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United States-Assisted Studies on Dose Reconstruction in the Former Soviet Union*

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Abstract. Following the Chernobyl accident, the US and the USSR entered into an agreement to work on the safety of civilian nuclear reactors; one aspect of that work was to study the environmental transport and health effects of radionuclides released by the accident. After the break-up of the USSR separate agreements were established between the US and Ukraine, Belarus, and Russia to continue work on dose reconstruction and epidemiologic studies of health effects from exposure to external radiation and the incorporation of radionuclides. Studies in Belarus and Ukraine related to the Chernobyl accident now emphasize epidemiologic studies of childhood-thyroid cancer and leukemia, and eye-lens-cataract formation in liquidators. Supporting studies on dose reconstruction emphasize a variety of ecological, physical, and biological techniques.

Studies being conducted in Russia currently emphasize health effects in the workers and the population around the Mayak Industrial Association. As this production complex is an analogue of the US Hanford Works, advantage is being taken of the US experience in conducting a similar, recently completed dose-reconstruction study.

In all cases the primary work on dose reconstruction is being performed by scientists from the former Soviet Union. US assistance is in the form of expert consultation and participation, exchange visits, provision of supplies and equipment, and other forms of local assistance.

1. Introduction

Following the Chernobyl accident the United States and the former Soviet Union (FSU) entered into an agreement in 1988 to work cooperatively on the safety of civilian nuclear reactors. As part of this agreement a Joint Coordinating Committee on Civilian Nuclear Reactor Safety (JCCNRS) was established, and the formation of twelve working groups soon followed. Most of these working groups were concerned directly with safety aspects of the reactors still operating in the former Soviet Union. One working group, number 7, was concerned with environmental transport of the radionuclides released and with long-term health effects.

The general goals of Working Group 7 were to develop validated models for rapidly projecting doses and health effects in the event of a future reactor accident, to provide the basis for the

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physical dosimetry needed to reconstruct doses for the FSU citizens exposed to the higher doses following the Chernobyl accident, and to study the health effects of the accident. In order to implement these goals many subworking groups were established that included those to study

- a. Research on atmospheric dispersion modeling,
- b. Wind-driven resuspension of toxic aerosols,
- c. External exposure and dose from deposited radionuclides,
- d. Transport of radionuclides through terrestrial food chains and the resulting dose to man,
- e. Long-term dose from the contamination of aquatic food chains,
- f. Modeling the behavior of radionuclides in a soil-aquatic system including rivers and reservoirs,
- g. Intercalibration of methods for measuring radioactive contaminants in the environment,
- h. Acute radiation syndrome in man,
- i. Population registries,
- j. Biological dosimetry,
- k. Epidemiologic study of thyroid disease, and
- l. Epidemiologic study of leukemia.

These tasks were generally agreed upon in 1989-1990, and the work was begun to implement most of the agreed upon research. The National Cancer Institute was asked to lead the epidemiologic studies indicated above, and the US Nuclear Regulatory Commission provided additional funding and support for the studies.

These research plans were changed markedly by three separate events. The first was the implementation of the International Atomic Energy Agency (IAEA) sponsored work at the request of the USSR government by the International Chernobyl Committee, which undertook what can be described as a massive quality-assurance audit of the response by the USSR government to the Chernobyl accident. The work of this group obviated the need for some studies, such as the intercalibration studies indicated above.

The second event was the collapse of the government of the USSR in 1991. Following this collapse (and the generally poor economic conditions in the FSU) the prior agreements could not be adhered to and other separate agreements eventually followed between the US and the individual governments or agencies of Russia, Ukraine, and Belarus.

The third event was the transfer of the Working Group 7 studies from the basic research arm of the Department of Energy (DOE) to the Office of the Assistant Secretary for Environment, Health and Safety (EHS) within DOE. The latter's responsibilities include a focus on the definition of radiogenic health effects in man.

As a result of these changes the US-assisted studies underwent a substantial change. The general research studies were phased out, and a focus was maintained on epidemiologic studies of radiogenic health effects in man. In addition to the studies on leukemia and thyroid disease noted above, studies on eye-lens cataracts have been added more recently. As it is impossible to study meaningfully radiogenic health effects without knowing the doses to which the study enrollees have been exposed, a major component of these continuing studies is dose reconstruction.

In addition to the studies noted above and in keeping with the focus of EHS on the elucidation of radiogenic health effects in man, a separate agreement was negotiated between the US and Russia to study radiation-health effects in general. This work is being implemented through the Joint Coordinating Committee on Radiation Effects Research (JCCRER). Current focus of the JCCRER research is on epidemiologic studies on the workers and the general population in the vicinity of the Mayak Industrial Association in the Urals.

2. Studies of Thyroid Disease in Belarus

The first epidemiologic studies defined under the work of the JCCCNRS were studies of childhood-thyroid disease in Belarus. Two separate studies were defined—a case-control study and a cohort study.

2.1. *Case-Control Study*

The case-control study involved the study of 107 cases and 214 controls of two separate groups. The first control group was drawn from the general population and matched to the cases according to age, sex, and urban/rural type of residence. The second control group was matched as above, but also matched to the cases according to experience with diagnostic procedures that brought the cases to diagnosis.

A few of the enrollees in the study had had their thyroids measured directly during the few weeks immediately following the accident, but most had not. Most of the enrollees had been interviewed in an effort to determine residence and lifestyle information, but most of the questionnaires did not contain lifestyle information that could be considered adequate.

Therefore, in order not to bias the results, a “lowest common denominator” approach of dose reconstruction was used. Thus, information that was not generally available for all enrollees in the study was ignored.

The general information used in the method of dose reconstruction included:

- a. Country-wide information on the deposition density of ^{137}Cs ,
- b. Limited information on the deposition density of ^{131}I , and
- c. A databank of thyroid measurements of approximately 200,000 people that was used to infer the relationship between adult-mean-thyroid dose and the deposition densities of ^{137}Cs and ^{131}I .

Particular information on residency immediately after the accident was used, but only default values were used for food consumption. Appropriate methods were also used to adjust mean-adult-thyroid doses to doses for children of the appropriate age. Preliminary results of this case-control study were presented at the World Health Organization Conference in November 1995 [1,2], and further details of the general dosimetric methods are provided in Gavrilin et al. [3,4].

2.2. *Cohort Study*

The cohort study is planned to follow actively 15,000 children. The cohort has not yet been defined, but efforts are being made to include in the cohort only those who had their thyroids measured in 1986. Thus, the children will be drawn from the most heavily contaminated areas in the oblasts near to the Chernobyl Nuclear Power Plant (NPP). In order to maximize the power of the study to detect any increase in thyroid disease, special efforts are being made to enroll as many persons as possible in a high-dose group. Depending upon the results of current investigations, it may be possible to add some people from the Brest Oblast with thyroid measurements to this high dose group. The Brest Oblast is distant from the Chernobyl NPP but is thought to have been rather heavily contaminated by radioiodines. Otherwise, it will be necessary to add persons to this group who are believed to have received high doses, but whose thyroid activities were not measured.

The basis of the dose reconstruction will be the results of thyroid measurements, information on the extent of the radioactive contamination in the subjects' locations, and information on lifestyle as gained from questionnaires. If subjects must be enrolled who did not have their thyroids measured, they will be selected from locations where "passports" of radioiodine doses have been derived on the basis of residents who did have their thyroids measured [3,4].

Some of the important steps that must be completed for this dose-reconstruction study are accurate calibrations for the instruments used for the direct measurements of thyroids and calculation of the radiation doses due to sources in addition to ^{131}I .

The calibration of the instruments is necessary, because survey instruments not designed for this purpose were used for the thyroid-activity measurements. Collimators were not used, and the influence of clothing contamination and the procedures used for "background" subtraction must be investigated and defined.

Other sources of radiation exposure to be calculated include internal irradiation from the intake of short-lived radioiodines and of ^{132}Te ; internal irradiation from the intake of ^{137}Cs ; and external irradiation from radionuclides deposited on the ground. As these sources of exposure may be more effective per unit dose in inducing thyroid cancer, these inclusions may be particularly important.

3. Epidemiologic Studies in Ukraine

In Ukraine epidemiologic studies of thyroid disease are also approved, and in addition there is a study underway on the induction of eye-lens cataracts in liquidators. An extensive study of leukemia in liquidators has been planned.

3.1. Thyroid Disease

A cohort study has been defined that will consist of those individuals

- a. Who were less than 18 years of age at the time of the accident,
- b. Who had their thyroid activity measured in 1986 in eight raions and the City of Pripyat, and
- c. Who can be located at the beginning of the study.

It is estimated that the number of children satisfying these conditions is 57,000. Individual-thyroid doses will be required for all members of the cohort. The general procedures to be followed have been described in Likhtarev et al. [5]. Primary inputs consist of the deposition density of ^{137}Cs with adjustment according to the polar coordinates from the Chernobyl Nuclear Power Plant and individual data from questionnaires. The sources of exposure in addition to ^{131}I (as named above) will be considered in this study, also.

3.2. Leukemia in Liquidators

A case-cohort study is being planned to study the radiogenic induction of leukemia in liquidators. The underlying cohort for this study consists of all liquidators first employed between 1986 and 1990 and who lived in the City of Kiev and the six oblasts of Dnepropetrovsk, Donetsk, Lugansk, Kiev, and Kharkov at the time of first employment. This target cohort is estimated to contain about 90,000 individuals. A subcohort will be selected from this cohort, and this

subcohort will serve as a control group. The size of the subcohort will be in the range of 1000 to 2000 individuals.

All cases in the target cohort will be identified; the number of cases that will occur is estimated to be approximately 100. Individual doses will be required for the members of the case and the subcohort classes.

Dose reconstruction for these groups will be more difficult than for the children enrolled in the thyroid studies, as the exposures for the liquidators occurred under very individual-specific conditions that are not known with great precision.

It is planned that dose reconstruction will be performed with the following tools:

- a. All administrative and other records that provide historical estimates of radiation exposure,
- b. Any reconstructed estimates of dose based upon examinations of groups of individuals with a variety of physical dosimetric information,
- c. Construction of a matrix (over time and space) of all known measurements of exposure rate or dose,
- d. Specification of time and motion steps that led to the exposure of individual liquidators that, when combined with item c above, can be used to estimate doses,
- e. Measurements of chromosomal translocations by the fluorescent in situ hybridization (FISH) method (this method will not work for treated cases of leukemia), and
- f. Measurements of electron paramagnetic resonance of teeth.

Substantial research, development, and validation of the techniques enumerated above will be required in order to provide the required doses.

3.3. Eye-Lens Cataracts in Liquidators

A cohort of 10,000 liquidators will be defined and actively followed in order to examine the occurrence of eye-lens cataracts. Individual doses will be required for all 10,000 members of this cohort.

The dose reconstruction for this group will be based upon all of the techniques mentioned above in order to provide a base of underlying information. However, in this case it is significant that the tissue of interest is the eye lens. It is possible that beta doses to the eye lens were the dominant sources of exposure that must be quantified. This is a very difficult problem, as there are currently no validated techniques of estimating the possibly critical pathway of deposition of beta emitters on the eye lens itself or of generally specifying the magnitude of beta exposure.

Thus, a substantial effort of research, development, and validation is required in order to produce eventually the required information on individual dose to the eye-lens tissue.

4. Epidemiologic Studies in Russia Related to the Mayak Industrial Association

Feasibility studies of epidemiologic studies of radiogenic disease in the workers at the Mayak Industrial Association and in the general population in the vicinity were begun in March 1994. These one-year feasibility studies will result in reports and recommendations for the conduct of continuing work.

4.1. Workers at the Mayak Industrial Association

The Mayak Industrial Association was opened in 1948 to produce plutonium and other materials related to nuclear weapons [6]. The cohort of workers includes about 20,000 people who started work between 1948 and 1985. High doses of external gamma radiation were received by the workers during the first few years, and at the radiochemical reprocessing plant workers were also exposed to plutonium. Approximately 5000 workers (1700 females) worked at the complex when the exposures were large (more than 1 Sv). External gamma exposure was always monitoring by film-badge or thermoluminescent dosimeters, and plutonium exposure has been monitored by urinary assay and tissue analysis of cadavers.

Recent studies of the worker cohort have shown excess risks of leukemia and solid tumors [7]; a separate study demonstrating excess lung-cancer mortality has also been published [8]. These studies, however, currently lack proper controls and adequate follow up.

The creation of a more refined dosimetry-data base has been proposed. This does not require "reconstruction" as much as it requires the assembly of all existing external gamma-dose information into a more refined data base, and the reassessment of all bioassay data for plutonium into a data base consistent with the most recent data on plutonium-excretion rates, etc. This study is considered by the authors very likely to proceed beyond the feasibility phase, due to the generally good dosimetry records and the interest in this very unique population of highly exposed individuals.

Another subcohort of this population will be studied in order to examine the deterministic effects of occupational exposure in this highly exposed cohort. Dosimetry records will be compiled according to the process indicated above.

4.2. Techa River Cohort

Between 1949 and 1956 about 10^{17} Bq of liquid wastes were released into the Techa River from the Mayak facility [9]. This resulted in substantial exposure of a large number of persons living downstream. Dose-reconstruction activities have been proceeding for some time [9], as have epidemiological studies [10]. A cohort of approximately 29,000 persons has been followed and studies reveal an excess incidence of leukemia and solid tumors. The latter incidence data, however, are complicated by the fact that two distinct ethnic groups are being followed, and these two groups have quite different background rates of cancer incidence.

Dose-reconstruction studies performed so far have depended heavily upon measurements of ^{90}Sr in teeth and upon thermoluminescence measurements of external gamma exposure in environmental materials. Only group doses to village residents have been calculated. For future work it is proposed to consider more general and complete methods of dose reconstruction and to provide individual estimates of doses for the approximately 29,000 members of this cohort. Again, the authors estimate that it is likely that this project will extend beyond the feasibility stage due to the large number of people known to be exposed to moderately high doses at relatively low dose rates.

Dose reconstruction for this cohort will depend upon additional data envisaged to be gained from measurements of chromosomal translocations and from electron paramagnetic resonance measurements of teeth samples.

Additional effort will also be devoted to defining more accurately the source terms for the material released to the Techa River and also released to the atmosphere. It is known that large amounts of ^{131}I (approximately 2×10^{16} Bq), and perhaps other radionuclides, were released to the atmosphere. Once these source terms are defined attempts to model the movement of the radioactive materials in the environment will be undertaken.

4.3. East Urals Radioactive Trace (EURT) Cohort

In 1957 an explosion in a radioactive waste-storage facility (the so-called Kyshtym accident) resulted in the release of approximately 7×10^{16} Bq of radioactive materials into the atmosphere and formed the EURT. About 30,000 people are included in an EURT registry; these people were exposed to both external and internal irradiation. Some work on dose reconstruction and epidemiological follow-up has been done for this group.

Another task of the feasibility studies currently being conducted is to evaluate the possibility and desirability of performing individual-dose reconstructions for this cohort and engaging in a long-term epidemiologic study.

4.4. The Mayak Children Cohort

Another task in the feasibility studies is to identify approximately 40,000 persons born between 1948 and 1973 who lived for at least one year in the vicinity of the Mayak Industrial Association. One of the primary routes of exposure to this cohort was the release of materials to the atmosphere from the facility. An evaluation will be made concerning the possible individual and collective doses and whether a long-term dose-reconstruction and epidemiologic study would be useful.

5. Other Cohorts of Interest

Three other cohorts have been proposed for feasibility studies to be conducted under the auspices of the US-Russia Joint Coordinating Committee on Radiation Effects Research. These proposals will be considered by the JCCRER in April 1996.

One cohort consists of children exposed to high radioiodine doses from the Chernobyl accident and who live in the Bryansk, Kaluga, and Tula Oblasts in Russia. The proposal is to conduct a dose-reconstruction effort and to define a cohort to be the subject of an epidemiologic study.

Another subject of general interest is the exposures that have occurred in the Altai Oblast, Russia, from the testing of nuclear weapons at the Semipalatinsk Polygon in the Republic of Kazakhstan. Fairly substantial exposures are known to have occurred, especially from the first test that was conducted in 1949. The proposal is for the US and Russia to work jointly on dose-reconstruction efforts. A primary goal would be to develop a common methodology that could be tested and validated against data from both countries' experiences. If this dose-reconstruction effort is approved and is successful, it might be followed by joint epidemiologic studies of the population of interest in Russia.

6. Pattern of US Cooperation

In nearly all of the situations addressed above the primary work on dose reconstruction is being performed by scientists in the former Soviet Union. US assistance has been in the form of expert consultation and participation; exchange visits; and the provision of medical, computational, and dosimetric equipment. In addition financial assistance to the cooperating institutions has been provided on a limited scale.

A primary goal of the US-assisted efforts is to publish the obtained results in peer-reviewed western journals. This goal is being facilitated by the joint authorship of such articles with the lead authors being those from the FSU responsible for the primary intellectual input.

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