranium ore is mined at the surface, and half underground. Mines and processing plants serve as sources of contamination, since ore processing produces tremendous amounts of "tailings." These highly toxic wastes will remain radioactive for millions of years. They must be isolated. Some believe that in order to protect the environment from elevated radioactivity, it would be desirable to extract the natural, untouched uranium from the ground and use it as nuclear power plant fuel.[16] According to these calculations, an atom of ^{235}U left in the ground will release 40 MeV through α emissions and 5 MeV through β and γ emissions during its decay lifetime, while the corresponding amount of buried decay products will release one-fifth of a MeV through β and γ emissions and an insignificant level (about a quarter of a MeV per hundred years) through α emissions.

According to UNSCEAR 1998 data, the actual exposure doses received from the entire nuclear cycle (of nuclear power plant radioactive releases) when the plant is operated normally is significantly less than those from natural radiation sources. By 2010, these will be only 1% of the natural background.[2]

Methods of protecting against artificially created radioactivity have been under development for many years. The International Commission on Radiological Protection (ICRP), which develops the basic concepts and rules for handling radioactive materials, was formed back in the 1920s. Every country that operates a nuclear power industry develops its own national standards based on ICRP recommendations.

Every year, as the sphere of application of radiation grows, the number of people who come into contact with ionizing radiation in their daily lives grows. These include the personnel of nuclear reactors and accelerators; doctors and nurses in radiology wards and clinics; geologists working with radiation devices; miners and mining engineers; nuclear physicists; biologists and agronomists; specialists studying radiation biotechnology; and all those involved in the disposal of radioactive wastes, including servicemen in the military-industrial complex.

In order to protect people from exceeding the maximum allowable scientifically established dose, radiation sources are shielded and located away from work places, time working with them is limited, remote manipulators are used, and protective suits are worn. Even so, neither lead nor concrete and barite barriers can completely absorb hard γ- and X-rays; they merely reduce the flux. It is even more difficult to protect against neutrons. Lead and concrete are ineffective, so neutron sources are often held underwater, and paraffin and plastics are also used.

The arsenal of measures to protect man from radiation is quite extensive.[17] Recommendations and rules have been developed against the possible occurrence of a radiation hazard. There are physical, pharmacological, and biological radiation protections, which also include a large group of radiation protectors (things that reduce the effects of radiation).

The treatment of human radiation injuries is a separate field of clinical medicine that includes therapeutic and surgical approaches. Depending on the stage of radiation sickness and its course (acute or chronic), hematopoetins, bone marrow transplants, peripheral blood transfusions, immunomodulators, and many other means are used, including special complete diets and spa and sanatorium care.

A high level of medical care is especially important in restoring the health of people living in unfavorable environments. This fact plays a key role in monitoring people's condition if they receive small doses of radiation, which can relate to the long-term consequences of the Semipalatinsk tests. The condition and longevity of people who managed to survive the nuclear bombings of Japanese cities in 1945 confirms this dependence on good treatment and preventive observation. The thorough and prolonged examinations of 91,228 people and their 31,150 children has not revealed the expected outburst of breast and thyroid cancers, leukemia (these particular types of cancers are radiation-induced) over the next four and a half decades. Nor has it revealed an increase in the number of genetic anomalies in children of exposed parents relative to a control group.[18] However, the problem of the Japanese tragedy remains open, research is continuing, and final conclusions have not been drawn.

Radiation Sensitivity

All life on Earth is affected by ionizing radiation. However, the measure of radiation sensitivity (the alternative is radiation tolerance or resistance) of a particular biological species belongs to that species alone, and differs from others. In other words, a particular dose of radiation could, for example, prove lethal to a human, but have a salutary effect for certain bacteria or insects. There are bacteria that reproduce successfully in nuclear reactor channels at doses of 100,000 grays.

Within a single species, the degree of radiation sensitivity can also vary by gender and age. In addition, even within a single specimen, cells and tissues of different systems can be radiation sensitive (the hematopoietic system, the epithelium of the intestinal mucosa) or radiation resistant (muscle, nerve, bone tissues). The decisive link in the response of multicellular biological systems to radiation exposure has been proven to be the cell, which contains the genetic material. It is also indisputable that the main target of radiation is the biological membranes, which regulate the cell's relationship with its external environment.[19]

The reasons for variation in radiation sensitivity have not been completely explored. Highly organized beings have been found to be more easily injured by radiation than lower forms of life, but this relation is not always linear. A link has been found between radiation sensitivity and aspects of nutrition and the organism's chemical makeup. For example, switching Midday gerbils (*Meriones meridianus*) to a vivarium diet noticeably reduces the animals' radiation resistance.

Radiation sensitivity criteria are based on the survival rates of biological specimens. This is measured by the $LD_{50/30}$, the lethal (fatal) dose of radiation at which 50% of the studied specimens die within one month. Table 4 shows tentative values of $LD_{50/30}$ for overall γ-ray exposure of several biological systems based on data from various authors.

The rather wide range of radiation sensitivities is not caused by species variations alone. All life has inherent individual sensitivity. It has long been noted that people react differently to radiation exposure. Some radiation therapy patients exhibit vertigo, nausea, and weakness after the first few sessions, while other s complete the entire course of treatment without any discomfort. The body's overall condition, the severity of concomitant diseases, and immunity play a big role in this. Organisms are highly sensitive to radiation during gestation. A dose that is not harmful to the mother can cause serious disruptions to a fetus.

Table 4. Radiation Sensitivity of Various Subjects to a Single Gamma-Ray Exposure

Subject	Dose, Gy
Sheep	1.5-2.5
Guinea pig	1.5-3.5
Donkey	2-3.8
Dog	2.5-3
Human	2.5-4
Monkey (various species)	3-6
Mouse (various lines)	6-15
Rat (various lines)	7-9
Birds, fish	8-20
Rabbit	9-10
Insects	10-100
Snakes	80-200
Higher plants	10-1500
Algae	180-1000
Bacteria (various species)	50-7500
Viruses (various classes)	4500-7000

Different animal, plant, and microbial species react differently to radiation exposure. Some are the most radiation-sensitive members of the biogeocenosis (a homogenous piece of the natural environment with a certain membership of living organisms and indirect components that are interrelated with one another, synonym “eco-system”). Radiation in-juries to members of such species occur at consid-erably lower doses than in other natural communities. Such highly radiation-sensitive species are usually called “indicators.” In terms of his level of radiation sensitivity, man occupies a middle position among the mammals. Cold-blooded animals are considerably more radiation-resistant than warm-blooded ones. Plant organisms are more tolerant than animals, but their radiation sensitivity also varies widely from species to species. The most radiation tolerant are the microorganisms (bacteria, protozoa, yeasts, etc.). Knowing the level of radiation sensitivity is an important defining criterion for judging the degree of radiation damage to a given natural area that is unfavorable in this respect.

Bioindication

The ubiquity of pollution of the natural environment by chemical and physical factors, including radiological ones, is forcing society to an intensive study of the problems of environmental monitoring. The most effective form of seeking a pollutant is the reaction of highly sensitive biological systems, or bioindicators. Radiobiologists also continually search for biological methods of indicating the effect of ionizing radiation and subjecting it to quantitative analysis. At the level of the organism, the achievement of this objective is considered in terms of various cy-togenetic, biochemical, immunological, hematological, and biophysical criteria. The basic requirements for bioindicators of radiation impact include the effect’s dose dependence and the organism’s sensitivity, specificity, and universality. However, despite the existence of a huge number of species in nature, from plants to mammals, the circle of bioindicators is small. Among the animals, attention from the standpoint of bioindication focuses on three groups possessing the needed qualities. These include mammals, soil mesofauna, and microfauna.[20]

The soil is packed with living organisms. They comprise 90-99% of the zoomass of land ecosystems. Many of their forms are very sensitive to the effects of radiation and can concentrate radionuclides.[21] It has been established that long-lived soil invertebrates (earthworms, carapace mites, centipedes, some insect larvae, etc.), as well as microarthropods living in the tiniest pores in the soil, are promising bioindicators of radioactive contamination.[22] In the Chernobyl area, earthworms, wood lice, mollusks, daddy longlegs spiders, and *Hemiptera* disappeared immediately after the accident and began reappearing a year later.[23]

Along with soil invertebrates, small mammals, who spend most of their lives in the topsoil and litter, are also highly subject to the effects of radioactive contamination. This was also noted in the study of the aftermath of the disaster at Chernobyl and at Kyshtym. Murine rodents have long been regarded as the most promising bioindicators for any anthropogenic impact. The extensive class of rodents comprises half of all mammal species and is the best studied in ecological terms. They meet all the requirements for bioindicator groups of vertebrates. These animals occur in all landscape-geographic zones, are numerous, have active metabolisms, and are in continuous contact with the studied anthropogenic factor. Living primarily in and on the soil, rodents receive the maximum dose of radiation over their whole bodies, including β-rays, because the sizes of their bodies are comparable to the run lengths of the particles. The little beasts are available for capture, and can be used without harming the ecosystem.[24]

Because only observations of mammals can be extrapolated to man, rodents, with physiological parameters close to ours, are the most optimal bioindicator model. In addition, it has been established[20] that only vertebrates can serve as bioindicators of ^{137}Cs contamination. They are also sensitive to ^{90}Sr. Among the invertebrates, only those with calcified skeletons (for example, shell-bearing mollusks) react effectively to ^{90}Sr.

The many years of research on the aftermath of the Chernobyl and South Urals accidents[10,12] have revealed much higher absorption of radiation by wildlife systems than by man. For example, at Chernobyl, dose burdens produced radiation absorption 40-115 times higher in coniferous and deciduous trees than in man, 46-95 times higher in meadow ecosystems, and 30 times higher in rodents in ground ecosystems. In the Ural Mountain environment, at very high doses on the order of 1000 Ci/cm^2, murine rodents exhibited the most varied radiation effects. Their mortality rose and their lifespans fell. But after 15 years, when 30 generations had passed, their populations had completely recovered. At the same time, the populations of mammals such as elk, deer, wolf, lynx, and hare showed no strong radiation effects. The above is convincing proof of the effectiveness of choosing rodents as bioindicator species to represent the mammals.

In reviewing the radiation sensitivity of the plant cover, agricultural plant ecosystems, that is, agricultural crop plantings, are generally less tolerant both of the action of ionizing radiation and of all deleterious factors of anthropogenic life than natural plant ecosystems. Of the natural plant systems, coniferous forests, especially their needle and apical meristem, are the most radiation sensitive compared to other types of ecosystems. Critical indicator links also include forest undergrowth and the thin upper layer of virgin soils, and lichen and moss communities of benthic organisms in aquatic ecosystems. Lichens are good bioindicators and radioactive waste accumulators.

In plots with high levels of radioactive contamination (180 Ci/cm^2), as resulted from the Kyshtym explosion, pine forests were the primary victims ("red-headed" forest, also seen at Chernobyl). Birch forests proved more tolerant, dying only in plots that received 4000 Ci/cm^2, and meadow communities were next. In all the events that occurred, secondary effects (microclimate, lighting, precipitation, etc.) also played a role. For example, the thinning of the forest and increase in available light produced rapid reproduction of grassy species, whose total mass rose three- to five-fold compared to uncontaminated forests. Consequently, the associated secondary climate changes affect the manifestation of bioindicator properties.

High and Low Doses of Radiation

Radiation biology, an experimental science that arose in the middle of the now-last century, studied primarily the biological action of ionizing radiation in lethal doses on the molecular, cellular, and organism levels. It has determined that at high radiation exposure doses, both man and other mammals suffer acute injury. This effect of radiation begins at "threshold" doses. This information was obtained in the radiation treatment of cancer. It turned out that the severity of the body's injury depends on whether the person receives a certain dose in one exposure or over several sessions. A patient tolerates a broken series of small radiation doses much more easily than a single total dose, since most organs have some ability to heal radiation injuries. In addition, it has become clear that whole-body exposure is always more hazardous than local exposure. Table 5 gives a picture of man's general radiation exposure according to dose.

Research in the high-dose area continues because the results are needed to assess the consequences in case of a nuclear war, nuclear plant disasters, etc. The problem of low doses has gained priority in radiobiology today. The more time passes after manmade nuclear explosions and nuclear weapons tests, the more acute the question of the

Table 5. Human Biological Effects under General Irradiation

Dose, Gy	Effect
2000	Death on the spot
50-100	Cerebral form of radiation sickness (coma, death within 1-2 hours)
10-50	Intestinal form of radiation sickness (internal bleeding in the gastrointestinal tract, death within 1-2 weeks)
4-6	Bone-marrow form of radiation sickness (severe injury to bone marrow, 50% mortality within 1-2 months)
2-4	Moderate radiation sickness (3-9 years reduction in life expectancy)
1-2	Immunodeficiency (post-radiation carcinogenesis, etc.)
0.5-1	Disturbance of hematopoiesis, primary disturbance of immunity, doubling of mutations, increased frequency of malignant neoplasms
0.1-0.5	Temporary male sterility
0.05-0.1	Mutations recorded
0.002-0.05	Stimulation of metabolism
0.001-0.002	Optimum metabolism
Under 0.001	Suppression of metabolism

consequences of long-term (chronic) exposure to small, low-intensity doses on all living things becomes. Only living things, their reactions and condition can give biological meaning to precise physical measurements and an answer about an environment's suitability for human life! So it is perfectly obvious that whatever precise dosimetry exists for measuring the radioactivity of contaminated lands, the chief criteria for the assessment remain biological indicators. In other words, radioecological issues cannot be resolved without studying the living things in the corresponding plots.

"Low doses" differ in size for various species of plants, animals, and man, because the radiation sensitivities of living beings, as we have seen, vary greatly. It is currently accepted that low doses include those that are five to ten times the natural background on the one hand and about one-hundredth of $LD_{50/30}$ on the other. For man, who as we have already said occupies a middle position among the mammals with respect to radiation sensitivity, low doses are 0.03-0.05 Gy in a one-time exposure.

The effects of low doses are usually mild; they are difficult to record, unlike those of large doses, which are easily identified experimentally on laboratory animals. At present, scientists' opinions are quite contradictory when it comes to defining "low doses."[25] Some decry the increased danger of low doses, while others reject all aspects of their effects. Still others cite evidence of the beneficial effect of radiation in small doses, right up to reductions in cancer mortality and increased lifespan. The stimulant effect of low doses of ionizing radiation on physiological functions has been termed "radiation hormesis."[26] Confirmation of the favorable effect of low doses of ionizing radiation comes from numerous examples of the stimulation of the growth of agricultural crops and the physiologic activity of bacteria, the increased lifespans of aquatic organisms (inhabitants of the aquatic environment) and certain species of rodents, the increased radiation resistance to a second exposure at injurious doses, a phenomenon that has been named "adaptive response," and much more.

Nevertheless, radioactive contamination of broad areas of land around the globe worries the public and makes it urgently necessary to perform a comprehensive investigation of the effects of low doses of technogenic and natural radiation on ecological systems, communities, and biocenoses. From the standpoint of the impact of low doses, great problems have arisen with the lands that have suffered from the long years of nuclear explosions at Semipalatinsk and other Kazakhstani test sites, the accidents at Chernobyl, in the Southern Urals, etc.

Analysis of the Chernobyl and Kyshtym events is also ambiguous. On the one hand, the extensive literature that explored Chernobyl's tenth anniversary[23,27] attests only to the negative consequences of low doses of radiation on human life and the environment. On the other hand, it has been convincingly shown that over a long period of time after these accidents, as the soil cleanses itself, the biosphere also cleanses itself, and animals and plants undergo environmental adaptation to low doses of radiation.[10,12] Similar phenomena are occurring at the Semipalatinsk Test Site lands.[24] Here we should emphasize that the Chernobyl or Semipalatinsk conditions cannot be reproduced in simulations, so their genetic and biological effects are unpredictable. They must be studied only in these zones themselves.

Radiation Adaptation

The problem of animals' adaptation in radiation biogeocenosis (ecosystems) is now coming to the fore. Where trace amounts of radionuclides have been fond over large areas, they do not go unnoticed by living things, which must exist in that environment and adapt to it. The term "adaptation" denotes the organism's adaptation to the environmental conditions, expressed as changes in their external and internal features. Animals' adaptation to chronic radiation exposure has interested researchers for a fairly long time. They have learned that radiation adaptation usually accompanies phenomena such as radiation-induced variability and radiation-induced selection.

Practically all the literature dedicated to the radiation adaptation of animals describes research performed on rodents, which once again confirms the acceptance of this type of mammal as the leading terrestrial bioindicator of radiation biocenoses.[24] Observations have led to the theory of population radiation adaptation, which says that ionizing radiation causes an increase in feature variability in natural populations, which in turn intensifies radiation-induced selection.[28] This process accelerates synergy, that is, the combination of chronic radiation exposure with other physical and chemical factors. As a result, the population gains more resistant forms of animals, which produce progeny with increased resistance both to ionizing radiation and to ordinary environmental factors.[29] Thus, the population acquires new radioecological qualities that support its adaptation to the changing conditions of life. All this enhances survival under the new radiation conditions.

Numerous experiments on rodent populations performed under conditions with increased radioactivity have revealed that both external and internal parameters of the organism are subject to variability. Population measures change (fertility and lifespan increase), and internal parameters (relative weight of the liver and spleen, blood counts, etc.) increase. The mean weight of rodents in the population on plots with elevated natural or artificial radiation is somewhat greater than in animals on nonradioactive lands.[20,28] The degree of feature variability also depends on the species of animal and its radiation sensitivity. Organisms' resistance to radiation is largely linked to their physiological state, biochemical makeup, and ecological and evolutionary features.

Our rich experience studying the aftermath of unique nuclear accidents and disasters has made a substantial contribution to solving the problem of radiation adaptation. For example, 15 years after the accident in the South Urals, murine rodents have undergone complete readaptation, and their radiation tolerance has risen 30%. An initial population decline has yielded to complete compensation. In aquatic ecosystems, vegetarians (common and crucian carp) proved most vulnerable, but their populations returned to normal after three years. Other aquatic ecoystems (plankton, vegetation, invertebrates) showed no ill effects from the radiation. Genetic research begun five years after the accident recorded mutations. However, as the dose rate declined, many mutation features stabilized and were later eliminated by natural selection.

The fairly high radiation resistance of natural and cultivated ecosystems to the action of ionizing radiation has also been noted at Chernobyl.[12] However, signs of radiation-induced damage in living things at "lower" levels of organization (below the ecosystem) were found over large areas. These include cytogenetic disturbances in various animals and plants. Similar phenomena have been recorded even as far away as Norway.

Thus, numerous experiments performed on wild rodents exposed to artificial internal or external radiation, and the study of the aftermath of nuclear explosions and disasters, indicate that under the influence of chronic radiation exposure, animals develop marked adaptive features that enable the organism to reach a new ecological and physiological level. The radiation adaptation promotes population survival and the appearance of individuals with qualitatively new qualities.

Even so, the mechanism of adaptation of animal populations to ionizing radiation is not fully understood. The most likely basis for this mechanism is the link between an increase in the radiation resistance of populations and the natural selection of radiation-tolerant forms through improvement in the recuperative abilities of individual specimens and the population as a whole.

The study of the mechanisms of radiation adaptation of the entire diverse fauna of the regions of Kazakhstan, which have been affected by the aftermath of nuclear testing, is an incontrovertibly important objective in solving the problem of environmental health.

Radioecological Studies of Life on the Test Site Grounds Before and After Closure

Ground and atmospheric explosions at the Semipalatinsk Test Site were detonated from 1949 to 1963. Later tests, which were underground, continued until the site's closure on August 29, 1989. All this time, the test site was classified. Much of the documentation from that period remained in Russia after the collapse of the Soviet Union. Hardly any scientific research was done on the wildlife on the test site grounds during its operation. Not until 1984 did an associate at the Moscow Institute of

Biophysics of the USSR Ministry of Health defend a candidate's dissertation entitled, "Radioecological Assessment of the Natural Populations of Rodents Inhabiting the Territory of the Radioactive Plume from an Excavating Underground Nuclear Explosion."[30] The work was done under the "top secret" seal, in manuscript form only. In the "Scientific Novelty" box on the abstract form, the author stated that the research had been done for the first time.

Observations were made at the confluence of the Shagan and Ashchi-Su Rivers, where the radioactive plume from the last underground thermonuclear explosion, with a power of 140 kilotons, had passed 1.2 km away from ground zero. The control plot outside the plume area was located 8 km from the test plot. The external γ-ray exposure dose was 1-1.5 mR/hr in the first plot, and 10 μR/hr in the second, i.e., it corresponded to the regional background level. Levels of ^{90}Sr and ^{137}Cs in the soil and vegetation of the test plot were two to three orders of magnitude higher than those of the control. Environmental systems of the test plot alone contained detectable ^{60}Co and tritium. Both areas were identical from the standpoint of natural climate, soil and vegetation. The flora consisted of the same species: white sagebrush (*Artemisia leucodes*), sheep's fescue (*Festuca ovina*), prostrate summer cypress (*Kochia prostrata*), fisheye (*Ceratocarpus arenarius L.*), chee grass (*Lasiagrostis*), and pea tree (*Caragana*). The mass of vegetation per unit of area (1 m^2) was approximately the same in the test and control plots. Agrochemical analysis of the soils and the humic matter, available nitrogen, phosphates, potassium, calcium, and magnesium contained in them were quantitatively similar.

Thus, the factual data showed that the two plots differed only in radiation factors.

The study used two rodent species as bioindicators: the red-cheeked ground squirrel (*Spermophilus erythrogenys intermedius*) and the long-tailed field mouse (*Apodemus sylvaticus*). The four-year study established that animal populations that inhabited the study area for long periods were exposed to chronic external and internal radiation 50-100 times higher than the control background levels, that is, low doses of radiation.

The red-cheeked ground squirrel population was adversely affected by the exposure, judging by certain morphological signs (loss of weight, plumpness, liver and spleen indices, i.e., the ratio of the organs' weight to the total body weight) and ecological measures (decline in population, increased incidence of stillbirths and parasitism). Nevertheless, the reproductive ability of sexually mature male and female ground squirrels inhabiting the contaminated lands did not differ from that of controls (rodents usually bear two litters per year). It is remarkable that the radiation tolerance of the females was higher than that of the males (criteria: weight and plumpness, rate of parasitism). The radiation resistance of adults was higher than that of juveniles (criteria: body weight, organ indices, testicular histology) that had not yet adapted to the environmental conditions.

Unlike the ground squirrels, the field mouse population suffered absolutely no ill effects from the low levels of radiation. All studied morphophysiological and most ecological measures of the test group were at the control levels. The study was the first to establish that populations of the two species of studied rodents inhabiting a radioactive plume from an old underground nuclear explosion develop species-specific adaptive reactions to the action of ionizing radiation as an environmental factor. The author noted that the adaptation processes in the two studied rodent species appeared both in the retention of the reproductive ability of males and females and in the stimulant effect on spermatogenesis. The observed variability in certain parameters in the ground squirrels was a sign that usually accompanies adaptation phenomena.

These results form the only faunistic study before the test site closed are unique in their own way. They indicate the mammals' strong adaptive reaction to chronic ionizing radiation on the test site lands, accompanying the lives of many generations of bioindicator species, as well as the rise in their radiation resistance, recorded 20 years ago.

The study's conclusions are also extremely important; they concern the plant cover and soil quality in the radioactive plume in the early 1980s, which were absolutely identical in the test and control plots.

More than ten years after the study described above was completed, and still unaware of its classified existence, we began our own radioecological research, also on rodents (as bioindicators) inhabiting similarly located districts of Semipalatinsk Region.[24,31] The results of the two studies proved comparable with one another, and also had much in common, notwithstanding certain methodological differences.

Our many expeditions to Abay District and to a territory on the boundary of Aksuat and Kökpekti Districts, which the special services stated had not been radioactively contaminated, usually took place between spring and fall. In Abay District, where the test site was located, we selected test plots in the Uzynbulak River valley (Delegen Massif), which was near the former ground zero for nuclear tests ("Delegen"), and in the Shagan River valley (Russian *Chagan*), below where the Ashchi-Su River empties into it ("Shagan"). The control was a plot in the Bugaz River valley ("Bugaz"). All plots had similar climates.

The methodological approaches to the performance of the study conformed to standard zoological ecophysiological requirements,[32,33] and also included a large number of biochemical, hematological, and other unified techniques. Ground radiometry was carried out using an SYa1-88N instrument, and soil samples and tree cuttings were tested for radioactivity at the Physical-Technical Institute of the RK National Academy of Sciences. Prolonged route observations and accounts included study of the biotope (the species' habitat), the feed base, the type of nest, the dialing activity, and behavioral reactions. The animals were captured in consistently placed nonlethal traps. The percentage of animals entering the traps was recorded twice daily. Some of the rodents were dissected on site and studied for all necessary parameters. The rest were taken to the laboratory for further research. We note immediately that no elevated radioactivity with respect to ^{137}Cs or ^{90}Sr was detected on any of the three plots.

An assessment of the biospecificity and population aspects was performed using indices such as population size (or density, sex and age makeup, testicle size, etc.), field signs and biology (nutrition, type of nest and daily activity), and morphometric parameters and indices. In doubtful cases, to clarify the rodents' taxonomic status, we determined their craniological signs and performed cytogenetic analysis of their chromosome sets.

The investigation of morphometric parameters included generally accepted measurements of body weight, tail and hind paw length, condylobasal skull length, and width of the interorbital space. This included a study of morphophysiologic indices. Later, it involved organs such as the liver, heart, adrenal glands, kidneys, and spleen. Only after studying all these measures did we judge a given rodent community's similarity to or difference from the control.

Our research showed that in all plots (both zones of the former test site and the control), rodent biology and field signs were similar, corresponding to species characteristics and habitats of these animals as described in the zoological literature.[33] This conclusion also applies to such measures as population size, sex and age ratios, and reproductive

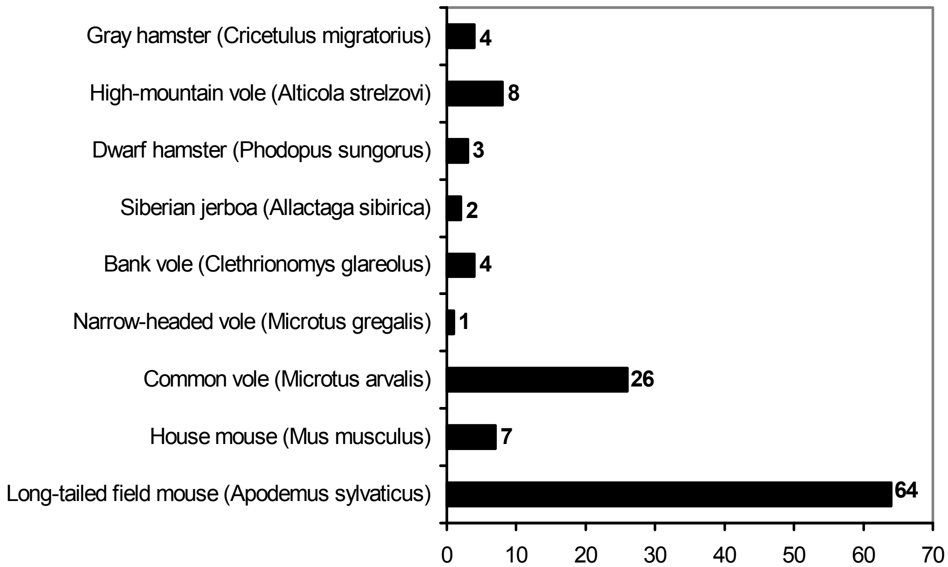

Figure 2. Species breakdown and numbers of rodents caught in the Shagan River basin. Abscissa—number of individuals; ordinate—species.

capacity. The species and quantitative breakdown of captured rodents are shown in Figure 2.

The chart data show that the rodent diversity based on the total of two catches in the Shagan River basin is represented by ten species, with the long-tailed field mouse dominating. The field mouse' prevalence is noted in the aforementioned seasons in all three plots, which agrees with the literature data.[33] However, the animal's population depended on the habitat. It turned out that it was 65% in Delegen, up to 75% in Shagan, and 18% in Bugaz. Consequently, the field mouse's frequency in the test site zone was much higher than in the control district. The percentage of sexually mature individuals in catches was about 81% at Bugaz, 91% at Shagan, and about 75% at Delegen, which is close to the literature data for fall field mouse populations.[34]

According to observations made at the expedition team's camps, the field mouse was active around the clock, especially in twilight and at night, which is typical of this species. The animal lived in burrows 25-30 cm underground, or in above-ground nests covered with twigs and dry grass. These mice fed mainly on green parts of plants and cereal seeds, less often on berries, and their stomachs occasionally contained the remains of insects. We did not find any anomalies in the field signs or biology of these rodents.

Average biometric parameters for sexually mature field mice captured in the three study plots are given in Table 6.

The data in the table show that no reliable differences were observed for most morphometric parameters in the three groups of rodents. The increased variability of craniological measures for rodents living under conditions of elevated natural radiation indicate the distinctiveness of these populations' development.

To assess the animals' metabolic activity, researchers generally use the sizes of internal organs whose functions are directly linked to metabolism and energy in the body, such as the heart, kidneys, and liver. Indices for these organs are calculated for the purpose. The dependence of the weight of internal organs on the weight of the body is so stable that it is called the scale law. It is considered mandatory to account for the effect of this law for inter-population comparisons and ecological assessment of adaptation reactions. Any significant deviations from normal values are indisputable

Table 6. Biometrics of Sexually Mature Long-Tailed Field Mice in the Test Site Area and a Control Plot

Index	Sex	Rodent Capture Location		
		Bugaz (control)	Shagan	Delegen
Weight in grams	Male	16.6 ± 0.8	16.0 ± 0.5	16.3 ± 1.0
	Female	18.2 ± 1.9	16.4 ± 0.7	14.9 ± 1.0
Body length in mm	Male	83.6 ± 1.6	86.9 ± 1.4	83.4 ± 0.6
	Female	84.8 ± 2.9	88.2 ± 1.4	82.8 ± 2.4
Tail length in mm	Male	69.4 ± 1.4	69.3 ± 1.8	72.2 ± 1.3
	Female	73.3 ± 4.3	68.9 ± 1.5	71.2 ± 2.3
Paw length in mm	Male	19.0 ± 0.2	19.3 ± 0.3	18.4 ± 0.4
	Female	18.8 ± 0.2	19.4 ± 0.1	18.3 ± 0.3
Ear height in mm	Male	11.5 ± 0.2	12.2 ± 0.2	11.4 ± 0.4
	Female	11.8 ± 0.6	12.2 ± 0.3	11.6 ± 0.3
Cranial length in mm and index	Male	24.4 ± 0.2 0.292	23.5 ± 0.2* 0.270	23.3 ± 0.3 0.279
	Female	24.8 ± 0.5 0.292	23.3 ± 0.1* 0.264	23.5 ± 0.2* 0.284

*—Differences from control significant at $P > 0.5$.

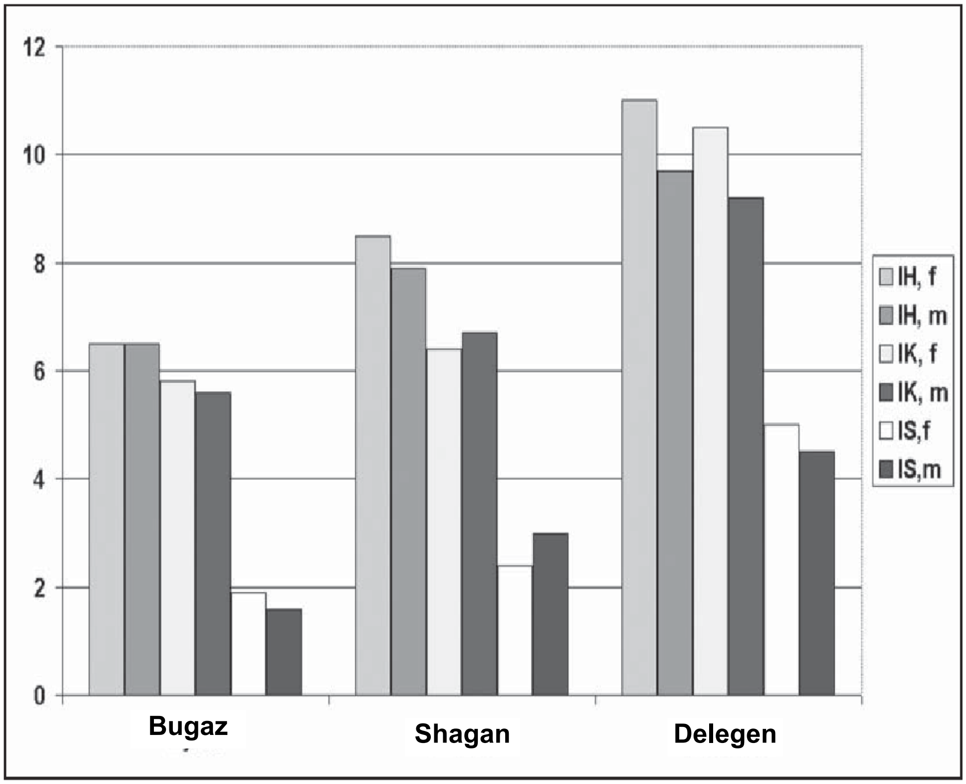

Figure 3. Indices of the internal organs of adult long-tailed field mice in Semipalatinsk Region.. Abscissa—rodent capture locations; ordinate—ratio of organ weight to body weight, permille. *IH*—heart index; *IK*—kidney index; *IS*—spleen index; *f*—females; *m*—males.

evidence of a change in the populations' living conditions. The indices of internal organs of the studied mice are given in Figure 3.

A substantial increase in the heart and kidney indices of rodents at the test site, as Figure 3 shows, is indisputable evidence of the populations' adaptive response to their changing living conditions. The point is that in these cases, the animals' total activity grows, and their metabolic rate, that is, the level of exchange of materials and energy related to the functions of these organs, rises. The adaptive response of the rodent populations to the combination of test site conditions is shown by the simultaneous rise in their spleen indices; the spleen participates directly in hematopoietic processes. Ilyenko and Krapivko describe a similar phenomenon for voles inhabiting areas with elevated natural radiation levels.[28]

A study of the liver index of long-tailed field mice captured in all three plots was practically the same (from 45.1 ± 1.9 to 48.0 ± 1.6). These values are within normal limits for rodents.[32] The liver index is known to reflect primarily its function as a storer of rapidly mobilizable nutrients. Given this, the data we obtained indicate both that the organ is functioning well in test site mice, and that the available food in all the test plots was complete.

Our biochemical studies concerned the main generator of the body's metabolism, which is the liver. This organ performs the most vital processes of protein, carbohydrate, and lipid (fat) metabolism. Unlike the weight indices, biochemistry describes the direct status of intracellular and tissue metabolism. The scope of our studies included determining parameters of the activity of a whole series of key enzymes: various ATPases (adenosine triphosphatases), 5'-nucleotidase, acid and alkaline phosphatases, ALT (alanine aminotransferase), AST (aspartate aminotransferase), levels of total, protein, and nonprotein thio groups, sialic acids, glycogen, as well as the lipid profile, cholesterol level, hydroperoxide values, diene conjugates, etc. The broad coverage of biochemical characteristics is important both for an understanding of the functioning of this very important organ and for finding intracellular indicator systems in wild mammals. A knowledge of biochemical indices is especially critical in studying the effect of chronic low-dose radiation exposure on the living organism. The work is continuing, but for several rodent species captured in the study plots, it has already enabled us to establish reliable interspecies, sex and age, and seasonal distinctions and established that this organ is functioning fully in various rodent species on the grounds of the former test site.[24]

Laboratory studies of animals have also revealed a series of hematological and bone-marrow features in the test site rodents. For example, the total bone marrow cell count in female long-tailed field mice was 23.3 ± 2.3 million in the Delegen population, 23.1 ± 2.1 million in the Shagan population, versus 19.7 ± 1.9 million in the control. In males, this parameter was 27.3 ± 3.8 and 23.1 ± 1.5 million, versus 19.2 ± 1.1 million in the controls. In the males, these differences were significant ($P < 0.05$). The elevated bone marrow count we noted, combined with the rise in the spleen index, could indicate an intensification of hematopoietic processes in mice in the test site zone. These data are confirmed by an increase in the peripheral average blood cell counts in the studied animals (Figure 4).

As the histogram shows, the field mice in the test site had elevated red blood counts. It is important to note that this rise was accompanied by a corresponding increase in the concentration of hemoglobin in the blood, so that its total content per red blood cell remained fairly stable (12.9-13.3 pg) and agreed with the values for the control group (13.1-13.3 pg). Especially significant in test site rodents was increased the average white blood count ($P < 0.001$). But their complete blood count showed no substantial abnormalities.

Thus, we can say that the most common rodent species in Semipalatinsk Region, the long-tailed field mouse, and therefore the best bioindicator, regardless of its habitats, has no abnormalities in such important characteristics for the population's survival as biology and sex and age ratios, biochemical and hematological indices. The extremely high number of murine rodents in the test site zone is noteworthy. The rise we noted in the intensity of basic metabolism and hematopoiesis is a

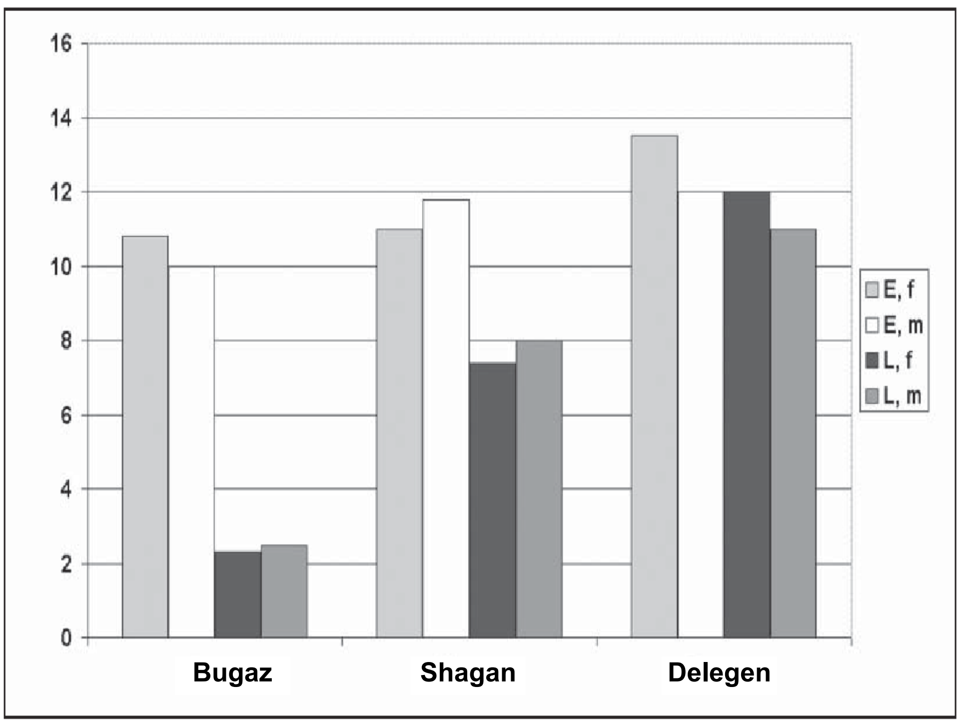

Figure 4. Peripheral erythrocyte and leukocyte counts in sexually mature male and female long-tailed field mice in the test site area and a control plot. Abscissa—rodent capture locations; ordinate—cell counts. *E*—erythrocytes (RBC) in millions per µl of blood; *L*—leukocytes (WBC) in thousands per µl of blood; *f*—females; *m*—males.

reflection of the organism's variability and points to the rodents' developed abilities to adapt to environmental conditions. Thus, the complete set of the wide range of ecological and physiological indices we studied, together with our analysis of established patterns, demonstrates that the natural selection and adaptation that have been going on for many tens of generations in these ecosystems have produced rodent populations with qualitatively new qualities and high levels of viability. All this indicates the preservation of ecosystem homeostasis in the test site plume plots.

A study of vegetation in the study areas also showed no noticeable differences. The prevailing landscape in the test and control plots is sheep's fescue–needle grass and sheep's fescue–sagebrush steppe. The banks of shallow rivers where the traps were usually set up are overgrown with trees and shrubs (willow, low-growing birch, wild rose, pea tree, currant, clematis, and spirea), as well as sandy and pebbly flood plains with motley grass and cereal meadow communities. The density of the vegetation at the rodent capture sites differed somewhat, but the nature of it was identical.

There is no doubt that in the past decades continuous biosphere self-cleansing processes have eliminated short- and medium-lived radionuclides and reduced the radioactivity of long-lived radionuclides in the 18,500 km^2 of the Semipalatinsk Test Site and in its plume. Now that joint American-Kazakhstani efforts are closing the adits where the nuclear explosions took place, the total radioactivity of the former test site is being reduced even more rapidly. The first 59 adits were closed back in 1997 (*Panorama*, No. 44, November 14, 1997), and by 2000, the 190th and last adit had disappeared (*Argumenty i fakty Kazakhstana*, No. 50, 2000). The low doses that Leongardt recorded two decades ago[30] are undetectable by this author in her study plots.

Concerning this question, it is important to emphasize that often, Kazakhstan science programs and publications describing research on the consequences of the test site's activities boldly state that low doses of radiation are everywhere in the test site and adjacent lands, believing this judgment to be self-evident. The authors ascribe all the data concerning man or animals obtained in these studies to the impact of low doses without thinking. Moreover, some of them try at all costs to discover pathology and link it to radiation, sometimes refusing to perform objective and well-considered differential diagnosis. All this brings substantial dissonance to the radiobiological science of low doses, which has the rapt attention of the world scientific community, and distorts the actual state of affairs in the republic.

At the same time, the ecological problems (ecology: the science of the relationships of plants and animals and their communities with one another and the environment) of the Semipalatinsk Test Site rest completely on the study of the results of low dose impacts in those areas where they actually exist. Unfortunately, the dose dependence for the entire Semipalatinsk Test Site has not yet been fully delineated.

Modern Methods of Biological Assessment of the Environment

There is no unified opinion yet on the status of biological systems around the Semipalatinsk Test Site. The inconsistent, sometimes contradictory results of scientific studies do not give a unified picture in this respect. We believe that the time has come to discard panic and thoughtfully, calmly review the true picture of today's test site plume areas. Today, dosimetry of the broad areas adjacent to the test site report primarily normal background radiation. Based on my own studies described above, we believe that the direction of further environmental observations with respect to the environment in the test site plume should be based primarily on exact information on the presence of low-dose radioactive contamination and mandatory dosimetric proof of this using standardized measurement methods. These particular lands, especially if they are near populated places and include farmlands, should be followed by regular observations of the soil–vegetation–fauna–man chain. But chaotic expeditionary trips to any interesting district of Semipalatinsk Region, as the practice has been, are a waste of time.

In our view, it is inadvisable to carry on the already endless studies of known "areas" at the test site, where a mosaic of elevated radiation levels has remained. It is good that people did not and do not live at the test site, so there has been no need to evacuate them as at Chernobyl, and the doses are different, too. Now we need only a powerful covering force to permit people and pets to enter.

We know that a key point in judging the consequences of nuclear testing is to assess the environmental quality, its favorability for human life. Now, radiobiologists are finding it more and more obvious that the criterion for this assessment should be based on the test of the viability of the diverse animal and plant species. It is not for nothing that they say, "The health of living beings and ecosystems is a condition for human health. You cannot be healthy in a sick environment." Consequently, at low levels of radioactive contamination, when ecosystems function normally and high biodiversity is observed, the question of environmental monitoring turns on the viability of living beings that have settled these lands. However, it is not enough to limit ourselves to the animals' population characteristics, population size, and external signs. As the researchers of the Chernobyl disaster summed up,[19] "no one now would think to characterize the health of a population by its size," or "Big and fat does not mean healthy."

Modern methodology is based on a comprehensive approach to the determination of environmental quality. The method was developed on an international basis, and is used in many countries in researching all types of anthropogenic (industrial, etc.) pollution of the environment, including radioactive contamination, and is known by the name "Biotest."[35] It is highly sensitive, permitting detection of even initial (still reversible) changes in the condition of living beings in response to deviations in environmental parameters (Figure 5).

The scientific approaches to the study of environmental quality shown in the figure are accessible to appropriate specialists and are described in detail in the cited literature.[23,35] The main principle of the methodology is that the assessment of environmental health is not led by ecosystem and population parameters, but by the condition of various animal and plant

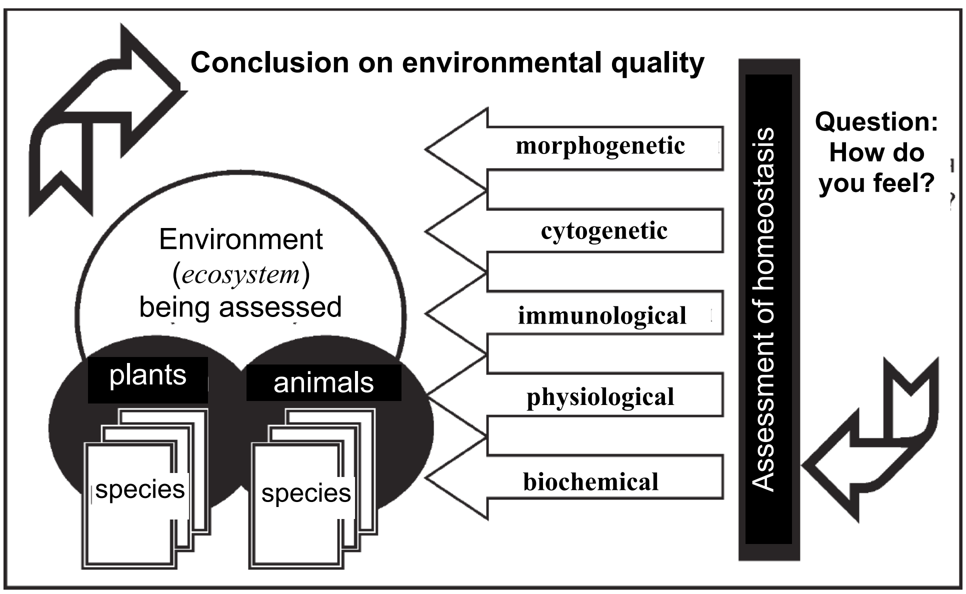

Figure 5. Biotest environmental health assessment methodology.

species. The central target here is homeostasis (constancy of physiologic functions) of the organism or of a baseline characteristic that assures its normal function. The system for assessing the homeostasis of an organism's development includes a broad range of mutually independent test methods. The number of tests can be limited by the need to choose and use those that give an adjusted response. Similarity of responses from various species ensures a reliable assessment of the change in the ecosystem's health.

To judge the Chernobyl aftermath, the Moscow Division of the Biotest Foundation included parameters that are usually used for comprehensive assessment of human health; these are listed in the accompanying figure. The authors of the proposed methodology believe that each designated scientific approach subsumes a variety of methods. The main objective is to make the right selection. For example, when assessing cytogenetic homeostasis, the micronuclear test[36] and a variety of others that are good for primary assessment of chromosome stability in natural populations have proven themselves. A detailed analysis would require the use of more sensitive cytogenetic methods.

Biochemical homeostasis assumes, first of all, an assessment of the basic parameters that characterize the oxidation-reduction (redox) processes in the body. These parameters have proven to be sensitive indicators of various types of environmental stress. For example, under the impact of radiation, the effect of xenobiotics and hypoxia can increase, which raises the level of single-electron oxygen reduction products, presenting a serious danger to the cell's viability and disrupting the permeability of cell membranes,[19] and has a deleterious effect on the organism as a whole. To detect these processes, researchers determine the number of cellular superoxide radicals and the enzyme that controls their formation, superoxide dismutase (SOD), as well as hydroperoxide and the corresponding enzyme system. From these measurements, they can judge the organism's exposure to oxidant stress.

Immunological homeostasis or immune status, which are maintained by the constancy of the antigen system of the organism's internal environment, is determined in a similar way. Immunologists know very well that any serious changes in the habitat is reflected in the functional activity of immunocompetent cells. To assess the severity of these states, they use tests that give information on the condition of the three main cell populations comprising the immune cells (phagocytes, B-lymphocytes, and T-lymphocytes). A detailed description of these tests is given in *Consequences of the Chernobyl Disaster: Environmental Health.*[23]

A brief outline of the recommendations made by the authors of this methodology for integrated assessment of ecosystems and individual species is given here as a model for specialists in each of the fields shown in Figure 5. The study of morphogenetic homeostasis (developmental stability) and physiologic homeostasis are built on the same principle.

All scientific approaches defined in this methodology, as Figure 5 shows, also concern plants. For example, in the case of the study of physiologic homeostasis in plants, analysis of photosynthesis is effective. The rate of photosynthetic processes can be measured using fluorimetry.

Drawing on the experience gained by studying the aftermath of the Chernobyl disaster to study the Semipalatinsk lands, it is important to choose the chief criteria for the selection of model systems to characterize the ecosystems' status.[23] These include the following:

- choice of representatives of various systematic groups that occupy various positions in the ecosystems;
- choice of species, whose normal migrations do not leave the study areas;
- choice of relatively large organisms that are less dependent on microbiotic conditions and are suitable for a description of the study area as a whole;
- choice of background species for collection of necessary material on all study plots;
- choice of species for extrapolation of the data obtained to man.

In accordance with these criteria, plants and mammals were used to assess the status of the Chernobyl ecosystems, and fish and amphibians were used to characterize the aquatic ecosystems. In addition, the parasitological status was studied, since parasitic diseases in animals (tapeworm invasion, coccidiosis, etc.) considerably reduce their specific and nonspecific immunity. They cause substantial biochemical changes in the host-parasite system, etc. All this requires attention when assessing the status of the chosen biological system.

The phenomenon of synergy can be an important link in the study of biological systems on lightly contaminated lands. As concomitant factors, the researcher should consider all possible chemical and other anthropogenic impacts. Hence it is obvious that appropriate corrections must be made when analyzing the data obtained.

Based on all the above, we believe that the environmental condition of the Semipalatinsk Test Site lands can be successfully predicted only by consolidating all currently available and future scientific evidence produced in the framework of the methodological approach presented here (which has existed for over ten years now) and processed by mathematical statistical methods specifying the level of confidence.

We believe that the publication of a regular, readable scientific and practical magazine or bulletin in the republic, that covers the problems of human health and the natural environment of all remaining radioactively contaminated lands at the Semipalatinsk and other former nuclear test sites in Kazakhstan, would considerably expedite the analysis and solution of our radioecological problems.

In concluding the review and my own scientific research that has been presented here regarding issues of modern radiobiology and the environmental consequences of the Semipalatinsk nuclear tests, I express my hope that the information here will prove useful both to the untrained reader and to specialists in the fields of radiobiology and radioecology.

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APPENDIX C: RESEARCH METHODS

Overview of Field Research Methods

All work under field conditions began with an inspection of the locale where samples were to be collected from various environmental systems. Then the specific sampling locations were selected, exposure dose rates and densities of surface contamination by α and β particles were measured at the sampling locations, and environmental samples were collected.

Soil Sample Collection Methodology

Soil samples were collected in accordance with the *Instructions and Methodological Instructions for the Assessment of Radiation Conditions on Contaminated Land,* approved by the Interdepartmental Commission on July 17, 1989.[173]

Soil samples were collected using a special sampler or a sapper (modernized) shovel. The shovel was used to dig a pit, usually 30 cm deep, and then the ground, along with the sod, was removed layer by layer.

There were various methods of collecting soil samples: "square," "quincunx," and "triangle." The most common was the "quincunx" method, which consisted of the following: soil was collected with a specified depth (up to 12 cm) and area (100 cm^2) at the corners and at center of a square in the plot. The soil collected at these five points, which was then pooled, made up the sample (the raw sample). This sample was weighed and quartered several times, and screened to produce a working mass weighing about 2 kg. The resulting soil sample was poured into a polyethylene bag with a tag or explanatory note and packed so as to prevent mechanical damage. The tag specified the location and date of the sample, the geographic coordinates, weight, code number, and surname of the sample collector. At the same time, an entry was made in a sample collection field journal.

Vegetation Sample Collection Methodology

The collection of samples of various plant species in order to discover any properties of these species and obtain characteristics of the status of phytocenoses included spot samples in plots. The collection methods, quantity, and weight of the samples collected or formed were specific to each plant species and were established in accordance with the aim of collecting samples.

Vegetation samples were collected after ground inspection of accounting areas 2×3 meters across. In a plot where soil samples were also to be collected, vegetation was cut (with shears, a scythe, or a long knife). The height of the lowest cut had to be at least 3 cm from the soil surface. Depending on the purpose of the inspection and the expected commercial purpose of the plot being studied (pasture or mowing), the height of the cut and the weight of the sample collected varied.

The cut vegetation was placed in a package whose weight could not exceed 1.0-1.5 kg. In individual cases, in order to study patterns of radionuclide accumulation by certain dominant plant species (for example, lichens or other plants), clean samples of specific plant species were collected. The vegetation sample was packed in tight paper or a clean dry container (bag, wax paper, paper packet, polyethylene bag) and tagged or labeled. The numbering or code of the vegetation sample corresponded to the number or code of the soil sample. The label specified the sample name, the place and date collected, the area of the plot, the species makeup, the name of the dominant plants and phytocenosis, the weight of the raw sample, and the exposure dose rate. An entry was made in the field journal.

Exposure Dose Rate and Surface α and β Contamination Density Measurement Methodology

We should note that the exposure dose rate is one of the principal measures of environmental radiation levels. The exposure dose rate characterizes the intensity of the ionizing radiation (γ ray) field in terms of its ionizing ability. This field is produced everywhere by the emissions of natural radionuclides, as well as by the emissions of radionuclides of manmade origin. The principal natural radionuclides are contained in the Earth's rocks. They include ^{40}K, ^{87}Rb, and the nuclides of two radioactive families that originate from ^{238}U and ^{232}Th, respectively, which are long-lived isotopes and have formed part of rocks from the very beginning of life on Earth.[176]

To convert exposure dose rate (describing the field) to absorbed dose (describing the interaction between the field and the exposed medium), we must know the characteristics of the exposed medium. If this medium is a person, we must use the characteristics of his biological tissues.

The levels of the Earth's radiation are known to vary from place to place on the globe, and depend on the concentration of radionuclides at the specific location on the Earth's crust. In the Republic of Kazakhstan, 95% of the population lives in places where the exposure dose rate ranges from 10 to 20 μR/hr, and the annual exposure dose averages 0.3-0.6 mSv/yr.

An inspection of radiation levels and an assessment of the environmental status of the test site grounds began with a ground inspection, namely, a determination of the exposure dose rate and the density of surface α and β contamination, as well as parameters of X-rays ranging in energy from 17 to 60 keV.

Measurements of exposure dose rate were performed in accordance with the 1989 *Instructions…* from the Hydrology and Meteorology Service (*Gidrometsluzhba*), using calibrated and graduated Sinteks, PDR-77, DRG-01T, SRP-88 or SRP-68-01 dosimeters at a height of 1 meter or 3-4 cm above the ground, with the measuring instruments arranged parallel to it.

The dosimeters used permitted measurement of exposure dose rate within the following ranges: in Search mode, from 100 μR/hr to 100 R/hr with a measurement error of ± 30%; in Measure mode, from 10 μR/hr to 10 R/hr with a measurement error of ± 15%. The instrument was considered suitable for measurements if its readings differed from those previously taken by a standard instrument by no more than the allowable error.

At dose rates below 0.2 R/hr, five successive sets of measurements were taken, and the average was considered the exposure dose rate of the particular system. Exposure dose rates with readings varying by 150-200%, were considered random, and could have been due to instrument malfunction. The measurement results were entered in a field journal according to the recording form.

The density of surface α and β contamination was measured with KRA-1 and KRB-1 instruments, which include BDZA-03 scintillation detection units. When the density of surface contamination was measured using α and β radiometers, a parcel had to be chosen that permitted the fullest contact between the sensor and the contaminated surface without damaging the detector's protective film.

Measurements with these instruments were performed in strict compliance with the instruments' operating instructions.

Method of Determining Geographic Coordinates

Geographic coordinates were determined using a GPS NAV 5000 DLX, a marine navigation aid designed to measure coordinates with an accuracy of 15 meters. To prevent leakage of information on the precise position of military and state facilities, the US Government has introduced the Selective Availability (S/A) function. S/A introduces random errors into the transmission of data on satellite ephemerides, which in the absence of differential correction degrades the accuracy of coordinate measurement to 25-100 meters (95% probability). The GPS NAV 5000 DLX collects data from satellites comprising the GPS (global positioning system) through five channels and calculates position coordinates, altitude above sea level, speed, and navigational data. The device's memory permits storage of data from 1000 measurements.

Gamma Spectrometry Laboratory Methodology

This method is intended for measurement of the γ radioactivity of selected radionuclides comprising samples collected for assessment of radiation levels on the test site grounds and in adjacent districts.[178]

The method's use is limited to measurements of low radionuclide concentrations on semiconductor spectrometers (4-6 Bq/kg with a total error of ± 20% at 95% confidence).

The method of γ spectrometric measurements is based on the different emission spectra and half-lives of the radionuclides comprising the samples. The principal sources of information on the nuclide makeup of samples are the hardware spectra, which directly reflect the primary energy spectra of the emitters, as well as data on the nature and features of the sample, its history, age, and nuclide mixture.

The sensor and analyzer convert γ quanta of various energies to electrical pulses of various amplitudes.

The number of pulses registered during processing of the measurement results is used to calculate the activity of radionuclides contained in the sample.

Each spectrometry system consisted of a γ-ray detection unit, a pulse analyzer, and various input/output devices.

The following types of devices were used as part of the spectrometry systems:

- LP-4900 and LP-4900B pulse analyzers;
- Facit printer;

- teletype;
- TDC-3000 tape recorder;
- DGDK-63V No. 1694 and 1584 semiconductor detectors;
- Canberra pulse analyzer;
- ORTEC GMX-13180-S semiconductor detector;
- Notebook;
- AI-1024-95-17 pulse analyzer;
- DGDK-63V semiconductor detector;
- YeS-1841 personal computer;
- SM 6337 printer.

In order to set up the γ spectrometer to make measurements, the spectrometer had to undergo energy calibration and the γ-ray registration efficiency had to be determined.

To measure selected nuclides or mixtures of nuclides, a relation had to be established between the emission energy and a spectrometer channel number. For convenience, the graduation mark had to pass through the coordinate origin. The unit was graduated to standard spectrometric γ sources. The selection of standard sources was determined by the principle of uniform distribution of their emitted energy over the entire energy spectrum.

The radionuclides making up the radioactive products generally had a wide range of γ-ray emissions. So the spectrometer scale had to be graduated over the entire γ-ray energy spectrum. The calibration graph consisted of a straight line passing through the origin.

If this requirement was not met, the analyzer's input unit had to be adjusted. After adjustment, linearity was rechecked.

The efficiency of γ-ray registration by the spectrometer depends on the shape and size of the preparation studied and the measurement geometry. So the calculation was performed based on three measurements of all types of samples in the requisite geometries. The dependence of efficiency on γ-ray energy was easily determined, since the absolute activity of the standard samples of radionuclides with various energies was known.

The processing of spectrometric measurement results included two phases:

- identification of the composition of the emitters;
- calculation of the quantitative content of selected radionuclides.

Depending on the type of sample, the preparation methodology also varied. Preparations were affixed to substrates and covered with film in beakers, with precise labeling of all sample parameters—recording journal number, field number, identifying code of the object of investigation, weight, and other information. Special requirements were imposed for vessel cleanliness.

One of the requirements for sample preparation was to maximize the standardization of measurement geometry.

Data from numerous laboratory measurements on semiconductor spectrometers established that the total rms error of measurement and calculations using this methodology did not exceed ± 20% at 95% confidence.

Aspects of Radiochemical Laboratory Methods

The most difficult task that had to be performed in the radiochemical laboratory was to *determine plutonium concentration* in various environmental samples. This work began with preparation of the soil sample for analysis.

First, a soil sample weighing 1000-2000 grams was desiccated on an aluminum tray in a desiccating cabinet at 120-130°C for two hours with periodic mixing until it reached a constant weight.

An average weighed portion of the soil (170-200 g), after weighing, was placed in a porcelain dish and cinerated in a muffle furnace for two hours at 350-400°C. Then the temperature was raised to 600-650°C and the sample was calcined for another 3.5-4 hours with one intermediate mixing.

A 20 g portion of the calcined sample was taken for analysis. This amount was sufficient to determine $^{239,240}Pu$ in soil if its concentration was at the 1.0 Bq/kg level.

A solution of a radioactive label (^{236}Pu or ^{242}Pu) was added by uniformly dropping it with a capillary pipette into the sample for analysis, which was placed in a porcelain dish in the desiccating cabinet at 120-130°C for 20-30 minutes. After the dish had cooled, the indicator label was homogenized, breaking up clumps with a fluoroplastic pestle and further mixing the contents, which were then calcined again in the muffle furnace at 600-650°C for one hour.

The calcined sample was transferred to a glassy carbon dish for acid leaching of plutonium radionuclides. Then acid leaching of plutonium from the calcined sample for analysis was performed, followed by and radiochemical purification of plutonium on a chromatography column filled with AV-17·8 anion exchange resin. The resulting solution formed the initial fraction of plutonium for application to a metal substrate.

Alpha-radioactive working preparations with plutonium were made using substrates consisting of rectangular or square plates of stainless steel grade Kh18N10T ~0.1 mm thick with surface finish corresponding to class six (rolling group three) large enough to afford a working area of 450 mm^2.

The working area of the stainless steel substrate was wiped with a gauze pad dipped in acetone, and then with ethanol and isopropanol (to remove grease spots and prepare the surface).

After 5-7 minutes, a nitric acid solution with the plutonium was transferred from the sample bottle to the plate by multiple spot dropping using the entire working surface of the substrate. A capillary pipette was used for the dropping. The volume of the whole plutonium fraction should not have exceeded 0.6 cm^3, and the acidity of the nitric acid should have been between 0.4 and 1.0 mol/l.

The α-emitting source was dried in air for a half-hour, and then in the desiccating cabinet at 65-75°C for the same time, and finally by instantaneous calcining for several seconds in the muffle furnace at 400-450°C to fix the "layer." The surface density of the layer formed on the substrate did not exceed 0.005 mg/cm^2. The resulting α-radioactive preparation was intended for measurements on the α spectrometer.

The spectra of the analysis samples were measured using an α spectrometer based on an SEA-01 spectrometry unit, consisting of:

- BDEA-01 detection unit;
- Bus I2-50 preamplifier;
- SES-13 spectrometric amplifier;
- AI1024 pulse analyzer;
- UVTs2-95 digital printer;
- 2NRV-5DM forepump;
- model 112 vacuum gauge.

The source, ready for measurements, was placed in the vacuum chamber of the BDEA-01 detection unit. Measurements were made over 450-500 minutes.

The sample analyses of water and vegetation were done similarly, but in the initial phase of the analysis of water, the dry residue was obtained after cinerating the filter and evaporating the water sample (at least 1000 cm^3). Vegetation samples were also cinerated, and after further processing, the analysis was performed as described above.

^{90}Sr Measurement

Strontium-90 was measured in accordance with the *Methodological Instructions…*.[179] The ^{90}Sr concentration was determined by the concentration of its daughter nuclide, ^{90}Y, which was extracted by classical oxalate precipitation. The calcined sample underwent acid "exposure": the strontium was transferred to solution, and then through a series of chemical operations, including precipitation of carbonate hydroxides, the radionuclides that would interfere with the measurement of strontium were extracted, leaving the ^{90}Sr in the solution.

The resulting solution was left to accumulate ^{90}Y, the daughter of the decay of ^{90}Sr. After 14-16 days, the ^{90}Sr-^{90}Y system reached radioactive equilibrium. Then oxalate precipitation of the ^{90}Y was performed. The chemical yield of strontium was determined by x-ray spectrometry, and that of yttrium by weight spectrometry. The resulting count sample was applied to a metal substrate and measured on a low-background unit. The measurement of ^{90}Sr by ^{90}Y was performed on an RUB-01P low-background radiometer using a BDZhB-06P detector. The sensitivity of the method depended on the measurement time: if the count sample was measured for 60 minutes, the sensitivity was 0.07 Bq.

Method of Measuring Tritium

Tritium was measured in water samples as follows: a water sample was passed through a paper filter to remove mechanical impurities. Then 1 ml of the water to be studied was added to 9 ml of ZhS-8 liquid scintillator. The mixed liquid sample was measured on an RZhS-05 unit. This method permitted measurement of tritium from 1.9×10^3 to 3.7×10^7 Bq/l. The limits of the radiometer's allowable basic error in measuring the volume activity of selected radionuclides was no more than 30% at 95% confidence.

Thus, we can say that the very important work performed at the Institute of Radiation Safety and Ecology (*IRBiE*) to improve the scientific methodology and hardware support of research to assess the present-day environmental radiation levels on the grounds of the former Semipalatinsk Test Site and surrounding areas helped produce objective data on the scale and extent of radioactive contamination of the environment after nuclear testing at the site.