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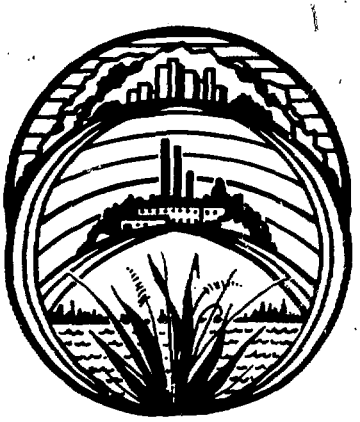
# Environmental Decontamination

## Proceedings of the Workshop

December 4-5, 1979
Oak Ridge, Tennessee



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The Energy Division
Solar and Special Studies Section
Oak Ridge National Laboratory

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Conrad V. Chester
Chairman

George A. Cristy
Helen C. Jernigan
Editors

Date Published: February 1981



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## FOREWORD

The Environmental Decontamination Workshop was conducted at Oak Ridge National Laboratory by the Solar and Special Studies Section of the Energy Division on December 4 and 5, 1979. Twenty-seven invited papers were presented to a group of about 60 persons who have had experience and/or continuing involvement with decontamination problems. The speakers represented various U.S. industries, national laboratories, and the Department of Energy. Each was asked to present state-of-the-art information learned from actual participation in environmental decontamination projects. Questions and informal discussion from the floor often followed the talks.

The data base formed by these presentations covers most of the U.S. experience (and some USSR developments) in environmental decontamination. The information will provide the starting point for further studies of large-scale decontamination of the environment. The Department of Energy is committed to program development leading to plans and procedures for decontamination work; the commitment is a result of communication between DOE and the Congressional Subcommittee on National Resources and the Environment, a subcommittee of the Committee on Science and Technology.

We thank all the participants for their fine cooperation: the information was presented in good form, on very short notice. We also appreciate the patience and help of the participants in preparing the Proceedings for publication.

George A. Cristy
Helen C. Jernigan
Editors

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# OPENING REMARKS

Conrad V. Chester
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Oak Ridge, Tennessee

In the wake of Three Mile Island (TMI), there was some correspondence between the Environmental Subcommittee of the House Committee on Science and Technology and the Department of Energy (DOE). The chairman and staff of the committees wanted to know what ability, capability and plans DOE had for cleaning up a large-scale environmental contamination such as might have resulted from TMI (1) if the containment systems had not worked and (2) if our pessimistic models of behavior of fission products had been accurate. DOE wrote back and said "We will look at it." This symposium, or workshop, is one result of that correspondence. We are bringing together for the first time as many people as we can find who are working on matters related to environmental decontamination. We probably haven't included everyone, though we have, I think, a fair fraction.

In the last week of November 1979 in Hershey, Pennsylvania there was a meeting of general public utilities people, DOE, and some Canadian people, sponsored by DOE and EPRI (Electric Power Research Institute). The purpose of that meeting was to bring together the people responsible for recovery of TMI and people who had had experience at high-level decontamination with DOE and in Canada. It was a very interesting meeting. Some of you were there.

We discovered at that meeting that there were some things we did not cover well in our list of subjects for this workshop. The one that impressed me most was the importance of beta radiation when dealing with uncovered fission products. Those of us who are used to thinking of radioactive solutions being in pipes or tanks--or maybe outside of shelters--tend to overlook betas. But when coming to grips with them on a practical or literally a hand-to-hand basis they're quite important. The beta dose to the skin can be 100 to 400 times the gamma dose and usually is the controlling exposure. That is something that we will have to cover in future meetings and workshops.

The importance of planning was stressed repeatedly. We have included some of that in the workshop--perhaps not enough. The importance of special equipment was discussed, and we are just hinting at that toward the end of this seminar. There was discussion of the importance of air suits in working in a highly contaminated environment and the problems of heat fatigue of people using unventilated C-zone clothing, especially with beta shielding.

This workshop may be too heavily concentrated on the present severe problems of dealing with extremely low levels of radiation or radioactive contamination that are required by EPA standards. There is a lot of concern about how you analyze for them--how you prove that you have gotten down to a level that low. That would be important eventually, at some stage of the large-scale decontamination, but not initially.

We think we have covered a number of subjects which are important and relevant. We've included the Russian incident at Kyshtym, a large-scale contamination that occurred in the late 1950s in the Urals. It is alleged that perhaps hundreds of square miles were contaminated to the point where they had to be evacuated. This is the type of problem that the House Committee may have had in mind when they initiated correspondence with DOE.

We included one paper which will review recent research on source terms. This research is directed toward getting a better model of what would come out of a reactor in an uncontained meltdown. TMI showed that our previous

models assuming a dry containment are grossly pessimistic--many, many orders of magnitude grossly pessimistic. There is an attempt now to find out just what the magnitude of the problem is. It almost certainly is vastly smaller than the experience at Kyshtym.

We have a review of ARAC and AMS (the Atmospheric Release and Advisory Capability and the Airborne Monitoring System). These two facilities played a very important role in the crisis at Three Mile Island and would be heavily involved in any future incident or threatened incident. I think it is important that all of us know of their existence and their capabilities.

We have a number of talks on actual experience with decontamination, work with soils, and work with concrete. The work with concrete would be quite important if an urban environment were involved. Along that line, we have a paper on combustion of waste. This would also be important if a built-up area were contaminated, particularly a residential or a wooded area.

We have a couple of papers on river cleanups. This is something with which the Russians apparently have had a good deal of experience, but ours is quite limited. Fortunately, we've never had a major radioactive contamination of a water course. However, there is work going on now with attempts to decontaminate the Hudson River and the St. James River from chemical contaminates PCB and KEPONE, respectively.

We have a couple of papers that will be surveys of potential technological improvement. In the past, large-scale decontamination has always been done on an ad hoc basis. Events were invariably not planned for and were done with whatever was available at hand. We would like to introduce the possibility of the traditional American approach to big jobs involving technology and mass production methods. We think this would be an important direction for DOE research in the future.

Once again, I welcome you all to the seminar.

Dup

# 1. RUSSIAN EXPERIENCE*

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The Soviet literature on radioecology and decontamination of soils, as summarized by Polyakov,[1] indicates that most of their environmental decontamination philosophy has been directed toward remedial measures for contamination resulting from catastrophic events (i.e., from nuclear weapons or major accidents) that could contaminate hundreds of square kilometers of land and water surfaces. As a consequence, very practical approaches have been suggested to deal with these problems. The approaches that seem to be preferred are those employing equipment that is generally available for soil decontamination and techniques that are most cost-effective.[1] Some of the apparent practicality may have been required to deal with relatively large, contaminated land and water areas in the Urals, originating--at least in part--as a direct result of a major nuclear accident.[2]

## TERRESTRIAL DECONTAMINATION

Much of Soviet terrestrial decontamination research deals with strontium-90, which poses the greatest long-term problem in terms of human food chains. In certain parts of the Soviet Union, because of particular soil types, cesium-137 also plays a major role in human radiation exposures via food-chain pathways.[3] Short-term decontamination does not appear to be a major objective, but rather the emphasis has been on reclamation of areas which may have been evacuated or reserved for restricted use until decay of short-lived radionuclides. The implied objective, in the case of strontium-90, was to reduce its concentration from some higher level to approximately 0.1 to 1 $mCi/m^2$ or less,[4] at which concentration human body burdens resulting from food-chain transfer would be acceptably low.[1]

One means of accomplishing this objective has been to move strontium-90 down into the soil profile by chemical leaching in situ.[1] This may be done with a calcium-chloride leach, although this has not been effective. Soviet authors report that after about seven years, about 80% of the strontium-90 in the original surface layer had moved down below the rooting zone of plants. There are obvious problems with the technique. Around 10 to 30 tons of calcium chloride per hectare are applied and the resulting salinity is lethal to much of the original vegetation. One also has to be concerned about how far strontium-90 moves down into the soil profile, lest groundwater contamination result. Another technique suggested has been fixation of the strontium-90 with a sodium-carbonate treatment which raises the soil pH, co-precipitating calcium and strontium as carbonates. Both techniques have effectively isolated about 80% of the strontium-90 under ideal conditions,[1] while most other chemical treatments (fertilization, liming, etc.) were less successful.

A more effective method has been to remove the surface layer of soil, i.e., to scrape it off mechanically.[1] Russian authors report that road scrapers have been favored for this work, and they have provided considerable detail on both equipment specifications and calculations of the land surface that can be decontaminated with a given piece of equipment in unit time.[1] For an agricultural soil with good physical properties, they estimated that their most effective equipment could decontaminate about 50 hectares per year, working only about 100 days per year due to weather limitations. Topography, soil type, degree of rockiness,

*Research sponsored by the Office of Health and Environmental Research, U.S. Department of Energy, under contract W-7405-eng-26 with Union Carbide Corporation.

etc., all affect soil decontamination by mechanical processes.

Special problems were reported to be associated with removal of surface layers in vegetated areas, cropland, and forests. For example, the bulk of the activity in fallout onto a pine forest was contained in the branches and needles of the trees and in the litter layer.[5] Most of the radioactivity would not have reached the soil for many years if it had been applied to a forest canopy.[1,2] Decontaminating a forest was, therefore, a difficult problem and may not have had a practical solution. However, on the positive side, up to 98% of radiostrontium applied to certain agricultural regimes could be readily removed along with the vegetation and/or associated mulches (minimum tillage practices).[1]

The ultimate disposal of large volumes of contaminated soil, etc., posed a considerable problem. One suggestion was to transport the soil to closed water courses and/or arid areas and to dump it there.[1] In most cases this was not practical, and Soviet authors state that a recommended solution is to put the contaminated material in natural pits and depressions or man-made excavations, or in other areas where it could be protected from both the influence of groundwater intrusion and wind and water erosion.[1] It is interesting to note that Soviet émigrés who lived in the area of the alleged Kyshtym-Urals nuclear accident reported that around the countryside there were fenced enclosures containing piles of topsoil, known locally as "the graveyards of the earth."[6]

The technique that the Soviets seem to have concluded was most effective in soil decontamination, particularly in agricultural areas, was deep plowing.[1] A special plow was used which takes uncontaminated lower soil and inverts the soil strata. This was not a perfect technique, and soil structure obviously had an important role in determining how practical it was. Plowing does not result in perfect turnover of soil layers; instead, mixing of layers results.[1] The objective, of course, was to place the contaminated surface material below the rooting zone of vegetation so that the area could be used for agriculture. Soviet authors reported a decontamination factor of 10 by plowing to about 70 cm. An even more effective technique was the combination of deep plowing with other treatments. For example, it was reported that strontium-90 uptake by soybeans was reduced by a factor of 1000 after plowing to 75 cm and following with application of a sodium carbonate/ isopropylphenylcarbonate mixture which prevents root intrusion.[1] A decontamination factor of 1000 on a large scale seems excellent, but the long-term effectiveness or practicality of such a combined technique has not yet been demonstrated. It also must be recognized that any kind of treatment may affect soil fertility, and Soviet authors note particular concern about this consequence.

It is also interesting that one of their experiments on deep plowing was done on a plot of 18,000 $m^2$ (roughly 5 acres). We are told that the area was contaminated with 5 to 10 μCi of strontium-90 per $m^2$ and had not been used for two years before the study began, although before that time it had been used for vegetable culture. This is but one example of a group of studies which may be related to a reported Soviet nuclear accident.[2] These studies were conducted in an unidentified locale, beginning some years after the contaminant had been applied to soil which had been removed from normal land use. Another set of authors, apparently occupied with the same topic, suggested that the need for soil decontamination could be obviated in agricultural areas that were too heavily contaminated for food production by changing the land use to forestry.[7]

## AQUATIC DECONTAMINATION

Soviet aquatic research in decontamination apparently has been directed at purification of water rather than biota and sediments. An interesting series of papers originated from the laboratory of the Ural Affiliate of the Academy of Sciences of the USSR in Sverdlovsk in the mid-1950s and ran through the mid-1960s.[8]

These were all laboratory studies, and they appear to be extremely simplistic in design: a series of cascaded aquaria (as many as ten) to mimic cascaded reservoirs or lakes interconnected on a river system. Radioactivity was metered in at one end and allowed to flow slowly through (and interact with) the entire system of reservoirs; the output activity was then measured. Various combinations of sediment types, vegetation, and flow regimes were used to simulate a variety of natural aquatic ecosystems.[8]

However simplified this research tool might seem, it allowed Soviet researchers to estimate the effectiveness of sorption, hydrologic manipulation, and hydrologic isolation as tools in decontamination of aquatic ecosystems. Results from both laboratory[8] and field[9] studies showed that strontium-90 was sorbed less strongly than cesium-137. Concentrations in sediment relative to water were 30-2000 vs. 200-20,000, respectively. Both could be significantly desorbed by passing a current of clean water through a contaminated system.[8] Although concentrations of both strontium-90 and cesium-137 were higher in vegetation than in sediments, the fraction of the isotopes contained in the biomass was always less than a few percent of the total activity in the systems. Thus, decontamination of water bodies by harvesting biomass alone did not appear to be practical.

Even under optimum conditions for radioisotope retention in the model system (strongly sorbing sediment, large biomass, lowest flow rate), approximately one percent of the strontium-90 activity added at the upstream end was discharged at the output end over 30- to 60-day periods. Roughly the same amount of activity was discharged when clean water was passed through the previously contaminated system. Thus, although hydrologic manipulation of flow rate could reduce the amount of activity which was transported out of contaminated systems, a significant and continuous release of desorbed radioactivity would issue forth as long as any water movement occurred.

In 13 natural water bodies (lakes with closed drainages) contaminated with strontium-90 as a result of a single accidental input,[2,10] a pseudo-equilibrium for water and sediment was reached after 2 to 2.5 years. Between 78-97% of the added activity became associated with surface sediments by means of sorption and ion-exchange.[10] Diffusion processes became evident over the next 10 to 15 years,[11] as concentrations in water were reduced by another factor of 2 to 3. The importance of the stable calcium pool in sediment-water strontium-90 exchange and of sediment type and average depth was also demonstrated.

Although concentrations of strontium-90 in the water of these lakes were reduced by factors of 10 to 100 below initial levels, concentrations in bottom-feeding edible fish did not change significantly over the period from 4 to 14 years post-contamination.[11] The reason for this was that the sediment inventory was primarily contained in a relatively thin 5- to 10-cm layer and did not change significantly over the same period; sediment was the primary dietary source to bottom-feeding fish. Concentrations in bottom-feeding fish were over 10,000 times greater than those in water.[11] Thus, one could conclude that a contaminated lake might be usable as a water supply under conditions which would not permit operation of a fishery (i.e., food production). Restoration of fisheries would probably require surface dredging or burial of essentially all mud and peat deposits in such a system. In the case of accidental airborne inputs, prevention of recontamination by runoff-groundwater sources in the watershed would also be required.

Controlling the spread of contamination in flowing waters, such as rivers and estuarine systems, is a much more difficult problem and one for which satisfactory solutions are not presently available. One solution may be to gain time by constructing a series of cascaded reservoirs (as needed) downstream from a contaminant input, to slow its movement, while constructing a bypass channel for water diversion around the primary contamination zone.

This appears to have been done by the Soviet Union in order to isolate a highly contaminated area (Fig. 1.1) resulting at least in part from a nuclear accident in 1957-58.[2] The Techa River, near a reported Soviet nuclear accident site,[2] no longer drains from Lake Irtyash through Lake Kyzyltash and from Lake Kyzyltash as a free-flowing stream. Water which would have entered Lake Kyzyltash from Lake Irtyash has instead been diverted into a canal. The canal transfers water around Lake Kyzyltash and two new reservoirs (built since 1954) to a point downstream. A new drainage for Lake Irtyash has also been provided, through Lake Berdenish, into the same canal. Former tributaries of the Techa, which entered in the reach between Lake Kyzyltash and the new reservoirs, now drain into canals; flows are similarly diverted to a point well downstream.

The fact that these two new reservoirs and Lake Kyzyltash have been isolated hydrologically from the surrounding drainage area (hardly a typical practice) strongly indicates that they have been specifically designed to prevent waterborne contaminants (such as strontium-90) from moving further downstream in the Techa

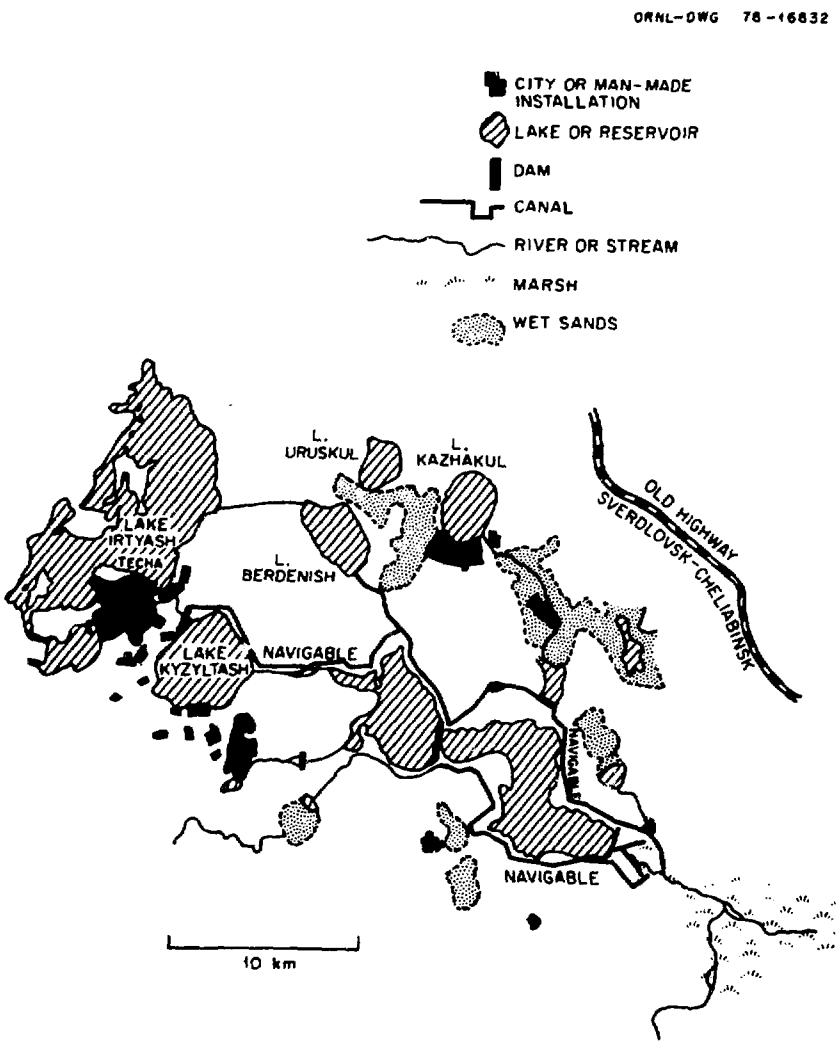


Fig. 1.1. Reservoir/canal system apparently constructed to reduce hydrologic transport of radioactive materials down the Techa River system near a Soviet nuclear accident site. Map is based on post-accident (1973) features.

River system. It also may be significant that two of the water bodies believed to be associated with this site now also appear to have artificially elevated aqueous calcium concentrations (110-226 mg/l)[12] as opposed to 7-33 mg/l in other study systems.[10,12] This raises the possibility that in situ decontamination of the isolated system (leaching of sediments without dredging) is being attempted at the present time. More information on this possibility could be extremely valuable.

## CONCLUSIONS

Soviet research in terrestrial decontamination appears to have paralleled that of the U.S. in many respects.[13] However, the probability exists that long-term evaluations of decontamination techniques (over 10-20 years) have been carried out at one nuclear accident site (a marked divergence from U.S experience). The area of aquatic decontamination seems to offer the most intriguing possibilities for new information acquisition from the USSR; at this point we can only speculate on its potential importance.

A hydrologic isolation system of the type described above is only possible in systems which have relatively low flow rates and a net annual evaporation-precipitation deficit, e.g., Techa River in the Southern Urals of the USSR. Large rivers and estuaries, and smaller rivers in areas of relatively high rainfall, would not be suitable sites for application of such a technique. Such areas have been chosen for a large fraction of the nuclear power plants in the U.S. because of the large volumes of water available for more efficient, flow-through cooling systems. At this point, it seems appropriate to ask whether control of accidental contamination releases is an important criterion in nuclear plant siting, even though the engineering design of power reactors is based on complete containment. Self-contained cooling reservoirs have been constructed for some nuclear power plants both in the U.S. and in the USSR. These systems would appear to provide an option for containment of accidental radioactivity releases.

Hopefully, the present reluctance of the Soviet Union to provide detailed information about the source and consequences of extensive environmental contamination near one of its nuclear sites in the Urals will be overcome, and the Soviet scientific community, which was engaged in extensive research following the Kyshtym-Urals event, will be allowed to share pertinent information with others who are concerned with the safe development of nuclear energy. Soviet experience, gained during unparalleled application of remedial measures at this site, is clearly unique. It would be invaluable to the world nuclear community. More research on environmental decontamination probably exists, documented but internal to the Soviet Union. This limits a proper assessment of our own research needs in this vital area.

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# 2. FISSION-PRODUCT SOURCE TERMS*

Richard A. Lorenz
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This presentation consists of a review of fission-product source terms for light water reactor (LWR) fuel. The information is based primarily on work performed by R. A. Lorenz, J. L. Collins, A. P. Malinauskas and M. F. Osborne, all of Oak Ridge National Laboratory.

A source term is the quantity of fission products released under specified conditions that can be used to calculate the consequences of the release. The source term usually defines release from breached fuel-rod cladding but could also describe release from the primary coolant system, the reactor containment shell, or the site boundary. The source term would be different for each locality, of course, and the chemical and physical forms of the fission products could also differ.

## CHARACTERISTICS OF IMPORTANT FISSION PRODUCTS

Characteristics of some important fission products are listed in Table 2.1. The fission gases, cesium, and iodine are important because their fractional release from fuel is usually the highest. The fractional releases of fission gas, cesium, and iodine from uranium dioxide pellets are similar in magnitude.[1] However, their escape from a reactor site during an accident may differ markedly because of differing chemical properties. The fission gases behave essentially as ideal gases, and they are not easily retained except in leak-tight enclosures. In many accident situations, cesium released from fuel pellets tends to be retained inside the cladding even though the cladding is perforated.[2,3] That which escapes from the failed fuel is water soluble and does not readily become airborne. Like cesium, iodine is partially retained within failed cladding;[2,3] however, volatile iodine species will form under certain circumstances.

The three major chemical forms of fission-product iodine are listed in Table 2.2. Iodine is usually released from LWR fuel initially as

*Research sponsored by the Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, under Interagency Agreements 40-551-75 and 40-552-75 with the U.S. Department of Energy under contract W-7405-eng-26 with the Union Carbide Corporation.

Table 2.1. Characteristics of Important Fission Products as Released From Fuel Rods

| Fission Product | Characteristics |
|---|---|
| Fission gases (Xe, Kr) | Inert, ideal gases<br>Not retained in human body<br>Only $^{85}Kr$ has long half-life |
| Cesium | Usually occurs as CsI, CsOH<br>Very soluble in water<br>Long half-lives<br>Does not form highly volatile species |
| Iodine | Chemical form (and volatility) varies<br>Concentrates in human body<br>Half-life of longest important isotope is 8 days |
| Particulates | All fission products may be released as particles of fuel |

Table 2.2. Chemical Forms of Released Fission-Product Iodine and Their Characteristics

| Chemical Form | Characteristics |
|---|---|
| Inorganic iodides (usually CsI) | Low volatility<br>Completely soluble in water<br>Can slowly oxidize to form $I_2$ |
| Elemental iodine ($I_2$) | High volatility<br>Very soluble in water<br>Easily sorbed on charcoal<br>Can slowly form organic iodides |
| Organic iodides ($CH_3I$) | Gaseous<br>Low solubility in water<br>Difficult to trap in adsorbers |

cesium iodide; conversion to the other more volatile forms can follow.

## SOURCE LOCATIONS WITHIN THE FUEL ROD

Although all fission products are formed within the $UO_2$ grains, fission-product releases from LWR fuel originate from three different locations as shown in Fig. 2.1. With time and high temperature, significant quantities of cesium, iodine, and the fission gases diffuse as atoms or transport as small bubbles to the grain boundaries, where they are retained fairly well unless the fuel temperature is higher than average. With continued time and high temperature, some of the fission products trapped in the grain boundaries escape to the void spaces between the pellets and cladding; some cesium, iodine, and gases diffuse directly from the grains to the void spaces.

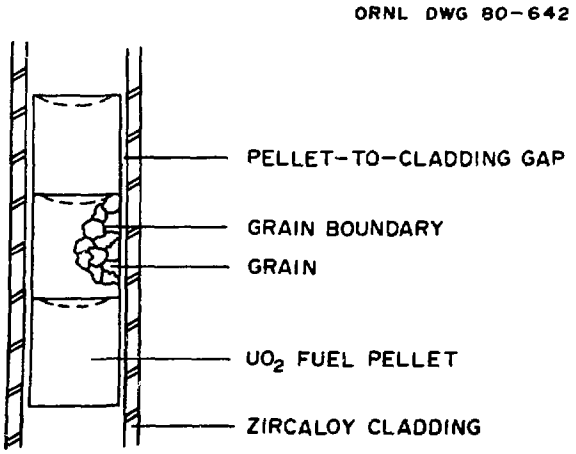


Fig. 2.1. Locations in LWR fuel rods of potentially releasable fission products.

Because this movement is a slow process, the fission products reaching or residing in the pellet-to-cladding gap space (the gap inventory) are depleted in short half-life isotopes when compared with those existing within the grains. Only a very small fraction of the young fission products escape to the gap space by direct fission recoil or recoil knockout.[4] When the cladding is perforated or otherwise fails in an accident, fission products located in the gap space escape at lower temperatures than those residing in the grain boundaries.[5] Very high temperatures and long heating times are required to release fission products initially residing toward the center of the grains.[6] These differences in distributions of isotopes in the various source locations have not been studied fully, yet they are important in determining source terms, especially for short decay times.

## TYPES OF LWR ACCIDENTS AND RELEASE MODES

Several types of accidents that might occur with LWR fuels are listed in Table 2.3. Some fission-product release into the reactor primary cooling water is expected to occur during normal reactor operation. According to reactor vendors, four or five rods out of a total of 36,000 in a reactor might have pinholes.[7,8] In a controlled loss-of-coolant accident (LOCA), the cladding temperature rises to a maximum of

Table 2.3. Fission-Product Release Modes

| | |
|---|---|
| In-reactor accidents | Pinhole in cladding (normal operation)<br>Controlled loss-of-coolant accident (LOCA)<br>Extended LOCA (above 1200°C or 2200°F)<br>Fuel melting |
| Out-of-reactor accidents | Pool storage leaching<br>Shipping<br>Crushed fuel<br>Oxidation |

1200°C. In an extended LOCA like the one at Three Mile Island, the cladding and fuel can exceed 1200°C, and additional fission-product release from grain boundaries in the $UO_2$ can occur. Fuel melting is another possible source of releases at higher temperatures. Out-of-reactor release modes include leaching during pool storage, shipping accidents, crushed fuel, and oxidation.

## RELEASE DURING NORMAL REACTOR OPERATION

Pinholes in the cladding, which account for some fission-product release from fuel rods during normal reactor operation, can occur from hydriding or stress-corrosion cracking. The stress is from pellet-cladding interaction (a mechanical force), which usually occurs during rapid start-up, or perhaps during an increase in reactor power from a previous constant power setting. Iodine is thought to be the primary causative agent of stress corrosion, but some other fission-product elements have also been implicated. Fission gases, cesium, and iodine are slowly released to the primary coolant from these pinholes. Fission gas is collected and decays in charcoal traps; cesium and iodine are removed from the water by the de-ionizer. Some iodine is collected on charcoal traps, but very small (I should emphasize very small) amounts of iodine escape from the reactor complex as organic iodides.

## RELEASE DURING THE CONTROLLED LOCA

In an ordinary controlled LOCA, a pipe break or other opening causes loss of reactor primary cooling water. Emergency cooling systems operate to keep the maximum cladding temperature to 1200°C (2200°F). In spite of that, some cladding will rupture: the internal pressure described previously (Table 2.3) causes heated cladding to balloon and rupture. All of the fission gas in the plenum and fuel-rod void spaces of the ruptured fuel rods is released. This may amount to very roughly 2% of the total inventory in the rod but may range from 0.2 to 20% depending on the operating history of the fuel rod.[9] An additional amount of fission gas, perhaps 1.5% of the total rod inventory, will be released[3,9] from fuel gas atoms shallowly embedded in the fuel and cladding surfaces.

The venting plenum gas (burst release) carries about 0.04% of the total rod inventory of cesium and iodine in vapor forms and an additional 0.003% as fuel dust.[3] The vapor form of the released cesium is about 10% cesium iodide and 90% cesium hydroxide. The fuel dust released with the burst will contain all fission products that are present in the rest of the fuel. In our experiments, we find that a rather large-particle dust is ejected. We measured several of the larger particles and found them to be 100 to 150 μm in diameter. The smallest ones identified were perhaps 10 μm in diameter, although smaller particles may have existed. Probably because of the high density of $UO_2$ fuel and the large particle size, this dust does not have a tendency to remain airborne.

Additional heating after the blowdown may release very roughly 0.01% of the fuel rod

inventory of cesium and iodine. The chemical forms of released iodine are usually about 99% cesium iodide and roughly 0.5% $I_2$. A published quantitative model[9] for cesium and iodine release during a controlled LOCA shows that the burst release depends on the gap inventory, temperature, and volume of plenum gas vented at rupture. Postblowdown release depends on time, temperature, gap inventory, and width of the gap space.

## THE EXTENDED LOCA

In an extended LOCA, the fuel and cladding heat to above 1200°C, which was the case in the Three Mile Island accident when the emergency cooling system was turned off. At these temperatures the cladding becomes extensively oxidized, brittle, and fragmented. For the extended LOCA, the burst release is similar to that which occurs in a controlled LOCA. Diffusional release of the contents of the gap inventory will be 100% complete if the temperature is above about 1300°C for 10 minutes or more. At temperatures between 1300°C and 1800°C, depending on burnup, release will begin to occur from fission products previously accumulated in the grain boundaries.[5] At still higher temperatures (1300-2500°C) or longer times, diffusion from the grains themselves can become significant. At these high temperatures tellurium, barium, and strontium release will also occur but in amounts much lower than for cesium and iodine.[6] The released cesium and iodine exist in chemical forms that are initially completely soluble in water.

Figure 2.2 is a graphical representation of some of our data covering temperature ranges of interest in controlled and extended LOCAs. The figure shows the amounts of cesium, iodine, and krypton released into steam in the 10-minute period following the burst release. This data was obtained from H. B. Robinson fuel--pressurized water reactor fuel irradiated to 30,000 MWd/MT at slightly lower-than-average heat rating. The line at 0.3% is the gap inventory for cesium and iodine. Other fuel rods

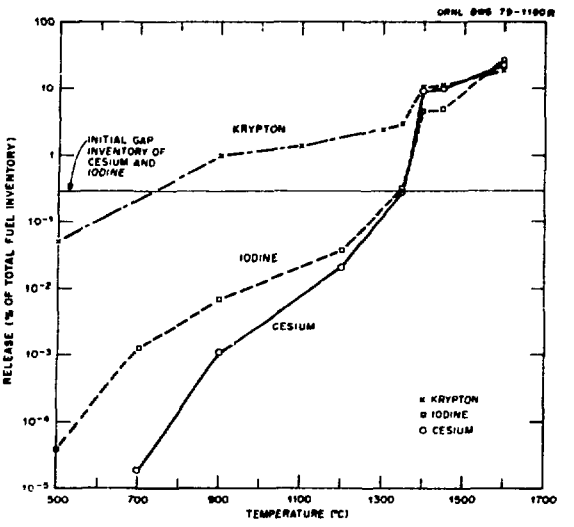


Fig. 2.2. The release of fission products from ruptured H. B. Robinson fuel by diffusion in steam in 10 minutes.

irradiated at higher temperatures could have gap inventories as high as 10 or 20%. For H. B. Robinson fuel at temperatures applicable to the controlled LOCA (i.e., up to 1200°C), it can be seen that the cesium and iodine releases are much less than the gap inventory. By 1300°C, most of the gap inventory is released. At about 1350°C grain boundary release begins; this is seen in Fig. 2.2 as a rapid increase in release. At higher temperatures, release from the grains themselves will become significant if the heating times are lengthy.

## MELTED FUEL

Some characteristics of melted fuel are shown in Table 2.4. No specific melting point is given because the various materials in a reactor core melt at different temperatures. Pure $UO_2$ melts at about 2850°C. Zirconia or zirconia-$UO_2$ eutectic has a melting point somewhat lower, and the melting point of Zircaloy cladding is approximately 1850°C. Eutectics will form with Zircaloy at temperatures considerably below the melting point of pure Zircaloy.

Table 2.5 lists amounts of several fission products released in 5 minutes from molten fuel[6] or molten fuel mixtures.[10] One is

Table 2.4. Typical Melting Points of Fuel Element Components

| Component | Melting Point (°C) |
|---|---|
| $UO_2$ | 2850 |
| $ZrO_2$-$UO_2$ eutectic | 2550 |
| Zircaloy | 1850 |
| Zircaloy eutectic | <1850 |

Table 2.5. Fission-Product Release From Molten Fuel

| Element | Amount released in 5 minutes (%) | |
|---|---|---|
| | Corium at 2200°C | $UO_2$ at 2850°C |
| Xe, Kr | 100 | 100 |
| I | 100 | 90 |
| Cs | 70 | 90 |
| Ba | 0.4 | 8 |
| U | 0.1 | 0.8 |

corium, a mixture of $UO_2$ fuel with Zircaloy and 55-wt% stainless steel; this is used to simulate a mixture that might occur if some stainless steel structural material melted along with the fuel rods. According to information obtained from Ref. 10, the corium mixture is almost completely molten at about 2400°C. The data in the last column were obtained from Ref. 6. Fission-gas release from these molten materials is complete. The release of strontium is usually similar to that of barium. Uranium is released primarily as vaporized $UO_2$; refractory-type fission products will be released in similar amounts. The released $UO_2$ and fission products of low volatility transport primarily as an aerosol that has the appearance of dense smoke.

## OUT-OF-REACTOR RELEASE

Fission products can be released in several out-of-reactor accidents that we have not studied formally, but we will discuss them briefly here. During pool storage, cesium and iodine will leach as from pinholes that existed while in the reactor. Iodine from these leakers tends to slowly form volatile species during pool storage. Therefore, the water system as well as the atmosphere above the storage pool must be cleaned up.

The most commonly analyzed shipping accident is the case where heat from an external fire might cause cladding rupture. We have read recently of a number of propane tank cars that have burned; this is one of the heat sources analyzed in shipping accidents. If the fuel rods should heat up sufficiently, a burst release and diffusional release of a small fraction of the gap inventory can occur just as in a LOCA. Shipping casks are designed to remain leak-tight in spite of impact and heat-up. Retention of fission products on cask surfaces has not been investigated. Chemical forms that we would expect to be released from the fuel

rods are cesium iodide and cesium hydroxide (at least upon contact with moisture). In our test apparatus we used silica or quartz as a containing material, and we found that the released cesium or cesium hydroxide reacts rapidly and is retained very well by this material. Volatile forms of iodine can be expected to form slowly following release from the fuel rods in this type of accident.

Crushed fuel resulting from a dropped fuel bundle or from the deliberate shearing or cutting of fuel rods will consist of a range of particle sizes. Examination of fuel rods cut to facilitate dissolving as part of fuel reprocessing studies[11] revealed that the mass median diameter of sheared fuel is 1 mm, and about 0.2% of the mass is less than 3 μm in diameter. A large surface of fuel is exposed, and we could expect leaching of some cesium and iodine from the fuel if water or some solution were applied. In addition, we would expect some formation of volatile forms of iodine.

## RELEASE FROM OXIDIZED FUEL

Uranium dioxide oxidizes in air at temperatures above 300°C; the maximum oxidation rate for sintered $UO_2$ pellets occurs at about 500°C. Fission gas, iodine, cesium, ruthenium, and tellurium are released from bare oxidized fuel with about 1 to 10% of the material being released at temperatures up to 900°C.[6] Under such oxidizing conditions, the chemical form of iodine released is assumed to be elemental iodine.[2,3]

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# 3. ATMOSPHERIC RELEASE ADVISORY CAPABILITY

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The ARAC system (Atmospheric Release Advisory Capability) is a collection of people, computers, computer models, topographic data and meteorological input data that together permits us to to calculate, in a quasi-predictive sense, where effluent from an accident will migrate through the atmosphere, where it will be deposited on the ground, and what instantaneous and integrated dose an exposed individual would receive.

The original mission of ARAC was to develop a real-time capability for dose assessment from accidents, a mission that dates back to the days of Atomic Energy Commission. The project started about six years ago. First, let me describe the system briefly (Fig. 3.1). The ARAC center consists of mini-computers, people, and codes--all linked together in a real-time communication system with the Lawrence Livermore Laboratory main computer center where we have three CD C7600 computers, one Cray machine, and two Star machines. We are linked to the National Weather Service, from which we get real-time meteorological observations and forecast products. We are also linked to the Air Force Global Weather Central in Omaha, Nebraska, where we can get real-time-response weather data for the entire world--not just that limited to the continental U.S., as is most National Weather Service data.

At present, ARAC is tied directly to four DOE facilities. These are Savannah River Laboratory, Rocky Flats Plant, Mound Laboratory, and Lawrence Livermore and Sandia (considered as a joint system).

One of the major ARAC roles is linked to DOE emergency response, i.e., NEST (Nuclear Emergency Search Team) and any type of nuclear incident for which DOE is called out. Shortly, I will go through a list of some types of call-outs with which we've been involved. This has been our most active area.

Another area that has proved to be very effective is our ability to provide advisory and warning service to the FAA in the event of atmospheric testing, by China or any other nation, for high-altitude radioactive debris that may affect aircraft passengers and crew. Even at Three Mile Island there was a possibility of dose to low-level aviation coming into the Harrisburg area.

Back in 1973 (Fig. 3.2), the concept was developed that we would need a quasi-real-time response capability within the DOE community for

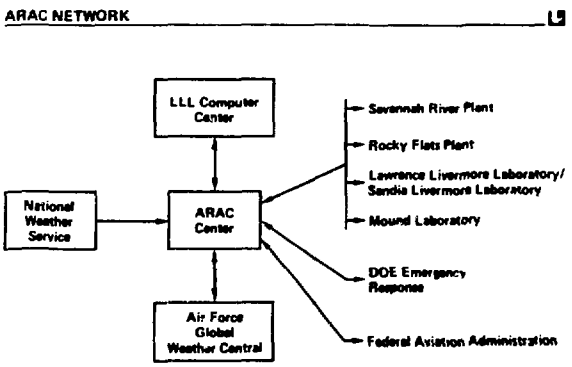


Fig. 3.1. ARAC network.

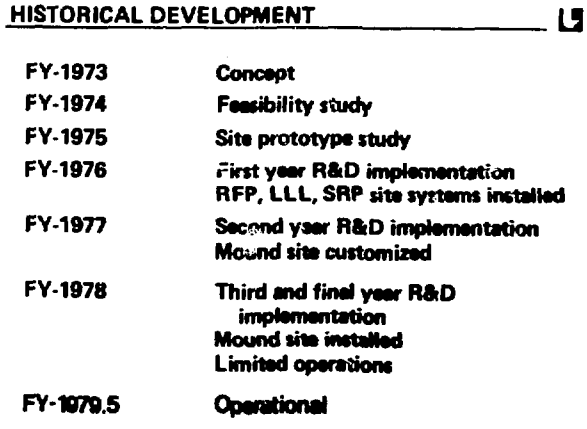


Fig. 3.2. Historical development of response capability within DOE community.

responding to accidents, to provide some immediate assessment of dose to individuals both within plant site and off-site, to follow up with calculation of any regional or area contamination that may result, and to prepare for a decontamination effort. A feasibility study was performed in FY 1974; a prototype study was conducted in FY 1975. During FY 1976, sufficient funding was provided for models R&D and the start of hardware implementation at Rocky Flats, Lawrence Livermore, and Savannah River laboratories. Implementation was completed at these sites in FY 1977 and R&D continued for the tying-in of multiple computers to weather-data systems and preparation of model inputs for our 7600 computer codes. The Mound Laboratory site installation was started that year.

A third and final year of R&D was 1978, when all the existing pertinent models at Livermore used for the ARAC center were linked together, and the whole software data stream was tailored to real-time response calculations. At this time on-site installation was completed, and limited operation was begun.

In 1979--actually during Three Mile Island, on April 2 of this year--ARAC was funded operationally for the first time. In other words, we moved out of the R&D mode and into an operational mode.

The uses of ARAC have been several (Fig. 3.3). As I said before, nuclear-debris cloud tracking has been primarily for FAA. We've tracked the various Chinese shots for the past several years. We have provided calculations of airborne concentrations that might affect the Concorde at its flying altitude of 55-57,000 feet and for commercial aviation going into Japan shortly after Chinese tests. This has become significant since the coming about of the Boeing 747 SP, which flies above the tropopause level (lower) stratosphere in the wintertime. We also have the capability of treating explosive dispersal of radioactive materials. This can come as a result of a non-nuclear accident where there may be some detonation of high explosives, such as a bomb, a DOD accident, or a weapon involved in an airplane accident. Certainly stack releases are included: one might categorize TMI as an excessive stack release. Surface accidents, transport accidents--a whole series of accidents can be envisioned. Here we have been involved in only a few, but we have the capability of response to a whole series of accidents.

**ARAC USES**

- Nuclear Debris Clouds
- Explosive Dispersal of Radioactive Materials
- Stack Releases
- Surface Accidents
- Others

Fig. 3.3. Uses of ARAC.

Figure 3.4 summarizes ARAC activities over the past four to five years. There was a moderately significant tritium release at Savannah River during the prototyping study in 1974, and

**ARAC UTILIZATION**

| | |
|---|---|
| 1974 | SRP tritium release<br>2 Threat assessments |
| 1975 | USS Belknap accident<br>2 Threat assessments |
| 1976 | Chinese 4 MT test<br>2 Threat assessments |
| 1977 | Train accident involving $UF_6$<br>Voyager I and II launches<br>Chinese test<br>Analysis of 1957 RFP fire, analysis of source of Cs found near RFP |
| 1978 | COSMOS 954 re-entry<br>Fort St. Vrain<br>Rocky Flats Be fire<br>Chinese test |
| 1979 | *Three Mile Island Accident* |

Fig. 3.4. Summary of ARAC utilization.

ARAC got its first workout before it was really totally put together. It was more "people power" than anything else at that point, but we showed that within a two-hour time frame we were able to run calculations on the release of tritium at Savannah River and to provide advisory service for propagation of tritium off-site. ARAC was called on for two accidents involving nuclear material back a couple of years ago. One of these was a train accident--I think it was either in Tennessee or North

Carolina--in which hydrogen hexafluoride was involved. ARAC was on standby as part of a DOE contingent for Voyager I and II launches because of the nuclear power sources on these spacecraft. We were involved in DOE NEST exercises including the NEST 77, a 72-hour exercise.

The first fairly long-term involvement was during the COSMOS 954 reentry. ARAC got involved in anticipatory calculations several days before the actual burn-in of the spacecraft; then after impact or burnup in the atmosphere we were involved in the exploratory sense of where debris could have gone if it had been in certain size ranges. If any object did strike the earth and was located, we were on a standby mode to begin calculations immediately to find where any effluent from that object may have migrated.

At the same time, a very hectic period began for us because (shortly after COSMOS 954 came in) the St. Varain power reactor in Colorado had an accident with a small release. Initially the magnitude of the accident was not known, so we worked very intensely at simultaneous problems. About three months later, the Rocky Flats plant had a beryllium fire. We were involved in calculations of the effluent transport from that fire. Over the past four years there have been at least seven threats of use of radioactive material, for which we have been called into a standby and preliminary calculational mode for the NEST environment. In addition, ARAC has had at least eight real-time tracer release studies, seven of which were run in conjunction with Savannah River. Another was run with the Idaho Falls plant.

The type of services that ARAC most frequently provides is information about instantaneous airborne concentrations of released materials (Fig. 3.5). This is information that is immediately useful upon occurrence of an accident for marshalling of personnel and for decision-making regarding evacuation plans. A concurrent type of calculation is for the integration of airborne concentrations. We have found, though, that in most accident cases one

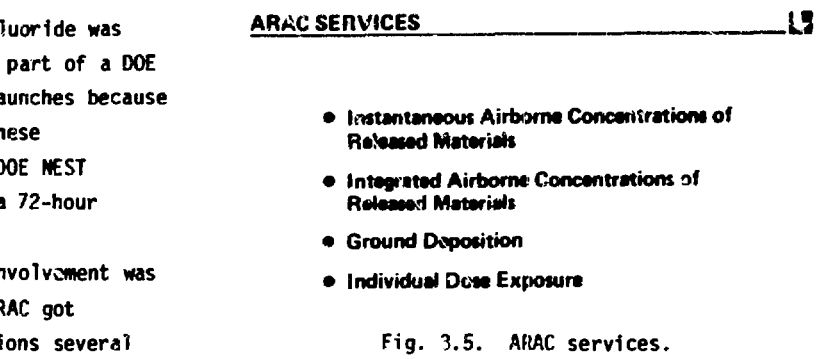


Fig. 3.5. ARAC services.

is really unable to do this to any great extent unless the source term is known. So we have not done this routinely in accident situations. At St. Varain there was some confidence in knowledge of the range of the source term at least, so we did the worst-case integration on that for about four hours.

Ground deposition would certainly be a subject of interest to most of you here. Most of the accidents with which we have been involved have dealt with gases, so, except for iodine-131, deposition calculations have not been required. Exercises have consisted of other possibilities. We have the capability to calculate ground deposition on a quasi-real-time basis, and by that I mean within about an hour of notification. Again, individual dose exposure is linked to the integrated concentration calculation. This can be only a relative calculation unless we know the source term, but it is the kind of thing that is getting to be of greater and greater interest. For example, at Three Mile Island, working in conjunction with people who were taking measurements, we were able to use our calculations to arrive at estimated dose exposure.

I'll take you on a quick, step-by-step walk-through to show how we address a problem when we are alerted (Fig. 3.6). I'll show you some of our models, and I'll lead into some results. Then most of the emphasis will be on TMI, because I was asked to emphasize what we did during the accident there.

Startup of a problem always comes out with the standard questions. The only one we don't really ask, although it is in the back of our

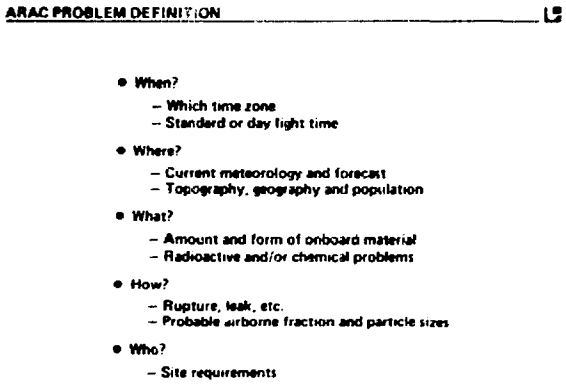


Fig. 3.6. ARAC problem definition.

heads, is "Why?" We go through this whole scenario of which time zone we are in. This may seem trivial, but it gets to be a real operational problem when we are on the West Coast trying to find out what time people want to use at the accident site. TMI was a perfect example: some people wanted to use Eastern Standard, other people wanted to go with the meteorological reporting time of Greenwich Mean Time. We wound up using Greenwich Mean Time, or Zulu Time, throughout the accident.

The "where" involves getting current meteorology and forecast information for the geographic area, trying to identify all potential sources of meteorological information within the surrounding area. That means going considerably beyond plant site; for example, at TMI one needed to get meteorological information for a 30- to 50-mile radius if at all possible and to provide this type of information to models for regional transport calculations. Other kinds of information we need for our calculations are detailed topography information and follow-on geography and population information. We did not deal with population information during the accident at TMI, but we did include this information in a post assessment. Of course, we need to know what type of accident occurred and if at all possible the amount and form of release of on-board material--the source term. This is the greatest problem we have in just about every accident situation. The clearest or cleanest situations we have dealt with (this has only been in an exercise mode) have been DOD-weapons accidents where one can fairly readily identify what was involved. Then, through some access to classified information, one can determine the source term--or at least an upper limit on a source term. Then we need to know where the release is coming from: a surface, a stack, a cracked containment vessel? Is it an explosive type of release, a puff, a continuous plume? If particles are involved, some estimate of the particle size and mass distribution must be known. Who requires the information, to whom are we sending it, and in what form should the information be?

For most significant accidents and exercises the ARAC center sends one or more people to the site to interface between the ARAC center calculations and the users of that product. At TMI, during the 21 days that ARAC was in a 24-hour/day mode, four of our people spent about one week each at the DOE Harrisburg Command Center for the accident assessment. Having four people there over that time-frame allowed a better interpretation of our product and interaction between those taking measurements and the calculations, to come up with such things as a plausible source term.

Once we've answered most of the questions shown on the preceding figure (Fig. 3.6) we try to determine the output requirements, i.e., what is needed, what is most essential. We collect the meteorological information most important to the models and find meteorological information for the type models we'll be running, with source definition if at all possible.

Next we make a choice of models; three classes are indicated here (Fig. 3.7). In our language, a "simple" model is a Gaussian type of model. We have an intermediate type of model that does not deal with terrain. It treats horizontal and vertical resolution in a somewhat coarse manner. We call it the "PATRIC" model. The "complex" model is a three-dimensional, mass-consistent, wind-field model (MATHEW) coupled to a particle-in-cell code (ADPIC). The complex model requires the largest amount of input data but provides the best answers. Input

preparation varies for these three sets of models; I'll go through that in a little more detail. But first I want to point out that normally when ARAC runs a problem we will run the simple model first to get an immediate answer. The time-frame for this calculation during our normal day would be to get an answer (the first calculation) out in 10 minutes and to have it available to an accident site in that time. During our off-duty hours, a response may take from one to three hours. In the beginning, we try to run a simple-model calculation in conjunction with the complex-model calculation, as a double check or consistency check (Fig. 3.7). For example, we compare centerline calculations, of the Gaussian against the more complex model calculations, to see if everything is reasonable and consistent; then we can go ahead and transmit to the site and have discussions between ARAC and the site personnel.

Looking at source inputs (Fig. 3.8): we have a suite of models which can consider puffs, a single-plume or continuous-plume model, and more complex models that treat multiple puffs or plumes. MATHEW/ADPIC, the most complicated set of models, treats both topography and three-dimensional wind flow in a mass-consistent sense.

Figure 3.9 summarizes the meteorological inputs. For the simple models we only need a single-wind velocity that is akin to most Gaussian calculations. The fallout codes require a single vertical wind profile; this at least gives vertical wind-shear and treats the meteorology a little better. The more complex models need multiple-surface and vertical meteorological observations as well as topographic information.

The selection of models at the time ARAC is called into an accident or response situation is shown in matrix form in Fig. 3.10. We can treat the spectrum from long-range, high-altitude calculations which we provide to the FAA for atmospheric tests of China and other nations, all the way to the short-range, low-altitude calculations. This brings us to the most complex models, MATHEW and ADPIC.

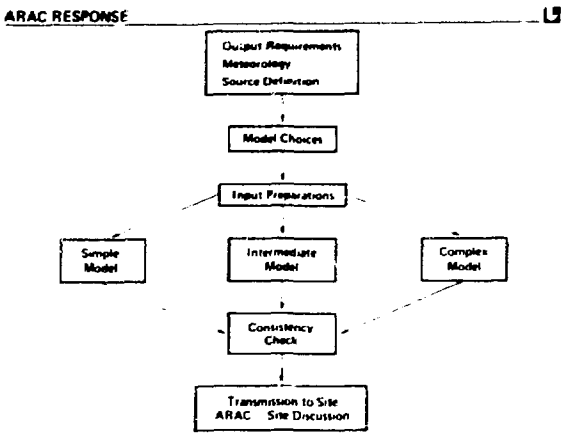


Fig. 3.7. ARAC response.

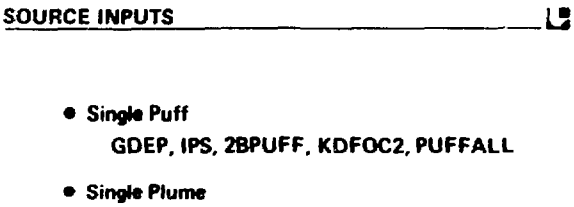


Fig. 3.8. Source inputs.

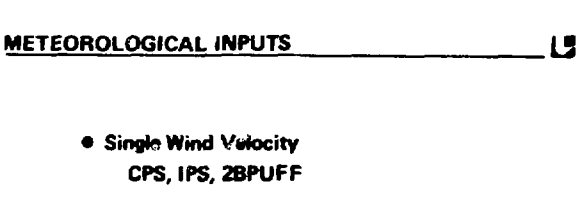


Fig. 3.9. Meteorological inputs.

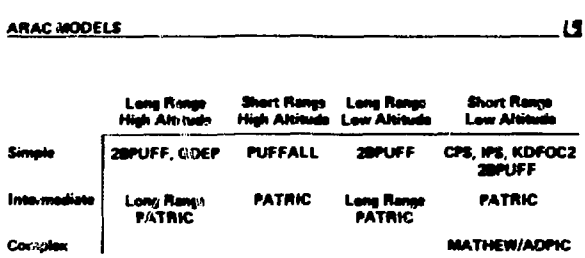


Fig. 3.10. ARAC models.

MATHEW (Fig. 3.11) is a variational calculus diagnostic meteorological model used to calculate three-dimensional, mass-consistent wind fields over complex terrain. The terrain is treated explicitly as the lower boundary; all other boundaries are flow-through. Meteorological data from the actual accident site is used as input and, if it is available, we include all the National Weather Service surface and upper-air data for the local region. Any additional or supplemental meteorological measurements are used as well. Good sources of information, particularly in urban areas, are the air-pollution control districts, universities, and various nonstandard reporting sites that have meteorological information. One of the first things we do when we go into an accident situation is to try to locate all these supplemental meteorological measurements. Of course we also need the local topography for these calculations. ARAC has the complete USGS topographic data base for the United States from which to extract this information.

**MATHEW**

A variational time-independent meteorological model used to calculate three-dimensional mass-consistent wind fields over complex terrain. Input to this model includes:

- Site meteorological data
- NWS surface and upper air reports
- Additional meteorological measurements from municipalities, pollution control districts, industry, etc.
- Local topography

Fig. 3.11. MATHEW.

ADPIC (Fig. 3.12) is the code that is coupled with MATHEW. This is a three-dimensional pollutant transport diffusion code that is particle-in-cell with transport and diffusion based on a pseudo-velocity method. It treats the total three-dimensional distribution of pollutants in space and time dealing with variable topography--the identical topography field employed by the mass-consistent, wind-field model. It can handle varying three-dimensional wind-fields, including the calm

**ADPIC**

A three-dimensional pollutant transport and diffusion code based on the particle-in-cell and pseudo velocity methods for modeling the concentration distribution of pollutants in space and time. ADPIC can simulate:

- Instantaneous and continuous, single and multiple sources
- Radioactive and inert pollutants
- Variable topography and surface roughness
- Time varying three-dimensional wind fields
- Time and space varying diffusion parameters
- Wet and dry deposition
- Gravitational settling for prescribed particle size distributions

Fig. 3.12. ADPIC.

situation, as well as time- and space-varying diffusion parameters. The model can treat a series of sources and species, and it can carry five species at one time and have up to five source points. The model treats radioactive decay of released species, wet and dry deposition, and gravitational settling for specified particle size distributions.

Figure 3.13 shows some of the verification information on tracer studies that have been run in conjunction with Savannah River and Idaho Falls. The best way to read this is by consideration of the "factor that the calculations are within." For example, 70% of the time results were within a factor of 3 of the measurements and 80% of the time within a factor of 5 of all measurements. We find that most of our diffi-

**MATHEW/ADPIC MODEL VALIDATION**

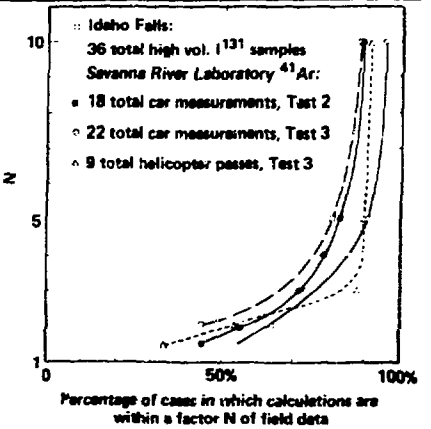


Fig. 3.13. Model validation (MATHEW/ADPIC).

culties in outlying points have to do with that classical problem of measurement of a plume in the environment. A few degrees across a plume edge, or just out by the plume edge, can make a considerable difference in verification if the plume is off by just a few degrees. Nearly all of our verifications have indicated that the plume is always within the proper sector and the centerline is very consistent with measurements. Figures 3.14 and 3.15 show the more detailed scatter diagrams for concentration resulting from the tracer experiments at Savannah River and Idaho Falls, respectively.

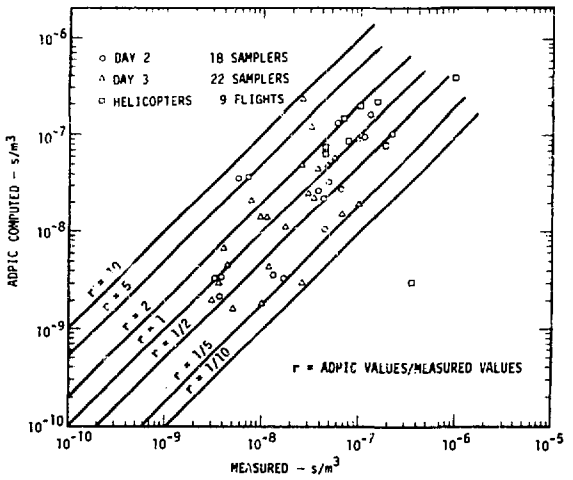


Fig. 3.14. Savannah River plume measurements.

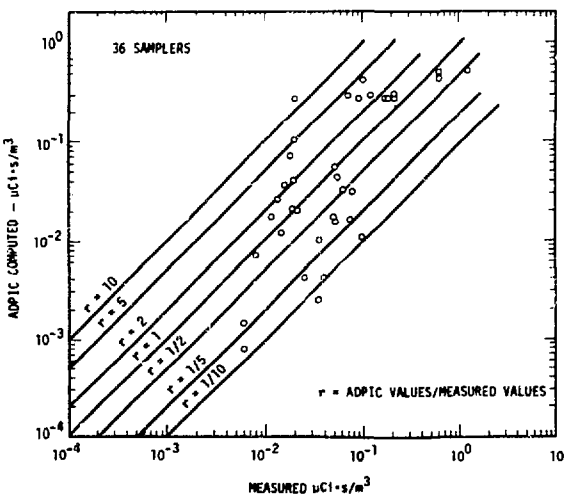


Fig. 3.15. Idaho Falls plume measurements.

To prove that this isn't just all on paper, the ARAC center at Livermore (Fig. 3.16) has four mini-computers all linked together in a real-time communications environment through which we can dial the various sites that are currently hooked on-line and retrieve meteorological data from them on a current-time basis or on a four-hour interval. We get a complete dump of their 15-minute average data and their 5-minute reporting data. We routinely collect data from the Air Force Global Weather Center for major metropolitan areas and the region surrounding all sites that are currently on the system. The systems process that meteorological data, in conjunction with site data, into input files. These files are immediately ready for transport to our large-scale computers, where a complex model provides calculations if needed. We do this in a real-time mode 24 hours a day, seven days a week, at the present time. Figure 3.17 is a closeup of two of the ARAC computers with some of the kinds of information we receive. This plot of an upper-air sounding (on the left CRT) gives the wind and thermal structure of the atmosphere in the vertical for the region of interest. This happens to be the Oakland area, which we collect routinely for Livermore. This is a Hewlettt-Packard computer system, the link to the Air Force Global Weather Center. The computer on the right is a DEC PDP11/34, serving as an information processing or display center. It enables us to look at the model calculations and to do a quality control or consistency check before transmission of products. The Livermore site is shown with an overlay of a simulated dose calculation of integrated air concentrations at the laboratory.

At this point, I'll go through some of the kinds of calculations we did for Three Mile Island. Figure 3.18 is a display of what the topography looks like to our three-dimensional, complex models. ARAC has the entire USGS topographic data base for the U.S., consisting of 300 magnetic tapes that contain the horizontal topography information at 62.5-meter resolution. We process that data and average it to a cell size that is normally no finer than half-a-

Fig. 3.16. ARAC equipment at Livermore.

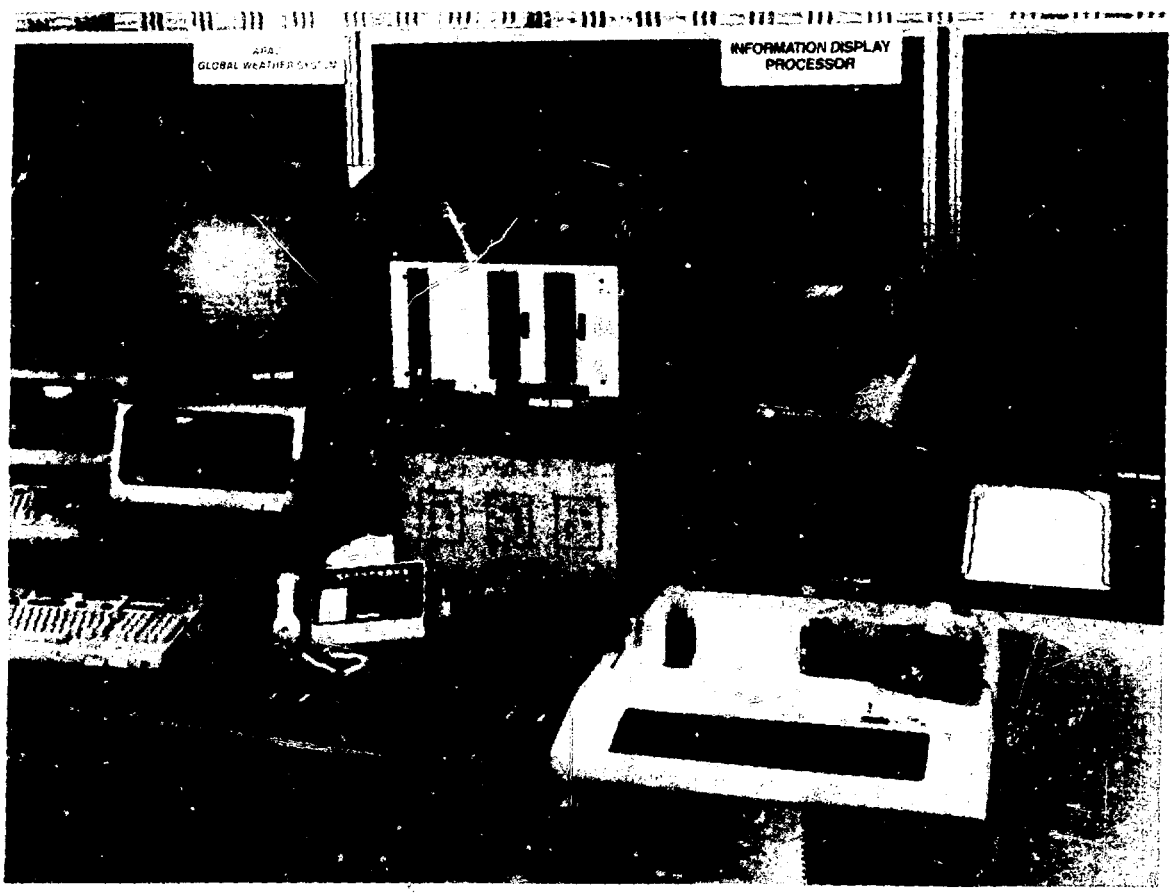


Fig. 3.17. ARAC computers (closeup).

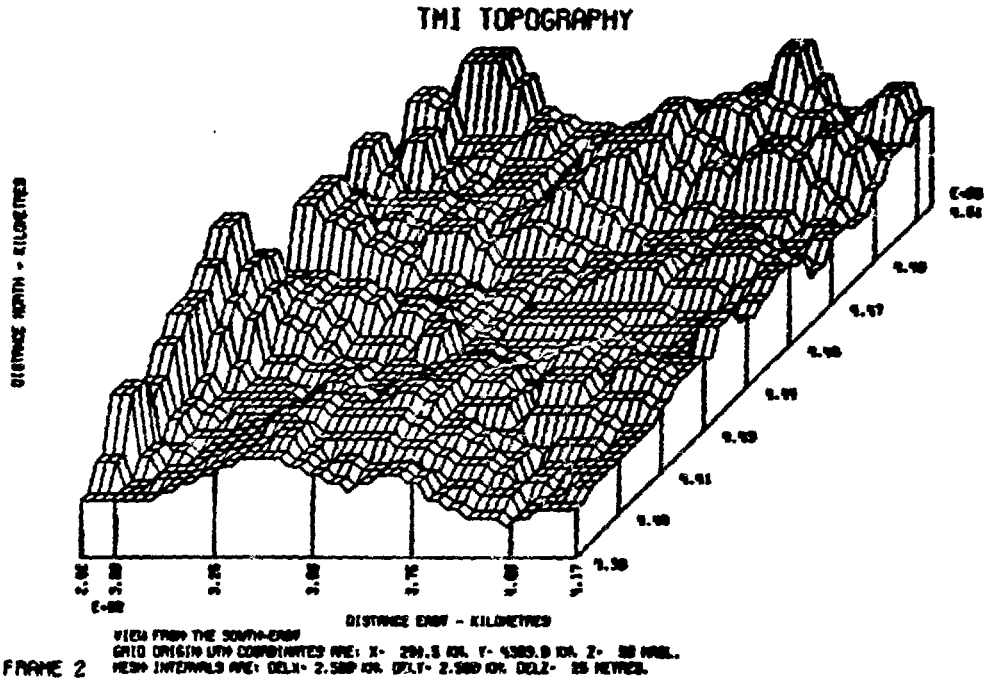


Fig. 3.18. TMI topography.

kilometer, because that is about the finest scale on which ARAC runs problems. This figure displays a 2-1/2-kilometer mesh; that is, each cell represents a 2-1/2-kilometer square. Vertical resolution is 25 meters. Obviously, the vertical scale is greatly exaggerated. Harrisburg and the TMI plant site are situated near the grid center. It is not as clear as you would like it to be, but this is how you deal with the computer. The Susquehanna River runs diagonally through the region.

Figure 3.19 shows the type of calculation one gets when an accident occurs at a site other than those four that are currently tied into the ARAC system. We were unprepared for this geographic area--ARAC had no geography information resident in the system. When we have resident geography, it is called customizing or tailoring of the system to the particular site. These are the kinds of calculations that were presented to the people at TMI and also to the various emergency operation centers requesting the ARAC products. We call this "relative concentration" or "instantaneous air concentration." This kind of plot gives you an idea

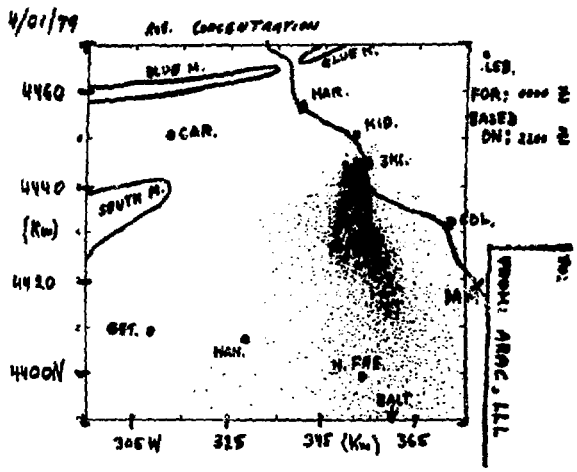


Fig. 3.19. Plume prediction at TMI.

where an effluent plume is migrating--to what location it is being transported and diffused. Each particle depicted here is carried within the code. It has its own relative energy state, related to the source term as put into the model at the time. However, you can get no information about concentrations directly from this, other than some relative idea of spacing. Figure 3.20 shows a contour plot of the same

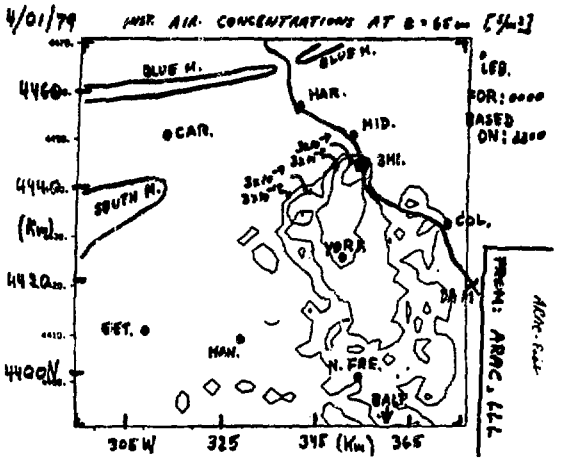


Fig. 3.20. Contour plot of plume prediction (TMI).

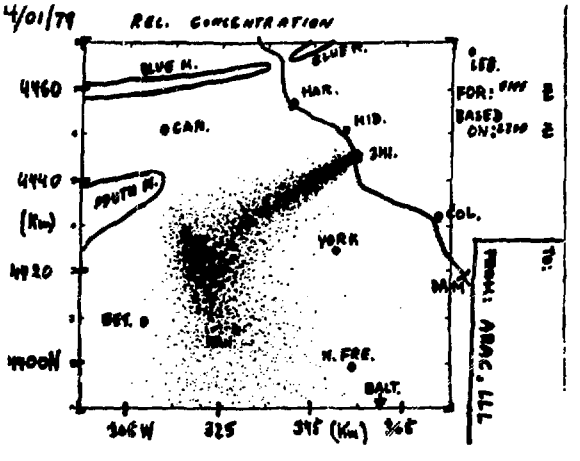


Fig. 3.21. Plume prediction one hour later (TMI).

calculation, giving the magnitude of the instantaneous air concentration. In the entire Three Mile Island accident we used a unit-source release or a 1-Ci/sec release rate. Lacking anything else, that is our standard release rate. One can then scale this information up or down when more significant information about the source is obtained. This type of information can also be used if one has measurements; this was done at TMI to try and work backwards for an estimate of the source term itself. Obviously, if the material being released were of a type that would deposit on the ground, one could very quickly get an idea of what a deposition pattern would be. Figure 3.21, produced one hour later, shows how quickly a plume can change as the meteorology changes. There was a significant shift in this one-hour time period as the winds rotated at Three Mile Island. Figure 3.22 shows the relative concentrations in contour format. Figures 3.23 through 3.29 depict some final calculations that were done as an assessment for the President's Commission during August, 1979. This was done so that the Commission could assess population dose in person-rem. This series was calculated at six-hour intervals for the first 48 hours of the accident. Figures 3.28 and 3.29 indicate a period when the wind slacked and stability increased. You can see puddling and a diffuse--very diffuse--plume.

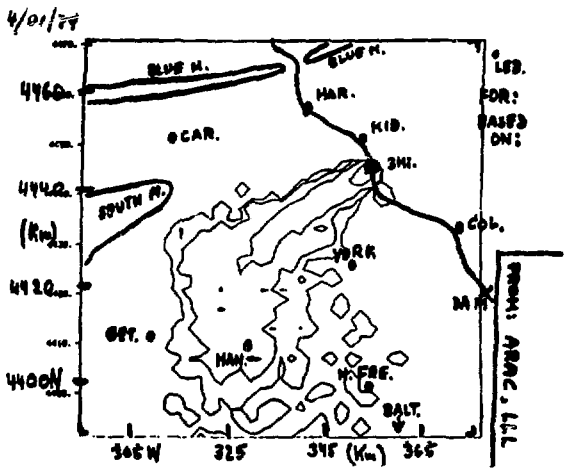


Fig. 3.22. Contour of plume one hour later (TMI).

Figures 3.30 through 3.36 show contours of integrated air concentrations at six-hour intervals. The pattern can be seen developing, and if we were dealing with deposition you could see rapidly how a material would be deposited on the ground as the meteorology changed and as the source term changed. This all reflects the Presidential Commission source term (xenon-133) as provided to us and so gives real source-term information. Figure 3.37 shows the final integrated air concentration calculation for 10.5 days after the start of the accident.

Figure 3.38 shows the calculation of the person-rem. It indicates use of a gridded popu-

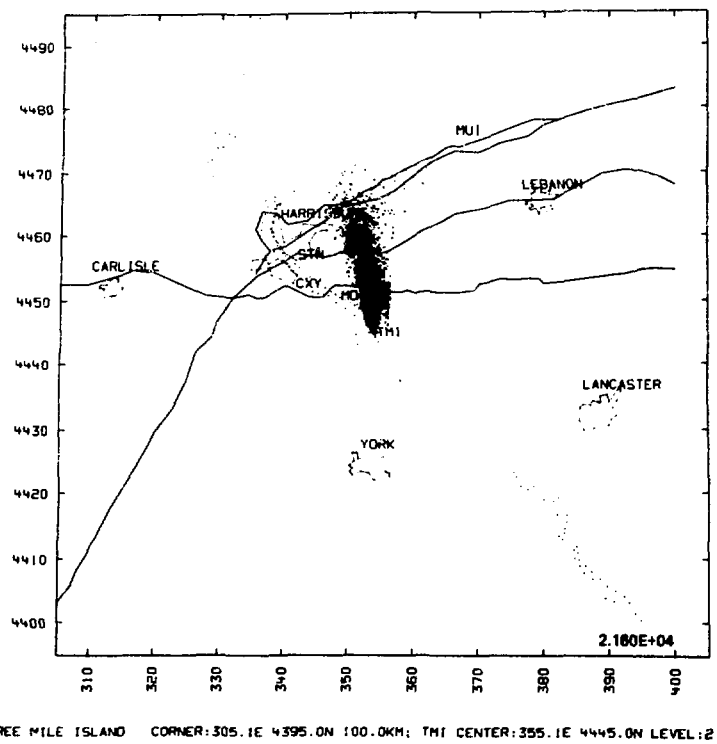


Fig. 3.23. Plume prediction for President's Commission on TMI (6 hours after postulated release).

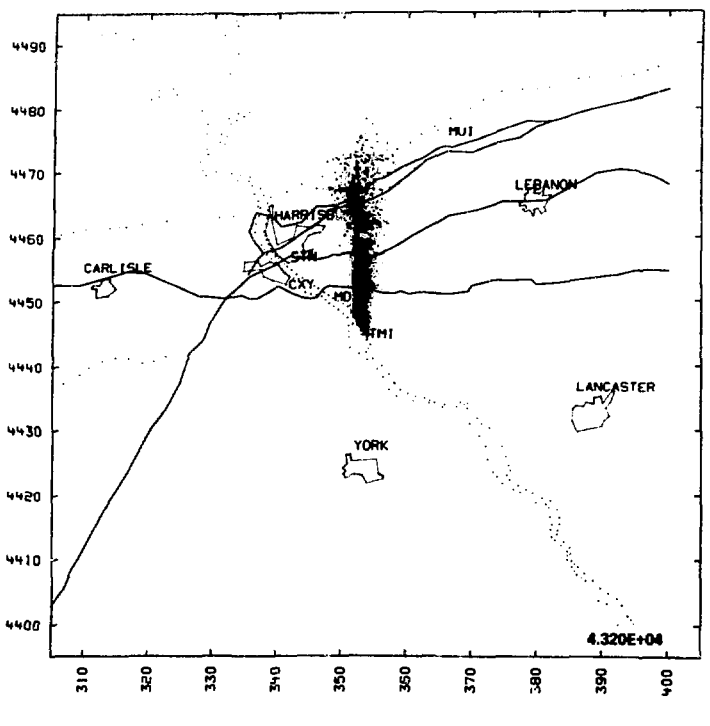


Fig. 3.24. Plume prediction for President's Commission on TMI (12 hours after postulated release).

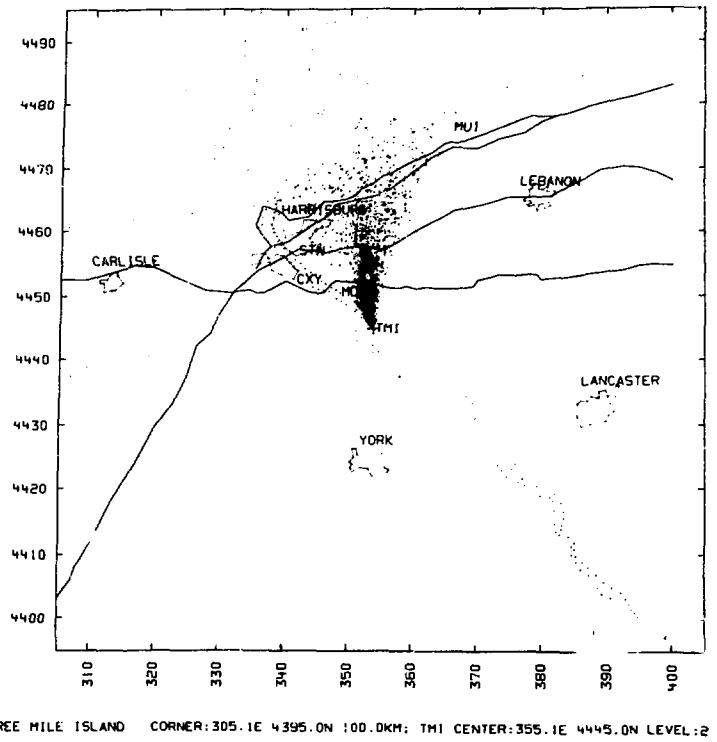


Fig. 3.25. Plume prediction for President's Commission on TMI (18 hours after postulated release).

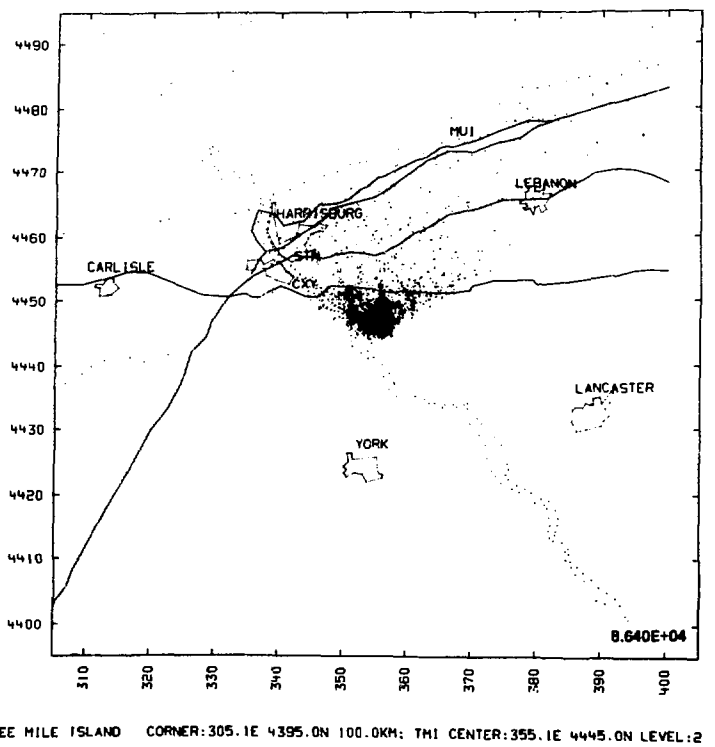


Fig. 3.26. Plume prediction for President's Commission on TMI (24 hours after postulated release).

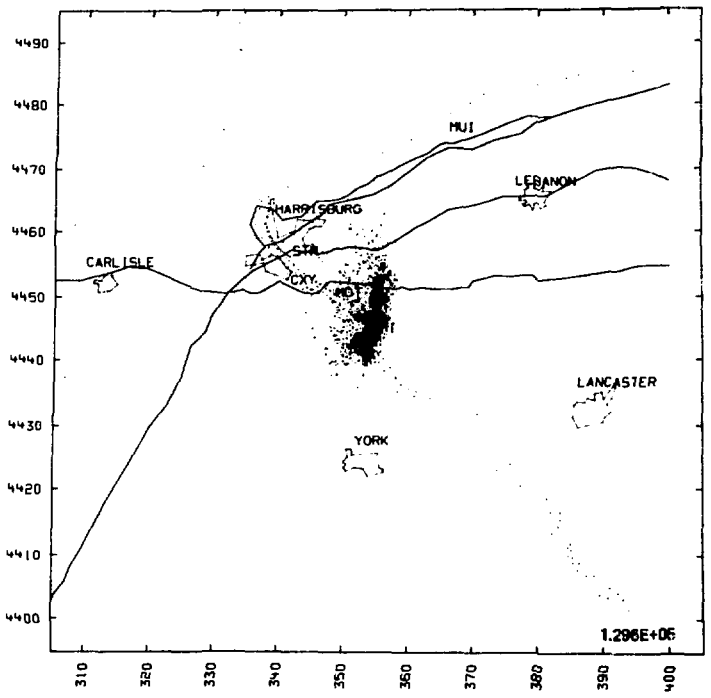


Fig. 3.27. Plume prediction for President's Commission on TMI (30 hours after postulated release).

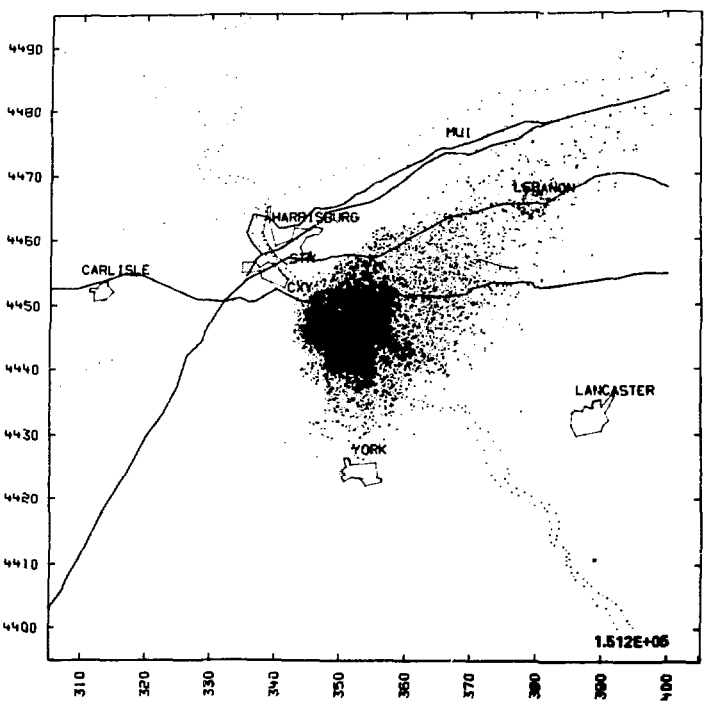


Fig. 3.28. Plume prediction for President's Commission on TMI (36 hours after postulated release).

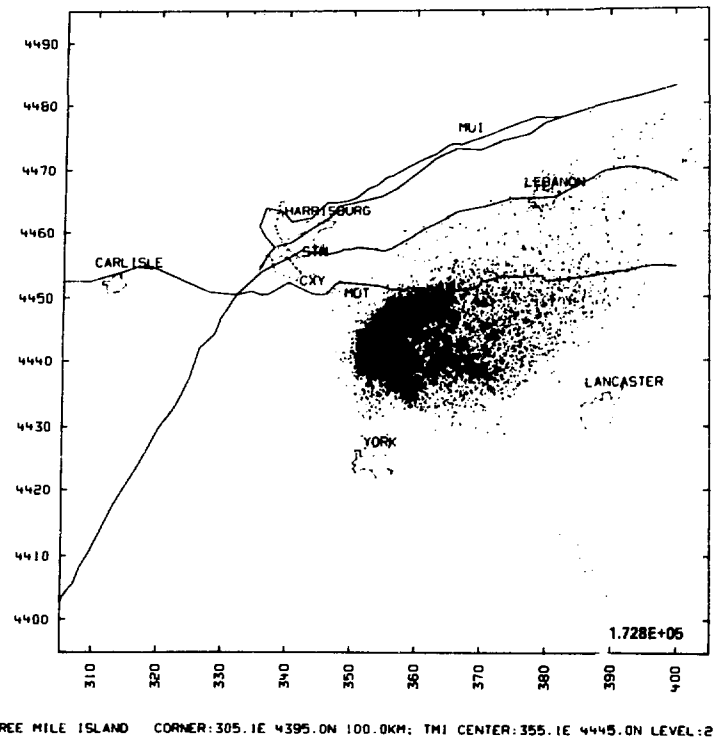


Fig. 3.29. Plume prediction for President's Commission on TMI (42 hours after postulated release).

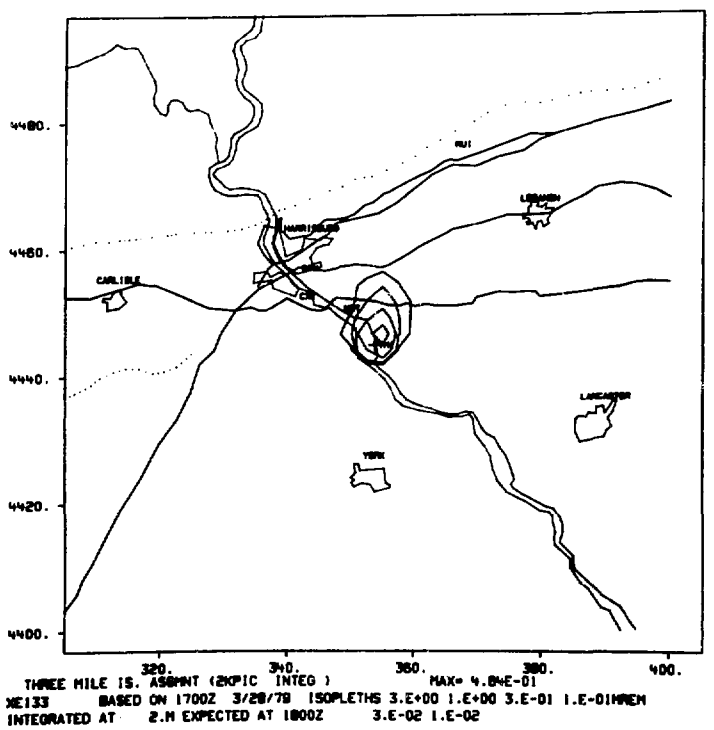


Fig. 3.30. Contours of plume prediction for President's Commission at TMI (6 hours after release).

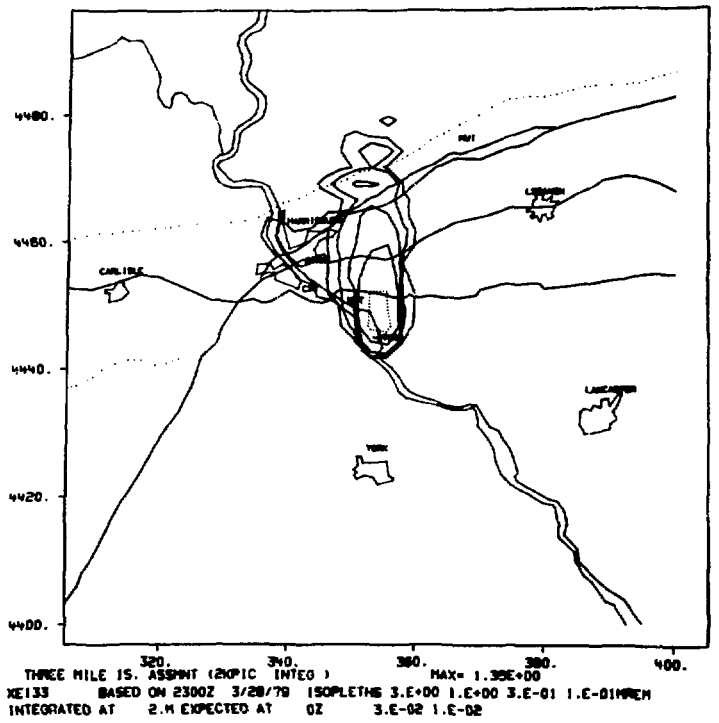


Fig. 3.31. Contours of plume prediction for President's Commission at TMI (12 hours after release).

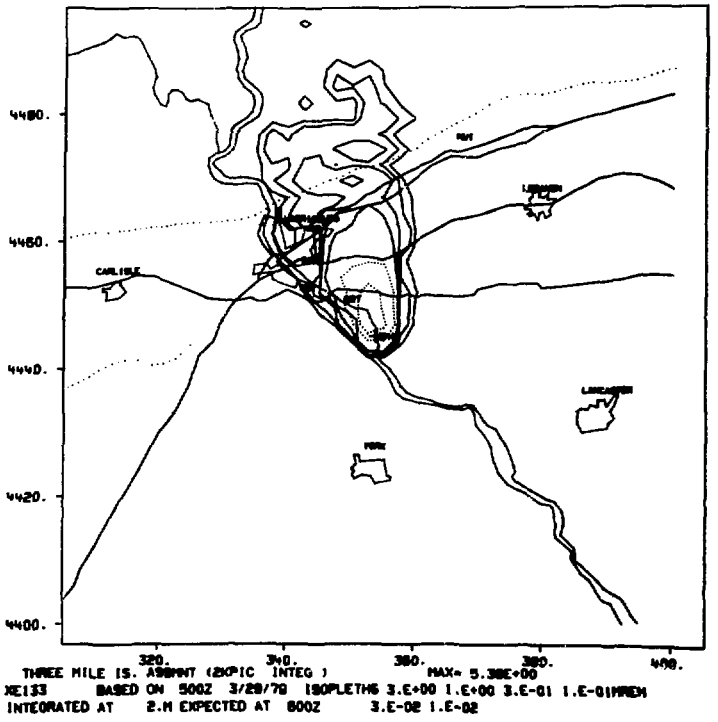


Fig. 3.32. Contours of plume prediction for President's Commission at TMI (18 hours after release).

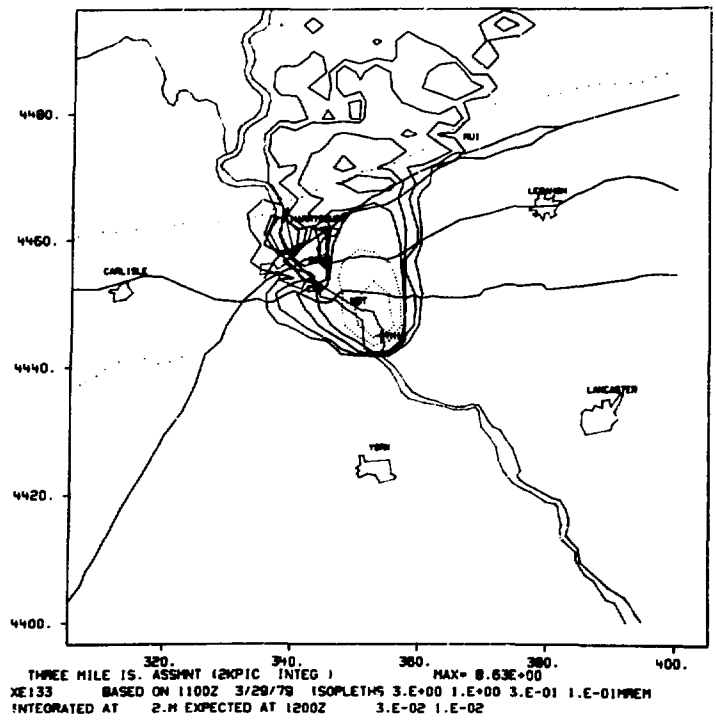


Fig. 3.33. Contours of plume prediction for President's Commission at TMI (24 hours after release).

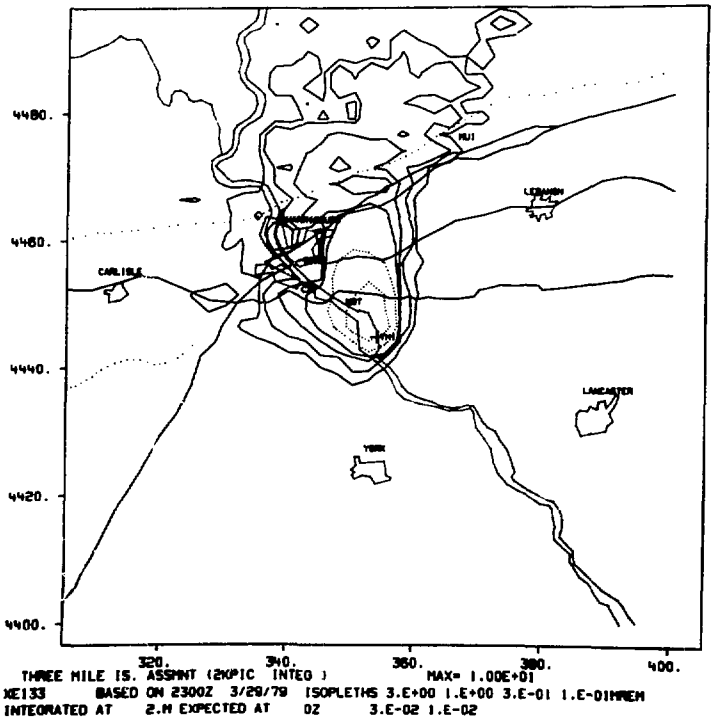


Fig. 3.34. Contours of plume prediction for President's Commission at TMI (36 hours after release).

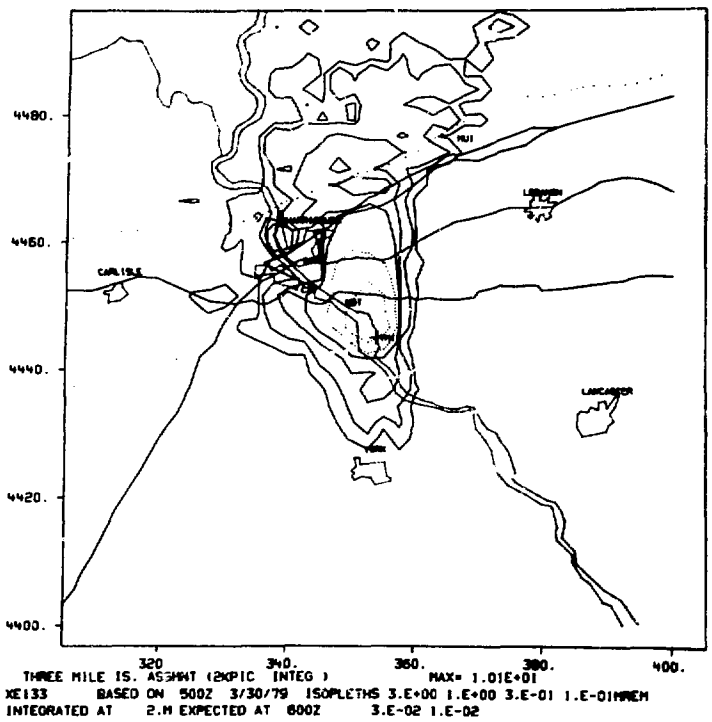


Fig. 3.35. Contours of plume prediction for President's Commission at TMI (42 hours after release).

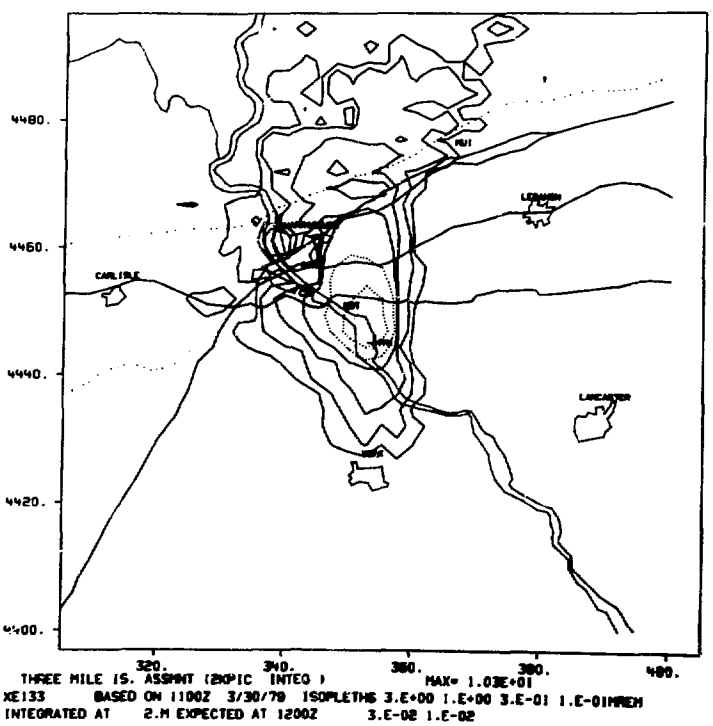


Fig. 3.36. Contours of plume prediction for President's Commission at TMI (48 hours after release).

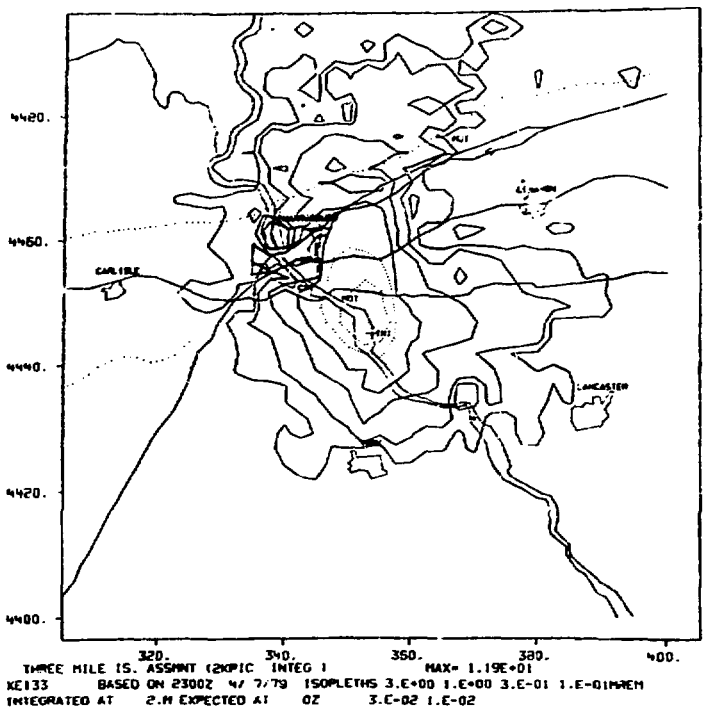


Fig. 3.37. Contour of plume prediction for President's Commission at TMI (final air concentration after 10.5 days).

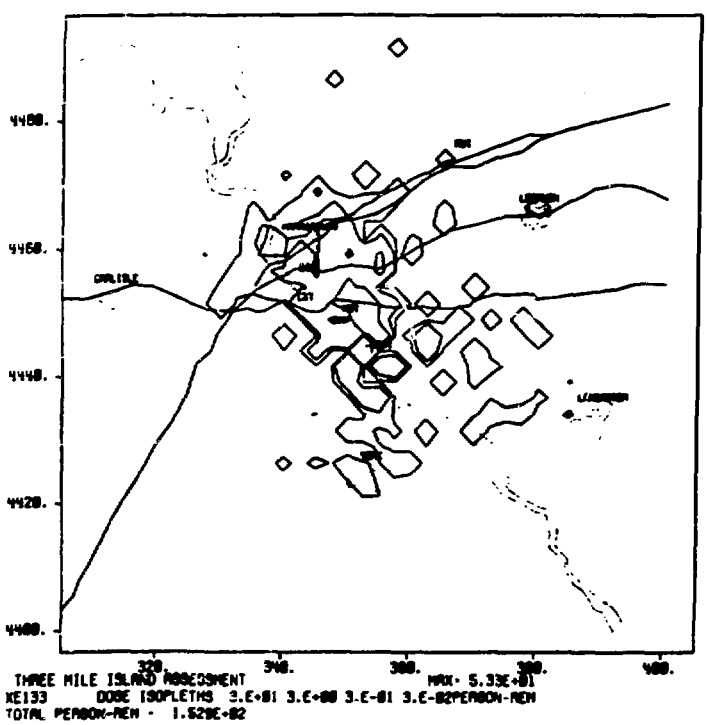


Fig. 3.38. Person-rem contours, President's Commission at TMI.

lation data base; i.e., what the exposure or dose is to individuals--what a dose pattern looks like when you use gridded population information. The largest dose for one 2-1/2-kilometer cell turned out to be 53.3 person-rem. Table 3.1 presents a person-rem summary by sector and radial interval. The total person-rem for xenon-133, the dominant species, was 180.8 person-rem.

With that I will conclude. I have a number of results that may be of further interest to some of you; I will be glad to talk with you later.

# 4. GROUND VERIFICATION OF AIRBORNE MONITOR SURVEY

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Oak Ridge National Laboratory
Oak Ridge, Tennessee

The work to be discussed is part of an overall program conducted by the Off-Site Pollutant Measurements Group of Oak Ridge National Laboratory's Health and Safety Research Division. This work is done for the Department of Energy (DOE). The principal activity of the group is to perform radiological characterization surveys at a number of facilities that were utilized in the early days of the country's atomic energy program. These were associated with the Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC).[1]

The location of sites of formal surveys that have been completed in this program, or that are in progress at the present time, are shown in Fig. 4.1. ORNL staff members have performed some of these surveys; others have been conducted by the Argonne National Laboratory and the Los Alamos Scientific Laboratory. The area for ORNL generally extends in a triangular fashion from St. Louis, Missouri, down to Tampa, Florida, and up to Beverly, Massachusetts.

The scope of formal ground surveys was limited initially to a survey of the property inside site boundaries. It was not known at the time this program was initiated whether there was any contamination off-site. It was suspected that off-site contamination did exist, but the initial survey included only that area within the site boundary. Because of some things that have turned up and some of the things discussed here, the current radiological survey objective is to locate radioactive deposits and quantify those at on-site and off-

ORNL DWG 80-20409

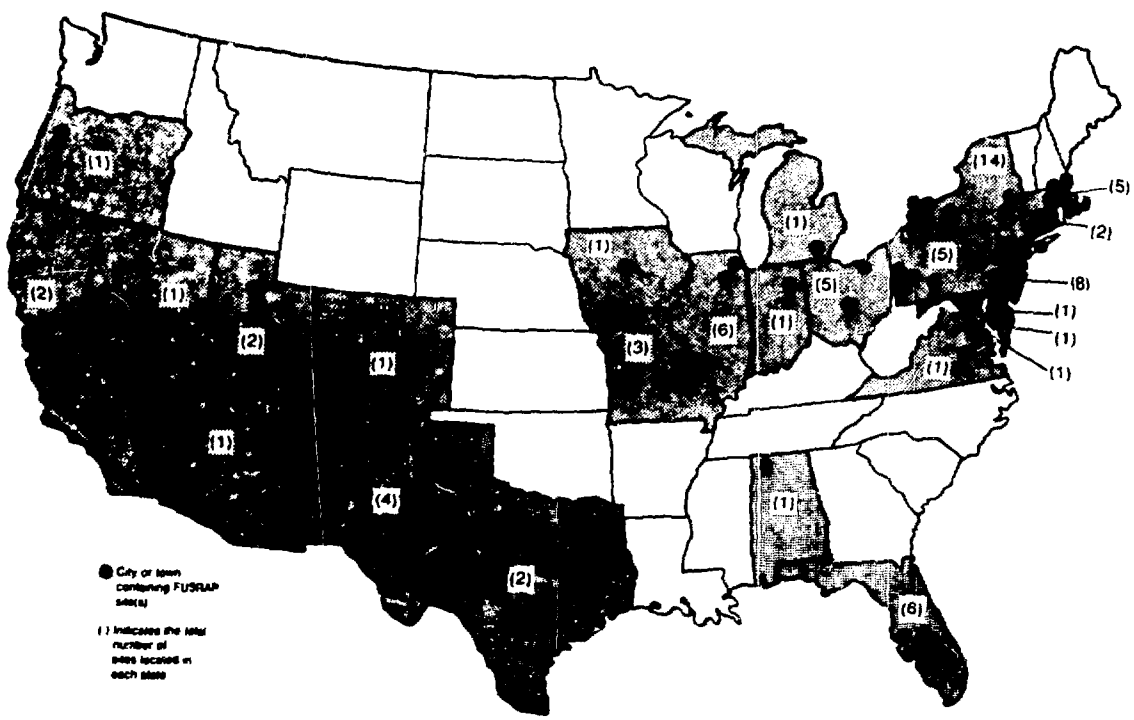


Fig. 4.1. Map of U.S. depicting the location of formal radiological surveys conducted as part of the Department of Energy's formerly utilized MED/AEC sites--Remedial Action Program.

site locations. It was determined that the most effective way to assess off-site radioactivity was to conduct a large-area aerial survey, followed by an investigation of elevated radiation levels carried out by a ground-level radiological monitoring team. Only the latter activities are conducted by ORNL.

A list, possibly incomplete, of locations where aerial surveys and follow-up ground surveys have either been done or are planned is shown in Fig. 4.2. When the aerial surveys were conducted in Canonsburg, Pennsylvania and Middlesex, New Jersey, ORNL was asked to provide some monitoring that would indicate whether there was a radon cloud drifting back and forth around the site. If there is substantial airborne radon which originates from the ground, it can be seen easily from the air and could be erroneously interpreted as ground deposits of radioactivity.

Locations of Combined Aerial/Ground-level Radiological Surveys

Completed

* Niagara Falls
* Lewiston, NY
* Middlesex, NJ
* Canonsburg, PA

Planned

* Middlesex, NJ (expanded area)
* Canonsburg, PA (expanded area)
* Curtis Bay, MD
* Attleboro, MA
* Norton, MA

Fig. 4.2. Lists of radiological survey locations were combined. Aerial/ground-level surveys have been conducted or planned.

In the vicinity of the Lake Ontario Ordnance Depot, near Lewiston, New York, continuous radon monitoring stations were also put into service at a campground away from the approximately 200-acre site, and at other off-site locations nearby. The objective was to monitor the radon concentration continuously at these places during a period of several days while the aerial survey of this site was underway. The data were collected and passed on to the aerial-survey contractor. A summary of the results of these measurements has been published.[2] Probable source areas of radon at this site are shown in Fig. 4.3. A large pile of earth (the spoil pile) exists as a result of earlier decontamination efforts. Several buildings have residues stored in them, and these could act as sources of airborne radon as well as the ground-level deposits.

It is our opinion that ground-level measurements, either during or after an aerial survey, should be done in such a way that the measurements themselves (radiation measurements and radionuclide concentrations in environmental samples) can be applied to the aerial-survey data to lend some "ground truth" to the aerial-survey measurements. During the time that the aerial survey was going on at this site, samples were collected at various places, designated as LTO-1, etc. in Fig. 4.4. Gamma radiation measurements were made at the same time and at the same off-site places. Also, there were some measurements made on-site during the aerial survey.

In the greater Niagara Falls area, there are a number of locations where radioactivity may be found as a result of human activities. Most of the natural radioactive deposits in that area are not associated in any way with former MED and AEC activities. There is a residue material (appearing to be a slag) that contains elevated concentrations of radium and uranium, which has been used throughout the area as roadbed and parking-lot paving base and as gravel. It was identified as being a synthetic (or psuedo) wallastonite similar to natural calcium silicate. It probably originated from the electro-chemical separation of elemental phosphorus in the Niagara Falls area during World War I. Some of the material has shown up in residential areas where blacktopped driveways have an underlayer of gravel. It turns out that a lot of this slag contains uranium and radium

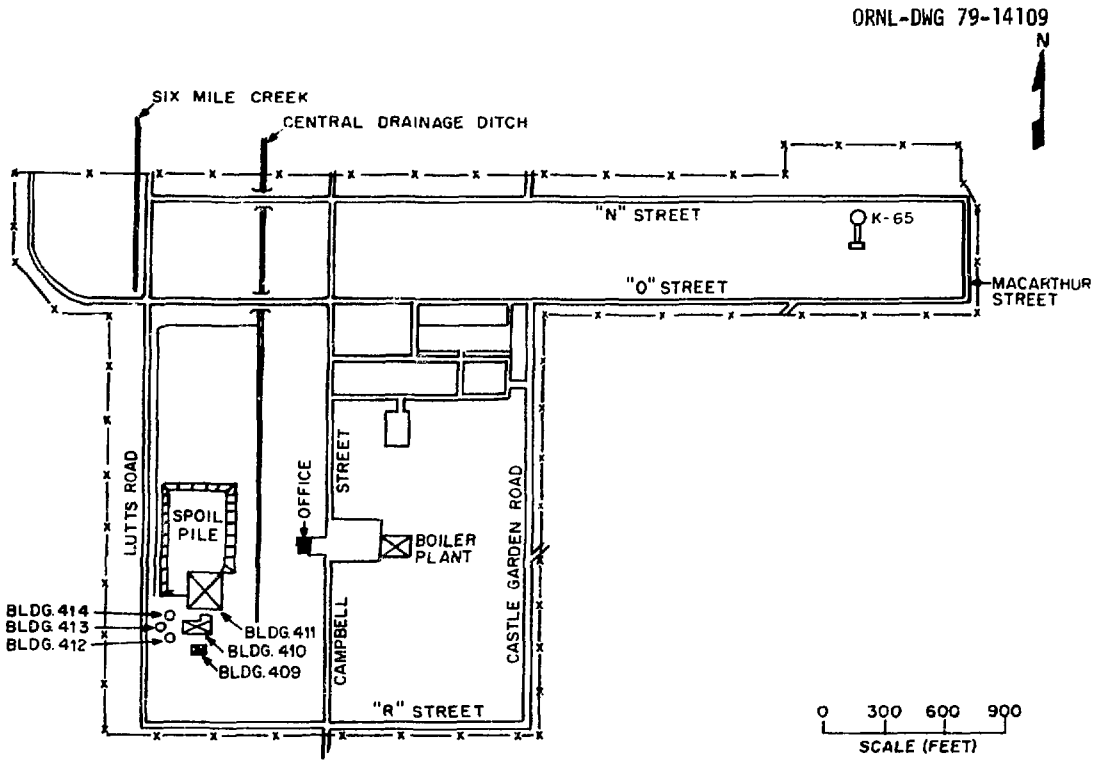


Fig. 4.3. Plan view of the government-owned Lake Ontario Ordnance Works area, showing the location of potential radon sources, spoil pile (lower left), and K-65 tower (upper right).

in the neighborhood of 30 to 40 pCi/g. With the normal terrestrial concentration of near one pCi/g, the material may be spotted readily in aerial and ground-level surveys. This material was also found as crushed rock filler under asphalt pads. One additional type of slag, containing elevated concentrations of thorium-232, was also found. Activities in the Niagara Falls area that could account for this material include the extraction of columbium and tantalum from tin slag.

In the Middlesex, New Jersey area, a few places were found to contain radium-bearing materials which for one reason or another had been moved from the site of a former ore-sampling plant in Middlesex. Results of the aerial survey showed 13 areas with elevated radiation levels. Most of these could be explained as natural phenomena: shale outcroppings, granite rock, and the like. Of the three areas found to contain material which originated at the ore-sampling plant, one was already known to exist, one was the rectory of the Catholic Church, and one was a private residence. At the rectory, it appears that radium-bearing materials were used to fill depressed areas on the site before the structure was built, or were used as backfill around the foundation walls of the building. Radon levels inside the house are elevated substantially, as are surface radiation levels outside the building.

In Canonsburg, Pennsylvania, there is a former radium separations plant which was used in the early part of this century. In the 1940s and 1950s, this plant was used for the extraction of uranium from ores and from salvaged equipment and waste which had come from various AEC plants throughout the U.S. The work was done under a U.S. Government contract. A comprehensive radiological survey was conducted at this site in 1977.[3] This facility is now used as an industrial park in Cannonsburg and houses a number of small light industries. A view of this site is shown in a photograph made

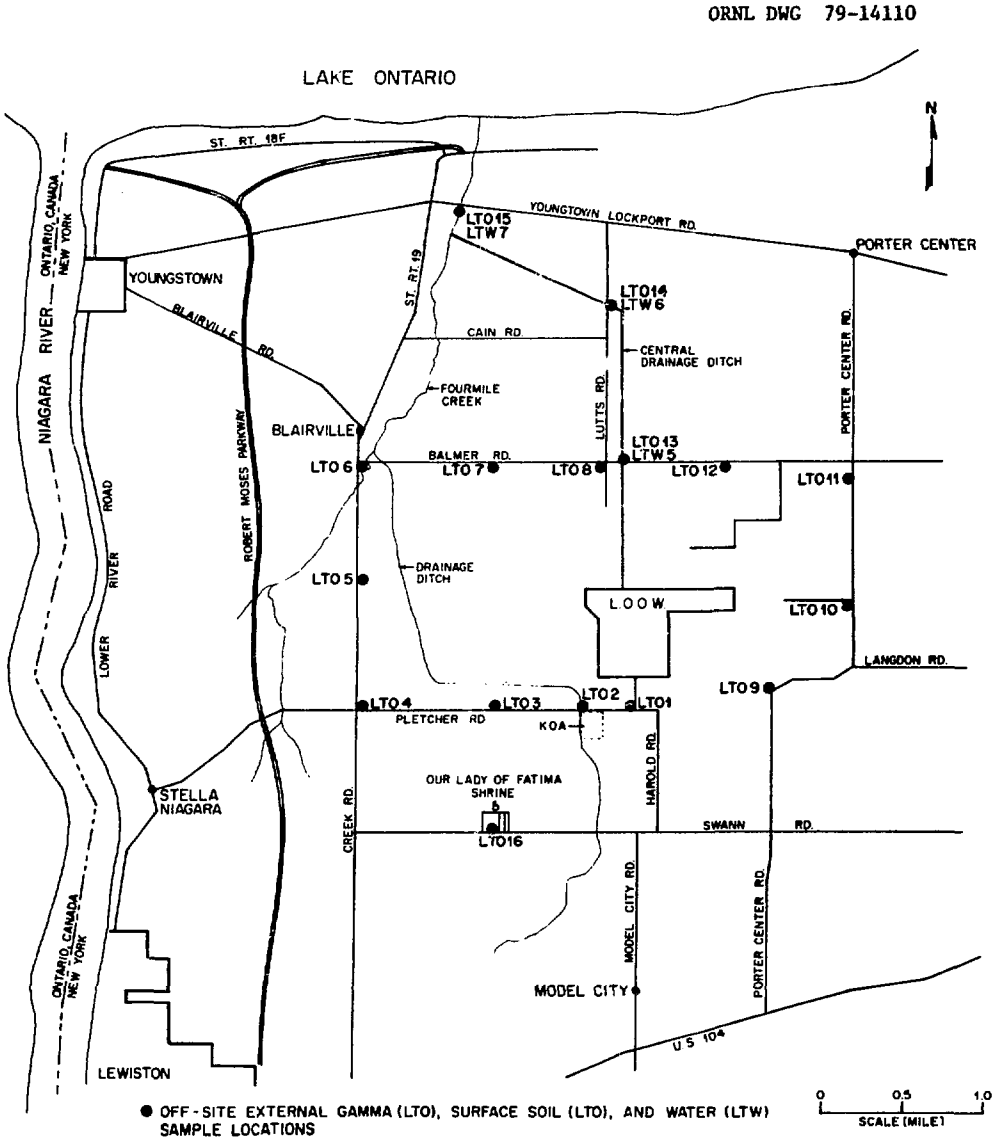


Fig. 4.4. Plan view of area surrounding the Lake Ontario Ordnance Works site (shading) showing the location of off-site radiation measurements and environmental samples.

by the aerial survey team (Fig. 4.5): it shows generally the boundaries of the principal survey area. The plant site consists of a series of buildings situated on one of three parcels of the property. The site is bounded by a creek, a railroad, and another industrial property, formerly a pottery plant. A series of isopleths describe the radiation levels around the site. ORNL was requested by DOE to determine why the background isopleth (represented by the outermost line in Fig. 4.5) was not symmetrical with the rest. There are very good reasons for the irregular pattern of this isopleth and for its appearance in the adjacent village. The history of this site reveals that from 1911 to 1922 it was used for radium extraction--generally for radium to be used in medical practice. From 1930 to 1942, uranium and radium--principally uranium--were extracted by the Vitro Corporation of America. It is believed that uranium was

ORNL PHOTO-2710-80

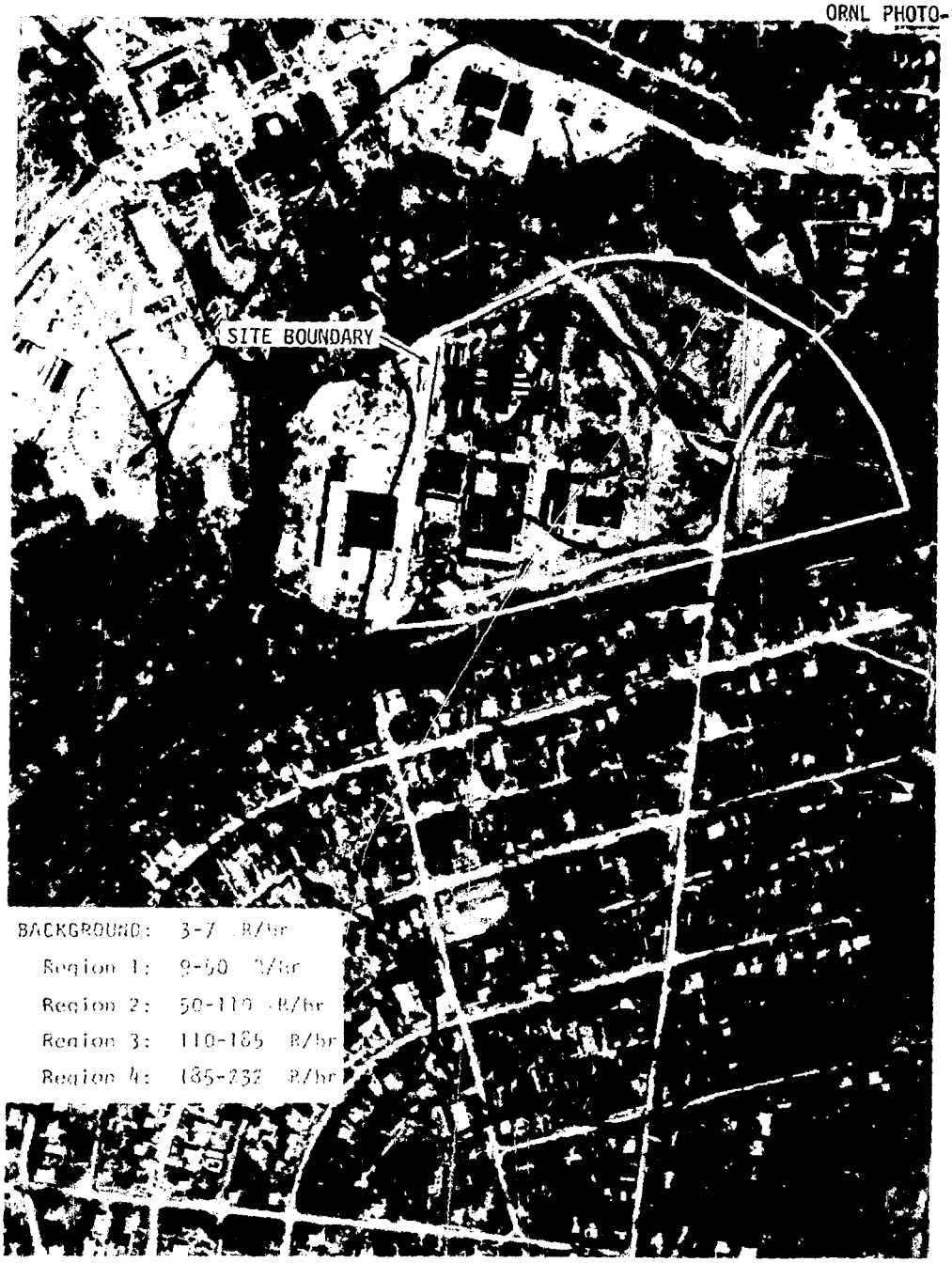


Fig. 4.5. Aerial photo of the former Vitro Rare Metals Plant, Canonsburg, Pennsylvania (see outlined site boundary), including results of aerial radiation survey measurements. Photo used with permission of EG&G, Inc.

extracted for use in pigments in the ceramics industry. From 1942 to 1957 it was used for the extraction of uranium both from residues on the property and from other ore and also to reclaim uranium from scrap materials from various AEC plants around the country. Since 1967 it has been used as an industrial park.

There were two periods of site inactivity: during 1922-1930 and 1958-1967. It is believed that materials may have been removed from the

site for private purposes during those two periods. The ORNL approach for a ground-level investigation consisted of a survey of all private property in the village, using a sensitive gamma-ray detector mounted in a mobile laboratory van, followed by discrete property surveys (measurements on the grounds and inside buildings). The ground survey team used the mobile gamma-ray scanning system (Fig. 4.6) in both directions along each street and alley to determine whether any private property appeared to have radium-bearing material on it. Hundreds of parcels of property were surveyed, but it turned out that there were only 54 properties that were contaminated--or appeared to be contaminated--with radium-bearing materials. Once those were identified, arrangements were made to conduct a pilot survey in the vicinity, to test the validity of the mobile survey data. In this pilot survey, properties were chosen that were either contaminated or thought to be, and five properties that, during the scanning operation, appeared not to be contaminated.

In the survey of those 33 off-site properties, seven were not contaminated and the radiation level at nine of the properties amounted to only a minimum-nuisance radiation exposure. Fourteen of them were of practical concern. At three of the properties, it is our opinion that some measures need to be taken to eliminate potential radiation hazards.

This series of investigations by combined aerial- and ground-level radiological survey teams has demonstrated the effectiveness of such efforts in evaluating the magnitude of potential radiation hazards in areas where radioactive material has been used for private purposes. Aerial surveys covering several square miles have been effective in locating small isolated areas with elevated radiation levels, even those widely dispersed. Results of these surveys are used as input to the ground-level investigations, and tend to minimize the time required to confirm aerial survey results.

There are additional areas around the Canonsburg, Pennsylvania community where mobile

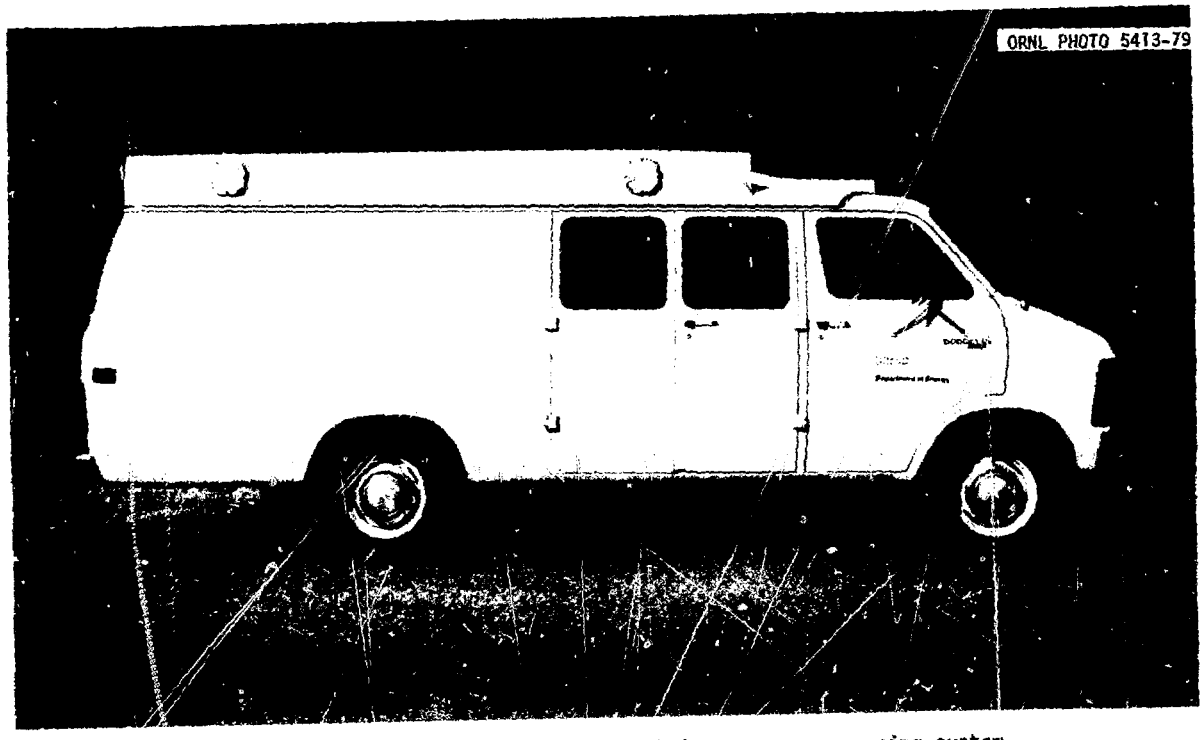


Fig. 4.6. Vehicle used to house the mobile gamma-ray scanning system.

gamma-ray scanning operations are yet to be completed. It is anticipated that this work, as well as similar operations in New Jersey, New York, and Massachusetts, will be conducted in the summer of 1980.

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Chester: We have time for a question or two.

From the floor: I'm Gary Boothe, with Rockwell Hanford Operations. I've had quite a bit of experience with phosphate slags. Do you recall what the radiation rates were above this parking lot?

Haywood: Yes, generally the radiation level--let's say above large, plain deposits of this material--was in the neighborhood of 30 to 40 μR/hr at a meter above the ground, with levels generally around 60 μR/hr at the ground surface. In that one case where we found some thorium-bearing slag, the radiation level through the floorboard of the car was a few hundred μR/hr and there were radiation levels of the order of one mr/hr at the surface.

Chester: Wow!

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Dup

# 5. SOIL MONITORING INSTRUMENTATION*

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The Los Alamos Scientific Laboratory (LASL) has an extensive program for the development of nondestructive assay instrumentation for the quantitative analysis of transuranic (TRU) materials found in bulk solid wastes generated by Department of Energy facilities and by the commercial nuclear power industry. Included are wastes generated in decontamination and decommissioning of outdated nuclear facilities, as well as from old waste-burial-ground exhumation programs. The assay instrumentation is designed to have detection limits below 10 nCi/g wherever practicable. Because of the topic of this workshop, only the assay instrumentation that is applied specifically to soil monitoring will be discussed here.

Projects aimed at exhumation of outdated waste burial grounds and at measurement of transuranic migration in current burial grounds have necessitated the development of techniques for rapid and quantitative analysis of transuranic materials in soil. One technique is the portable phoswich detector[1] for field surveys (Fig. 5.1). It consists of three components: the detector package (having a mass of 4.4 kg), a front chest module with count ratemeter readout and scaler-timer, and a main electronics package located inside the backpack. Total mass of the system is 8.8 kg. The system is similar in use and application to the field FIDLER[2] which uses a thin sodium iodide detector. The phoswich detector is a thin NaI crystal coupled to a thicker cesium iodide crystal, all coupled to a single phototube. Pulse shape discrimination allows the unit to reduce Compton-related backgrounds by a factor of two to three compared to the single thin NaI detector. This is for field use where shielding cannot be carried along. For stationary use where several inches of iron shielding can be added, the background reduction approaches a factor of six compared to thin NaI detectors. The phoswich system, when held at ground level, has an on-line and real-time detection limit of less than 1 nCi/g for plutonium and below 100 pCi/g for americium-241. The system is now being manufactured by a commercial nuclear instrumentation vendor.

Fig. 5.1. Field phoswich detector system for low-level monitoring of TRU contamination.

A second soil-assay instrument is a portable zinc sulfur system[3] that provides a detection limit of 25 pCi/g for gross alpha counting, using a 5-minute count and a 30-minute sample turnaround time. We use a commercially available ZnS alpha scintillator probe that is

*This paper is based on work performed under the auspices of the U.S. Department of Energy.

10 cm in diameter with a single-channel analyzer equipped with a timer-scaler and HV supply (also commercially available). The system can be powered either by line or internal battery.

Soil samples are placed in plastic bags and the bags of soil are massaged to homogenize the sample sufficiently. Enough soil (~ 75 g) from the sample bag is carefully scooped into an 88-mm diameter x 13-mm deep plastic petri dish. The soil surface is leveled off so that it is even with the top of the petri dish; small rocks and debris are removed. The soil in the petri dish is dried under a heat lamp and allowed to cool before counting. If the soil sample is very wet, it is dried, ground up with a mortar and pestle to break up aggregates, and returned to the petri dish for redrying. If the soil sample is not dry enough, moisture tends to condense on the mylar face of the probe during counting, reducing detector sensitivity. The petri dish is then placed in a depression in a black wooden holder and the probe is placed on top of the dish. The holder is black in order to minimize scattered light, since the 1 mg/cm$^2$ aluminized mylar covering the probe face is not completely opaque to light. Integral ribs on the probe provide a consistent 1.6-mm spacing between the top of the soil sample and the probe face. Samples are nominally counted for 5 minutes. The total amount of time that elapses from receipt of the sample to measurement results can be as little as 30 minutes.

The system is calibrated using a carefully homogenized soil sample spiked to 2000 pCi/g with plutonium-239. This sample gives 0.135 counts/min/pCi/g. The 1-sigma statistical error on the calibration factor is less than 3% for a 5-minute count on samples $\geq$2000 pCi/g. System background (using an empty petri dish) is 0.5 to 1.0 counts/min. Natural alpha emitters in soils in the Los Alamos area result in background counting rates of 4 to 8 counts/min. An uncontaminated soil sample from the type of soil being measured is used to determine the natural alpha background.

This technique permits rapid assessment of alpha-emitter contamination in soils, to low enough concentrations for efficiently directing large field operations. Because the soil samples are not completely homogeneous, a ZnS gross-alpha analysis may not compare favorably with $^{239}$Pu radiochemical analysis of the same sample (although the majority of our comparisons are within a factor of 2). However, we feel this disadvantage is offset by the advantage of being able to analyze a large number of samples in a relatively short time.

More selectivity and even better intrinsic detection limits are provided by a photon spectroscopy system.[4] An intrinsic-germanium detector provides nondestructive assays of soil samples with detection limits <45 pCi/g for plutonium and <170 fCi/g for $^{241}$Am in a 5-minute count. The system is shown in Fig. 5.2. Using count times of four hours, the plutonium detection limit lowers (improves) to below 15 pCi/g. The $^{241}$Am detection limit improves to below 50 fCi/g. Quantification is based upon the 60-keV gamma ray emitted in $^{241}$Am decay and upon L X rays (energies from 13 to 22 keV) emitted by TRU isotopes during their alpha decay. The detector is a single-crystal, intrinsic-germanium planar detector (commercially available) with a surface area of 21 cm$^2$. Sensitivity is increased by incorporating a detector entrance window with a larger-than-normal surface area. A large-volume Ge(Li) detector is added to the system, opposing the intrinsic-germanium detector (Fig. 5.2), to provide simultaneous fission product analysis (for $^{137}$Cs, $^{60}$Co, etc.). LASL has built a second system with two opposing intrinsic-germanium planar detectors for increased sensitivity for the TRU materials. The soil samples are approximately 20 g and are contained in custom plastic dishes with locking lids.

Our latest development in monitoring instrumentation is a newly designed portable multichannel analyzer[5] (MCA) that has improved the physical and performance characteristics very much over previous designs. The instrument is very compact (25 cm wide x 14 cm deep x 21 cm high) and has a mass of 4.2 kg (9.2 lb). The device has 1024 channels and is microprocessor-

Fig. 5.2. Computer-controlled intrinsic germanium/Ge(Li)-based soil monitoring system. The white dewar on this side of the sample wheel contains the intrinsic germanium detector for quantifying TRU materials. A large-volume Ge(Li) detector is directly opposite the sample; it monitors for higher energy photon emitters such as $^{137}Cs$.

controlled. The instrument has most of the standard features of present laboratory-based pulse-height analyzers, including CRT display, region-of-interest integration, etc. Battery life of the MCA is nearly eight hours, with full charging overnight. An accessory case carries a small audio cassette recorder for data storage. The case also contains two different NaI (Tl) detectors. Another case contains a 10%-efficient intrinsic-germanium (HPGe) detector for very high-energy resolution gamma-ray spectroscopy. That detector (commercially available) is portable and can carry enough liquid nitrogen for 10 hours of field use. All necessary electronics to acquire data from the various detectors are located on the detectors themselves. No additional power supplies, NIM equipment, or the like, are necessary for field operation. A second MCA model has now been designed that has a digital cassette recorder built into the main chassis along with an extra PROM card that plugs into the top face of the unit and further customizes the software for a specific user or task. Both versions of the MCA are shown (Fig. 5.3), along with the portable intrinsic-germanium detector.

While not directly related to soil monitoring, we have developed several instruments based on cadmium-telluride detectors. Our latest is a small radiation warning "chirper"[6] that clips to a shirt collar. The chirper (Fig. 5.4) demonstrates the application of CdTe crystals as GM tube replacements. The use of large crystals (when available) in portable micro-R type instruments has immediate applications in soil screening and environmental monitoring.

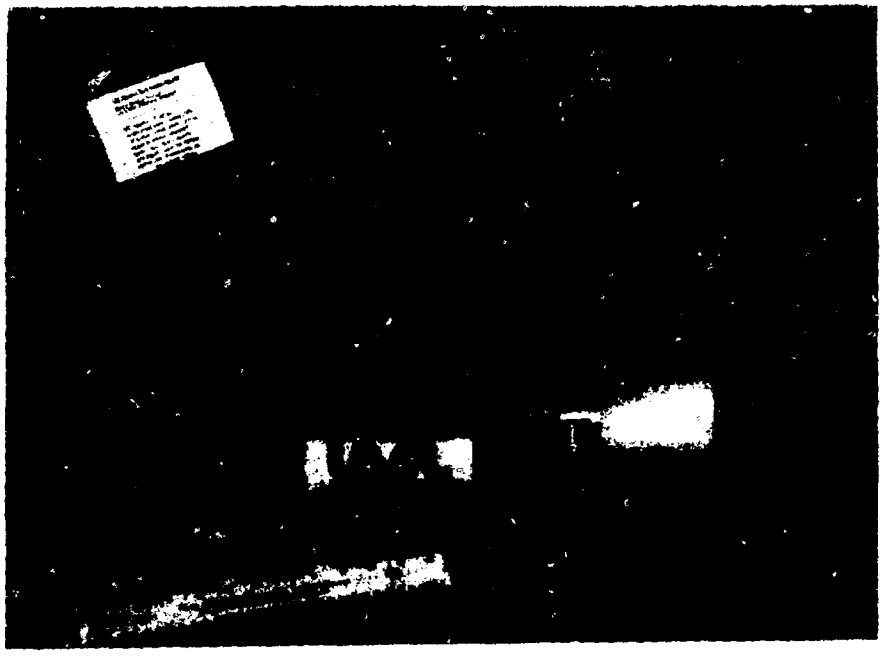

Fig. 5.3. Models 1 and 2 of the LASL portable MCA are shown with the portable intrinsic-germanium photon detector in front. Both MCAs have 1024 channels; Model 2 on the right has a built-in digital cassette recorder and an extra PROM card that inserts into the top deck.

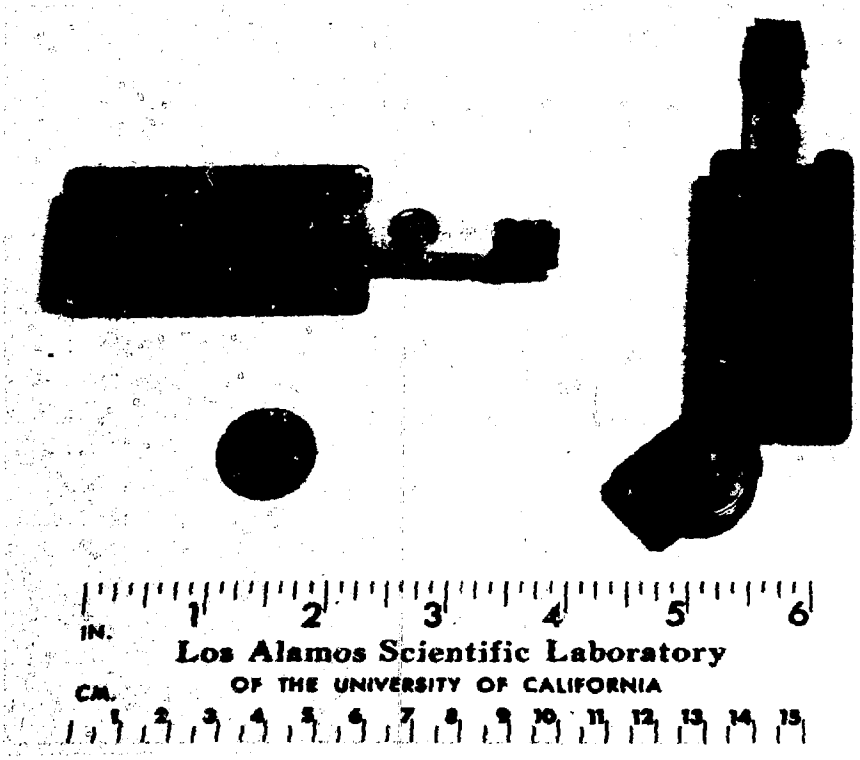


Fig. 5.4. Cadmium-telluride detector-based miniature radiation chirper. Note the nickel coin for size comparison.

Chester: One of the main concerns right now at EPRI* is to find some way of making available to citizens at large a radiation detector that is convenient and accessible, to reassure them that they are not being exposed to radioactivity.

Umbarger: Jerry Nichols, at EPRI, called me last week. I told him how I would approach it, but that I was also very concerned about giving radiation detection devices to every Joe in the street. What is going to happen if my number isn't the same as my nextdoor neighbor's number? I suggested that perhaps you might want to put those in police stations or post offices so that everybody can go down and read, but at the same time you, the developer, can monitor and make sure that it is working properly. You can't monitor 50,000 chirpers if they are out in the field with digital readouts.

Chester: And especially if they fail in such a way as to indicate an off-scale reading.

*Electric Power Research Institute.

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# 6. LASL EXPERIENCE IN DECONTAMINATION OF THE ENVIRONMENT*

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Since 1971, the Los Alamos Scientific Laboratory (LASL) has been actively engaged in radiological surveys of potentially contaminated lands formerly utilized by the Atomic Energy Commission (AEC) or by its predecessor agency, the Manhattan Engineer District. LASL also conducts a vigorous program of environmental decontamination in conjunction with present decontamination and decommissioning (D&D) activities. This discussion centers around a major environmental decontamination project conducted at LASL in 1975-1976,[1] representative of how such work is presently conducted at LASL. The discussion includes methods and recommendations based on our experience.

## HISTORY OF TA-1

The main technical area (TA-1) at Los Alamos was constructed in great haste during 1943-1944 to provide facilities for research and development (R&D) on nuclear fission weapons. The sense of urgency continued into the 1950s during development of a nuclear fusion weapon for the United States. Major R&D for these programs was conducted at TA-1 in Los Alamos (Fig. 6.1). A large number of crudely constructed buildings were tightly packed into a small land area. Radioactive materials including plutonium, uranium, and fission products were used here. This work resulted in varying degrees of

*This presentation is based on work performed under the auspices of the U.S. Department of Energy.

Fig. 6.1. View of a portion of TA-1 (mostly south of Ashley Pond) circa 1958.

radioactive contamination of some of the buildings, waste handling systems, and land. Research operations gradually moved to new and better facilities further away from the Los Alamos townsite, during the 1950s. When vacated, the obsolete TA-1 facilities were dismantled or decontaminated and removed. Structural debris and some soil were removed to the disposal pits. In 1966, after decontamination, the land was deeded to Los Alamos County or offered for sale to the public. The area now constitutes a major portion of downtown Los Alamos (Fig. 6.2). A motel, gasoline stations, and fast-food restaurants dominated the area in 1976, and active development continues. The relative positioning of major buildings then and in 1975 is shown (Fig. 6.3).

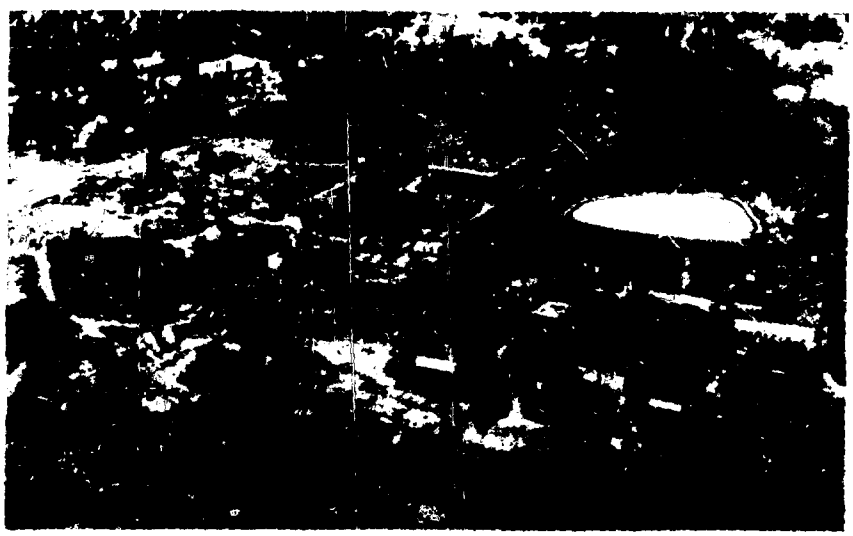

Fig. 6.2. Present land use (1976) in TA-1 area, looking north. Ashley Pond is in the upper right.

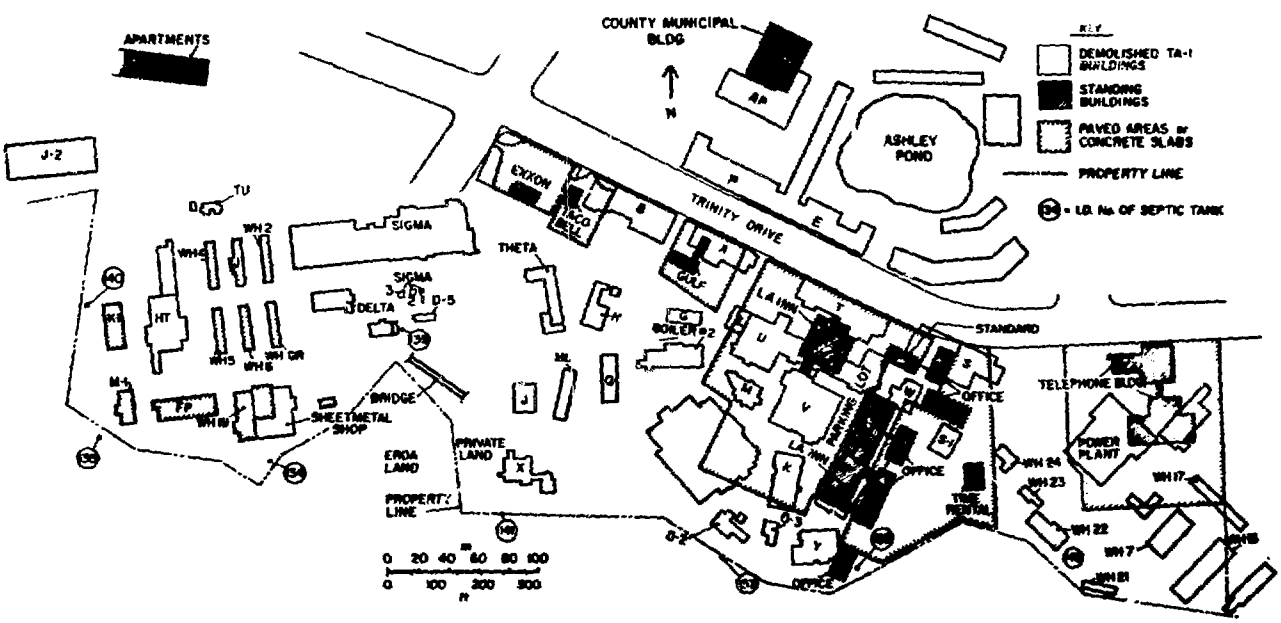


Fig. 6.3. Relative positioning of buildings, 1945 and 1975.

A 1974 land resurvey indicated plutonium contamination (up to 200 pCi/g) in a gully below a septic tank outfall located on a canyon edge. The septic tank served Building D-2, which housed, among other things, a laundry for contaminated clothing and safety equipment. Removal of the septic tank in August, 1975 led to the discovery of a pocket of contamination (to 125 nCi/g) of early-1945 Hanford plutonium approximately 1.2 m below the surface and a contaminated pipe fragment (4000 c/m alpha) on the ground surface nearby. The discovery of contamination of this magnitude and contaminated surface fragments indicated that considerably more exploration and possible decontamination were required.

The find of contamination was announced in a press release that was printed in newspapers throughout the United States. After a plan of action was developed, the proposal was presented to the landowners and the press at a public meeting. Landowner permission was granted, and work began in September 1975, with additional surveys and a thorough search to remove or monitor all surface debris that could be conceivably related to TA-1 activities.

## METHODS

### Historical Research

One of the most important pieces of early work was a thorough historical review of old drawings, documents, reports, and memos. We also interviewed old-timers to determine what happened, where it happened, and what contamination problems might exist. This was merely a starting place; records from early days were not always correct. For example, when removing the septic tank from the location identified, we expected to find a rectangular concrete tank full of dirt. Instead, we found a cylindrical metal tank full of sludge and water. Records indicated that laundry effluent was released on the ground surface and that the septic tank was put in place after the laundry was moved elsewhere.

Using the historical data, environmental sampling was concentrated in areas of suspected contamination, and an intensive survey was conducted throughout the area. Prior to moving any soil, a detailed photographic survey was made to establish "as-found" conditions. By terms of the agreement, the area was to be returned to approximate original contours. Should there be any questions, the photographs could help sustantiate findings. A small chalkboard with identification, time, and date of the scene was included in each photo to make it a legal document. This concept of the chalkboard was continued throughout the project, and many photos were made for the record.

### Environmental Survey Methods

A number of soil-sampling schemes were employed in the TA-1 surveys. In the 1974 survey, random and historically interesting locations were surveyed by taking gross gamma measurements with a high-pressure ionization chamber and a micro-R meter. Low-energy X rays were monitored with a FIDLER coupled to a portable 6-channel pulse-height analyzer. Plug soil samples (7.6 cm diam. by 5.1 cm deep) were collected at the corners and center of a 10-m square and were composited to form a single sample representing that location. Depth distributions were measured at several locations by taking samples with 61-cm-long, 2.5-cm-diam. PVC coring tubes.

From 1975 on, surface samples were scooped from chosen locations. Soil samples at depth were collected by PVC coring tubes; cuttings were taken from a portable gasoline-powered fence-post auger or truck-mounted drill rig (Fig. 6.4). Core samples (taken with a split-spoon sampler) could also be taken if there was concern about getting specific information below zones of contamination. However, auger drilling is five to ten times faster than split-spoon sampling, so auger cutting samples were the usual samples obtained with the drill rig. We found it useful to display depth information pictorially (Figs. 6.5 and 6.6) to help determine subsurface contamination patterns. In some

Fig. 6.4. Taking samples with a truck-mounted, auger-drill rig.

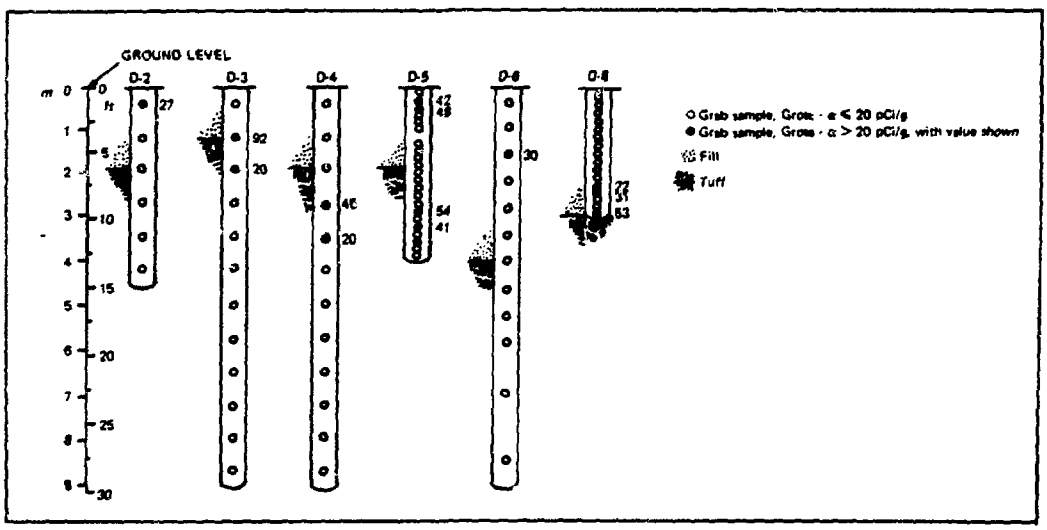


Fig. 6.5. Sample of depth information display (No. 1).

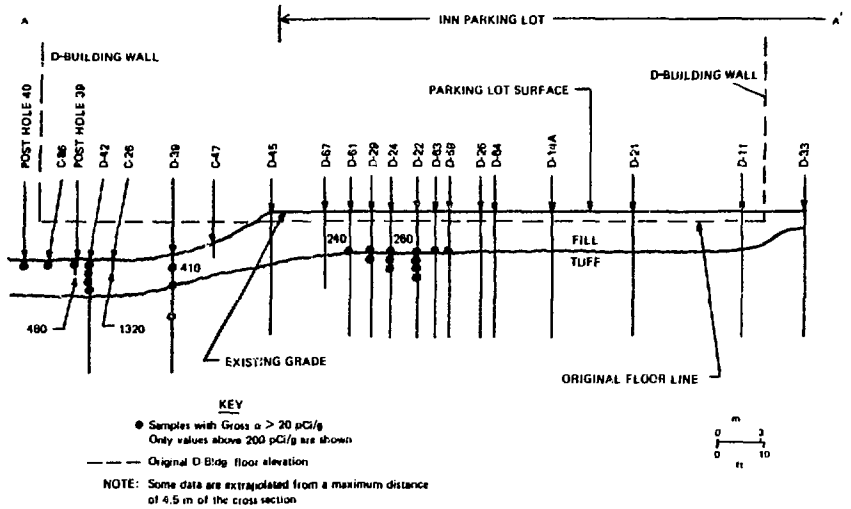


Fig. 6.6. Sample of depth information display (No. 2).

areas of known contamination, boundaries of contamination were evaluated by digging trenches with a backhoe. Samples at many horizontal and vertical locations can be collected rapidly to evaluate magnitude and uniformity of contamination. Portable instrument surveys are readily made of trench walls and surfaces to monitor for hot spots that might be missed by soil sampling. Unanticipated finds are also possible, e.g., in one trench we intercepted a zone of contaminated asphalt that had been covered with earth. Pictorial presentations of soil-sampling results from the trenches are useful in decision making (Fig. 6.7 and 6.8).

## Soil Analysis

Two phoswich detectors, normally used for lung counting, were adapted for field use to measure the low-energy X rays associated with the alpna decay of uranium and transuranic isotopes.[2] They have backgrounds (in the field) two to three times lower than that of FIDLER detectors. In a walking survey, detection limits are approximately 1000, 500 and 100 pCi/g for plutonium-239, uranium, and americium-241, respectively. The entire undeveloped portion of TA-1 (40 acres) was surveyed in a close grid to locate hot spots

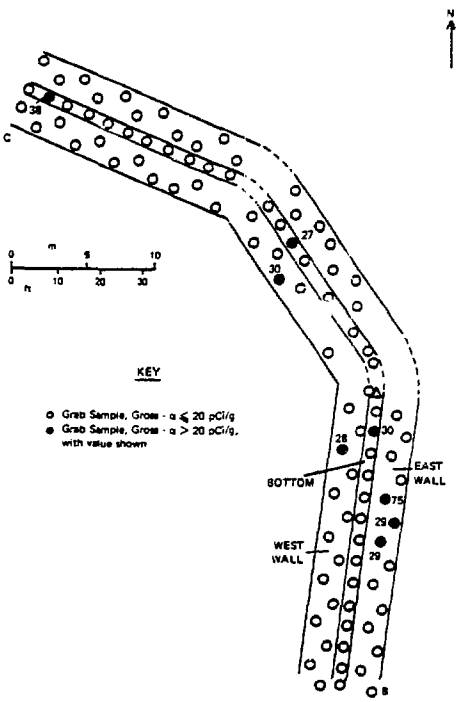


Fig. 6.7. Sample of trench information display (No. 1).

that might have been overlooked in other surveys. When a suspicious count rate was identified, surveyors removed surface soil and continued to monitor to see if the count rate

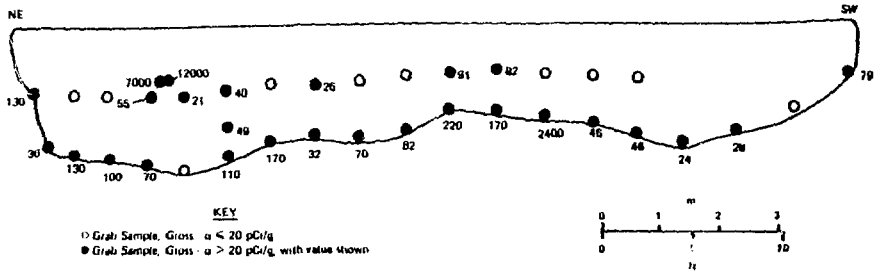


Fig. 6.8. Sample of trench information display (No. 2).

changed. If buried contamination were present, the count rate would go up. We were able to find a 15-kg piece of normal uranium buried approximately 0.6 m deep in this manner. The phoswich has now evolved into a commercially available, completely portable instrument as described by John Umbarger.[3]

Soil samples were screened using a ZnS alpha scintillation system (Fig. 6.9) which had a nominal 20 pCi/g detection limit (3σ) for alpha contamination in soil.[2] Because this was a rapid technique with reasonable detection sensitivity, it was used to direct exploration and decontamination efforts. Approximately 8000 samples were analyzed in this manner. Of course these results had to be backed up by definitive radiochemistry. Analysis techniques are summarized in Table 6.1.

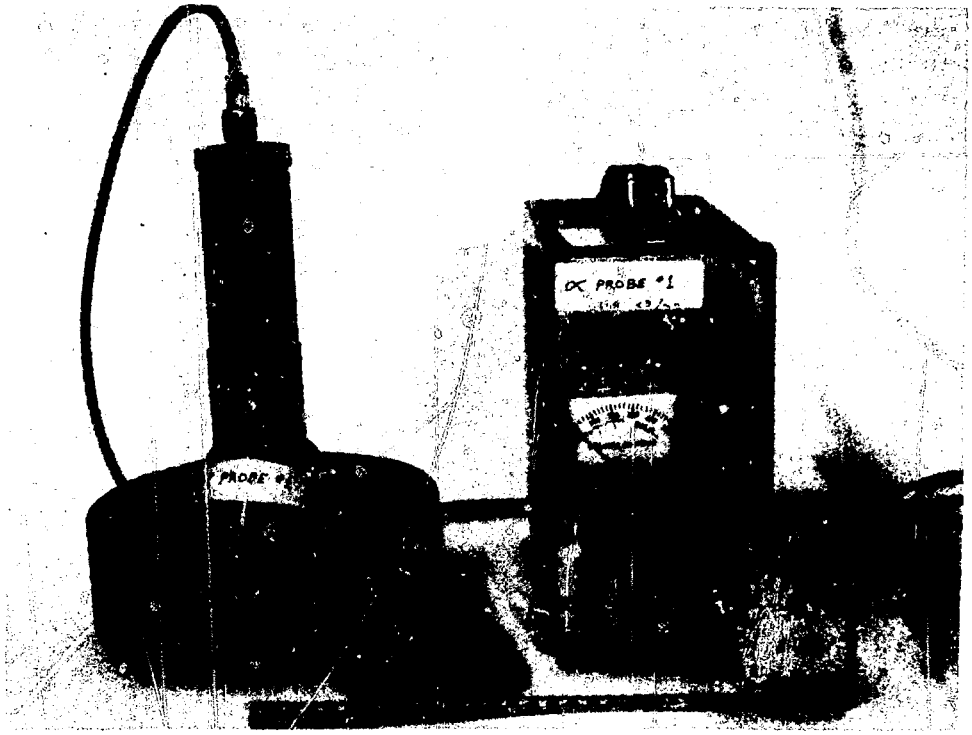


Fig. 6.9. Zinc sulfide alpha scintillation system.

Table 6.1. Soil Analysis Methods

| Location and method | Time until results available |
|---|---|
| Field | |
| Portable phoswich<br>Misc. health physics instruments | ≤ several minutes |
| Field laboratory | |
| ZnS alpha scintillator<br>Phoswich in a pig<br>Small Ge(Li) | ~ 1/2 hour |
| Chemistry laboratory | |
| Qualitative and quantitative analysis on all isotopes of interest | days |

Decontamination Methods

Because decontamination efforts were very close to commercial businesses, we took extra precautions to minimize the spread of contamination, particularly by airborne pathways. Thus, dust suppression was a key element in our methods.

For known hot spots which were usually rather limited in size, e.g., those at the end of contaminated discharge lines, laborers shoveled the material into plastic bags that were then loaded into trucks for pit disposal or put into drums for retrievable storage, depending on the isotope and concentration. This kept dust down and minimized the spread of contamination. For hard-to-reach places, a backhoe loaded soil directly into plastic-lined dump trucks (Fig. 6.10); each bucketful could be

Fig. 6.10. Excavation with backhoe. Soil is loaded directly into a dump truck.

monitored if necessary. Water sprayed from garden hoses was used to minimize dust. For the bulk of the soil removal, the ground was surveyed and any hot spots were removed by the above two methods. A ripper on the back of a crawler tractor loosened the soil (Fig. 6.11). Laborers followed the ripper blades, spraying the turning soil with water from garden hoses. A phoswich survey was conducted to see if any hot spots had been uncovered that should be removed by other means. Soil was then sprayed with water and pushed into a stockpile. Front-end loaders scooped the soil from the stockpile (Fig. 6.12) and loaded it into plastic-lined dump trucks. Water spray was used during scooping and loading operations for dust suppression

Fig. 6.11. Crawler tractor with bulldozer blade on front and ripper blades at rear.

Fig. 6.12. Front-end loader scooping up soil from a stockpile. (Note method of water spraying.)

(Fig. 6.13). Once a truck was loaded, the load was covered with plastic and a tarp was tied down over the load. The truck was driven across a pad of sand (to help scrub soil from the tires), through the access gate, and was then monitored for contamination (Fig. 6.14). After a satisfactory survey, the truck driver was given a slip of paper indicating load number and disposition at the waste disposal area (uranium and transuranic waste go into different pits). Trucks with loads of significant contamination or special loads such as contaminated septic tanks were escorted to the waste-disposal area by a health physics surveyor in another vehicle, who was in radio contact with the driver and the providers of any necessary emergency services.

Fig. 6.13. Soil being loaded into a dump truck from a front-end loader. (Note method of water spraying.) For most of the operation, plastic sheeting used in the dump trucks was twice the width of the plastic shown.

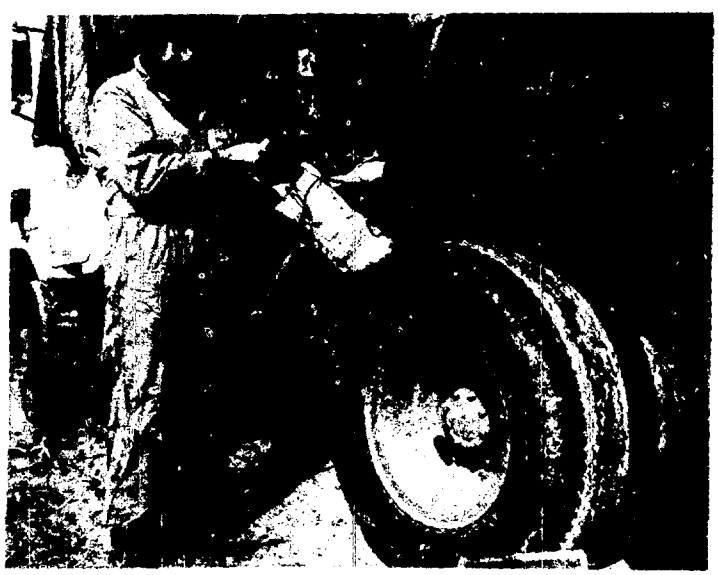

Fig. 6.14. Phoswich surveying of a loaded, tarpaulin-covered truck before the load is taken to the waste disposal area.

Health Physics and Environmental Control

Standard anticontamination clothing was used on decontamination operations and some surveillance operations. Portable air samplers surrounded the immediate work area to evaluate airborne exposure to workers. Nose swipes were taken from each worker at the end of each work day for early detection of inhaled radionuclides. The area was surrounded by a chain-link fence for contamination control and personnel safety. High-volume air samples (approximately 1 $m^3$/min) collected just outside the work fence were analyzed daily (gross alpha and beta) for early detection of environmental airborne radioactivity. Environmental air-net sampling stations were established at the three closest business establishments to provide documentation of airborne activity exposures to the public. Filters were changed every two weeks for radiochemical analysis of isotopes of interest.

Decision-Making and Documentation

The International Commission of Radiation Protection recommends[4] the following objectives for a dose limitation program:

1. Comply with recommended limits.
2. Avoid unnecessary exposure.
3. Provide operational control of justifiable exposure to satisfy two criteria:
   a. Doses are "as low as reasonably achievable" (ALARA), economic and social considerations being taken into account;
   b. Doses are justifiable in terms of benefits that would not otherwise have been received.

In dealing with the potential public exposure, we needed to meet then-current limits: 500 mrem/yr to the maximum individual and 170 mrem/yr to a suitable sample of the exposed population for the whole body, gonads, or bone marrow, and three times those values for other organs.[5] In 1979 the Federal Radiation Council, which is under jurisdiction of the U.S. Environmental Protection Agency (EPA), reaffirmed these limits for the cleanup of Enewetak Atoll. We would need to remove contaminated surface and subsurface soil to ensure that any doses from remaining contamination were at ALARA levels. A pathway analysis is required to understand the relation between soil concentration and dose to humans. At that time, J. W. Healy of LASL had issued the first of two documents[6,7] for recommended limits of plutonium contamination in soil. He calculated that 200 pCi/g, in the top 0.1 cm of soil spread over a wide area, could give 1.5 rem/yr to the lung or 1.5 to 3 rem/yr to the mineralized portion of the bone of the maximum individual.[6] (At that time, and to date, no official national or international standards exist for plutonium in soil. The EPA presently has proposed "guidance",[8] a de facto standard, but no official standards exist yet. All presently proposed standards refer to surface contamination; there is still no guidance for contamination several tenths of a meter deep--that is still an ALARA judgment.)

Before making an ALARA judgment, it is first necessary to determine who makes the final decision. For TA-1, the Energy Research and Development Administration headquarters delegated this authority to their Albuquerque Operations Office (ALO). ALO personnel made frequent visits to TA-1, attended briefings and made the final decision on when an area had been decontaminated to ALARA. For unrestricted use, given the long half-life of plutonium (our principal contaminant) and the penchant of man to move soil or dig deeply in it, contamination should be removed if the subsurface soil had enough contamination so that a significant surface area could become contaminated to levels near Healy's recommended limits if the soil were disturbed.

Figures 6.15, 6.16 and 6.17 indicate how one ALARA decision was made. The example area had been contaminated by activities associated with the building where chemical and metallurgical research on plutonium was conducted (Building D) and by the effluent from a laundry for contaminated clothing (Building D-2). In

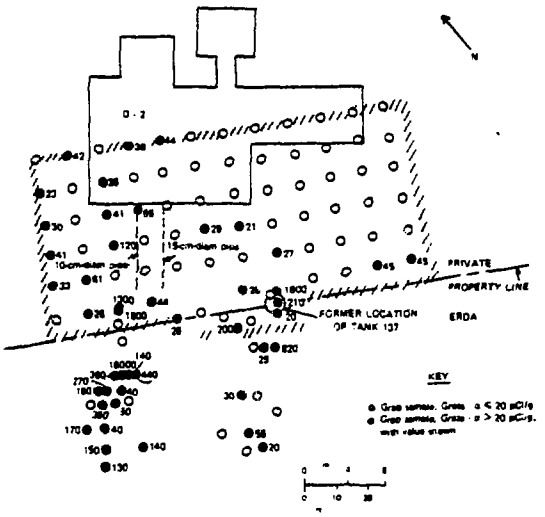


Fig. 6.15. D-2 area excavation and sampling results, December 5, 1975.

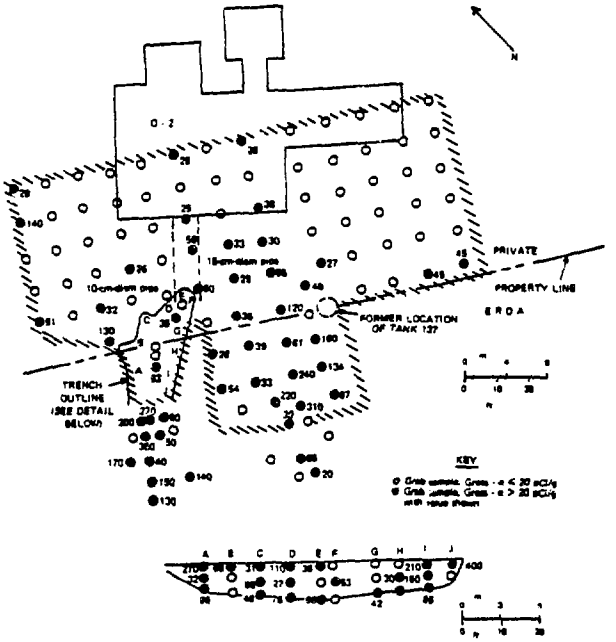


Fig. 6.16. D-2 area excavation and sampling results, December 19, 1975.

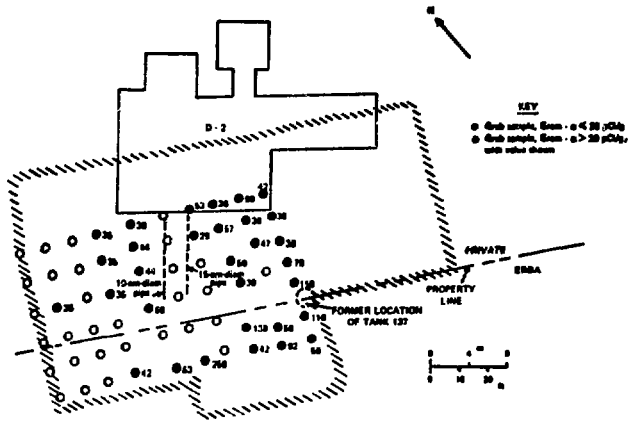


Fig. 6.17. D-2 area excavation and sampling results, January 19, 1976.

the excavated area in Fig. 6.15 we were below the depths of waste-water pipes, building foundations, and utility lines. Excavations were in apparently undisturbed tuff (the soft volcanic rock underlying Los Alamos). Thus, discovery of significant pockets of contamination was unlikely. Notice that with the exception of two known areas with phoswich detectable activity (at the end of former laundry drain pipes and in the former septic-tank location), the maximum contamination is 120 pCi/g of gross-alpha activity, although unexcavated gullies draining this area still have significant contamination. Approximately half the samples in the western half of the grid have activity >20 pCi/g. In the next iteration (Fig. 6.16), the western half of the grid has had another 0.6 m removed, the contaminated drainage channel has been excavated with the backhoe (to 2.7 m deep), and the excavation has been extended in the former location of septic tank 137. Comparison of Fig. 6.15 and 6.16 indicates that spots with activity >1000 pCi/g were removed along with much of the activity in the western portion of the grid. The deep trench was considered to be decontaminated to ALARA levels because (1) no phoswich detectable activity remained in the trench; (2) most of the activity that did remain was on ERDA-owned and controlled property; (3) steep terrain and a nearby canyon wall would have made excavation hazardous; and (4) most samples had gross-alpha activity <100 pCi/g. However, in the tank 137 area the new portion of the excavation indicated contamination levels slightly higher than surface levels. It was decided to remove another 0.6 $m^3$ in the new excavation area. Costs were \$50/$m^3$ for an estimated total of \$5000. If general concentrations remained the same or dropped, the area would have been decontaminated to ALARA. Comparison of Figs. 6.16 and 6.17 shows that the concentrations dropped slightly in this area. This portion of the D-2 excavation was considered decontaminated because (1) no phoswich-detectable activity remained; (2) a number of samples had gross-alpha activity >20 pCi/g, but the maximum was 250 pCi/g; and (3) the excavation was so deep in the tuff that a great deal of expensive soil removal would be necessary to improve results. Also, (1) the excavations were well below the drain pipes from Building D-2; (2) the excavations were in undisturbed tuff; and (3) the tuff had no apparent joints or cracks into which contaminated solutions would have leaked. Thus, major additional discoveries of contamination were unlikely. Possible reduction of small concentrations deep in the tuff near a steep slope and cliff did not justify the additional cost and physical hazards required to remove additional soil. Also, after backfilling 1.2 to 3.7 m, the area would not likely be disturbed by future activities. In the unlikely event of future site development, excavation in the area would dilute residual

contamination, which undiluted was basically less than Healy's guideline of 200 pCi/g for surface contamination.

This discussion is an example of the iterative process in determining ALARA for one of the more difficult-to-assess areas. We determined the isotope of concern, the extent and magnitude of contamination, the dollar costs of removing additional soil, the hazards to personnel and equipment in trying to remove the additional soil, and future land use concerns. In the latter case, it is possible that there will be more restrictive standards that may or may not include subsurface considerations. Having a disposal area within 12 km of the decontamination effort was certainly a factor in our deliberations. Had the area been farther away, ALARA would have been different due to costs. Another cost factor relates to speed of sample analysis. One needs to have the ability to rapidly determine contamination in soil so that decontamination efforts can be readily directed. It makes little sense to decontaminate an area and then have the crew stand by for an extended period awaiting results to determine if the decontamination is adequate.

When all is said and done, who is to say that what's been done is sufficient--in light of new knowledge or instrumentation some years hence? Should further decontamination be considered necessary, it is a must that the documentation of the as-left conditions be very thorough and accurate. Such documentation by those who went before would certainly have eased our effort. We made a thorough phoswich survey to insure that no hot spots remained; we took detailed grids of soil samples and reported all results. Grid corners and special sample locations were marked accurately by surveyors. Contours of the final contamination depths and locations were surveyed before backfill operations started. Liberal use of photography also documented our progress. Notes and data summaries must be kept up-to-date, to ensure that data do not get overlooked or confused because of a long time between data collection and analysis. Ample time must be alloted for the final report.

Considerable amounts of manpower and money were required to move 15,000 $m^3$ of contaminated debris and soil as well as to do environmental surveys, health physics surveillance, support documentation, and reporting. Because the dollar is not constant, only personnel time and equipment usages are presented in Tables 6.2 through 6.4 to provide information on the effort required to conduct such a project. More detailed breakdowns are available in Ref. 1.

Table 6.2. Equipment Use at TA-1

| Equipment | Total hours |
|---|---|
| Backhoe | 526 |
| Dump truck, large | 1523 |
| Dump truck, small | 3926 |
| Water truck | 933 |
| Compressor | 191 |
| Bulldozer | 367 |
| Front-end loader | 933 |
| Blade | 33 |
| Scraper | 42 |
| Roller | 98 |
| Miscellaneous | 176 |
| TOTAL | 8768 |

Table 6.3. Craft Charges to the TA-1 Project

| Craft | Total hours |
|---|---|
| Operators | 2864 |
| Laborers | 10564 |
| Teamsters | 8557 |
| Carpenters | 358 |
| Line Shop | 183 |
| Electricians | 295 |
| Fitters | 310 |
| Miscellaneous | 165 |
| TOTAL | 23296 |

Table 6.4. LASL Manpower for TA-1 Project (September 1975 through December 1976)

| Group | Man-months |
|---|---|
| Environmental studies | |
| Professional* | 35.4 |
| Technician | 35.9 |
| Health physics | |
| Professional | 16.4 |
| Technician | 34.4 |
| Construction | |
| Professional | 0.1 |
| Foreman | 8.3 |
| Survey | 5.2 |
| Other | 5.2 |
| TOTAL | 140.9 |

*Includes Project Manager through February 1976 and report preparation approximately 12.5 man-months. No estimate for report preparation in 1977.

This discussion represents one part of a major effort in soil decontamination. Since TA-1 we've removed a contaminated industrial waste line in the Los Alamos townsite,[9] dismantled a plutonium incineration facility, and dismantled a filter building contaminated with actinium-227. We are decontaminating the former plutonium handling facility and have surveyed canyons and an old firing site contaminated with strontium-90.[10]

## Other Considerations

The risk of decontamination versus the risk of doing nothing is often overlooked. One should carefully consider actual risks, e.g., the 6 x $10^{-4}$ construction risk (fatalities per year per individual),[11] and the risk of waste material transport should be weighed against conservatively estimated future probability of health effects often set at much lower risk levels.

For ALARA, it is likely that decontamination of a crowded urban setting might be different than decontamination of a lightly inhabited desert. If a portion of a desert or other fragile ecosystem near a population center has contamination slightly above guidelines, should we plow and thus destroy that ecosystem because soil contaminant concentrations do not meet a conservative radiological guide?

Many forms of guidance for soil contamination limits restrict exposures to a minor fraction of the radiation received from medical and natural sources. We should be very reluctant to establish standards which preclude these other considerations regarding the acceptability of given soil-contaminant concentrations.

Once reasonable dose limits are met, guidance as to ALARA should be flexible enough to consider several factors that become important in a field operation. Those are:

1. The particular contaminant involved.
2. Location of the contamination.
3. Conceivable future land use considerations.
4. The ability to detect the different types of radioactivity in field situations.
5. The cost of further efforts to reduce contaminant concentrations in terms of time, money, and physical hazards to personnel.
6. The quantities of waste materials generated.

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# 7. NEVADA OPERATIONS OVERVIEW

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Nevada has been in the site decontamination/decommissioning business for about 11 years, I guess, and we've cleaned up about that many sites. I'd like to give a brief overview of where we've worked and some of the lessons learned. Hopefully, more detail will be added by following speakers. I'd like to hit briefly on the history, on the operational factors in the context of "lessons learned," special problems, and long-term considerations (Table 7.1).

Table 7.1. Overview of DOE's Nevada Operations Office Site Decontamination/Decommissioning Experience

* Historical Summary
* Operational Factors
* Special Problems
* Long-term Consideration

The historical summary (Table 7.2) begins with an event site that didn't require ground-surface cleanup, because during the course of test operations we did not reenter the test vicinity. Essentially, all these sites are the results of weapons testing. The only exception is the Nuclear Rocket Development Station. All of the rest resulted from operations around nuclear weapons activities. Most often, the contamination problems arose from reentry into the vicinity of the shot point and the subsequent bringing of radioactive material to the surface. As indicated by the dates, we progressed right along through the 1960s and to sites such as GNOME, near Carlsbad, New Mexico. Actually, GNOME had two cleanups: one in the late 1960s and again about ten years later. The initial project was a fairly extensive cleanup for those years; the reason for the subsequent cleanup was criteria change or new public concern and considerations.

Table 7.2. Historical Summary
AEC-ERDA-DOE Decontamination and Decommissioning Operations

| Name | Event Date | Location | Year of Cleanup(s) |
|---|---|---|---|
| Shoal | (10/63) | Fallon, NV | Not Required |
| Faultless | (1/68) | Central Nevada Test Site | 1974 |
| Tatum Dome | (10/64)(12/66) | Hattiesburg, MS | May 1971-Feb 1972 |
| Amchitka | (10/65)(10/69)(11/71) | Amchita Island, AK | May 1973-June 1973 |
| Rulison | (9/69) | Rifle, CO | July 1972 and Sept 1976-Oct 1976 |
| Rio Blanco | (5/73) | Rifle, CO | June 1976-Sept 1976 |
| Gasbuggy | (12/67) | Farmington, NM | Aug 1978-Sept 1978 |
| GNOME | (12/61) | Carlsbad, NM | June 1968-Dec 1968 and July 1977-Sept 1979 |
| Enewetak | 1950s | Enewetak Atoll, Marshall Isl. | June 1977-Sept 1979 |
| NRDS | 1960s | Nevada Test Site | 1978-Present |

Tables 7.3 to 7.10 provide some idea of the cost and the various radionuclide species that drove the various cleanups. Basically, there will be some dominant isotope at each site that tends to drive the construction work or the recovery. Then I want to discuss criteria, the media that was cleaned up (in this case soil, liquids, and a lot of miscellaneous hardware),

Table 7.3. Tatum Dome

Cost: $1.08 million

Radionuclide Species: Sb-125, H-3

Cleanup Criteria:
$^{3}H$ : $>10^{-3}$ μCi/g
βγ : >.2 mrad/hr above background measured at 1 cm
α : $>10^{-6}$ μCi/g
βγ (except $^{3}H$) : $>10^{-5}$ μCi/g
Site average not to exceed .05 mrad/hr βγ above background at 1 cm

Cleanup Medium: Soil, liquids and contaminated miscellaneous hardware

Quantities and Methods of Disposal:

Injection of liquids and soil into event cavity
11,000 $yds^3$ soil and 1,300,000 gallons of water

Cost aproximately $40/$yd^3$ to excavate and dispose of soil

Returned 18 railcars of contaminated hardware to NTS.

Table 7.4. Amchitka

Cost: $20 million

Radionuclide Species: $^{3}H$

Cleanup Criteria:
$^{3}H$ : $>10^{-3}$ μCi/g
βγ : >.2 mrad/hr above background measured at 1 cm
βγ (except $^{3}H$) : $>10^{-5}$ μCi/g above background
Site average not to exceed .05 mrad/hr βγ above background measured at 1 cm

Cleanup Medium: Various debris

Quantities and Methods of Disposal:

A few small valves and a small amount of other debris cut in small pieces and buried under 4 feet of concrete in the reentry well cellar

Estimated total contamination <1 μCi disposed of

Table 7.5. Rulison

Cost: $175,000

Radionuclide Species: $^{3}H$

Cleanup Criteria:
$^{3}H$ : $>3 \times 10^{-2}$ μCi/g
$\beta\gamma$ : >.2 mrad/hr above background measured at 1 cm
$\beta\gamma$ (except $^{3}H$) : $>10^{-2}$ μCi/g above background
Site average not to exceed .05 mrad/hr $\beta\gamma$ above background measured at 1 cm.

Cleanup Medium: Solid and liquid waste

Quantities and Methods of Disposal:

1972 Cleanup
- 3000-gallon tanker containing 0.69 Ci tritium in liquids
- 32 packages of solids and six 55-gallon drums of liquid--estimated 73 mCi $^{3}H$

1976 Cleanup
- Sixty-eight 55-gallon drums of contaminated soil and other solid waste--approximately .018 Ci tritium
- 0.166 Ci tritium-contaminated waste water and drilling mud pumped into cavity

Packaged waste was sent to Beatty, Nevada for disposal for both cleanup operations.

Table 7.6. Rio Blanco

Cost: $300,000

Radionuclide Species: $^{3}H$ and $^{137}Cs$

Cleanup Criteria:
$^{3}H$ : $>3 \times 10^{-2}$ μCi/ml soil moisture
$\beta\gamma$ : >.2 mrad/hr above background measured at 1 cm
$\beta\gamma$ (except $^{3}H$) : $>10^{-5}$ μCi/g
Site average not to exceed .05 mrad/hr $\beta\gamma$ above background measured at 1 cm

Cleanup Medium: Soil (local contamination), liquids, solid waste and solidified liquids

Quantities and Methods of Disposal:

Seventy-three 55-gallon drums estimated .023 Ci--mostly $^{3}H$ with some $^{137}Cs$ and $^{90}Sr$ shipped to Beatty, Nevada

15.9 mCi tritium (575 barrels) evaporated to atmosphere

1341 barrels containing 68.5 mCi $^{3}H$, .7 mCi $^{137}Cs$ and .0007 mCi $^{90}Sr$ in liquid form injected into Fawn Creek Disposal Well.

Table 7.7. Gasbuggy

Cost: $300,000

Radionuclide Species: $^{3}H$

Cleanup Criteria: $^{3}H$ : >3 x $10^{-2}$ μCi/ml soil moisture
βγ : >.2 mrad/hr above background measured at 1 cm
βγ (except $^{3}H$) : >$10^{-5}$ μCi/g above background
Site measured not to exceed .05 mrad/hr βγ above background measured at 1 cm

Cleanup Medium: Sludge from equipment decon and miscellaneous hardware

Quantities & Method of Disposal:

60.5 barrels of $^{3}H$ contaminated water and sludge (avg. 1439 pCi/ml) and 7.3 barrels of $^{3}H$ contaminated water and sludge (avg. 350 pCi/ml) injected into cavity

175 barrels of low-level $^{3}H$ (1.31 mCi total) released to atmosphere

10 barrels of low-level $^{3}H$ (<1 mCi) solidified liquid packaged and shipped back to NTS

Table 7.8. Gnome

Cost: $1.9 million

Radionuclide Species: $^{137}Cs$ & $^{3}H$

Cleanup Criteria: $^{137}Cs$ : >2 x $10^{-5}$ μCi/g averaged over 1/4 hectare
βγ : >15 μR/hr above background
$^{3}H$ : >3 x $10^{-2}$ μCi/g of soil moisture

Cleanup Medium: Soil-salt and debris

Quantities and Method of Disposal:

23,000 yd of contaminated salt and soil were crushed, slurried and injected into cavity 1200 feet below ground

Contaminated and non-contaminated hardware and a small quantity of contaminated soil were shipped back to NTS for burial

Remaining uncontaminated salt (insufficient room in cavity) buried on site with 14 ft of overburden

Approximately .42 curies $^{137}Cs$ (average specific activity times quantity of soil disposed)

Table 7.9. Enewetak Atoll

Cost: $100 Million

Radionuclide Species: Transuranics

Cleanup Criteria: Condition A - 160 pCi/g averaged over 1/4 hectare
Condition B - 80 pCi/g averaged over 1/2 hectare
Condition C - 40 pCi/g averaged over 1/4 hectare
Condition D - Assay area--any 5 cm thickness of soil below surface >160 pCi/g

Cleanup Medium: Soil, debris, ordnance

Quantities and Methods of Disposal:

104,000 cubic yards of soil and 6,000 cubic yards of contaminated debris mixed with concrete to form dome on location.

100,000 cubic yards of soil and uncontaminated debris dropped to bottom of lagoon

Approximately 12.6 curies TRU disposed of in concrete dome

Table 7.10. NRDS

Cost: FY 1978 through FY 1982 (projected) $1.28 million

Radionuclide Species: Reactor fission and activation products

Criteria: As low as practicable
Area to remain under DOE control

Cleanup Medium: Debris removal from buildings and land areas
Soil removal from selected areas

Quantities Disposed of: Approximately 850,000 kilograms

Method of Disposal: Burial in DOE-approved areas NTS

and some of the methods of disposal. Most of our sites have been fairly convenient in terms of method of disposal, in that we've had the opportunity of putting soil and liquids back into the shot cavity created at detonation time. The material that we have been unable to place in these cavities was packaged and brought back to the Nevada Test Site for disposal. At Tatum Dome Site, we returned about 18 railcars full of contaminated hardware. Primarily, we did that because the radioactivity involved remained classified up to and through the cleanup.

Table 7.11 presents operational factors I wish to discuss with respect to lessons learned.

Table 7.11. Operational Factors

| |
|---|
| * Presurveys |
| * Cleanup criteria |
| * Criteria interpretation and implementation |
| * Topography and climate |
| * Historical information |
| * Sampling and analytical methods |
| * Project management |
| * Planning |

Presurveys, in terms of estimating the size of the cleanup of a job, is an absolute must. We went into the Tatum Dome Cleanup with a very meager presurvey; that led to a gross underestimate of the job in terms of time and actual cost required for completion.

The second item: cleanup criteria. Perhaps this is a pet peeve of mine, but I have been interacting with Headquarters and anybody else that will listen for a good number of years on the development of cleanup criteria. My thesis is that when you go to a site and try to perform decontamination and decommissioning, you have to have some kind of acceptable criteria in terms of soil concentrations for various radionuclides, so you can tell when the job has been completed. All that Alquist said earlier in terms of ALARA is true, and I agree with him. However, specific criteria can certainly dictate the magnitude of the job. We went through quite a process of iteration of criteria for the Tatum Dome site. We started very, very conservatively in terms of the numbers issued from AEC headquarters. That turned out to be something--trying to measure the background regions and trying to solve the problem of what is background and what isn't. We finally persuaded them that an order of magnitude greater than the background, which turned out to be about 10 pCi/g, was an acceptable criterion; that was done after a modicum of pathway analysis. (Again, I agree with the earlier speaker that environmental impact from soil pathway analysis is a necessity.) I'd like to show an example of what I call Criteria Interpretation Implementation. Even after you get the criteria, you don't necessarily have your problem solved.

Table 7.12 is a page from a report of a task group that recommended Criteria A, B, and C for plutonium. This is for the Enewetak Atoll--a cleanup that is just winding down after about three years of activity. Here you can see that basically there are specific concentrations for plutonium in soil. This case was more of a surface-area problem than a concentration problem. The variability of plutonium concentrations in soil does not help much in trying to determine and implement measurement technique; it makes meeting the criteria difficult.

The operating criteria (Table 7.9) were developed after lots of intense negotiation, investigation, and use of expert opinion. The various conditions described in Table 7.9 worked out well in implementing the criteria and judging just what material had to be cleaned up. Another thing that you have to keep in mind as criteria are implemented is that, generally, you are trying to minimize the amount of material removed and to minimize the cost and impact on the overall cleanup. That almost always is a driving force. So as operating procedures are generated, the kind of standard error or various other ways of interpreting the data that you generate can dictate the cost and how much goes into measuring a particular sample or particular area. Hopefully, that will be addressed in a little more detail later on.

I'd like to go back now to Table 7.11, Operational Factors. We have found in our experience that topography and climate are indeed very important. At Enewetak, there is a hot, humid, salt-spray environment, and instrumentation and operating procedures are dictated largely by that kind of climate. You have to be prepared with good instruments, a lot of repair capability, and the ability to really handle all instrumentation problems on-site. With the exception of the intrinsic germanium detector, we have handled repairs on-site. We had five or

Table 7.12. Report by the AEC Task Group on Recommendations for Cleanup and Rehabilitation of Enewetak Atoll
June 19, 1974

"Since there is no adequate scientific information which would support general guidance for cleanup of plutonium-contaminated soil, guidance can only be developed on a case-by-case basis using conservative assumptions and safety factors. With this in mind, the task group recommends the following for use in making decisions concerning $^{239}Pu$ cleanup operations at Enewetak:

A. <40 pCi/g of soil - corrective action not required.

B. 40 to 400 pCi/g of soil - corrective action determined on a case-by-case basis considering all radiological conditions.

C. >400 pCi/g of soil - corrective action required."

six of those particular detectors; they were shipped back to Princeton Gamma-Tech for repair. That provided logistical problems, along with all the others that we had. Operating in southern Mississippi also gave us lots of problems. Later, I'll show you some slides of operating in that area where you have lots of rainfall, various temperatures, and so forth. But this sort of thing has to be factored into your planning as you go into any particular site. Another significant factor about topography and climate is that it can dictate the spread of radioactivity, both in the historical sense of what has happened to the radioactivity since it was deposited and relative to leaching, spreading, tracking, and all kinds of things happening to that material in actual real-time situations. We had two or three cleanup sites at Tatum Dome that were recontaminated just because of additional rainfall--high rainfall with lots of inches per hour and the problem of flooding and spreading of contamination.

A few words about historical information: the examination of historical documents is extremely important. As-built drawings of how the cable runs or how various installations were built are extremely important. When you find a facility going into mothballs, these records need to be preserved. Somebody in a responsible position needs to recognize the importance of preserving them. Often, as sites go into inactivity, these records are tossed out and you can't really find them anymore. There is no one in an operating managerial mode who sees any future need of them, so out the window they go. These things are extremely important. We've found that they can be particularly important from the safety sense alone. Trying to pin down where operations were that handled radioactivity is often a real cloak-and-dagger sort of thing. You have to measure and investigate, and many times your problems are buried in holdup tanks or some other kind of processing. Only by looking at the historical facts can you really uncover them.

Now I'll say a few words about sampling and analytical methods. We have found that the kind of equipment you take to the field can pretty well dictate your flexibility in terms of turnaround. The most important point I'd like to make is that if you operate at remote sites and if you are looking for real-time information that is driving three or four expensive pieces of equipment, you've got to have a field laboratory at your disposal so you can have real-time turnaround of your numbers. If you have to wait

for information coming from a central laboratory hundreds of miles away or even tens of miles away, you find yourself locked into the position of holding up lots of expensive equipment and people. That can really dictate a lot of the cost of the overall project.

A few words about project management: we've learned from bitter experience (and we continue to learn because not all management will agree) that experienced people are extremely important. As you go to a project site, you usually hire local contractors. These people generally have no working knowledge of radioactivity and they don't appreciate how easily it can be spread around. I'm not only talking about their general knowledge of trying to contain a problem that you are trying to clean up. We have found that if the supervisor of the first-line labor or construction people doesn't understand your problem in terms of what you are trying to accomplish by containing and cleaning, he is going to do you a gross disservice in terms of having to do it over and over again. If I had my druthers, we'd sit down with the line supervisors months ahead of time and put them through an intensive training program, until they could not only speak the language but they would understand exactly what you are driving at. It is up to these people to communicate to the various laborers and craftsmen just exactly what is needed. I would also like to mention something that I've not had a lot of control over, but I think impacts a good deal on a particular project: getting some of your own people involved as project managers who, again, don't understand radioactivity too well and don't understand some of the operational problems you have from the aspect of health physics control. Maybe they are trying to drive the project and get it done on time, with the kind of budget that has been set up. Sometimes you have to set them down pretty hard and educate them that "Hey, this is a radiological cleanup." You cannot proceed in the same manner as if you were trying to drill a 2,500-foot well in three weeks.

I'd like to say a few words about planning. It has already been said, I believe at least once, that it is pretty tough to overplan any particular decommissioning or decontamination effort. I heartily agree with that. We spent probably 1-1/2 years on the planning stages of the Enewetak cleanup. That might seem like a long time, but for that particular project, I guess we could have spent another six months and really received some benefit from it.

Table 7.13 shows types of special problems. I've talked already about logistics. This is certainly a special problem, even if you are not talking about a particularly remote site. In today's world we have experience, for example, with transportation of reactor fuel from Turkey Point. That's an example that I will give: where states, communities or counties won't allow you to transport through their domain. So that even cleaning up a site like Middlesex or New Brunswick or some of the other sites may pose a real logistical problem in how to go about removing the material, how to go about decontaminating the equipment used, and the process of the decommissioning action. These are the kinds of things that need to be considered in the planning stage.

Table 7.13. Special Problems

| |
|---|
| * Logistics |
| * Waste disposal |
| * Public relations |
| * Other safety |

I've briefly mentioned waste disposal. At a meeting last September (Fred Haywood mentioned that it was at Middlesex), you had been told by Barnwell that you couldn't take Middlesex waste there--or was it the New Brunswick waste? [From the floor: Jersey City.] These are real problems in the country right now: How do we handle waste? Where do we dispose of it? These

current hard problems have to dictate planning and consideration of your decon efforts. For instance, you do not want to generate any more volume than absolutely necessary, and maybe you are going to end up doing a lot of things different with respect to the current climate than you would do in some other given situation. Public relations is certainly an item that you can't skip over anymore. We could, a few years back. Now we must meet the public on their ground and provide plain information to them. I mean information that they can understand about the problems of the site and what you are attempting to do through your decon action. The utility of the site will be when you accomplish your job. These things really need to be dealt with delicately. It is easy for headlines to appear in the local paper and local TV and radio that can give you all kinds of bad press simply because of your inattention to these kinds of details.

I mentioned briefly some other kinds of safety problems: I want to zero in on that just a few more minutes. This is particularly where as-built drawings, and so forth, come into importance. We had two serious near misses at the Tatum Dome site as a result of not having adequate as-builts. For example, we had a bulldozer operator scraping off an area, and he ran into electrical wiring that was still activated, even though we had taken great pains to deactivate all electrical wiring. In this particular case, an as-built would have been extremely important, but we learned that an as-built hadn't been made. That was the result of kludged-up wiring. As things happen in a kind of mothball state, people had kludged up the wiring to accomplish various jobs, and we had no way of knowing that particular line was there and still activated— a serious near-miss. There was another situation where we had a crane trying to pull up a tank that we had excavated around--it was almost totally excavated. What we didn't know--again, it was a result of people not adequately looking at as-built drawings--was that there were two "dead men" on that tank. The crane operator felt that he could remove the tank pretty easily, and so did all the rest of us. But we nearly lost him and the crane as a result of trying to pull the tank up and the cable snapping and the boom flopping. It was a miracle that somebody wasn't seriously injured. I mention these things to emphasize some of the things that have to be considered when we go into abandoned historical locations: you never know what you are going to run into.

Table 7.14 discusses long-term considerations: after cleaning up the Tatum Dome site, we added that location to a number of our other sites in what we call long-term hydrological monitoring, where we sample surface waters, springs, and wells on a quarterly or semiannual basis. At this particular site, a couple of years later, we started observing elevated tritium levels in some of the runoff water that was pooled in a catchment area. That monitoring led us back to the site, just this past year, where we completed a drilling program for monitoring that actually exceeded the inital cleanup cost by about a factor of two, trying to satisfy the question of where the tritium was coming from. I mention this particular situation because, even though it turned out to be a real bother to us in terms of time and cost, we were the ones who uncovered it and we were the ones who tried to solve the problem. It would have been a potentially embarrassing situation if it had been uncovered by an agency such as the State of Mississippi. We ended up satisfying the State and ourselves and other interested parties about the overall situation. Other kinds of action, such as walking away from the site and not having any consideration for what the long-term effects might be would have found us in an even worse situation.

Table 7.14. Long-term Considerations

| |
|---|
| * Long-term monitoring |
| * Land use |
| * Political aspects |

Land use has to be a consideration. I know a lot of that is a crystal-ball kind of activity, but if you don't try to forecast what the land is going to be used for, you may be overlooking some very serious consequences in terms of what current actions to take in regard to the cleanup.

I think I've already said enough about the political aspects. As we get into the cleanup of some of these old AEC and Manhattan sites--I mean "we" collectively as DOE and contractors--I think we are going to find lots of interesting problems associated with the political aspect.

# 8. IN SITU MEASUREMENT EXPERIENCES

Allen E. Fritzsche
EG&G
Las Vegas, Nevada

EG&G operates the Remote Sensing Laboratory for DOE in Las Vegas, Nevada and Andrews AFB in Washington, D.C. For more than 20 years this facility has been helping to locate and monitor radioactivity.

EG&G became associated with remote gamma sensing from aircraft when the U.S. Geological Survey asked the AEC to relieve that agency of the job in 1959; EG&G assumed the task in 1960.

In the early 1960s, EG&G tracked the radioactive "clouds" from atmospheric tests, Plowshare shots, and inadvertent vents as they emanated from the Nevada Test Site, with the sodium-iodide detector and air-sampling systems then in use.

As the 1960s progressed and major expansion in nuclear-powered electric utilities began, EG&G accelerated the use of the aircraft platform to map gamma emanation around nuclear reactor sites, both before and after the reactor became operational. In this way, the relative contributions of man-made isotopes to the environment could be detected and evaluated.

During the late 1960s and early 1970s the Remote Sensing Laboratory's capability was expanded to include multispectral photography and multispectral scanning. Today EG&G is prepared to respond to DOE's requirements in the following areas:

1. Gamma radiation mapping from airborne and ground-based platforms
2. Isotope identification and quantification for gamma surveys
3. Plume tracking
4. Aerial photography
5. Multispectral photography
   - 400-700 nm
   - 500-900 nm
   - 600-700 nm
   - 700-900 nm
6. Multispectral scanning
   - 10 optical channels: 0.38-1.10 $\mu$m
   - 2 thermal channels: 4.5-5.5 $\mu$m and 8-14 $\mu$m
7. Communications
   - Mobile telephone, HF and VHF links for emergency stituations

In the event of a major nuclear accident, EG&G is prepared to address the radioactivity mapping problem rapidly with:

1. East and west coast capability
2. Two-hour response
3. Rapid assessment of radiation release, major damage or significant spills, nuclear and non-nuclear

All of the EG&G capability is designed and packaged for quick deployment at the request of the Department of Energy.

The remainder of this presentation will describe the instrumentation, physics, and some results of the gamma survey problem.

## GAMMA SURVEY SYSTEMS

### Airborne Systems

Because EG&G began remote gamma measurements from aircraft, a brief outline of the DOE aircraft platforms is useful (Fig. 8.1). Current aircraft in the Aerial Measuring Systems (AMS) include two Hughes H-500 helicopters, two Boeing 105C helicopters, a King Air A100, a Convair 580T used currently for aerial photography and scanner work, and the original Beechcraft Twin Bonanza (E50) with which EG&G began gamma surveys. One of each of the H-500 and Boeing 105C helicopters and the King Air A100 are currently stationed at EG&G's Andrews AFB branch; the rest operate from the Las Vegas base.

Generally, the helicopters and the King Air serve as the gamma survey platforms; they use as

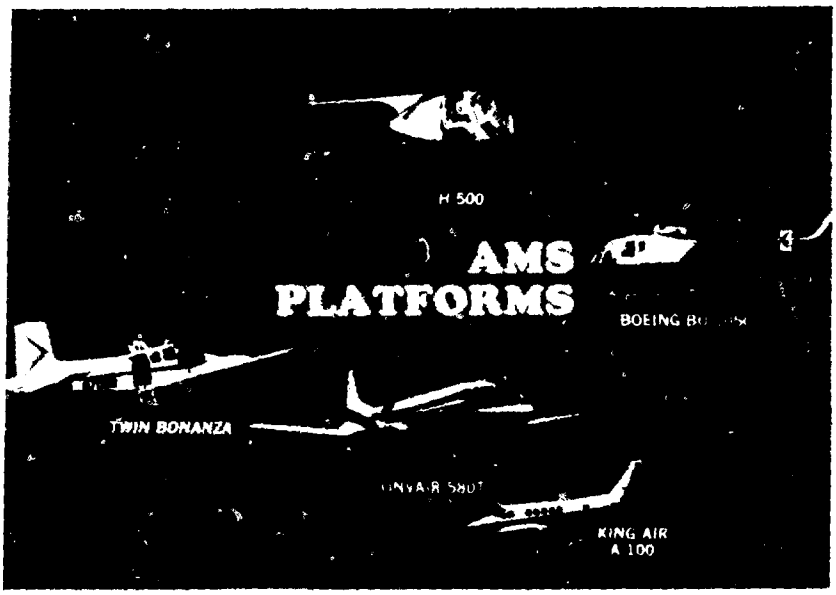



Fig. 8.1. Aircraft operated by EG&G for DOE.

many as 40 each 5"x2" NaI detectors. The helicopters are used for low-level work where maximum sensitivity is required. The King Air A100 is used for reactor surveys where a footprint of the radiologic environment is required. All these aircraft can be fitted with NaI gamma systems if the need arises.

Positioning of these aircraft during surveys is accomplished with microwave ranging units. Two units are set out on the ground or convenient high points and one master unit is aboard the aircraft. Signals from these units are fed to an on-board computer and transmitted to an indicator that guides the pilot along a selected flight line. Therefore, these aircraft may be flown over an area of interest along very accurate preselected lines at any required operational spacing.

Gamma signals, microwave range, altitude, and meteorologic data are fed into the data acquisition system which is called the Radiological and Environmental Data Acquisition and Recording System (REDAR) (Fig. 8.2). These systems were constructed by EG&G; they collect 300 channels of gamma energy data in one-second data blocks. The data are stored on magnetic tape for post-flight analysis. Provision is also made for real-time readout so the air crew may interpret data as it is collected.

To process aircraft data EG&G has fabricated two computer-equipped vans (one in Las Vegas and one at Andrews AFB) that may be driven or airlifted to a survey site (Fig. 8.3). Within hours after the data are acquired, aircraft or ground-based data may be processed on-site to yield isopleths of man-made or natural gamma radioactivity. These results are scaled to a map or site photograph so that the location of significant gamma activity is identified. Identification of the contributing isotopes is obtained from computer-analyzed energy spectra.

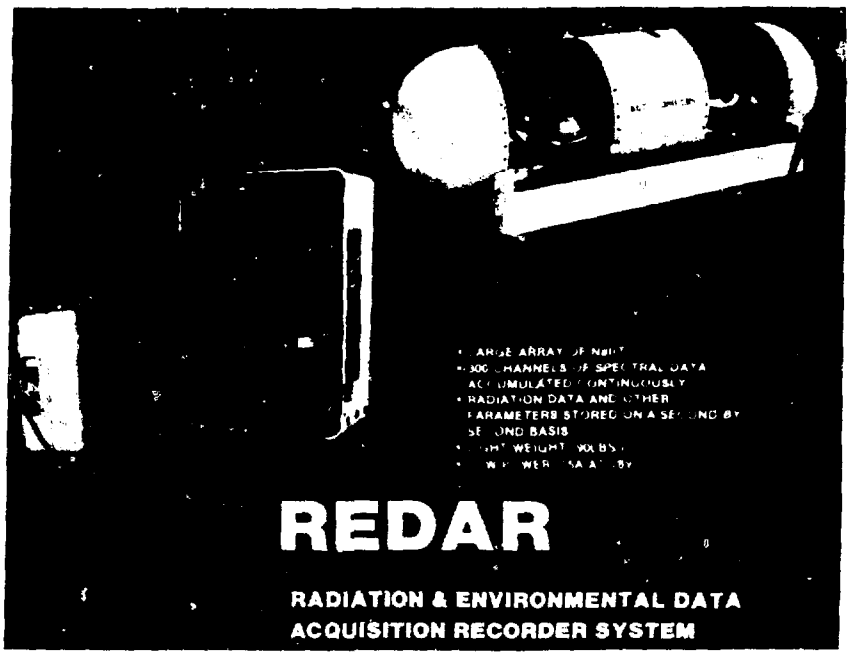



Fig. 8.2. The Radiation and Environmental Data Acquisition Recorder system.

Fig. 8.3. The Radiation and Environmental Data Analyzer and Computer system (REDAC).

Ground-Based Systems

In 1977 EG&G assembled three ground-based vehicles (IMPs) for use on the Enewetak Atoll cleanup project (Fig. 8.4). A four-wheel drive vehicle was assembled for use at the Nevada Test Site and is currently operated there by the Desert Research Institute (DRI).

These systems each utilize a large planar high-purity germanium detector mounted on a collapsible boom or mast at the back of the vehicle. The primary object of the Enewetak system was to measure the quantity of 60 keV gammas from americium-241 in situ. The ratio of $^{241}Am$ to the total transuranics ($^{238}Pu$, $^{239}Pu$, $^{240}Pu$, $^{241}Am$), as well as the depth concentration distribution, were found from soil sample analysis performed by Eberline Instrument Corporation.

A lead and cadmium conical shield forces the intrinsic germanium detector to "view" a 21-m-diameter circular area on the ground when the detector is at the normal height of 7.4 m. Gamma data were accumulated for 15 minutes over

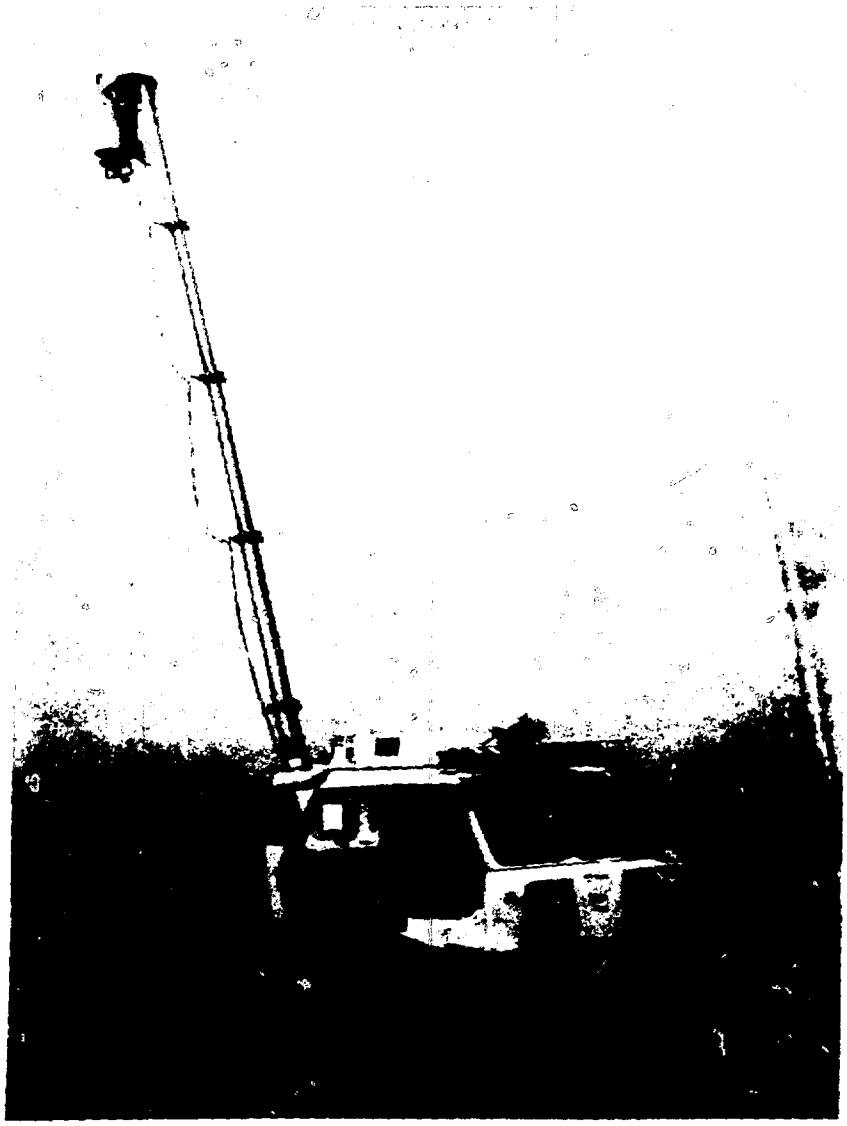


Fig. 8.4. The IMP gamma system.

each of the presurveyed stakes on the 16 islands surveyed on Enewetak Atoll. The stake pattern was generally a 50-m grid completely covering each island.

Gamma signals originating in the germanium detector were collected by an EG&G-constructed, 4096-channel pulse-height analyzer. At the end of the collection period, the energy spectrum data were transmitted to a calculator/computer and evaluated for isotopic content and $^{241}Am$, $^{137}Cs$ and $^{60}Co$ concentrations. The raw data were stored on cassette tape for further analysis. The system operator received a printout of the computed concentrations for real-time evaluation.

The data stored on tape then were collected by Desert Research Institute statisticians for reevaluation with soil-sample data and a determination was made of where contaminated soil should be removed. After soil removal, the area was remeasured to ascertain whether more soil should be removed.

The Remote Sensing Laboratory maintains and fabricates other mobile and portable gamma-measuring instruments related to measuring and mapping radioactivity. These airborne and ground-based gamma systems are supported by alpha, beta, and neutron instruments, both portable and laboratory based.

## THE GAMMA SURVEY PROBLEM

In large-area gamma surveys, the problem is divided into the following categories: (1) location of the activity for which a search method is required; (2) kinds of activity for which identification is required; and (3) amount of activity for which a quantifying method is needed. EG&G has developed and constantly updates techniques for both airborne and ground-based systems.

### Search

During the early days of airborne gamma surveys, the total count rate coming from an NaI detector served to locate areas of high activity. The total count rate is still a useful tool in locating obvious areas of very high activity.

In today's world of high-speed electronics, the entire gamma energy spectrum may be evaluated for collection periods of less than a second. This enables the surveyor to evaluate changes in energy spectrum shape through the energy window technique.

A very useful window technique employed by EG&G is called the man-made gross count method (MMGC). Since the longer-lived man-made isotopes generally emit gammas in the energy range below 1.4 Mev it is convenient to evaluate the total count in each of two energy windows, i.e., from about 0.05 to 1.4 Mev and from 1.4 to 3.0 Mev--a low-energy and a high-energy window. The method requires that the ratio of low-to-high, k, be established over a known background area and then the equation for MMGC applied over the area of suspected contamination:

MMGC = low-energy window - k x high-energy window.

Figure 8.5 illustrates this method as opposed to simply counting the total count from NaI detectors. Note the two elevated portions of the MMGC trace that are not so obvious in the gross count trace.

This same concept may be applied to $^{137}Cs$ and $^{60}Co$ (Fig. 8.6).

### Identification

If the large total count rate, MMGC rate, or other energy-window count rate indicate the existence of gamma-emitting isotopes, these can be identified from the energy spectrum obtained in the region of high count rate. The position of the photopeaks along the energy scale serve to identify the isotope from which the gamma came. Some of the characteristic gamma spectra seen at the Hanford reservation are shown in Fig. 8.7.

To enhance identification of man-made isotopes in an energy spectrum, a neighboring background spectrum may be subtracted from the total to yield the pure man-made gamma spectrum.

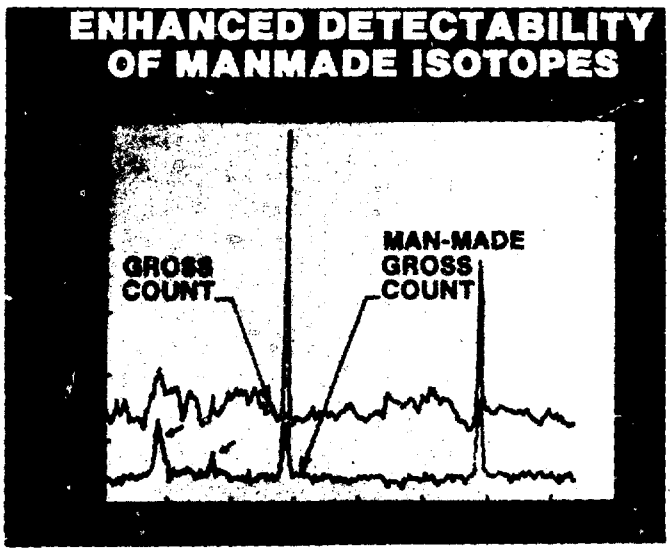



Fig. 8.5. Strip chart traces of the gross count and manmade gross count search methods.

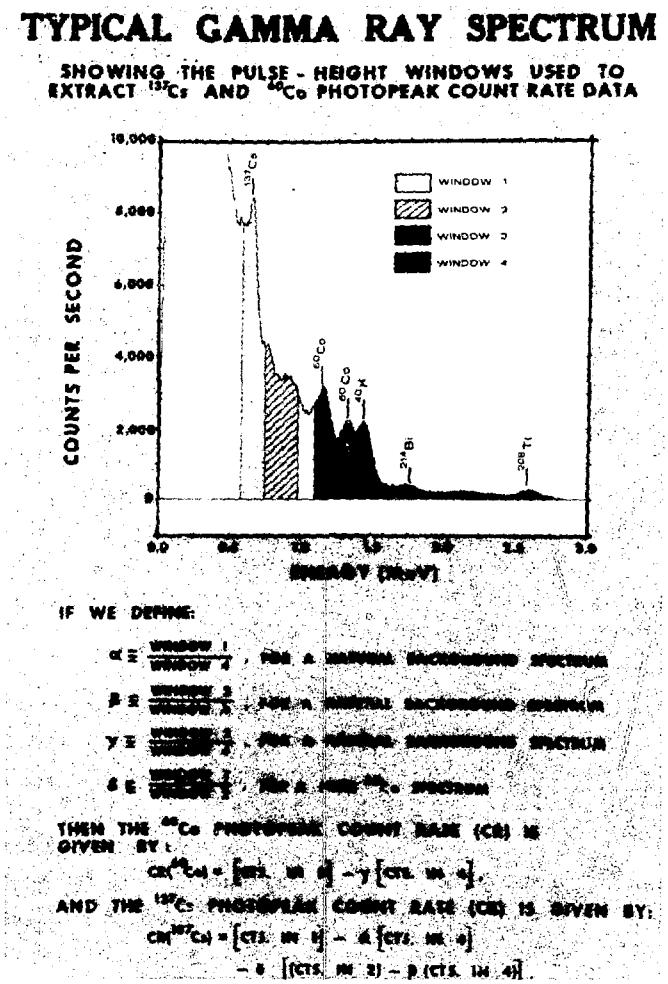



Fig. 8.6. The energy window method applied to $^{137}Cs$ and $^{60}Co$.

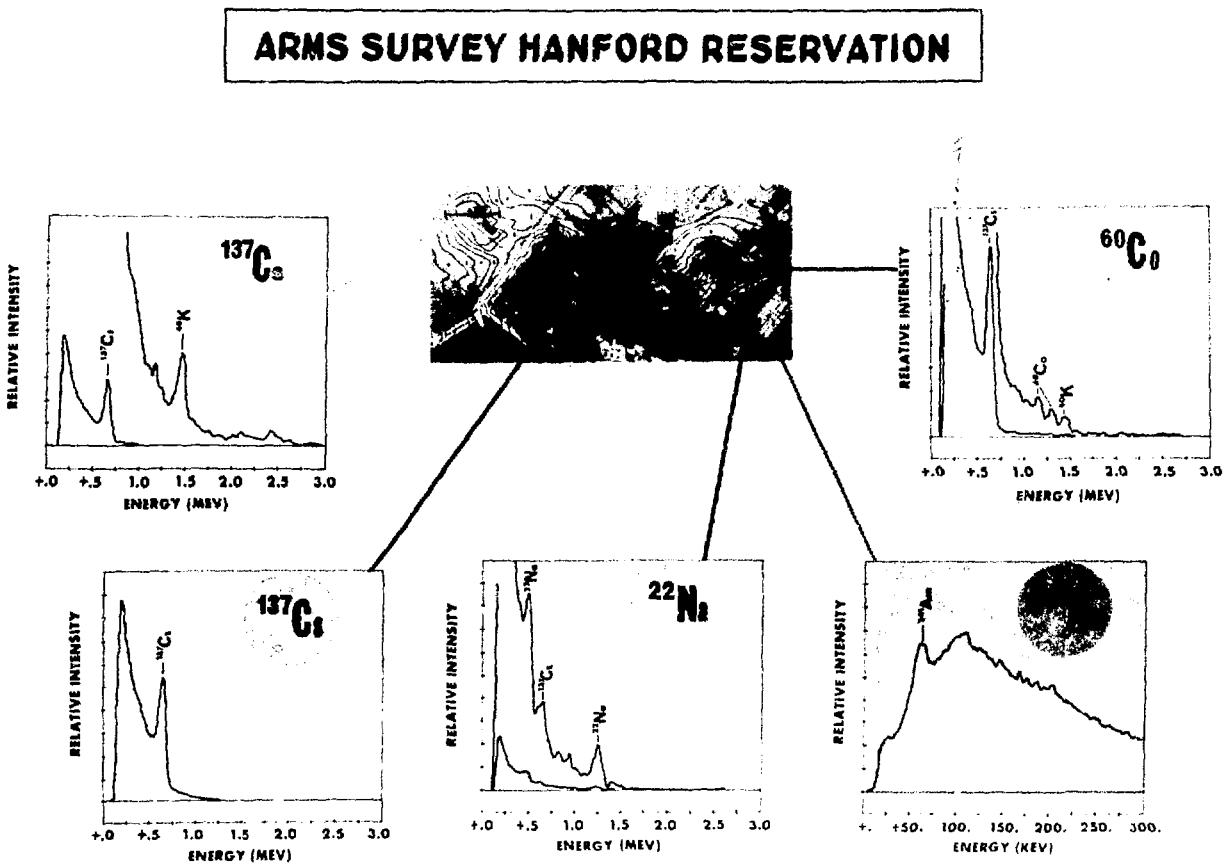



Fig. 8.7. The identification of isotopes from their characteristic gamma energy spectra.

When contamination concentrations are low--resulting in photopeaks not clearly visible after background subtraction--energy window techniques are generally employed. In these cases the presence of a specific gamma energy is computed from a statistical treatment of the result.

## Isotope Quantification

After a contaminated area is located and identified from an airborne or ground gamma survey, an approximation to the concentration and total inventory can be made (Fig. 8.8). With the detector located above the ground, this idealized geometry shows contamination both on the surface and mixed in the soil.

This geometry is used to derive an analytical expression for the count rate in a gamma detector due to unscattered gammas (Fig. 8.9). The unscattered gammas are those that reach the detector without suffering any energy loss in the soil or air: they are totally absorbed in the detector. These constitute the photopeak in the energy spectrum. Thus, photopeak count rate can be described from the physics and geometry of the problem.

In practice, the distribution of the isotopes in the soil, the density of the soil, and the elemental composition of the soil must be known. The angular response, R (θ), of the detector package is generally measured in the laboratory with known gamma sources.

Thus from a calibration and computation the sensitivity of the system to terrestrial isotopic concentrations may be obtained. The sensitivity, S, is written as:

$$S = \frac{S_v^o}{N_p} \qquad \frac{\gamma/cm^3\ sec}{cps}$$

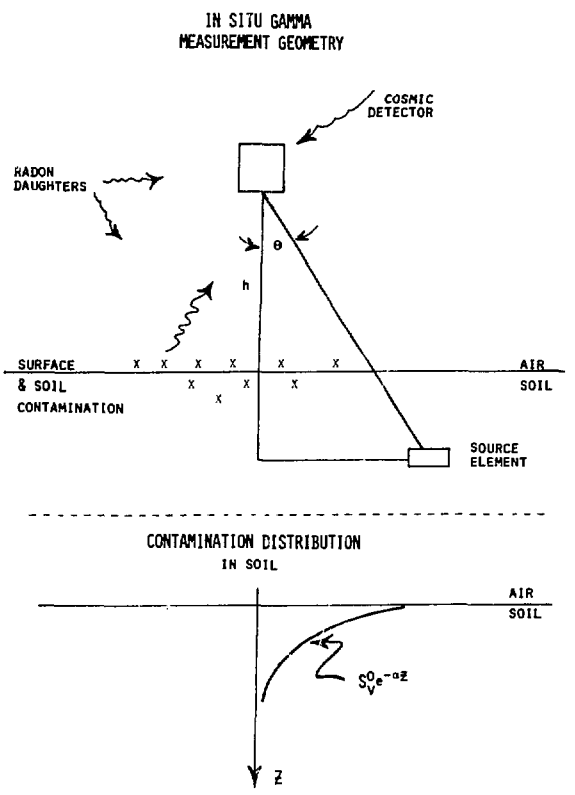



Fig. 8.8. The geometric and contamination conditions for the sensitivity computation.

In Situ Measurement Sensitivity

(uncollided gammas)

Count rate in photopeak:

$$Np = S_v^o \cdot \frac{A_o}{2} \int_{\theta=0}^{\pi/2} \frac{R(\theta) \tan\theta \, e^{-\mu_a h} \sec\theta}{\alpha + \mu_s \sec\theta} \, d\theta$$

where:

- $Np$ = photopeak count rate, cuts/sec
- $S_v^o$ = concentration, $\gamma/cm^3$ - sec
- $R(\theta)$ = detector angular response
- $\alpha$ = exponential depth distribution, $cm^{-1}$
- $h$ = detector height, cm
- $\mu_a$ = linear attn. coeff. for $\gamma$s in air, $cm^{-1}$
- $\mu_s$ = linear attn. coeff. for $\gamma$s in soil, $cm^{-1}$
- $A_o$ = effective area of detector at $\theta = 0°$, $cm^2$

Fig. 8.9. The in situ sensitivity equation.

where: $S_v^0$ = contamination concentration at the soil surface, $\gamma/cm^3$ sec

$N_p$ = detector photopeak count rate, cps.

The sensitivity, S, may be converted to pCi/g per cps and to any specific soil depth integral if soil samples are to be compared to *in situ* data.

The ability of either NaI or germanium detectors to measure gamma rays is limited by the presence of background gamma rays in the *in situ* configuration. Thus, there is a minimum detectable activity, MDA, for any gamma-emitting isotope. A few sensitivities and MDAs are listed for both NaI and germanium detectors in Fig. 8.10.

## RECENT GAMMA SURVEYS

The following examples illustrate the kind of data that can be obtained from airborne and ground-based gamma surveys.

### Uranium Tailings Pile

About 16 square miles were surveyed around the Tuba City, Arizona uranium mill tailings pile. Figure 8.11 shows the $^{226}Ra$ (a uranium daughter) concentrations obtained by analysis of the $^{214}Bi$ photopeak of the energy spectra. The highest level, L = 100 pCi/g or more, occurs over the dry tailings pond itself. It appears obvious that the windborne dust from the pond has redistributed some of the radioactivity two miles downwind. The occurrence of levels somewhat above background (A = 0.6 pCi/g maximum) in the river bottom has not been explained. Exposure rate, thorium concentration, and $^{40}K$ concentration isopleths have also been generated from this survey.

### Nuclear Power Plants

The Donald C. Cook Nuclear Plant in Bridgman, Michigan was surveyed in September, 1975 from the A100 fixed-wing aircraft at an altitude of 500 feet (Fig. 8.12). The isopleth

Sensitivity and Minimum Detectable Activity

| Isotope | NaI Systems | | Ge Systems | |
|---|---|---|---|---|
| | Sens. pCi/g / cut/sec | MDA (pCi/g) | Sens. pCi/g / cut/sec | MDA (pCi/g) |
| $^{241}Am$ | 0.1 | 8.0 | 9.0 | 0.5 |
| $^{137}Cs$ | 0.01 | 1.0 | 8.5 | 0.1 |
| $^{60}Co$ | 0.007 | 0.5 | 6.0 | 0.05 |

NOTE:

1. NaI system
   20, 12.7 cm diam. x 5 cm thick detectors
   30 m altitude
   1 sec acquire time

2. Intrinsic Ge detector
   1, 5.0 cm diam. x 1.6 cm thick detector
   7.4 m altitude
   900 sec acquire time

Fig. 8.10. Airborne NaI and ground-based Ge sensitivity to a uniform contamination distribution in soil.

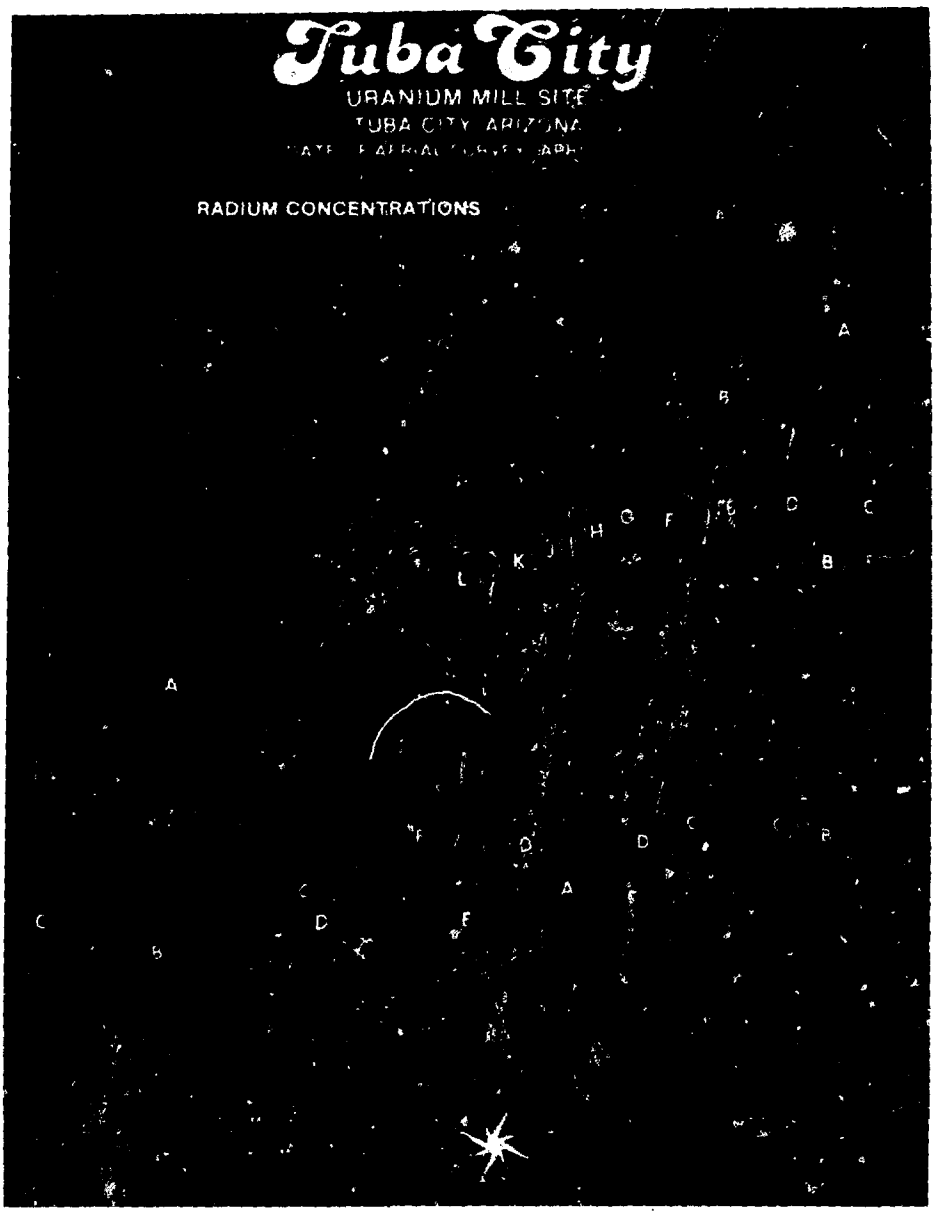



Fig. 8.11. Radium-222 concentrations at the Tuba City Uranium Mill Site.

levels here are annotated in μR/h or exposure rates. Generally these surveys cover an area of 625 square miles.

For reactor surveys, extra effort is made to look for man-made elements in possible plumes downwind from the plants and in rivers or waters used for cooling. Flights around the plants at several altitudes are used for plume search and flights above river banks are used for water contamination search.

### Plowshare Shots

GNOME, the first underground plowshare shot, was made near Carlsbad, New Mexico. It resulted in some radioactive debris on the surface of the site. By the time EG&G surveyed

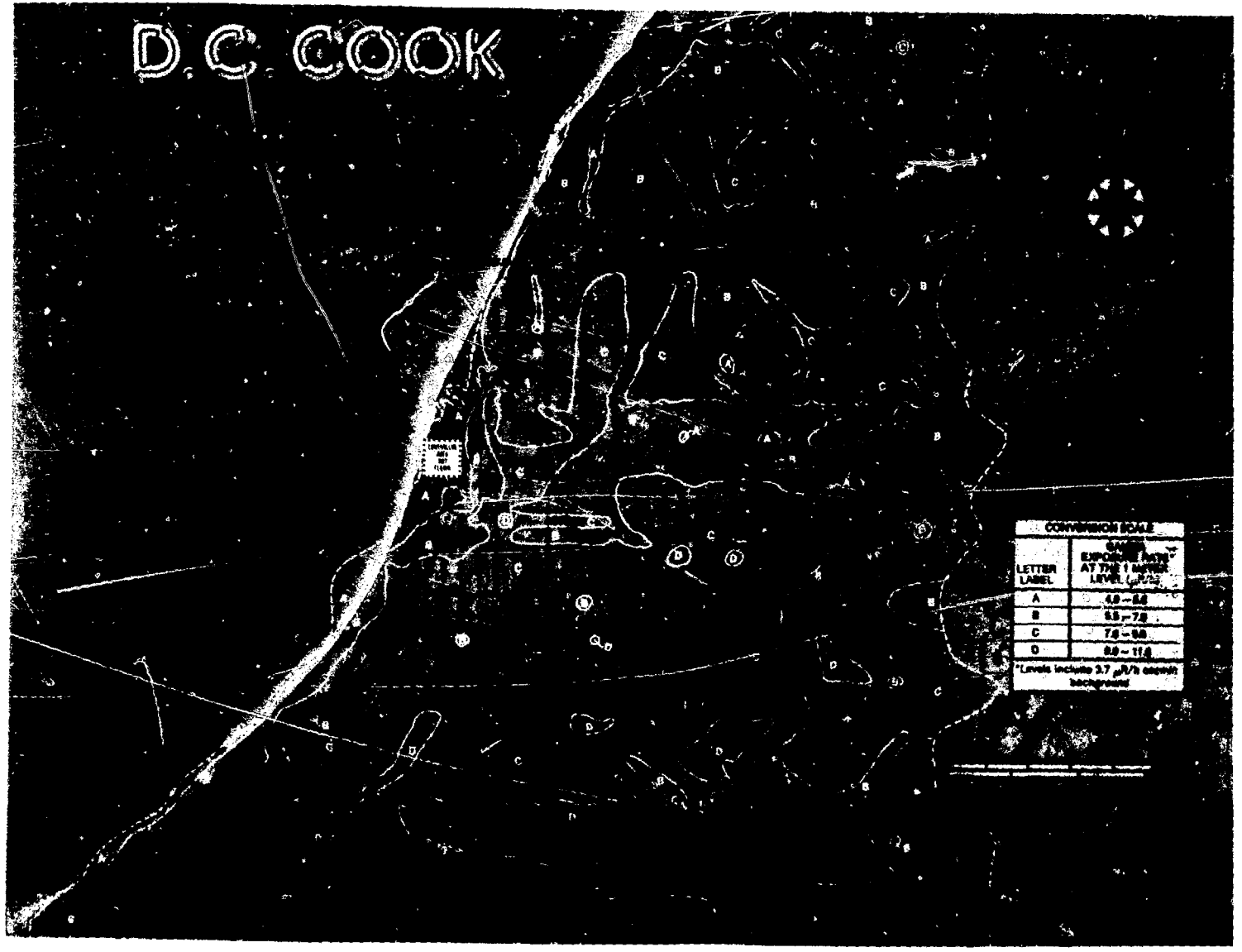



Fig. 8.12. Exposure rate isopleths from the Donald C. Cook Nuclear Plant Survey.

the site in 1977, only $^{137}Cs$ was detectable from the aircraft. The $^{137}Cs$ concentration levels in September 1977 are shown in Fig. 8.13. Cleanup of the site was done in the summer of 1979. EG&G performed another airborne survey in September 1979. The $^{137}Cs$-maximum concentration decreased somewhat (Fig. 8.14), but one can see that the general contaminated area remains the same.

Marshall Islands

EG&G performed airborne gamma surveys at eleven atolls in the Northern Marshall Islands in the fall of 1978. This survey located the fallout pattern from shot Bravo from Bikini Atoll in the 1950s. Included in this survey was a resurvey of the Enewetak Atoll where a cleanup or decontamination project was well

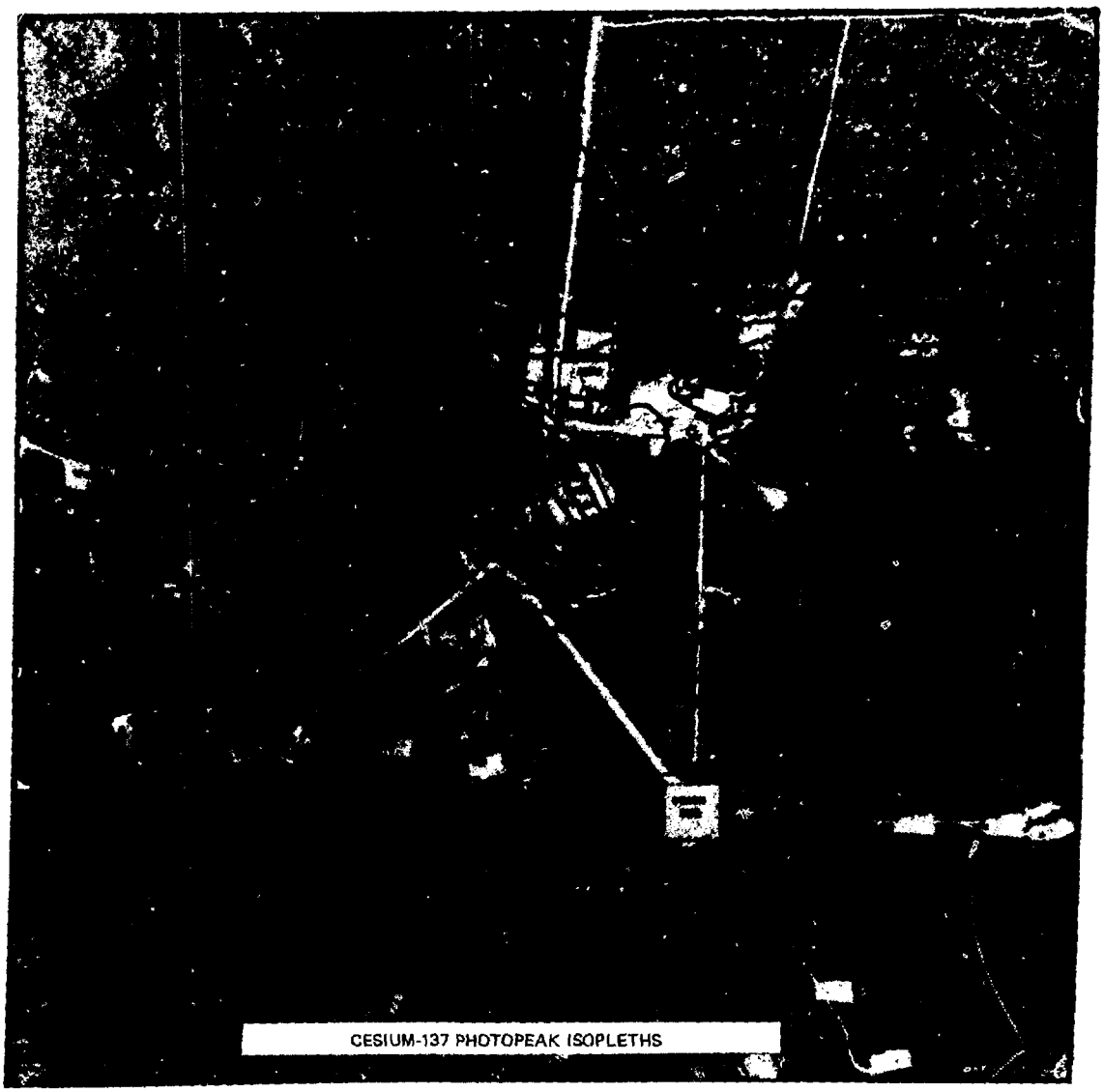
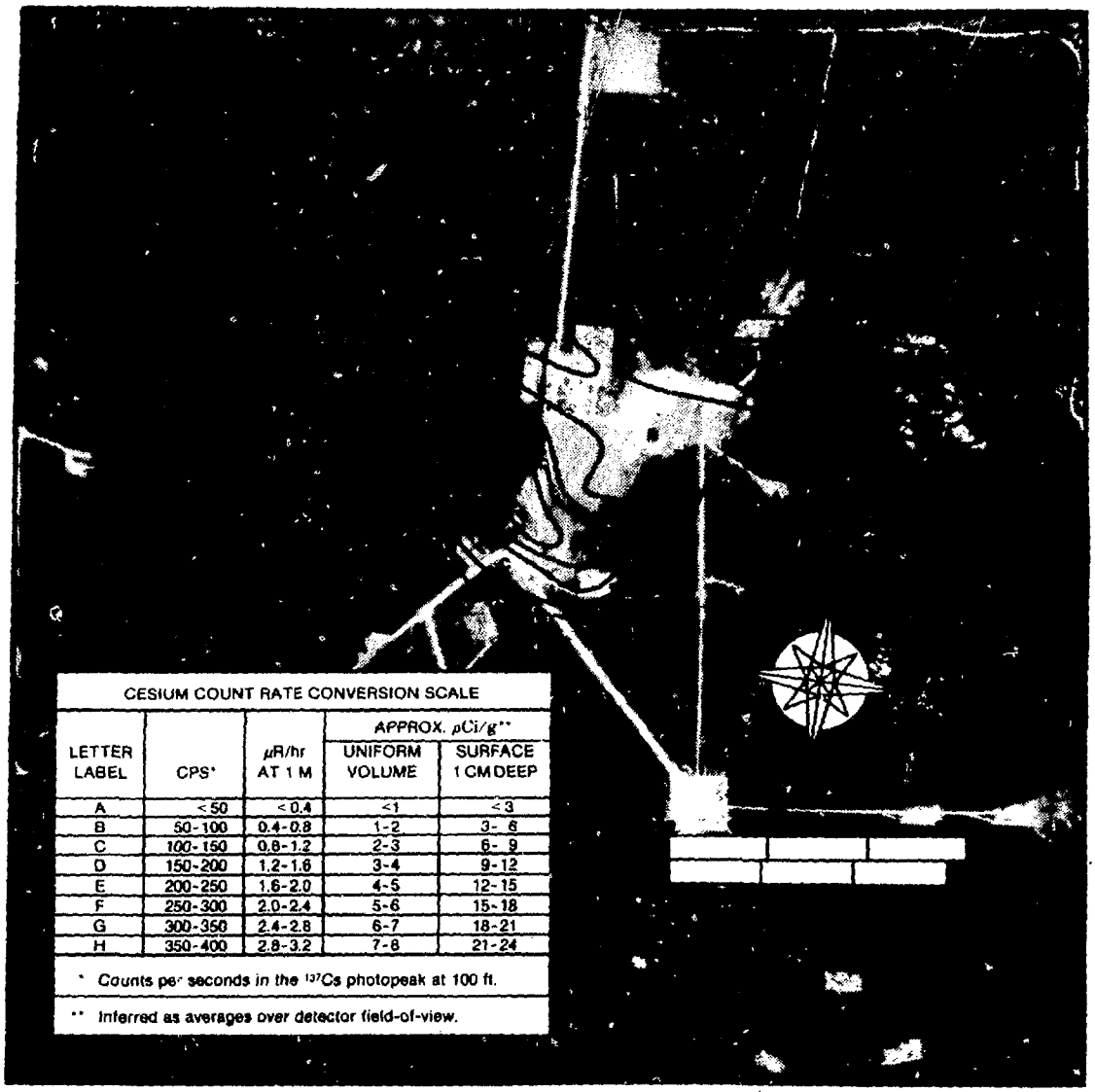



Fig. 8.13. Cesium-137 concentration isopleths in 1977 at the GNOME Site.



CESIUM COUNT RATE CONVERSION SCALE

| LETTER LABEL | CPS* | μR/hr AT 1 M | APPROX. pCi/g** UNIFORM VOLUME | APPROX. pCi/g** SURFACE 1 CM DEEP |
|---|---|---|---|---|
| A | < 50 | < 0.4 | <1 | < 3 |
| B | 50-100 | 0.4-0.8 | 1-2 | 3- 6 |
| C | 100-150 | 0.8-1.2 | 2-3 | 6- 9 |
| D | 150-200 | 1.2-1.6 | 3-4 | 9-12 |
| E | 200-250 | 1.6-2.0 | 4-5 | 12-15 |
| F | 250-300 | 2.0-2.4 | 5-6 | 15-18 |
| G | 300-350 | 2.4-2.8 | 6-7 | 18-21 |
| H | 350-400 | 2.8-3.2 | 7-8 | 21-24 |

* Counts per seconds in the $^{137}Cs$ photopeak at 100 ft.

** Inferred as averages over detector field-of-view.

Fig. 8.14. Cesium-137 concentration isopleths in 1979 at the GNOME Site.

underway. Enewetak had been surveyed by the EG&G AMS team first in 1972 for the Enewetak evaluation program and again in 1977 just prior to the cleanup project.

The cleanup project relied heavily on the instrumented ground vehicle, the IMP, described previously. Figure 8.15 maps an area called Kickapoo (from the nuclear test of that name) on island Aoman that was defined from IMP and soil-sample data as contaminated with transuranics ($^{238}Pu$, $^{239}Pu$, $^{241}Am$). This is a copy of the original map produced during the operational cleanup at the Kickapoo site. The area to the right of the dashed line contains concentrations greater than 40 pCi/g and the other smooth line defines concentrations greater than 100 pCi/g of transuranics. the soil containing transuranics greater than 40 pCi/g had to be removed.

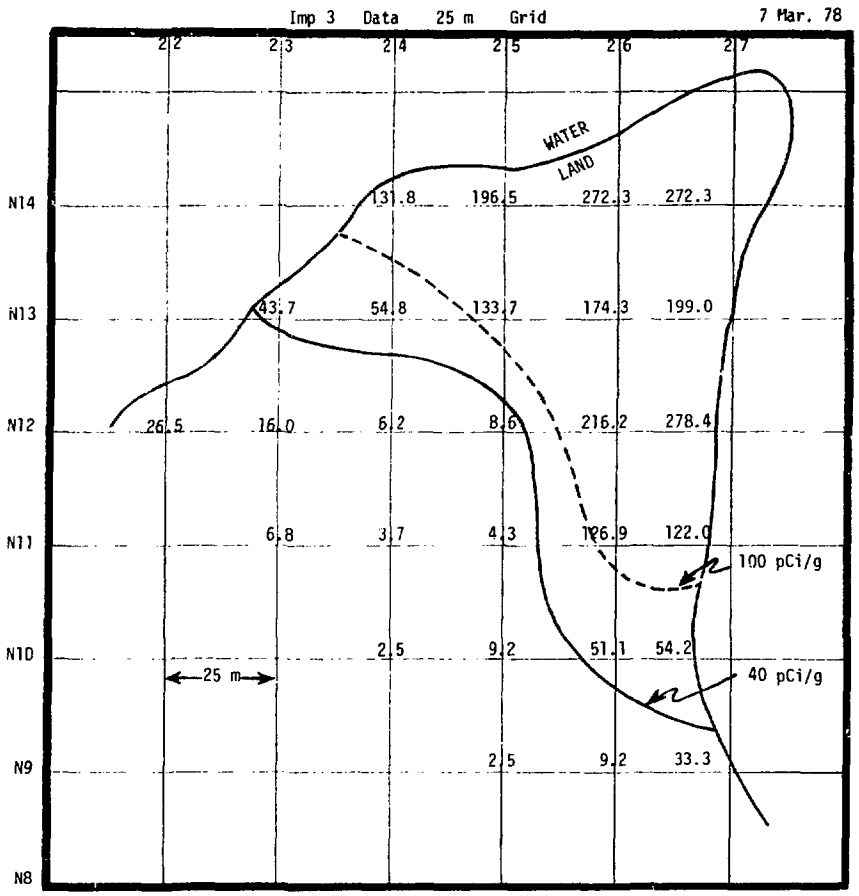



Fig. 8.15. Contamination at Kickapoo Site, Aoman Island. All numbers are crude estimates using a uniform ratio of 6:16.

### Other Gamma Surveys

Aerial gamma surveys are also performed on a continuing basis at sites where radioactive materials are routinely handled, processed, and stored. These include the Beatty, Nevada and Maxi Flats, Kentucky waste dumps, and DOE contractor sites at ORNL, Hanford and Savannah River.

Perhaps the most dramatic efforts in gamma surveys were the search for the Russian Cosmos satellite and the Three Mile Island accident. The man-made gross count method played a leading role in finding the radioactive debris from the Cosmos reactor near and on Great Slave Lake. Barium-140 and lanthanum-140 were the primary identifiers of this debris. At Three Mile Island, the Andrews AFB branch of the EG&G Remote Sensing Laboratory arrived with the H-500 helicopter only hours after a call for aid from DOE (Fig. 8.16). On the day of arrival, EG&G was able to track the plume of xenon and krypton and report its location to the Nuclear Regulatory Commission and the Department of Energy.

## CONCLUSION

The Remote Sensing Laboratory, operated by EG&G for the Department of Energy, is prepared to aid in the decontamination process. For many years EG&G has constructed and operated specialized gamma-sensing equipment for the evaluation of radioactive contamination. Many gamma surveys from both aerial and ground vehicles have helped find, identify, and quantify radioactive contamination. Gamma survey data overlaid on EG&G's

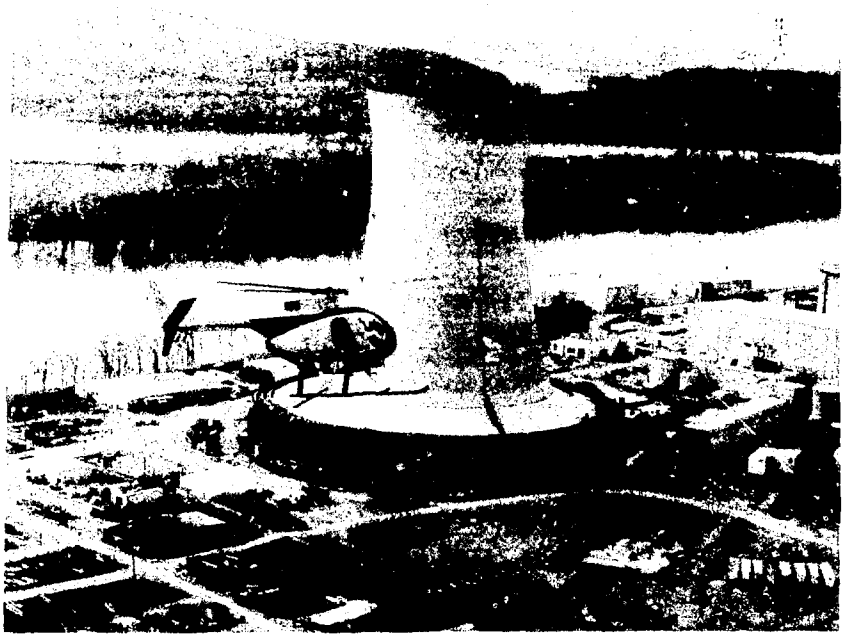


Fig. 8.16. The H-500 gamma-survey aircraft at Three Mile Island.

aerial photographs indicate the location of contamination with a high degree of accuracy. The recent addition of aerial multispectral scanning extends our capability to the determination of environmental effects.

EG&G is prepared also to deploy people and equipment quickly for the rapid assessment of nuclear and non-nuclear accidents and spills. Experienced personnel as well as sensing, photographic, and mobile communications gear are available to DOE within hours of a call.

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Chester: Thank you. Not many peole know that a major contribution made by EG&G at Three Mile Island was in communications. They have a fabulous portable communications system that is used in conjunction with NEST operations, and they flew that in. For a long time that constituted about 99% of the communications that were available to federal officials and emergency people at Three Mile Island.

# 9. LABORATORY-FIELD EXPERIENCE

Nels R. Johnson
Eberline Instrument Corporation
Las Vegas, Nevada

I'd like to speak today for a few minutes about Eberline's participation in decontamination projects and then describe a few problems we've encountered and our solutions to these problems.

Over a 30-year period Eberline has established a reputation for radiation protection services and instrumentation. The production of instruments began in 1952, and Eberline has provided radiochemistry, dosimetry, and environmental monitoring services since 1960.

## OPERATION ROLLER COASTER

In 1963 and 1964, Eberline participated in Operation Roller Coaster, administered by the Defense Atomic Support Agency. This operation involved non-nuclear detonations of nuclear weapons. Primarily, about 50 trained monitors were fielded in support of contamination surveys. Several unique devices were built to improve the speed and thoroughness of monitoring for plutonium over large land areas. A second objective was the determination of the scavenging effect of different materials on plutonium.

Following this field support, Eberline analyzed over 4500 samples of soil, vegetation, and structural material plus a variety of organs, tissue, and bones of exposed animals. Our laboratories developed a new procedure for analysis of plutonium in environmental media which was accepted in national laboratories at AEC installations.

## NTS OFF-SITE RADIOLOGICAL MONITORING

In February of 1967, the Nevada Operations Office of the U.S. Atomic Energy Commission awarded Eberline a contract to provide radiological monitoring services, medical services, and special studies required to support nuclear detonations at locations other than the Nevada Test Site. Events in which we participated included underground gas stimulation projects Rio Blanco and Rulison in Colorado and Gastuggy in New Mexico. Weapons testing programs included Faultless in Central Nevada and Milrow and Cannikin in Amchitka, Alaska. A unique feature of this support was that all services were available essentially on an as-needed basis. A small professional staff developed plans, cost estimates, operational procedures, and equipment requirements. Due to the requirement for mobility, all equipment was designed for compatibility with trailer-mounted facilities.

Eberline analyzed environmental samples and prepared the radiation contamination clearance reports for Amchitka, Rio Blanco, Rulison and Gasbuggy. The clearance report for Amchitka required only site-condition documentation; no cleanup activities were required. Clearance reports of Rulison, Rio Blanco and Gasbuggy all required extensive site monitoring and decontamination.

All cleanup activities were supported by an on-site mobile laboratory and counting capabilities. Routine analysis consisted of samples of soil, sludge, and water for tritium and cesium-137. Other analyses for plutonium and strontium were provided by permanent laboratories in Albuquerque and West Chicago.

## ROCKY FLATS

Between 1976 and 1978, Eberline collected and analyzed soil samples from the area surrounding DOE's Rocky Flats plant. Litigation proceedings by landowners in the vicinity of Rocky Flats required three concurrent sampling methods as defined by the local county, the Colorado Department of Health, and Rockwell.

This project was applicable to future decontamination efforts because of the requirement for security of the samples. Because of

possible future litigation by plaintiffs who believe they have been injured by contaminated land areas, it is imperative that all parties agree that the samples analyzed accurately reflect environmental conditions.

At Rocky Flats, sample locations were selected by a professional survey crew. Each location remained in view by either the survey or sampling crew until all samples were collected. Once collected, samples were placed within double containers, each incorporating a seal that would indicate tampering, and stored in a locked storage area or bonded warehouse. After delivery to the lab, individual samples were renumbered by an independent party with random numbers generated by a local computer.

## ENEWETAK

In the spring of 1977, the Nevada Operations Office of the Department of Energy contracted with Eberline to design, install and man a low-level radiological lab on Enewetak Atoll, Marshall Islands. Primarily, this lab was to be capable of detecting americium and plutonium in coral at concentrations of less than 1 pCi/g. Other analytical capabilities were to provide gamma analyses, air filter, nose swipe, and special analyses on a request basis. Responsibilities also included supervision of sampling and instrument maintenance.

Within about four months of the date the contract was awarded, the facility was designed and all the materials and equipment were purchased, shipped by sea and air, and installed on Enewetak. The complex included: (1) a sample-preparation trailer, (2) a chemistry trailer capable of isolating plutonium, americium, and strontium, (3) a counting trailer housing two intrinsic germanium detectors, four alpha spectrometry detectors, two Nuclear Data ND-600 analyzers, a Hewlitt-Packard HP-9831 minicomputer with disc drive and printer, a Beckman liquid scintillation counter, a Canberra low-beta gas proportional counter, and miscellaneous Eberline large-area gross alpha and beta counting equipment. There was also (4) an equipment maintenance trailer for calibration and repair of approximately 30 field-instrument packs with interchangeable probes.

From June 1977 to August 1979, Eberline stationed a minimum of four persons on Enewetak to supervise about 12 military personnel.

## URANIUM RESOURCE ORGANIZATIONS

Unrelated to our government contracts, Eberline has provided consulting, field sampling, and laboratory services to more than 30 uranium resource organizations. Our lab in Albuquerque specializes in the determination of uranium and its progeny in all types of environmental media. Eberline has many years of experience in measuring radon and its progeny in mines, effluents from mills, and in the environment. In 1970, our labs adopted the technique of using large scintillation cells to analyze samples for radon and radium.

Our consulting experience includes the preparation of mill licenses and environmental reports, training technicians, and working with other various regulatory agencies. To assist in the evaluation of environmental impacts from mill operation, several computer programs, including UDAD, have been used; the application of MILLDOSE is anticipated as soon as it is released. In-house support of these activities is provided by our own TLD commercial dosimetry service, bioassay capabilities, and instrument design.

In support of Argonne National Laboratory's preparation of the generic environmental impact statement on uranium mining and milling, Eberline designed and manufactured the only real-time radon and progeny in-air measuring device that is currently available. This instrument is currently being redesigned to operate either from AC or battery power, to make it more portable.

## NUCLEAR POWER STATIONS

Eberline provides laboratory or dosimetry services to about half of all U.S. commercial

nuclear power plants. In addition to routine support, other special studies have been performed. For example, there is currently a three-year program with Commonwealth Edison Co. to monitor off-site for gaseous effluence from their nuclear power stations. To determine whether thermoluminescent dosimeters are capable of detecting the extremely slight off-site variation in radiation levels due to normal plant operations, the program compares plant release data, meteorlogical parameters, pressurized ion-chamber readings, and quarterly TLD exchange results.

## EQUIPMENT DECONTAMINATION

The previous summary indicates the degree and scope of our pertinent experience. Next I will discuss specific procedures, events and problems associated with our most recent site cleanup activities.

At Rulison and Gasbuggy, Eberline applied steam-cleaning as the only method of decontamination. Tritium was the only isotope of concern. A large metal pan was fabricated on a graded slope adjacent to the steam generator. Controlled areas were established. A log of 551 items ranging from nuts and bolts to separators were cleaned, checked, and released by this method. Most of the contaminated water and fluid generated from cleanup activity was injected back into the cavity prior to final plugging of the reentry well. These fluids were injected through a perforation-free pipe to a depth of 4000 to 6000 feet.

Once reentry wells were plugged, any subsequent tritiated fluids were evaporated to the atmosphere. At Rio Blanco, approximately one millicurie of tritium was disposed of by evaporation. Analysis of air moisture, soil, and vegetation during and after the evaporation indicated that no detectable contamination had occurred.

Experience at similar sites had shown that cleared items may become recontaminated following a 12- to 24-hr delay after cleaning. Tritium which had previously migrated into the metal matrix under high temperatures and pressure was found to migrate back out to the surface. Selected items were checked as long as one week after the initial cleaning to confirm that the recontaminating phenomenon was not occurring.

At Rio Blanco, an in situ system was designed to facilitate internal cleaning of equipment and piping. Steam-cleaning facilities were also available for items not connected to the in situ system. This sytem was designed to circulate a de-tarring solution for removing oily sludge and residue, followed by an oxalic acid solution to scour the interior metal surfaces. Tritium and cesium-137 were routinely monitored to check the status of cleaning operations. Particulates picked up by the cleaning process were removed from the solution flowing through a desilter, sand filter, and cartridge filter. Certain areas were resistant to cleaning. Due to low flow rates out of the hydrocarbon tanks, a film residue remained on the interior of the walls; this required steam cleaning to remove. In areas where significant sludge buildup was found, the in situ system would have required extensive de-tar circulation. In these areas components were opened, scraped out, and steam-cleaned. A foaming problem was encountered when circulating de-tar or acid solutions. A commercial antifoam emulsion was found to be successful in defoaming the de-tar solution. The pH appeared to be critical in controlling the foaming of acid solution and the amount of cesium held in solution. As the acid circulated, the solution was neutralized, causing heavy foam and a drop in cesium concentration. The use of large quantities of acid was successful in maintaining correct pH.

Predefined criteria required three tests prior to the radiological release of contaminated components: a distilled water test, swipes, and a contact beta-survey reading through a 7 mg/cm$^2$ window. In practice, the distilled water test was the most restrictive

criterion, and the contact-beta survey was the least restrictive.

Eberline also conducted a decontamination effort for the U.S. Public Health Service in 1967 which may be directly applicable to future projects. This effort entailed a radiological survey of 15 aircraft instrument facilities contaminated with radium and its progeny. Dial-stripping operations in these facilities resulted in alpha contamination levels exceeding $10^5$ dpm/100 $cm^2$ in many areas, with the maximum being 1.6 x $10^6$ dpm/100 $cm^2$. The two employees of the facility with the highest level of contamination had body burdens in excess of 40% of the maximum permissible body burden for radium. Gamma radiation levels above 2 mR/hr were frequently found in storage areas, with the maximum being 13 mR/hr at 1 foot.

Decontamination of one aircraft instrument repair facility was conducted to evaluate decontamination methods for floors, benches, and equipment. The final survey of the facility indicated alpha contamination levels generally below 2500 dpm/100 $cm^2$ fixed and 30 dpm/100 $cm^2$ removable.

## MEDIA SAMPLING

After all decontaminated equipment has been removed from a particular area, environmental samples of the site are collected and analyzed. An important aspect of this phase of the decommissioning project is the review of records and reports to quantify the suspect radionuclides.

Once this review has been completed, a sampling program can be logically defined. Generally, our recommendation is to require a close sampling grid over known spill areas, a less restrictive grid over working areas, and a widely spaced grid over the entire site.

The critical sampling medium for decommissioning activities has been soil. However, since there were no specific regulations or even accepted guidelines for action levels of contaminated soil, each project was addressed on a case-by-case basis. In actuality, criteria were usually defined during early planning stages of the project and sometimes revised once field data became available.

As an example, the action level for tritium in soil moisture at Rio Blanco was 30,000 pCi/ml. Of the 482 samples collected in support of cleanup activity, only nine had concentrations greater than 1% of the criteria and only 78 had greater than 0.1%. Consequently, in keeping with an ALARA philosophy, any area with relatively significant contamination was excised, barreled, and shipped for disposal.

A similar situation occurred during the circulation of cleaning fluids in the in situ decontamination system. Previously defined release criteria required only fluids contaminated with radioactivity greater than 10% of concentration values listed in DOE Appendix 0524 to be disposed of by approved methods. As the cleanup program progressed, it became apparent that fluid concentrations were considerably below this criterion. Therefore, again in agreement with ALARA philosophy, the requirement was made that all contained liquids with detectable radioactivity were to be disposed of by approved methods and not released to the general environment.

Coral sampling efforts on Enewetak were directed toward three distinct goals: (1) to establish the plutonium-to-americium ratio, (2) to support the in situ van measurements of the americium-241 concentrations, and (3) to provide profile information of selected areas.

In situ van measurements required a calibration factor determined by wet chemistry techniques. To achieve statistical accuracy a well-defined sampling program was developed, consisting of multiple-surface composites.

Known or suspected burial areas required subsurface investigation. Originally, the use of sand augers was contemplated. However, trenching and side-wall sampling proved to be the preferred method. A backhoe was usually required to facilitate trenching. Deep burial areas encountered at the Aomon Crypt required the development of an underwater sampling tool.

As the Enewetak project neared the three-quarters stage of completion, evidence from Bikini Atoll indicated that subsurface concentrations of cesium and strontium could be hazardous to man through the terrestrial food pathway. In response, an additional eight employees were deployed within a 30-day period. Two sampling teams were formed and stationed in forward areas: one on Lojwa Atoll and one on the DOE-chartered support ship Liktaner II. Over a period of about 10 weeks these crews collected approximately 10,000 profile samples. To analyze this influx of samples, the lab on Enewetak was placed on a 24-hour schedule for approximately four months, using three intrinsic germanium counting systems. Representative samples were analyzed for strontium-90 by Eberline's Albuquerque laboratory.

Several problems were encountered during the Enewetak project, one of which was a typhoon which disabled the lab for about a week. Another problem was the lack of availability of qualified personnel to staff a remote facility. Rotating key personnel from our facilities in Santa Fe, Albuquerque, and Columbia, S.C., caused a discontinuity in supervision. To eliminate this problem, new employees were assigned on a voluntary basis to permanent positions on Enewetak--one individual for as long as 18 months.

An equally difficult problem was how to support a remote facility logistically. Air-mail requests and deliveries from the Albuquerque office often took 10 to 14 days each way. Surface transport required for plutonium and certain hazardous chemicals obviously took much longer. These long delivery times required an extensive warehouse of spare parts and backup equipment.

One problem was inter-island transportation provided by the military contingent. This usually meant boat transportation. Under design conditions, a sampling mission usually consisted of five hours of boat travel time to about four hours of actual productive work. Under actual conditions, communications and equipment failures often delayed missions for several days.

## DATA RETENTION

To provide for data retention a three-phase program was developed. All analytical data from the ND-600 and HP-9831, including collection data and system calibration parameters, were retained on hardcopy printout and magnetic tape. Electroplated discs, the result of wet-chemistry plutonium and americium analyses, were also retained. Thirdly, approximately 12,000 samples which defined the condition of the island upon completion of the project were archived and returned for storage at Nevada Test Site. This archiving program required the initiation of a sterilization process and the receipt of an import customs license from the Department of Agriculture.

A common misconception is that field facilities do not provide the accuracy required for the low levels of contamination encountered. Our field laboratories operate under the same quality-assurance programs prepared consistent with 10CFR50 and ANSI 45.2 which govern our permanent laboratories and dosimetry service. Indirectly, through our intra-laboratory inter-comparison program, our laboratories also participate in Environmental Protection Agency's cross-check program, Environment Measurements Laboratory's quality assessment program, and other QA inter-comparisons with National Bureau of Standards and International Atomic Energy Agency.

As you can see, our approach to support cleanup activities is by the installation of an on-site facility. It is our opinion that the capability to provide real-time measurements is invaluable to the radiological safety of workers and to effective time usage of cleanup efforts.

# 10. SITE DECONTAMINATION

Arden E. Bicker
Reynolds Electrical & Engineering Co., Inc.
Las Vegas, Nevada

Among the several DOE sites that have been radiologically decontaminated under the auspices of the Nevada Operations Office are three whose physical characteristics are unique. These are the Tatum Dome Test Site (TDTS) near Hattiesburg, Mississippi; a location of mountainous terrain (Pahute Mesa) on the Nevada Test Site; and the GNOME site near Carlsbad, New Mexico. In each case the contamination, the terrain, and the climate conditions were different.

This presentation will include a brief description of each site, the methods used to perform radiological surveys, the logistics required to support the decontamination (including health physics and sample analysis), and the specific techniques used to reduce or remove the contamination.

## TATUM DOME SITE

The Tatum Dome site is located near Hattiesburg, Mississippi, in an area of dense timber, flowing creeks, and permanent swamps. Nuclear devices were detonated in an underlying salt dome as part of the Vela Uniform program for improving detection methods. The nuclear tests took place in 1964 and 1966. Subsequent use included tests using explosive gases in the existing cavity. In 1970 a pre-cleanup survey was performed, and in 1971 operations to decontaminate and decommission the site were initiated (Fig. 10.1).

The pre-cleanup survey design was based on prior knowledge of the site as gleaned from participants and from review of existing documents. The design was severely limited because sufficient funding was not available. Various sample types were collected, e.g., water, soil, vegetation, animal, and surface swipes. Readings were taken from portable instruments to assist in identifying areas and items of concern.

Soil sampling techniques determined the grid sizes used; they varied according to the size of the particular area to be sampled, known history of the area, and portable instrument readings. In a typical area such as the Decontamination Pad, pre-cleanup samples were obtained using 4-inch-diameter holes drilled on a transect of 20 feet at 2-foot intervals. All soil was collected down to a 4-foot depth, homogenized, aliquoted (500 grams), and sent to the NTS for analysis. Duplicate aliquots were bagged, labeled, and stored at the TDTS for future, more detailed analysis if required. In some cases, sets of 10 aliquots were mixed, and a single sample was further aliquoted from these for analysis.

Pre-cleanup samples were obtained in the ground-zero area using a trenching technique. A soil sample from a 12-inch square was collected at each interval to a depth of 4 feet. Sampling continued to greater depths so long as positive readings (greater than background) were obtained using a portable scintillator radiation detector. One-half of each sample was mixed and homogenized with half-samples of the others over the total depth. This mixture was aliquoted and analyzed as a single sample. The other one-half of each layer sample was bagged, labeled (not mixed), and stored for future use if required.

Soil samples were obtained from remote, nonactivity areas whose history indicated little potential for contamination, using a 1000-foot grid system supplemented by random samples. These samples consisted of surface soil approximately 6 inches square and 1 inch deep. Core samples were obtained using a 4-inch diameter core tool to sample depths to 4 feet (Fig. 10.2). A one-pint aliquot was obtained from each core for analysis.

The soil samples collected by the above methods were analyzed for tritium, strontium-90,

Fig. 10.1 Tatum Dome ground-zero area during decontamination operation.

plutonium-239, and gamma emitters at the NTS laboratory. Based upon these sample results, portable instrument readings, etc., a composite picture of the test site was built and used as a guide for planning the cleanup operations. Antimony-125 was determined to be the limiting isotope. It was estimated that 1400 cubic yards of soil would have to be removed. In fact, 11,000 cubic yards were eventually excavated. Experience gained during the cleanup demonstrated conclusively the need for and value of much more extensive sampling efforts during the planning stage of any such large-scale land decontamination program. As a result of the limited nature of TDTS pre-cleanup sampling effort, the extent of the problems actually encountered were greatly underestimated. This resulted in increased costs, and more time was expended than had been planned originally.

Water samples were collected from all sources which were suspected of being contaminated; analysis was the same as that for soil. Originally, it was estimated that it would be necessary to dispose of 77,000 gallons of liquid; however, 1,300,000 gallons were actually handled during the cleanup.

Vegetation and animal sampling were conducted both on- and off-site. samples consisted of both terrestrial and aquatic biota, including animals used by humans for food in the local

Fig. 10.2 Tatum Dome site soil-sampling operation.

area: rabbits, squirrels, and quail. Analyses indicated the presence of $^{125}Sb$ in four species of vegetation; however, the levels reported were less than those for cleanup criteria for soil and, in all probability, the activity measured was surface contamination.

Additional samples of garden produce (turnips, radishes, rutabagas, mustard greens, and onions), chickens, eggs, pecans, and white-tailed deer from areas on the periphery of the site were collected and analyzed. No movement of $^{125}Sb$ from the site area was revealed by these analyses. Other radioisotopic levels reported in these samples were commensurate with world-wide fallout data.

A total of 13,000 surface swipes was taken prior to and during the cleanup. Both wet and dry swipes were obtained. Dry swipes consisted of 2-inch-diameter, Whatman #41 filter paper physically rubbed over 100 $cm^2$ of surface. Wet swipes consisted of water-soaked nasal swabs likewise rubbed over 100 $cm^2$ of surface to obtain a transfer of $^{3}H$ should any be present. Swipe samples were counted for beta-gamma using a proportional counter for filter-paper samples and a liquid scintillation spectrometer for $^{3}H$ transferred to counting vials from the wet swipes.

When the actual cleanup operation began in May 1971, a crew consisting of five radiation monitors, one laboratory technician, one instrument technician, and one supervisor was sent to the TDTS. In addition, backup support was provided as needed at the NTS, utilizing the services of laboratory, technical, and administrative personnel.

Nearly all samples collected at the TDTS were analyzed on-site, using the facilities in the two mobile laboratory trailers. Therefore, data were immediately available for interpretation and use in determining the radiological status of the TDTS during cleanup operations. Some samples requiring alpha analysis were sent to the NTS where the required sensitivity could be obtained.

To assure the continuing reliability of the on-site radiological measurements, a quality control program was maintained whereby selected samples were counted on-site and in the NTS laboratory. Intercomparisons of sample-counting data as well as continuing preparation of standards for field use proved to be invaluable in maintaining data reliability.

Full health physics support for all site workers was provided. External and internal dosimetry was done in accordance with NTS

procedures. Air sampling was accomplished at work locations. Adequate supplies of anti-contamination clothing and respiratory equipment were maintained.

Personnel decontamination capability was provided by the use of outdoor sinks and showers. Only minor cases of skin contamination were encountered during cleanup, and decontamination was easily and quickly accomplished using soap and water. Decontamination of protective clothing and gear was performed on-site, using the project laundry equipment. Industrial hygiene services were also provided.

The criteria for decontamination used at Tatum Dome were as follows: (1) surface waters in excess of 0.1 times the concentration values in AEC Manual Chapter Appendix 0524 were to go into the explosion cavity; (2) soil to the depth of four feet was to be excavated for disposition into the cavity when exceeding $10^{-3}$ $\mu$Ci/g for tritium, $10^{-5}$ $\mu$Ci/g for beta-gamma decay modes, and $10^{-6}$ $\mu$Ci/g for alpha decay modes; (3) soil containing residual beta-gamma radiation levels exceeding 0.2 mrad/hr above background (including fallout), measured at 1 cm through not more than 7 mg/cm$^2$ absorber, was to be excavated and disposed of in the same manner; (4) for buildings, equipment, and other hard surfaces, residual radioactive contamination remaining after cleanup operations were not to exceed 1000 dis/min/100 cm$^2$ or 0.4 mrad/hr at 1 cm from the surface.

Contaminated soil and water were poured through a drill pipe into the salt dome cavity. Excavation was accomplished with front-end loaders, clamshells, backhoes, and draglines. The material was hauled to the disposal facility. There was some difficulty with the soil disposal because of the debris it contained and the heavy clay texture. Hand chipping of large clay lumps was followed by manual removal of debris too large for the 9-5/8 inch casing. These procedures added significantly to the costs and increased the amount of health physics support needed.

During the cleanup, extensive soil sampling was required to further delineate the contamination. Grids were established, staked, and coded, providing sample locations every few feet, depending upon the area. Surface samples consisted of soil to an average depth of one inch for a total volume per sample of approximately one pint. Core samples were collected, using a coring tool having a cylindrical volume of 3 x 8 inches, from which a volume of one pint was extracted. Samples were collected at 6-inch intervals to a depth of 4 feet. However, the sampling depth was extended up to 9 feet in some areas. In those areas requiring repetitive resampling and excavation, soil samples were obtained in some cases on an empirical basis where localization of the extent of the contamination obviated the use of a formal grid system. However, grids were used in nearly all cases.

As cleanup activities proceeded, it became necessary to excavate some areas up to five or six times in order to comply with the criteria. This was caused by the inadvertent redistribution of contamination by the excavation equipment into previously cleaned areas. In such cases, new sampling grids were empirically determined and resampling was accomplished.

All hardware, materials, and equipment which had been surveyed, swiped, or otherwise determined by radiological measurements as being contaminated to a level requiring packaging were concentrated in a fenced area designated as the "Preparation Area."

Preparation of such materials involved removal of rust, scale, and other residues or loose material. Items such as drill pipe, subject to further oxidation and scaling or rusting, were plugged and painted. Large, bulky items were prepared by plugging all openings to seal any internal contamination. The ends of all pipes were sealed with plastic caps, covered with polyethylene, and taped to prevent any rust or scale from escaping. Some small-diameter pipes were placed inside larger pipes, and the ends were sealed by welding steel plates over them. Flanged-end pipes were sealed by bolting on wooden-blind flanges.

Smaller items were placed into strong, tight, wooden crates lined with a thick polyethylene liner. This liner was sealed with

waterproof tape after the box was filled, to prevent leakage of radioactive material and leakage of rainwater into the package under conditions normally incident to transportation.

A local trucking firm was contracted to transport the contaminated waste from the site to a railhead in Lumberton, Mississippi, and load it onto a special train.

During loading at the railhead, it was found that some of the boxes were leaking water. This water resulted from the extensive rainfall during the weeks that the material had been stored in the holding area. Swipe samples were taken from the leaking boxes, and some were found to be greater than 1000 dis/min. As a result, all boxes were thoroughly resurveyed, swiped, and repackaged as necessary to assure compliance with AEC and DOT guidelines. Upon completion of loading onto the train, DOT placards were affixed to all four sides of each rail car.

Upon leaving Lumberton, Mississippi, the special train was accompanied by supervisory and monitoring personnel.

A remote, fenced area on the Nellis Air Force Base in Las Vegas was utilized for unloading the train. A small counting facility was established at Nellis to evaluate swipe samples during unloading operations. Upon surveying the train during unloading, a flatcar was found to be contaminated. Upon investigation, the source of this contamination was determined to be a small reservoir tank on the rear of a tank trailer. Apparently a mounting bracket had rusted through, and vibration during transport wore a hole in the reservoir--allowing a small amount of contaminated liquid to spill onto the railway car. This contamination was completely removed by replacing the affected wooden planking of the car. The entire train was thoroughly surveyed and swipe samples obtained prior to its release. No other contamination was detected.

Upon completion of unloading operations, the waste was transported by truck to the NTS. The shipment was finally terminated upon burial at an authorized contaminated waste management site.

## PAHUTE MESA

On May 16, 1976, a spill of radioactively contaminated mud occurred at a postshot drilling site on Pahute Mesa at the NTS.* Dose rates at contact varied from 5 to 200 mrad/hr. The cleanup criterion was 1 mrad/hr at contact, which was the background level in the general vicinity.

The areas contaminated during postshot drilling at U20aa were the drill pad, a fan-shaped area immediately northeast of the drill pad, a flat area northeast of the fan-shaped area, and part of a canyon northeast of the flat area. The contaminated mud flow was approximately 2495 ft long with variable width from about 197 ft on the drill pad and fan-shaped area to less than 3 ft at several canyon locations. It should be noted that occasionally the mud sump, and normally a portion of the drill pad and the area immediately beneath the drill rig, are contaminated during the sampling phase of postshot drilling. Therefore, radiological cleanup in these locations is standard operating procedure.

Samples of radioactive mud were analyzed by gamma spectroscopy. It was determined through peak identification and half-life determination that the only resolvable radionuclides present were ruthenium-103 and ruthenium-106/rhodium-106. At the time of release, about 86% of the activity was due to $^{103}Ru$ and 14% due to $^{106}Ru/^{106}Rh$. The mud was also analyzed for its solubility in water at about 80°F, and was found to be relatively insoluble.

Shortly after the spill, caution signs were placed encircling the contaminated area. Prior

*The activities discussed here have been described in detail by T. Straume, C. R. Kellner, and K. M. Oswald in "Radioactive Decontamination Methods and Their Effectiveness as a Function of Terrain," Health Physics Journal 35, pp. 309-313 (1978).

to commencing cleanup operations, a control station was set up at the main access road. The station was manned with at least one technician who controlled all individuals and equipment entering or leaving the contaminated area by logging in/out, issuing pocket dosimeters and experimental film badges, monitoring for contamination of exiting personnel or equipment, and ensuring that proper dress procedures for anti-contamination clothing were followed. Contamination monitoring of personnel leaving the exclusion area was accomplished with a portal monitor. Air sampling was initiated prior to cleanup, and experiments were conducted to determine resuspension during equipment operation. Respiratory protection was not required. Dosimetry was accomplished by using the standard NTS film dosimeter for whole-body and skin exposures and thermoluminescent dosimeters (TLDs) for extremity measurements.

On June 14, 1976, an earthen dam was constructed in the canyon approximately 50 feet downstream from the termination of the contaminated mud-flow to prevent further movement of the mud should heavy rainstorms occur. The dam is about 165 ft long, 16 ft deep, and 26 ft wide at the top; it was to retain a collection and settling pond for the contaminated mud should it be dislocated due to rains. A spillway was constructed to prevent the dam from washing out and was thought to be justified by the mud's slow water solubility. Earth hardener was applied overall, and Cal-Seal cement was put on the spillway to prevent water erosion. The dam was completed prior to any significant precipitation in the area.

Cleanup operations began on July 12, 1976, using front-end loaders, road scrapers, dump trucks, water trucks with hose, a 13-$yd^3$ vacuum cleaner, shovels, and bags. Decontamination of the flat area downstream of the drill pad (Area 3) was first accomplished, and the light-colored drill mud was hauled to the subsidence crater for burial in a prepared location. The prepared area was about 165 x 165 ft and was located in the deepest part of the crater, approximately 46 ft below surface ground level.

The cleanup operation proceeded to the canyon, which is an area of rough terrain with large boulders and a stream bed. Farther down the canyon there was an area of relatively level ground with several large pine trees.

After the canyon was decontaminated to practicable levels, cleanup operations were moved to the fan-shaped area (Area 2) and the drill pad (Area 1). The contaminated mud was thickest immediately below the drill pad, where it reached a depth of 13 inches. The drill was scraped, and the contaminated mud was hauled to the crater disposal area.

The final cleanup phase consisted of decontaminating all roads inside the radiation exclusion area, decontaminating all vehicles and equipment used in cleanup operations, and covering all locations where decontamination to less than 1 mrad/hr at contact was impractical or impossible with adequate amounts of clean dirt. Both the mud sump and crater burial site were covered with enough clean dirt to give a dose at contact of less than 1 mrad/hr. Prior to departing the area, fences and signs indicating buried contaminated material were placed around the drill-hole cellar, mud sump and crater burial site. Approximately 900 man-days were expended and 2584 $yd^3$ of mud were removed. It is estimated that 900 mCi remained six months after the spill.

In level areas of considerable size, front-end loading was by far the most efficient method. However, considerable time and money can be saved if highly skilled operators are used who are familiar with radioactive decontamination procedures. In one area, considerable time was lost because the operator recontaminated areas that had been previously cleaned, dropping contaminated mud during truck-loading and driving the front-end loader over the contaminated area unnecessarily.

Front-end loading is also the method of choice in locations where the contaminant has seeped through the soil more than one or two inches. Deep penetration of contaminated mud was also found underneath and along the sides of large boulders. The mud had seeped alongside

and down the rock/dirt interface. The contaminated boulders and dirt were removed insofar as practicable, using front-end loaders and dump trucks. Decontamination factors (DFs) of approximately 10 were achieved in this area.

A vacuum cleaner was placed on the bed of a dump truck that had a maximum capacity of 13 $yd^3$ (Fig. 10.3). The contaminated mud could be removed from the vacuum cleaner through normal dumping of the truck bed. It was highly effective in flat areas of relatively hard ground where significant soaking or seepage had not occurred. In such locations, the contaminated mud was picked up with DFs of approximately 300. Due to the small chance of spreading contamination while using the vacuum cleaner, it does not require an experienced operator. The major negative aspect of vacuuming is that it is relatively slow compared to front-end loading.

In relatively small areas that are inaccessible to large equipment, such as front-end loaders or trucks, the contaminated mud was shoveled into bags and carried to a nearby truck for disposal.

The effectiveness of shoveling was shown to be greatly dependent upon the porosity of soil and whether large, partially subsurface boulders were present. In locations where the ground was fine-grained or soil-like, the contaminated mud had not penetrated to more than an inch or two of the surface, making shoveling a good method of choice and yielding DFs of approximately 100. However, if the grain was coarse or when large partially subsurface boulders were present, the contaminated mud was found at depths exceeding four feet. The gravel-like ground had allowed contaminated mud and water to penetrate and the large boulders allowed seepage along the rock/-soil interfaces. In such locations, the volume of contaminated ground was so large that removal of radioactivity to an acceptable level by shoveling and bagging was impractical.

Experience has shown that care should be taken not to recontaminate previously cleaned areas during shoveling operations. Personnel involved should be instructed concerning necessary precautions required to minimize recontamination.

In rocky canyon locations where digging or vacuuming was not practical nor possible, a water truck was used to hose contaminated mud off the rocks. A small dike was constructed

Fig. 10.3 Collection of contaminated soil with vacuum cleaner.

at the lower end of the rocky canyon area to collect the contaminated mud and water. Following a period of evaporation, the dry mud was scooped up with shovels, bagged, and hauled away. The rocky surfaces were readily decontaminated to 1000 DFs, while the cracks and crevices could only be decontaminated to an average value of 15 mrad/hr (at contact) or a DF of approximately 10.

## GNOME SITE

On December 10, 1961, a 3.1-kiloton nuclear device was detonated at a depth of 1184 feet in bedded salt rock, 30 miles southeast of Carlsbad, New Mexico. This event was code-named Project GNOME and was the first scientific experiment in the newly formed Plowshare Program. In 1962 and 1963, postshot activities including core sampling, steam generation, and cavity reentry resulted in some surface contamination at the site.

In 1968 and 1969, a cleanup of the mile-square site was accomplished within the guidelines established for the site. At that time, the guidelines specified the removal of all contaminated material above 0.1 mR/hr (beta plus gamma) as measured by a 30-mg/cm$^2$, C-M survey instrument. Various decontamination methods were used, including disposal into the GNOME shaft and burial of low-activity soil.

An inspection of the site in April, 1972 indicated that the salvage yard location contained exposed radioactive debris which originally had been covered by approximately two feet of clean fill. This caused concern, and eventually a decision was made to survey the site extensively. The guidelines established prior to the survey as cleanup criteria were $2 \times 10^{-5}$ µCi/gm beta-gamma and $3 \times 10^{-2}$ µCi/ml of tritium in soil moisture.

A comprehensive survey was conducted in 1977 and 1978. Prior data indicated that the predominant isotopes were $^3$H and cesium-137. Therefore, the survey methods were tailored to gamma and $^3$H measurements. It included a gamma survey via an airborne scintillation system. Extensive soil sampling was accomplished, and representative vegetation samples were collected. Portable survey instruments of the scintillation variety were used to perform monitoring at the background level.

A site-wide grid was established, based on New Mexico coordinates utilizing 100-foot centers. Microgrids with 20-foot centers were also utilized in known or suspect contaminated areas. Augered holes were driven to a minimum of 4 feet and a maximum of 20 feet. A downhole gamma probe incorporating a 2 x 2 sodium-iodide scintillator was used to survey the gamma field in each hole, and the data was recorded on strip charts. Soil samples of 500 cc volume were collected at the surface prior to drilling. The hole was drilled to a depth determined by background reading with the gamma probe. A composite sample of the tailing was taken, as well as a bottom sample. A 360° sidewall sample was collected at the point of highest gamma reading. Trenching was used in two areas of known buried contamination, to establish profiles.

All samples were gamma-counted, utilizing on-site mobile laboratory facilities. A fraction of the total collected was sent to NTS for $^3$H and $^{90}$Sr analyses, and for duplicate measurements. Cesium-137 was confirmed as the controlling isotope. Data from the soil-sampling program were manipulated via computer techniques for plotting and analysis.

Vegetation samples of those species utilized by cattle were collected. Sample locations were randomly selected from microgrid points so that correlation with soil could be established. A total of 65 samples was taken. (Animal life had been sampled at an earlier time by the EPA.)

A metal detector survey was accomplished to identify the location of metallic objects buried close to the surface. Excavation was done at the time of the survey. None of the removed material was contaminated.

Based on the survey results, a plan for decommissioning the site and disposing of the contaminated material was devised. In April 1979 cleanup began with the opening of a hole to

the GNOME cavity. A portable crushing plant was placed to receive and process the contaminated debris prior to downhole disposal (Fig. 10.4). Due to the low level of contamination and the moist nature of the soil, suspension of the material was not a problem. Water was brought from an existing brine well to flush the material into the cavity.

Excavation and movement of the salt muck pile was done with a large front-end loader. Because exact knowledge of the cavity volume was not possible, every effort was made to minimize the amount of disposed material. Thus, the mass contaminated portion of the muck pile was taken first, and the excavation process was monitored so that no uncontaminated salt was taken prior to removal of the contaminated portion. The cavity did indeed fill, prior to disposal of the clean salt. This material was buried in a trench excavated for that purpose immediately adjacent to the pile.

Other contaminated areas were excavated with a backhoe and small front-end loader. The material was trucked to the crushing plant for disposal.

Large contaminated items were packaged and shipped to the NTS. Final disposition was made at an established radioactive waste management site.

As the cavity contained tritiated water, pressure relief was provided through a hole into a tunnel which connected to the cavity. The exhausting air was passed through a condenser system and then through a silica gel filter.

Late in the cleanup, the cavity nearly filled with water. Therefore, water was drawn from the aforementioned tunnel for the flushing process. This water contained significant radioactivity, and certain surface installations became contaminated. All equipment and facilities were decontaminated to levels commensurate with release for uncontrolled use, and all decon fluids were disposed of in the cavity.

Upon completion of the disposal operations, the disturbed areas were physically contoured for erosion control and appearance. A final survey involving soil sampling and instrument measurements was accomplished. Demobilization and return to the NTS occurred in September, 1979.

Fig. 10.4 Portable crushing plant.

# 11. STATISTICAL ASPECTS OF THE CLEANUP OF ENEWETAK ATOLL

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The Desert Research Institute participated in the Enewetak Atoll Radiological Cleanup by providing data-base management and statistical analysis support for the Department of Energy team. The data-base management responsibilities included both design and implementation of a system for recording (in machine-retrievable form) all radiological measurements made during the cleanup, excluding personnel dosimetry. Statistical analyses were performed throughout the cleanup and were used to guide excavation activities.

The data base was developed both to store the information gathered so that it could be retrieved for decision making and to preserve the data gathering for future analysis, if needed. To this end, batches of data were periodically shipped to Las Vegas for offsite backup and compilation.

The islands of the Atoll were classified as residential, agricultural or food-gathering, depending on their past and intended use, and cleanup criteria were developed for each class of island. The criteria are:

1. CONDITION A: the surface concentration of TRU (transuranics), averaged over 1/2 hectare, must be less than 160 pCi/g.
2. CONDITION B: the surface concentration of TRU averaged over 1/2 hectare must be less than 80 pCi/g.
3. CONDITION C: the surface concentration of TRU averaged over 1/4 hectare must be less than 40 pCi/g.
4. CONDITION D: the concentration of TRU averaged over 1/16 hectare, 5 cm in depth anywhere below the surface, must be less than 160 pCi/g.

The primary measuring tool was an integrated mobile detection and analysis system nicknamed "the IMP".** The system consisted of a high-purity germanium detector mounted on the end of a retractable mast and an amplifier, 4096-channel analyzer, and a computer for spectrum analysis and data recording, all housed in the air-conditioned vehicle. In the normal measuring position, the collimated detector responded to gamma activity in a circle approximately 25 meters in diameter. The detection efficiency for a particle is a function of the position of the particle in the 25-meter circle, decreasing as the particle approaches the edge of the circle. The cleanup criteria, although developed with the IMP system in mind, do not contain explicit acknowledgment of the uncertainty inherent in the measurements obtained. Sources of the uncertainty include counting error, variation from level of the soil surface, and variability of percent moisture in the soil.

From a statistical point of view, the cleanup activities can be roughly divided into four categories: preliminary work, characterization analysis, cleanup analysis, and final analysis. Part of the preliminary work is the setting of cleanup criteria, development or choice of instrumentation, and the development of a sampling plan. The standard sampling plan was to take IMP spectra on a 50-meter grid. This was reduced to sampling on a 25-meter grid for small islands and sometimes further when refining the boundary for excision of contaminated soil. The design of the data base and

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*The presentation at the Workshop was given by Mr. Miller.

**The name IMP is the commercial trade name of the base vehicle, a tracked all-terrain vehicle manufactured by Thiokol Corporation. [Ed. note: See photo (Fig. 8.4), p. 74, In Situ Measurement Experiences, Allen E. Fritzsche.] By usage in the field, "IMP" became the term of reference for the entire system and, in fact, the verb denoting its function. The name IMP remains the property of Thiokol.

development of programs to implement it were also part of the preliminary work.

The criteria are written in terms of TRU (the sum of plutonium-238, plutonium-239, plutonium-240 and americium-241) but the IMP can detect only $^{241}Am$. Therefore, soil samples were collected for chemical analysis so that at least one ratio of TRU to $^{241}Am$ could be estimated for each island. The number of ratios on an island was influenced by the number of ground zeros on the island. Soil sampling plans for each island were developed, using information gathered in previous radiological surveys with additional sampling to define boundaries between areas with differing ratios. To estimate a ratio, different locations on each island were soil-sampled with each location consisting of two composites at each of three depths (0, 10, and 20 cm).

The number of samples for each island was dependent on the size of the island and how well the distribution of the ratio behaved. Every island was initially to have either four locations sampled or one location for every four hectares of area, whichever was larger. After these first samples were analyzed in the laboratory and ratios from each composite calculated, the decision was made as to whether more locations should be soil-sampled. If the range of ratios was small and the associated error on the mean of the ratios small, more soil samples were not necessary. However, if this was not the case, it could indicate that more than one population of ratios existed for an island. To determine boundaries between ratios and means of ratios within these boundaries, additional sampling was necessary. This occurred on islands where ground zeros were located.

Other multiplicative factors were applied to the IMP $^{241}Am$ data measured on Enewetak Atoll. Because of the dense vegetation on most of the islands, a brush correction factor was necessary to account for the attenuation caused by this vegetation. This number was determined empirically in an experiment conducted on one of the islands and was assumed to be constant for all islands. An error was also calculated for this factor.

The other two factors used for Enewetak data dealt with the detectors. Each detector had an efficiency factor associated with it that would be applied to the IMP $^{241}Am$ data. The other detector-related factor was necessary only for a certain time period when one of the detectors was operated at the incorrect (bias) voltage. An experiment was designed to estimate this factor and an uncertainty was calculated for it. To arrive at an error associated with the computed TRU, the counting error on the IMP $^{241}Am$ value, the error on the ratio calculation and the error on the brush correction factor were combined.

Using the IMP $^{241}Am$ data and ratio(s), TRU values were estimated and were used as input to a statistical technique known as kriging.[1] The area estimates produced by kriging plus 0.5 s, where s is the standard deviation of the kriging error, were compared with the island cleanup criterion to determine if soil removal was necessary. Frequently, before soil was removed, the area was measured on a finer grid to locate more exactly the area to be excised. Figure 11.1 shows an area on the island Aomon that was chosen for soil removal. The areas to be

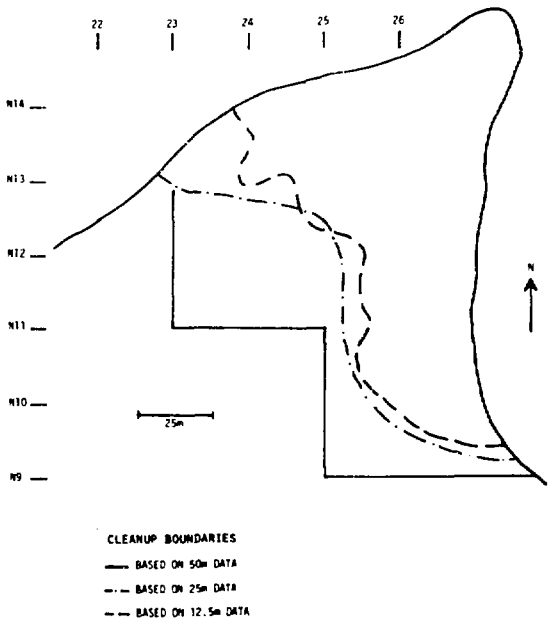


Fig. 11.1. Cleanup boundaries for Aomon.

excised to meet the 40 pCi/g criterion based on 50-, 25-, and 12.5-meter grids are shown for comparison. The boundary for the 50-meter grid was based on kriged estimates, while the other two boundaries were hand drawn. There is a reduction in the excision area by using the 25-meter grid contour, but only a small reduction in excision area by using the 12.5-meter rather than the 25-meter grid contour. In addition, it was believed that the 12.5-meter grid contour would be difficult for bulldozer operators to excavate accurately, so the excision was based on the 25-meter grid contours.

After some soil was removed, the area was remeasured to determine whether further soil removal was required. If so, the process was repeated until the remaining soil met the island criterion. The process could be completed rapidly when there was no reason to assume that the TRU-to-$^{251}$Am ratio changed with depth. If that assumption was tenuous, then there were delays of several days each at each iteration to allow for soil-sampling and chemical analysis.

Following all soil removal on the Atoll, the last step was to obtain a final characterization of the island. This involved reviewing the initial data collected for non-cleanup islands and the post-lift data for cleanup islands. Items of interest were the TRU ratio and IMP values. The concern about the ratio normally dealt with cleanup islands where a ratio may have changed because of the removal of soil. The ratios for non-cleanup islands had been closely checked during the initial characterization. With regard to the IMP numbers, it was necessary to make sure all the appropriate correction factors were applied. Once the final TRU values were calculated, isopleths could be drawn for the final characterization. The isopleths drawn for final characterization were of observed values and did not include a kriging error.

The previous discussion dealt with surface data only (0-3 cm). For Enewetak, subsurface TRU activity was a major concern. Two problems associated with subsurface activity were in locating and determining the size of the pockets of contamination.

The first step in the subsurface analysis was to design a sampling pattern for suspected and known areas of subsurface contamination. These areas were old ground-zero sites, suspected or known burial sites, and areas where an earlier survey indicated elevated TRU values. One known large burial site was called the Aomon Crypt and will be discussed separately.

The initial design was to sample on a coarse grid; when a high TRU value was found, additional soil samples would be taken at halfway points between high and low values. This sampling would continue until the area of high contamination was defined.

Later in the project, a Fission Products Data Base sampling was conducted which entailed collecting soil samples down to a depth of 60 cm on a 50-m grid. Results from this program revealed additional areas of subsurface contamination. A new sampling design was incorporated at these points. Figure 11.2 shows the design

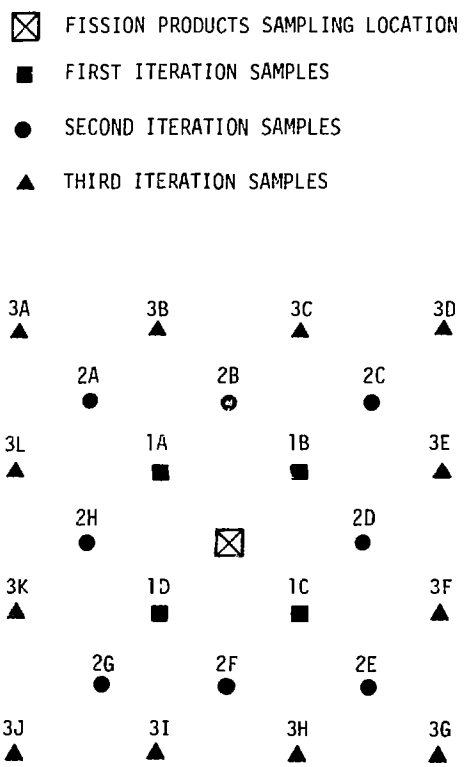


Fig. 11.2. Subsurface iterative sampling design.

for three sampling iterations; however, not all these samples would be collected after the first iteration. Those samples taken on the second round were determined by values greater than the criterion. For example, if 1B were the only sample of concern, then locations 2B, 2C and 2D would be sampled.

Following the subsurface soil removal, a sampling design was necessary to verify that the removal was complete. This involved doing bottom sampling of the excavated pit plus sidewall samples. Once the data verified completion of the soil lift, the area was usually backfilled with clean soil and the surface was remeasured by the IMP.

The Aomon Crypt was treated differently from the other subsurface areas. A rectangular area had been previously marked off as the area where contaminated soil and debris were buried. Sampling in this rectangle was done on a 5-m grid down to a maximum depth of 8.5 m. Based on these results, the area with TRU activity exceeding 400 pCi/g* was determined. The problems associated with the cleanup of the Aomon Crypt were the large amount of debris buried and the filling of the pit with water. To determine when all the contaminated soil was removed, bottom sediment samples were collected and analyzed. Once the pit was backfilled, IMP measurements were taken on the surface, and the backfill was core-sampled to a six-foot depth.

One of the big lessons learned on Enewetak was to document decisions, problems, and the like. This was done through daily logs, technical notes, standard operating procedures, memoranda, and official letters. The beginning of the project was not documented as thoroughly as the latter phases, and this lack of documentation caused additional problems.

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Chester: We have time for questions.

From the floor: Where did you put 100,000 cubic yards of soil?

Miller: Well, there was a crater left over on an island that was going to be sequestered because it couldn't be cleaned up. They wrote an environmental impact statement to justify putting it in one crater, and then they put it in another crater, and they put a dome on top of that crater which is the highest thing on the whole atoll--being about 25 feet above mean sea level. It is called Mt. Ruin [Runit] and it has, I presume, an 84th Engineering Battalion medallion on the top of it.

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*This number as a criterion was used only for the Aomon Crypt cleanup.

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# 12. SOIL DECONTAMINATION AT ROCKY FLATS PLANT

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In this presentation, I will describe work being done at Rocky Flats Plant (RFP) to decontaminate soil contaminated with plutonium-239. How the contamination came about will be described, as well as what has been done to contain it while decontamination methods are being developed. The purpose of the work is to decontaminate the soil so that it can be returned to the site instead of having to package, ship, and store it.

The studies that have been made to characterize the soil and the results obtained from those studies will be described. The initial decontamination process is wet screening with additives; next is attrition scrubbing with additives. Subsequent processes have not yet been identified; these will probably be more stringent leach conditions. Perhaps we will investigate ways of immobilizing the material so that it will not be so dispersible.

Conclusions based on the work to date are also presented, as well as future work planned for both lab and pilot plant.

Figure 12.1 shows a schematic of an area in the southeast corner of RFP that was found to be contaminated with plutonium in 1964. Barrels of contaminated lathe-coolant oil had been stored on this ground since 1958, and the barrels had corroded. When it was found that the barrels were leaking, they were removed, and processing of material and barrels was begun. By 1968, all of the material had been removed and processed. By November 1969, the area had been covered by an asphalt pad. Unfortunately, before the pad was put in place some of the material had been blown downwind, contaminating two additional areas. Preliminary soil decon studies showed the contamination was associated with very small particles which could be easily separated by wet screening. In 1976 a program was initiated to find methods for decontaminating the soil now under the pad. Soil samples were taken from six different locations beneath the pad, as well as from the windblown areas shown. Analyses of these soil samples gave the results shown in Table 12.1. Also shown is the depth of excavation required to reach soil containing less than 250 dis/min/g. A layer of bentonite clay acted as a barrier to penetration of the actinides. In spite of this help, it is estimated that we have approximately 22,000 tons of contaminated soil. Both the actinide content and plutonium-

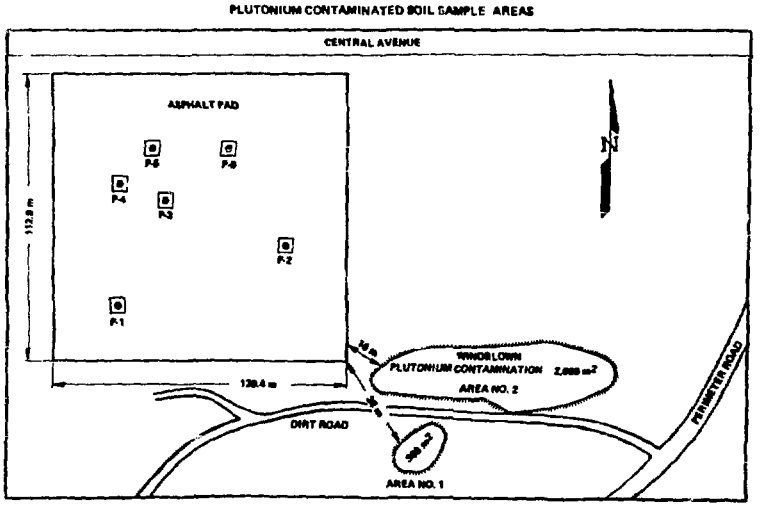


Fig. 12.1. Area contaminated with plutonium.

Table 12.1. Analytical Results of the Excavated Soil Samples

| Sample No. | $^{239}Pu$ (dis/min/g) | Sampling Depth from top of Pad* (cm) |
|---|---|---|
| A | 1,200 | -- |
| B | 11,900 | -- |
| P-1 | 940 | 46 |
| P-2 | 1,400 | 61 |
| P-3 | 8,000 | 56 |
| P-4 | 45,000 | 66 |
| P-5 | 14,000 | 61 |
| P-6 | 17,000 | 61 |

*Single determination; thickness of pad is 15 cm of gravel topped by 7.5 cm of asphalt.

to-americium ratio have a wide range. The 22,000 tons of soil contain some 80 to 85 g of plutonium. The highest contamination is 45,000 dis/min/g and the lowest is around 1000 dis/min/g, with the average being 12,000 dis/min/g.

Two types of contamination have been noted: particulate and disperse. Originally, the particulate material was finely divided plutonium metal; however, in the environment this was oxidized into plutonium oxide. The particulate phase has a mean particle size of 0.2u. Up to 50% of the contamination is in the dispersed form; that material will pass through a 0.01-micron filter. Both of these forms must be considered when decontamination methods are being evaluated. Water transport of contamination has not been observed since pad monitoring began in 1969. Despite that apparent stability, there was concern about long-term diffusion of plutonium from the site. Three alternatives were considered: the first was to stabilize the soil in place; the second was to remove, package, and ship it to the Nevada Test Site; and the third alternative was to decontaminate the soil. The first alternative, stabilization, was rejected because of the long-term concern about stability. Soil removal, packaging, shipment, and storage merely moves the contaminated soil to another area. The socio-political impact would be much improved if the soil could be decontaminated. This would also reduce the long-term hazard.

In addition, there are economic advantages. The cost to dig, package, and ship contaminated soil to the Nevada Test Site was estimated at $232 per ton. If 90% of the soil could be decontaminated and returned to the site, it would save $120 per ton. This became the justification for our soil decon program. The amount of soil excavated is also important. The Environmental Protection Agency (EPA) has issued guidelines for maximum levels of radioactivity in soil; that guideline is 200 $mCi/km^2$. This is equivalent to somewhere between 20 and 30 dis/min/g. Because of limitations imposed by instrumentation during survey of soil, DOE has said that any soil containing less than 1000 dis/min/g does not have to be excavated, but once excavated it must be decontaminated to less than 30 dis/min/g if it is to be returned to the site.

Several soil conditions exist at Rocky Flats that are advantageous to decontamination processes. First, the soil is very rocky, and the disperse contamination exists on the surface of the minerals. The surface-contaminated soil contains only 20% clay and organic material and the particulate plutonium oxide is small in particle size, as mentioned above. Because of this, screening and scrubbing processes are very effective. Four such processes have been investigated: (1) wet screening at high pH; (2) attrition scrubbing with Calgon at an elevated pH; (3) attrition scrubbing at a low pH; and (4) cationic flotation of clays.

The first process is a simple wet-screening process with the pH adjusted to around 12. The result of one such test is shown in Fig. 12.2. Typically, 60 to 75 wt% of the soil is decontaminated to less than 30 dis/min/g. This material can be returned to the environment. The remaining material either would have to be subjected

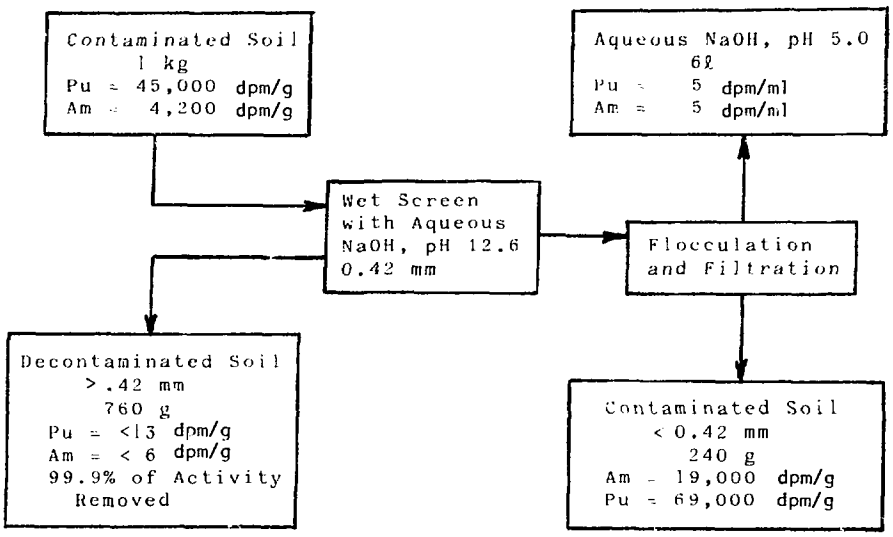


Fig. 12.2. Wet screening at high pH.

to further decontamination or packaged and shipped away for storage.

Attrition scrubbing with Calgon solutions at high pH also effectively decontaminates soil. Soil is scrubbed in a jar mill four times, and fines are decanted each time. A total of 99.9% of the activity was removed in the fines. This fraction represents about 20 wt% of the soil, so the remaining 80 wt% can be returned to the site.

Attrition scrubbing with low pH solutions has given us better results. The technique is really the same as the one we just described: scrubbing in a jar mill with fines being removed by decantation. About 84 wt% of the soil was decontaminated from 45,000 dis/min/g to less than 5 dis/min/g. The composition of the scrub solution used was approximately 2 vol% $HNO_3$, 0.2 vol% HF, 2 vol% pine oil, and 5 wt% Calgon.

The attrition scrubbing at low pH removes the amounts of plutonium shown in Table 12.2. The first scrub removes far more than any of the subsequent ones. Two processes are taking place that help decontaminate the soil: one is the attrition of the particles against each other; the second one is an actual etching or dissolution of the minerals and the plutonium contamination with the acid. An additional attrition scrubbing step with a lab-model Fagergren blender increased the amount of soil decontaminated with the low- and high-pH scrub processes by imparting high shear to the particles; the surface is more effectively abraded. With this

Table 12.2. Plutonium Removed by Low pH Scrub

| Wash | Volume Wash, ml | Plutonium Contamination Removed, % |
|---|---|---|
| 1 | 1000 | 88.1 |
| 2 | 250 | 7.1 |
| 3 | 250 | 3.5 |
| 4 | 250 | 1.3 |

NOTE:

Soil: 1 kg of dry soil
Plutonium concentration: 4500 dis/min/g
Total additives (four washes):
1750 ml $H_2O$,
75 g Calgon,
20 ml con. $HNO_3$,
2 ml conc. HF, and
2 ml pine oil
Plutonium in soil: 0.01%
Amount of soil decontaminated to <5 dis/min/g:
84 wt%

technique, about 3 to 5 wt% more soil is reduced below the EPA guideline.

As I mentioned previously, the primary decon process is wet screening; the secondary is attrition scrubbing with additives. Another process, investigated only briefly, is cationic flotation. This process takes advantage of the anionic surface of the clay particles. A cationic flotation agent such as an amine can be used to float the clay material in a conventional flotation process. Further research on this method is needed.

Tertiary methods for extracting plutonium from fine clay fractions are also being considered. These include leaching with such reagents as ceric nitrate solution or nitric and hydrofluoric acids.

The attrition scrubbing process at high pH is the most feasible process to scale up. The process flow diagram shown in Fig. 12.3 is based on the high-pH scrub. A feed rate of 10 tons per hour was selected for the full-scale facility. The soil would pass through a 4-in. grizzly to eliminate the large rocks. The material would then enter a rotary Trommel scrubber. A screen attached to the end of the scrubber separates material greater than 1/4 in. (6 mm). This fraction would contain less than 30 dis/min/g and would be sent to a landfill. The fines material would then be washed and screened at 35 mesh (0.420 mm). The material greater than 0.420 mm should be sent to a landfill. The fines fraction would be further processed using three stages of 1-in. (2.5 cm) liquid cyclones. The cyclones separate the soils fractions at 10 μm. The smaller fraction could be decontaminated by further treatment; this process would provide a weight reduction of 88%. Because the final plant must be mobile and self-contained, a water recycle system is shown on the diagram.

The Colorado School of Mines did pilot-plant testing with this flowsheet using cold soil at a rate of 600 lb/hr; the mass balance is shown in Table 12.3. Three stages of cyclones were used to separate the soil at 10 microns.

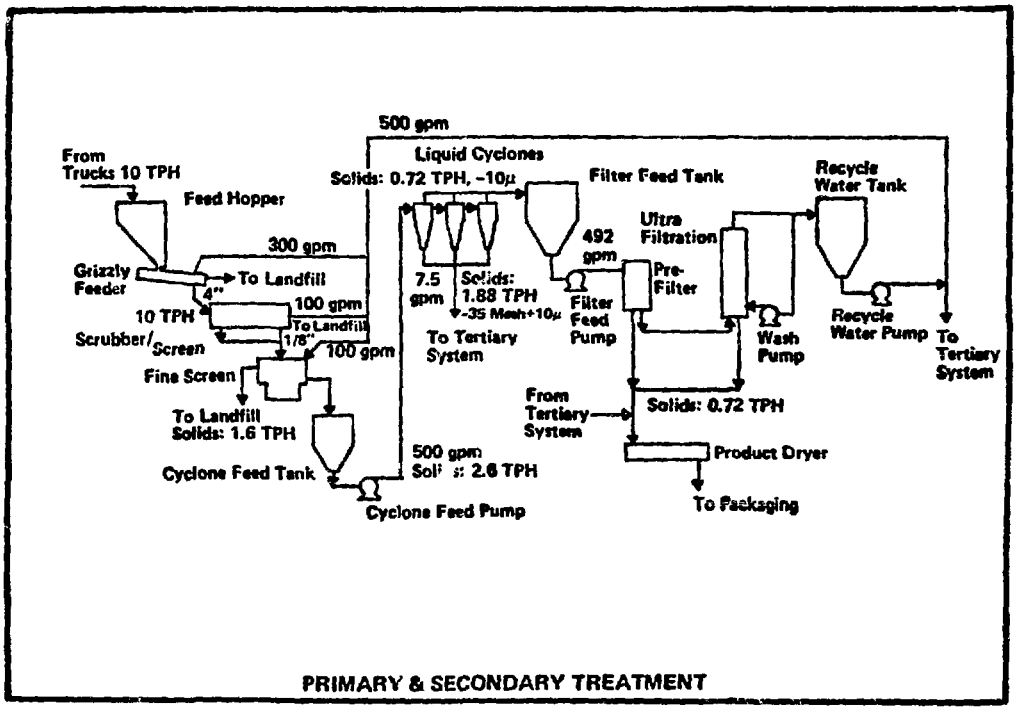


Fig. 12.3. Flow diagram of attrition scrubbing at high pH.

Table 12.3. Separation of Soil into Fractions--Mass Balance

| Equipment | Fraction Weight % | Size -37 μm, Weight % | Distribution -10 μm, Weight % |
|---|---|---|---|
| Grizzly >38 mm | 40.0 | 0.0 | 0.0 |
| Scrubber >6 mm | 26.5 | 0.6 | 0.4 |
| Vibrating Screen >0.42 mm | 10.9 | 0.06 | 0.04 |
| Cyclones, 2 Stages >37 μm | 6.4 | 1.6* | 0.4* |
| Cyclones, 3 Stages >10 μm | 5.1 | 0.0* | 17.0* |

NOTE: Feed rate, 600 lb/hr

*Percent of fraction sent to cyclones (<0.42 mm)

However, if three stages of cyclones are used, 17% of the contaminated material goes into the desired decontaminated product. And even with two stages of cyclones, 1.6 and 0.4% of the -37 and -10 micron material, respectively, goes into the desired decontaminated product. If the cut were made at 400 mesh (37 microns) after two stages, the amount of cross-contamination or recontamination of the product would be reduced. The weight reduction would then be 84%, rather than 88%.

Additional modification will be tested in the future. For example, if the cut were made at 100 mesh (149 microns), the cyclones and screens could be replaced altogether with spiral classifiers. This modification would result in a weight reduction of only about 80%, as opposed to 84% or 88%, but there are definite advantages: one of these is elimination of the screens and the cyclones. Spiral classifiers are more easily maintained than are cyclones.

Research is also planned using the modified circuit with an acid solution. Originally it was decided not to use acid because of concern that nitric and hydrofluoric acids would cause excessive corrosion of the equipment. However, tests have shown that the dominant factor is mechanical abrasion by the rocks and soil, not corrosion by the solution.

The use of mobile facilities to do soil decontamination work on-site is also being considered. Three trailers will probably be required: one containing the process equipment, one with two stages of HEPA filters, and one with water-recycle and power generation equipment.

Excavating equipment is also being studied. Figure 12.4 shows an example of one of the mining machines. There is an auger in the front that is continually against the face of the bank being excavated. It can be adjusted plus-or-minus 2 in., and this will cut down greatly on the amount of dusting. The material is augered onto a conveyor that moves the soil into a dumpster. Vacuum on that system would further reduce dust, so an air filtration system will also be needed. The excavator itself is standard equipment. Only the shroud and supporting equipment would have to be designed and prepared.

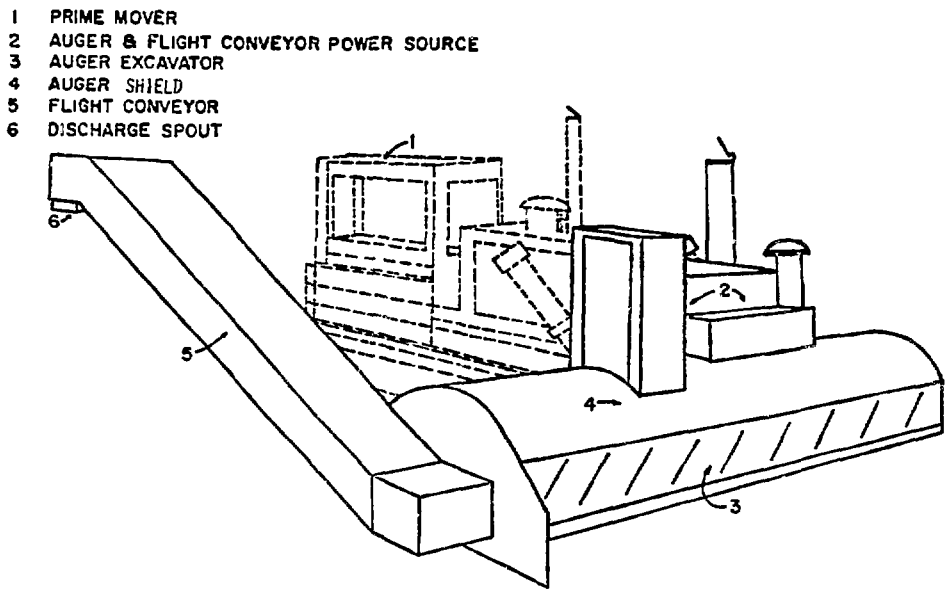


Fig. 12.4. Auger excavator.

Soils from other DOE sites are also being investigated and preliminary decontamination tests on these are encouraging. We have agreed with each of the sites that our findings will be made available to them before they are published.

To summarize: Work on contaminated soils is continuing. Preliminary results show wet screening and attrition scrubbing together can give 70 to 80 wt% reduction in the amount of soil that has to be packaged and shipped to a repository. Modifications may be possible that will increase this figure to our design basis of 90 wt%, the figure on which we based our economic analysis. We are looking at a total concept of contamination soil processing with lab and pilot plant work, as well as preliminary design of full-scale processing facilities and excavating equipment.

# 13. NEW DECONTAMINATION TECHNOLOGIES FOR ENVIRONMENTAL APPLICATIONS*

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Some very effective new decontamination techniques and associated contamination stabilization technologies are under development at Pacific Northwest Laboratory (PNL). Although these processes have been developed specifically for the decontamination of the large quantities of surface-contaminated waste generated by operating nuclear industry facilities and by the decommissioning of retired facilities, the basic methods and approaches should also be applicable in some measure to environmental decontamination needs.

The topics that will be discussed in this presentation include:

- Vibratory Finishing Techniques. These devices are capable of removing essentially all of the smearable contamination and most of the fixed surface contamination from metallic materials and from a surprising range of nonmetallic materials. This is accomplished with minimal secondary waste generation. In addition, this process is amenable to scale-up for handling large volumes of contaminated material on an automated basis.
- Fixatives. Work is in progress to identify, develop, and demonstrate improved contamination-stabilizing coatings. Tests to date show that some of these fixatives can be used as decontamination agents as well as to provide a means of obtaining and maintaining control of highly contaminated areas.
- Electropolishing Techniques. Electrochemical decontamination methods can rapidly remove gross amounts of contamination from metallic surfaces. Radiation levels can be reduced to background if required. The technique can be applied to removable components using immersion methods or, in the field, to external or internal surfaces using in situ electropolishing devices.
- Freon® Technology. Evaluation studies are in progress for a decontamination process that uses a high pressure spray of recirculating, purified Freon solvent to remove loose surface contamination. Advantages over aqueous decontamination approaches include ready removal of contamination associated with grease, oil, and other soluble substances; ability to clean electrical and other equipment without injury to delicate components; and capability for simple, effective purification and reuse of the cleaning solution.

## VIBRATORY FINISHING

Vibratory finishing is a commercial metal finishing process that has been developed at PNL into an effective decontamination technique for surface-contaminated material. The vibratory finisher is similar in principle to a rock polisher. However, instead of rotating, the bed containing the parts and abrasive medium (Fig. 13.1) vibrates at a high frequency (1000-2500 vpm) and amplitude (1/64-1/4 in.). The abrading action of the rapidly vibrating ceramic or metallic media dislodges loose and embedded surface contamination. The contamination is rinsed from the vibrating bed by a recirculating flow of filtered cleaning solution and collects in a settling tank.

The use of ceramic media to decontaminate carbon steel pipe clamps from the Hanford N-Reactor is illustrated in Fig. 13.2. Vibratory finishing will remove essentially all types of surface contamination, including plutonium. Although it will not decontaminate to the nondetectable levels obtainable with electropolishing, vibratory finishing does remove essentially all smearable contamination and

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†The presentation at the Workshop was given by Mr. Allen.

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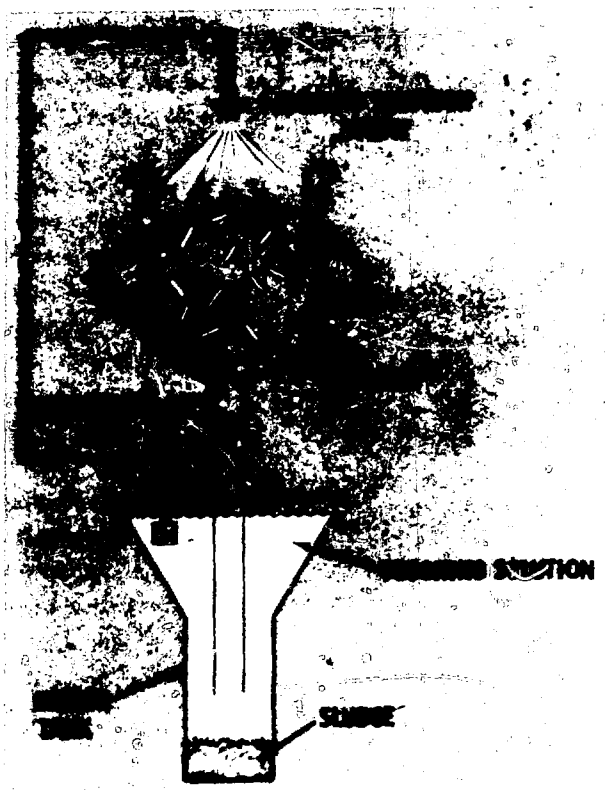

Fig. 13.1 Vibratory finisher system used to decontaminate metallic and nonmetallic materials.

Fig. 13.2. Contaminated pipe clamps being processed in a tub-type vibratory finisher using a ceramic medium.

reduces fixed contamination levels to well below the 10 nCi/g limit defining transuranic waste. In one test series, for example, 300 $ft^2$ of plutonium-contaminated pipe, ducting, and glove-box sections were decontaminated to an average final contamination level of 0.11 nCi/g. It should also be noted that the same abrasive action that decontaminates the parts also keeps the media at reasonably low contamination levels.

Although the various types of ceramic vibratory finisher media are effective in removing surface contamination, they do produce a significant volume of secondary waste (sludge) due to self-wear of the media. Studies using hardened-steel burnishing media show that almost the same degree of decontamination can be achieved, but with almost no self-wear. This means that essentially the only secondary waste produced by the vibratory finishing decontamination process using steel media is the paint,

grease, corrosion products, contamination, etc., removed from the contaminated surfaces. The metallic media are produced commercially in a variety of sizes and geometries (Fig. 13.3) to facilitate the cleaning of large surface areas while providing access to threaded areas and other restricted regions.

Fig. 13.3 Steel vibratory finishing media illustrating available sizes and geometries.

The ability of vibratory finishing to remove corrosion products and also to decontaminate the inside of a plutonium-contaminated pipe to below TRU limits is illustrated in Fig. 13.4. Tests indicate that the decontamination process should be effective for pipe or tube segments with internal diameters at least as small as 0.5 in. Although contamination, paint, grease, dirt, and corrosion products are readily removed by the vibratory finishing process, the amount of base material removed is quite low (<0.02 wt%/hr using metallic media).

One of the surprising findings of these studies was that vibratory finishing is equally effective as a surface decontamination technique for a variety of nonmetallic materials (Fig. 13.5). Plutonium-contaminated nonmetallic items successfully decontaminated to below TRU levels using vibratory finishing include plastic glove-box panels, epoxy-coated stainless steel panels, glass containers, plastic glove-port rings, rubber gaskets, rubber glove-box gloves, and even plastic bag-out bags. The thinner rubber and plastic items must be cut into pieces that are small enough to remain flat during the decontamination process.

All of the major metallic and nonmetallic components of a typical plutonium-contaminated glove box have now been successfully decontaminated to below TRU limits using vibratory finishing techniques as illustrated in Fig. 13.6. Vibratory finishing is capable of simultaneously decontaminating a range of materials,

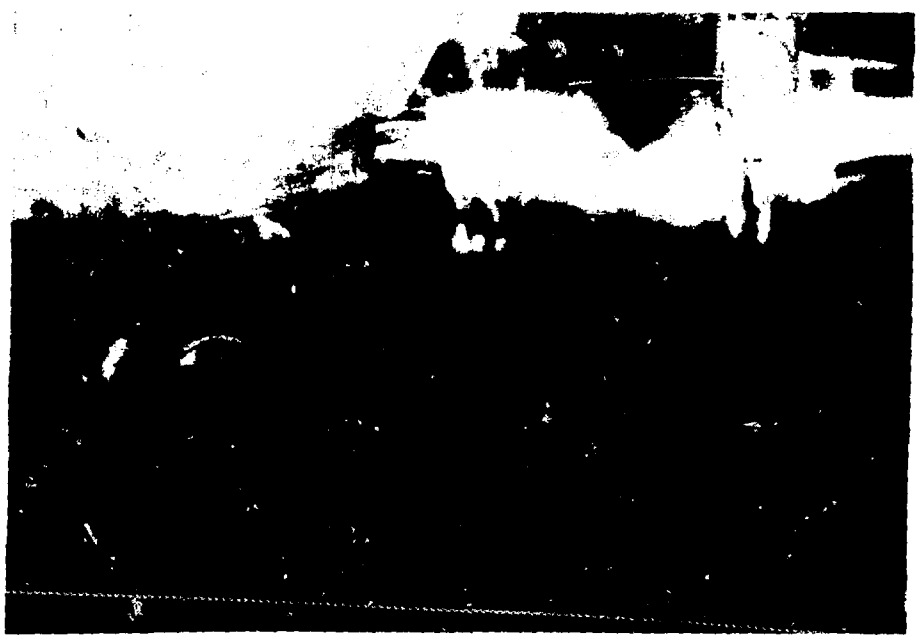

Fig. 13.4. Comparison of as-received pipe and corresponding section after processing by the use of vibratory finishing to remove rust and gross plutonium contamination.

Fig. 13.5. Representative plutonium-contaminated nonmetallic materials decontaminated to below the 10 nCi/g limit by vibratory finishing.

Fig. 13.6. Metallic and nonmetallic plutonium glove-box components decontaminated by vibratory finishing. (The metallic components in the upper left corner were decontaminated by electropolishing for purposes of comparison.)

components, geometries, and sizes to well below TRU limits. It produces material that is essentially nonsmearable and readily handled for subsequent transport or disposal. All of this is accomplished with minimal generation of secondary waste.

Moreover, vibratory finishing equipment is commercially available for scale-up to sizes capable of decontaminating large volumes of material on a continuous, automated basis. The example shown (Fig 13.7) is an annular type of vibratory finisher with 12-$ft^3$ capacity that has been used to decontaminate several hundred pounds of material at a time. Vibratory finishers with more than 50-$ft^3$ capacity could be obtained for environmental decontamination applications.

## FIXATIVES

Studies are in progress at PNL to identify, develop, and demonstrate improved contamination-stabilizing coatings. These coatings can be used to gain control of contaminated areas by "fixing" the loose surface contamination, to protect surfaces that will be exposed to contamination in their normal service environment, and to decontaminate surfaces through incorporation of the contamination in a removable coating. Examples of the use of these coatings for environmental applications would include: (1) treatment of the source region to tie down the bulk of the contamination, (2) application to corridors, roads, and other access/work areas to facilitate transport and decontamination operations, (3) application to tools and equipment to facilitate subsequent decontamination and minimize spread of the contamination, (4) as a decontamination technique to remove loose surface contamination, and (5) to protect the decontaminated areas.

A variety of different possible fixative materials (Table 13.1) have been evaluated and compared with respect to flammability, odor, toxicity, ease of application, drying time, durability (resistance to foot and wheel traffic, abrasion, and puncturing by tools), method and ease of application, and compatibility with other decontamination agents. In addition, the more promising of these fixatives

Fig. 13.7. Annular vibratory finisher capable of automated, high-volume processing of contaminated material.

Table 13.1. Fixative Evaluation Studies

| Fixative | Evaluation |
|---|---|
| Polyvinyl Alcohol | Water-based, non-flammable<br>Can be brushed, rolled, sprayed as received<br>Odorless, nontoxic<br>Abrasion resistant<br>Removed by washing with dilute basic solution |
| Polybutyl Dispersion | Water soluble, non-flammable<br>Can be brushed, rolled or sprayed after dilution with water<br>Odorless, nontoxic<br>Abrasion resistant<br>Removed by stripping |
| waterborne Vinyl Resin | Waterbased, non-flammable<br>Can be sprayed, brushed, squeeged<br>Slight odor, non-toxic<br>Abrasion resistant<br>Removed by stripping |

have been field tested at Hanford in support of recovery and D&D operations. As noted in Table 13.1, there are two basic types of fixatives. Strippable coatings (Fig. 13.8) can be removed as large sheets and are particularly good for applications involving structures and large equipment. Chemically removable coatings can be removed by washing with various chemical solutions and are useful for items that will undergo subsequent decontamination operations.

Strippable coatings are ideally suited for large-scale recovery/decontamination operations, because they can be applied easily and rapidly to large areas, with minimum personnel and equipment requirements. A pressurized application system as illustrated in Fig. 13.9 is generally the best technique for large surface areas, although brush, roller, or squeegee application methods can also be used. Shielding from soft beta radiation is an inherent property of fixatives. In addition, this shielding property may be enhanced by special formulation of the fixative.

Loose surface contamination in contact with the coating is incorporated by the curing process and is removed with the coating. This decontamination process can be quite effective.

Fig. 13.8. Strippable coating used to fix contamination, remove contamination, and protect uncontaminated surfaces.

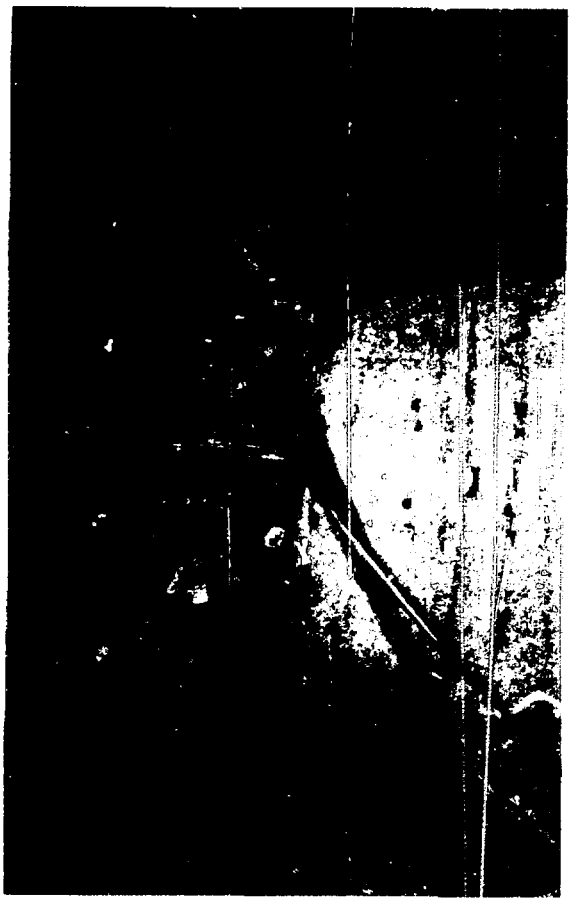

Fig. 13.9. Application of fixatives to contaminated surfaces using a pressurized liquid-spray system.

For example, horizontal surfaces contaminated with plutonium to levels of 4 x $10^6$ dis/min x 100 $cm^2$ were decontaminated to 10,000 dis/min x 100 $cm^2$ with a single application of a strippable coating. Similarly, four applications of a strippable coating were adequate to decontaminate a gold surface from 32,000 dis/min x 100 $cm^2$ to background. The degree of decontamination achievable with this process depends on the nature of the surface and the type and degree of adherence of the contamination. However, once incorporated into the coating, the contamination is in a form that is easy to handle and package for disposal.

The nonstrippable or chemically removable coatings are ideal for fixing contamination on material that will subsequently be decontaminated using vibratory finishing. Relatively thin layers (<0.001 in. thick) are generally adequate to fix loose surface contamination. For environmental applications, it should be noted that polyvinyl alcohol coatings of the type referenced in Table 13.1 are biodegradable and have been used to stabilize soil for erosion control purposes.

The effectiveness of the chemically removable and strippable coatings was demonstrated during decontamination/recovery operations in a plutonium-contaminated facility. The facility had contamination levels of 4 x $10^6$ dis/min x 100 $cm^2$ on floors and other horizontal surfaces. Entries made before the use of the fixatives resulted in a contamination level of 40,000 dis/min x 100 $cm^2$ on the protective clothing of decontamination personnel. Similar entries made after applying the polyvinyl alcohol fixative to the work area resulted in no detectable contamination on the protective clothing. During a subsequent entry into this same facility, the entire floor area and horizontal surfaces were sprayed with the polybutyl dispersion fixative. Entries and decontamination operations conducted after this application resulted in maximum contamination levels of only 600 dis/min x 100 $cm^2$ to shoecovers of personnel.

Comments have been made about exhaustion problems and other difficulties of working in protective clothing. In addition to fixatives, an effort was made as part of the aforementioned decontamination operations to help alleviate this problem through the use of a powered air-purifying respirator (Fig. 13.10). This system has a battery pack, filter, and a fan that delivers 4 $ft^3$/min of air to the facepiece. This system was substantially more comfortable to wear than the conventional type of nonpowered respirator. In addition, it provided a higher protection factor than the conventional respirator (1000, versus 50 for the nonpowered respirator and 2000 for a supplied air system). Use of the battery system provided greater freedom of motion as compared with a supplied air system by

Fig. 13.10. Battery-powered, air-purifying respirator used for plutonium decontamination operations.

eliminating the hose and the attendant possibility of stirring up additional contamination.

## ELECTROPOLISHING

Electropolishing is a very rapid and effective decontamination technique for metallic surfaces. The object to be decontaminated serves as the anode in an electrochemical cell (Fig. 13.11). Any contamination that is on or embedded in the surface is removed, along with a thin layer of surface material, by the anodic dissolution process. The phosphoric acid electrolyte serves as a complexing agent for metal ions, thus retaining the contamination in solution. In addition, the microscopically smooth surface produced by the electropolishing process facilitates the removal of any residual contaminated electrolyte by the rinsing operation. Because of these factors, electropolishing is capable of reducing even heavily plutonium-contaminated surfaces to levels that are below the detection limit for state-of-the-art measurement systems.

Electropolishing is a versatile decontamination process and has been appplied to immersible metallic items representing a variety of geometries, sizes, alloy compositions, and types of contamination. Some of the large items that have been decontaminated to background using immersion electropolishing techniques (Fig. 13.12) include pieces of typical plutonium-contaminated ventilation ducting, plutonium-contaminated glove-box sections, and beta/gamma-contaminated valves and components from the Hanford N-Reactor.

For environmental decontamination applications, the recent progress in developing in situ electropolishing techniques for field decontamination operations is of particular interest. For example, in situ electropolishing techniques were used to decontaminate a 5-$ft^2$ area on the inside stainless-steel floor of an operating plutonium glove box. The small portable electropolishing device illustrated (Fig. 13.13) reduced the contamination level of the floor from 1100 nCi/g to only 0.2 nCi/g. In comparison, efforts to decontaminate the glove-box floor using conventional scrubbing techniques could not reduce the plutonium contamination level below 470 nCi/g.

In situ electropolishing techniques are capable of scale-up to permit the decontamination of large surface areas and large equipment. The 5000-gal radioactive waste tank shown (Fig. 13.14) was decontaminated from an average radiation level of 20 mR/hr to background, using a variety of in situ electropolishing devices. Almost 85% of the interior surface area was decontaminated from the outside of the tank using a magnetically coupled moving cathode. The remaining interior areas were decontaminated using pumped-stream and brush or swab method. The entire decontamination of the 5000-gal tank was accomplished by the use of only 55 gal of electrolyte.

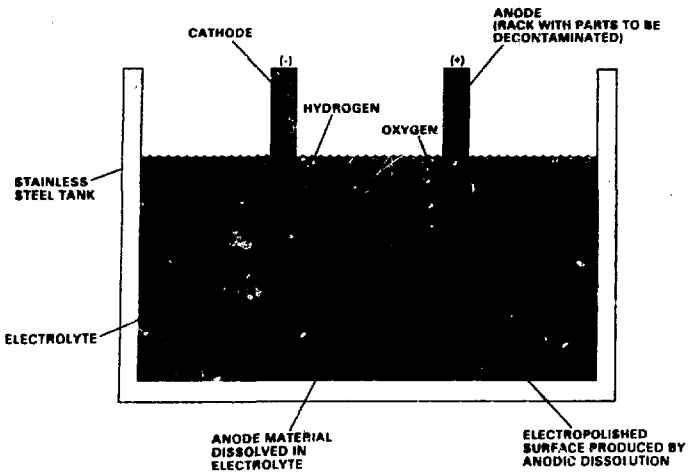


Fig. 13.11. Schematic drawing of electrolytic cell arrangement used for electropolishing.

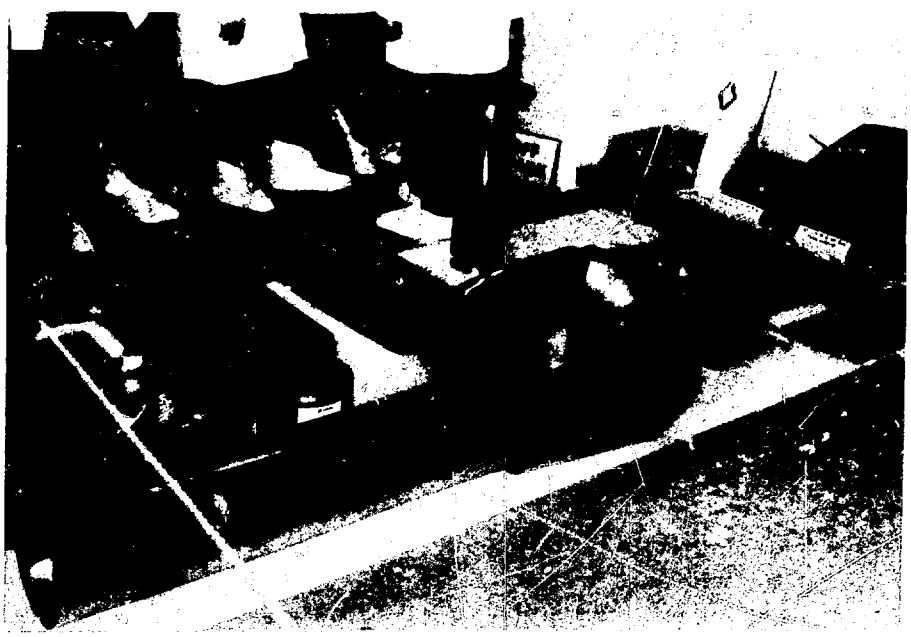

Fig. 13.12. Large items decontaminated using immersion electropolishing techniques.

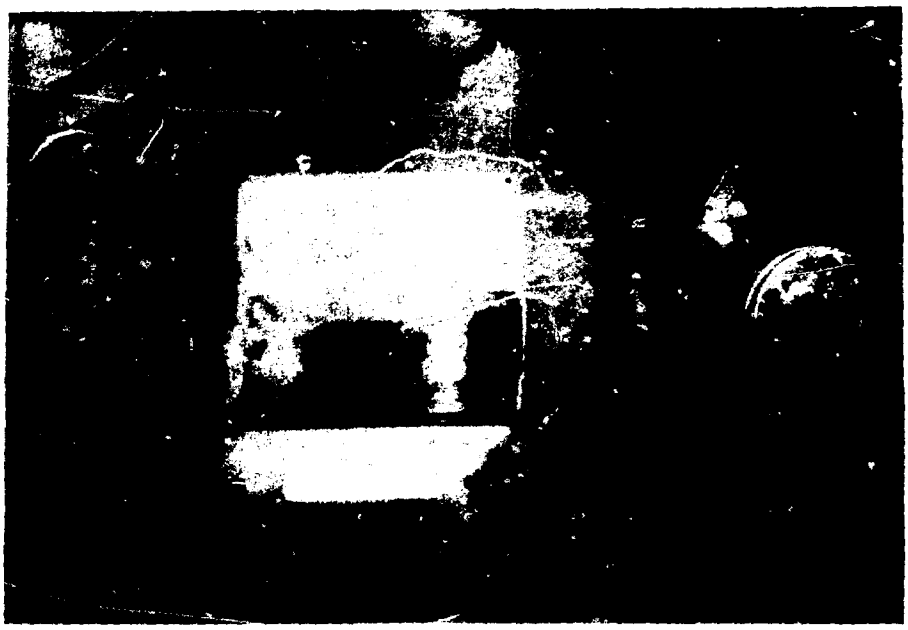

Fig. 13.13. In situ electropolishing device used to decontaminate the floor of a plutonium glove box.

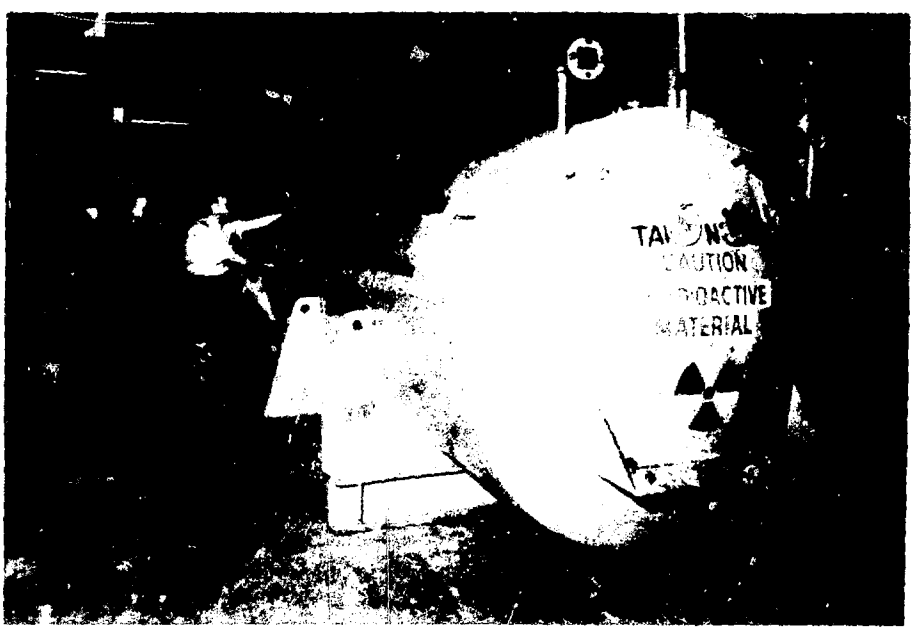


Fig. 13.14. A 5000-gal radwaste tank decontaminated using in situ electropolishing techniques.

*In situ* electropolishing methods also have been developed for decontaminating the insides of long pipes and tubes. Successive sections of the pipe are decontaminated using a moving, insulated cathode (Fig. 13.15). For example, the interior of the 4-in.-diameter by 24-ft-long sparger pipe inside the 5000-gal tank shown in Fig. 13.14 was decontaminated from the outside using a movable 4-in.-long cathode.

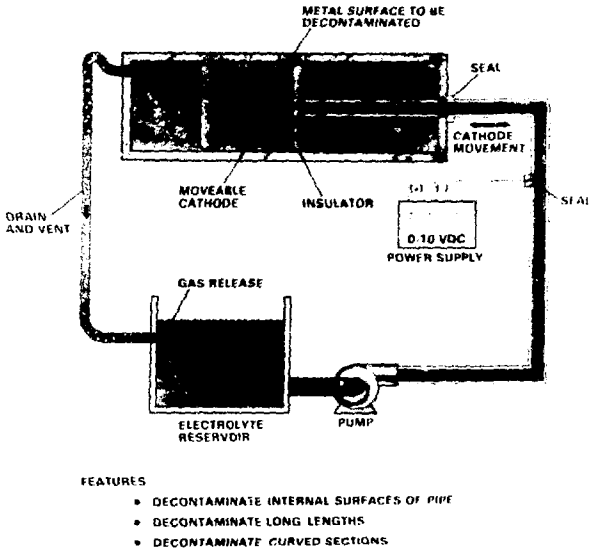


Fig. 13.15. Internal cathode electropolishing technique used to decontaminate the insides of long pipes and tubes.

## FREON CLEANING TECHNOLOGY

Studies are in progress to evaluate Freon cleaning technology for decontamination applications. The system illustrated (Fig. 13.16) employs a high pressure spray of Freon 113 solvent containing additives to remove loose surface contamination from metallic and nonmetallic surfaces. The contaminated Freon is purified and recycled using a combination of filtration, distillation, and cryogenic methods. The contamination and other material removed from the cleaned surfaces are recovered as a readily disposable solid.

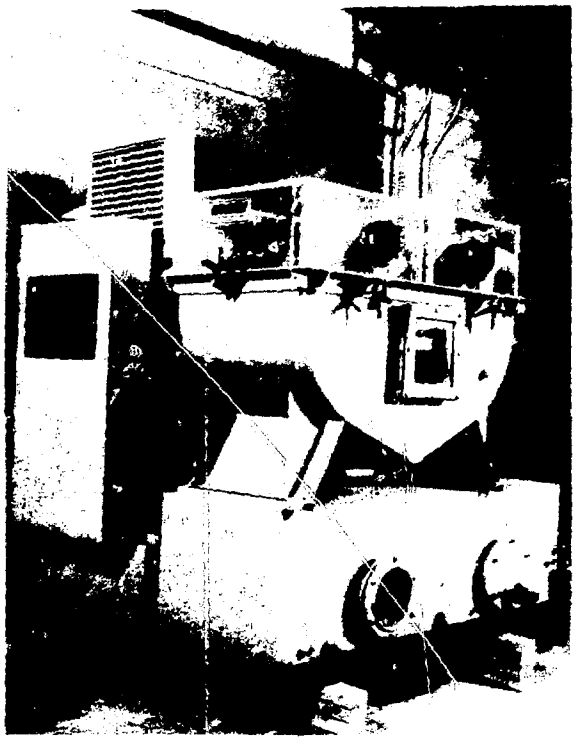

Fig. 13.16. Freon decontamination system used for evaluation studies.

The decontamination potential of Freon technology has not been fully explored at PNL. However, it definitely has unique capabilities for decontamination applications not covered by the previously discussed decontamination techniques. Advantages include the removal of contamination associated with grease, oil, and other Freon-soluble substances, the ability to nondestructively clean electrical (Fig. 13.17) and other delicate equipment, the capability for simple purification and reuse of the cleaning solution, and the advantage that there is no production of secondary waste other than the material removed by the cleaning process. Some of the typical items that have been decontaminated using Freon technology* include clothing, respirators, cables and hoses, tools, motors, and electrical cords.

*Health Physics Systems, Inc., Gainesville, Florida.

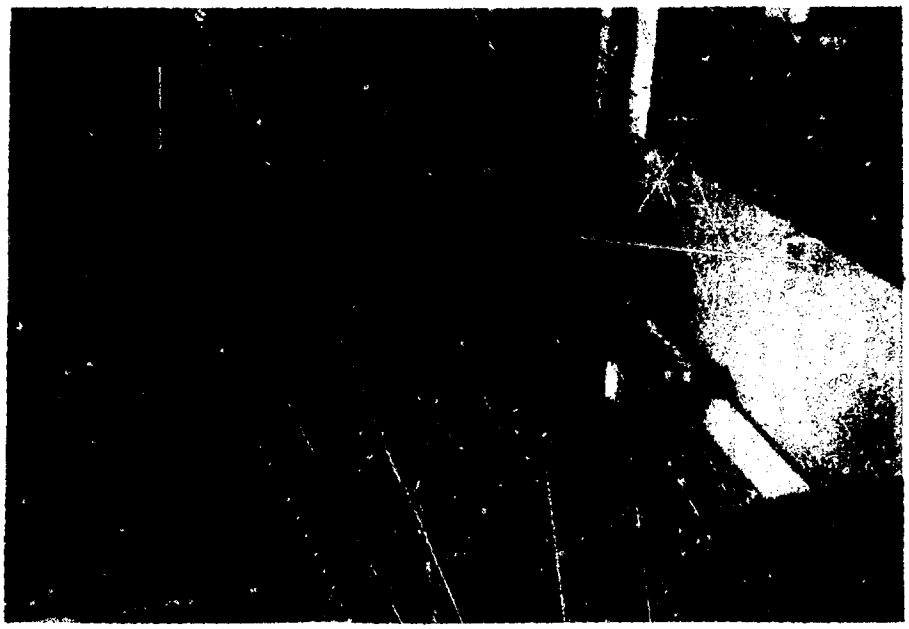

Fig. 13.17. Use of high-purity Freon to clean electrical equipment.

SUMMARY

The technologies discussed in this presentation represent a versatile collection of tools and approaches for environmental decontamination applications. The fixatives provide a means for gaining and maintaining control of large contaminated areas, for decontaminating large surface areas, and for protecting equipment and supplies used in decontamination operations. The other decontamination techniques together provide a method for removing loose surface contamination from almost all classes of materials and surfaces. These techniques should have wide application both as direct decontamination processes and for the cleaning of tools and equipment used in the decontamination operations.

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Chester: We have a few minutes for questions.

From the floor: Do you make an effort to recover the Freon after you've used it?

Allen: The system illustrated in Fig. 13.16 is totally self-contained, so essentially all of the Freon is reclaimed, purified, and continually recycled.

From the floor: You gave the impression that the use of the fan-powered mask eliminated the heat-stress problem. I want to make sure that you didn't leave that impression. The mask is far better to use in areas where heat is a problem, but in the particular application that you were showing, the time that people were working in there was limited to 45 minutes to an hour because of the high heat.

Allen: That is right. I hope I didn't imply that it solved the problem. It is more comfortable to wear than the conventional system, but certainly is not going to eliminate the problem. I think it is a step in the right direction, and one that needs to be pursued.

From the floor (Barbier): Do you have filters to prevent contamination from entering the respiratory systems of the workmen? You pump air out into these suits that you have shown; you pump air out of the surroundings. What filters do you have?

Allen: Yes, the air passes through a HEPA filtration system. In fact, one of the advantages of the fan-powered system as compared to a supplied air system is that, with a supplied air system, you have a serious problem if something happens to your hose. With the fan-powered system, if the fan should cease operation, you can continue to use it as you would a normal respirator to provide protection while exiting the contaminated area.

Chester: The canister strapped to the waist contains absolute filters.

Allen: Yes, and I can show you a diagram of the system afterwards if you are interested.

# 14. WASTE INCINERATION

Michael D. McCormack
EG&G Idaho, Inc.
Idaho Falls, Idaho

The problem we face at the INEL (Idaho National Engineering Laboratory) is not the classical D&D problem. It is the D&D of a burial ground. There have been about 3 million $ft^3$ of waste buried at the INEL, most of it from the Rocky Flats Defense Operation, containing plutonium and other transuranic elements (Fig. 14.1). Some of the drums that were retrieved in 1974 are shown in Fig. 14.2. These drums were buried in the mid-50s; they are not in very good shape.

As a result of the information gained from our retrieval projects, the decision was made to perform an analysis of all the available incinerators to determine which was best suited for processing the INEL waste.

A number of processes were evaluated (Fig. 14.3) for incinerators currently funded by DOE and for municipal incinerators. Slagging pyrolysis, the last process listed in Fig. 14.3, included the processes of three different manufacturers: Andco-Torrax, FLK and Purox.

A number of constraints were set up that we felt each process should meet (Fig. 14.4):

It was felt that the wastes must be inert and the residue from the process immobilized. At the time of the study there were some draft criteria (Fig. 14.5) for the Waste Isolation Pilot Plant (WIPP). A commitment to processing all the waste in a 20-year time frame would require the unit to process about 8500 $m^3/yr$. It was desirable that the process accept unsegregated wastes. The process of sorting wastes that were retrieved from the pits and trenches was not feasible. The large volumes of waste to be processed would require quite a few glove boxes and would result in unacceptable risk and exposure to personnel. The unit should be

TRU WASTE BURIED AND STORED AT RWMC

| YEAR | VOLUME $ft^3$ | CARTONS | DRUMS | BOXES | BINS |
|---|---|---|---|---|---|
| 1954-1970 (BELOW GROUND) | 2,300,000 | 13,000 | 194,000 | 6,042 | 0 |
| 1970-1977 (ABOVE GROUND) | 1,200,000 | 0 | 83,000 | 5,000 | 172 |
| 1978-1988 (PROJECTED AT 75,000 $ft^3$ yr) | 750,000 | - | 60,000 | 3,600 | 100 |
| TOTAL BY 1988 | 4,250,000 | (13,000)<br>0 | (194,000)<br>143,000 | (6,042)<br>8,600 | (0)<br>272 |

INEL-S-5685
Rev. 2

Fig. 14.1. Transuranic wastes stored at INEL.

Fig. 14.2. Drums containing wastes.

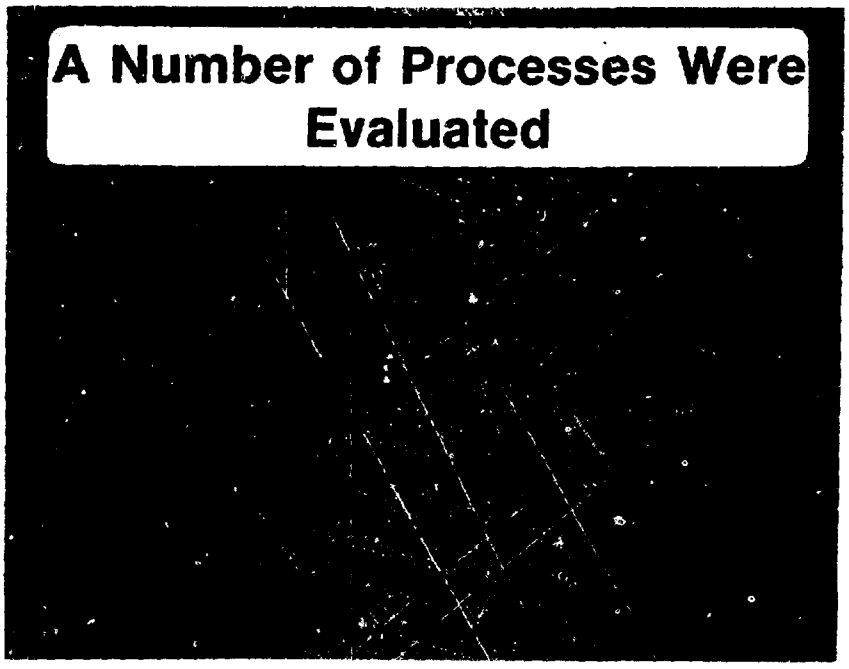


Fig. 14.3. Incinerator processes evaluated.

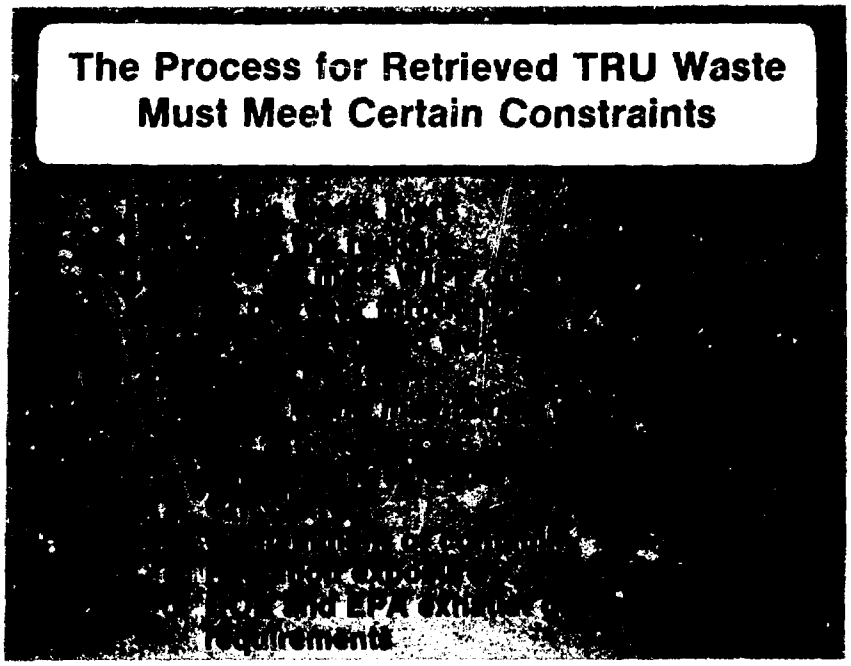


Fig. 14.4. Constraints for waste retrieval process.

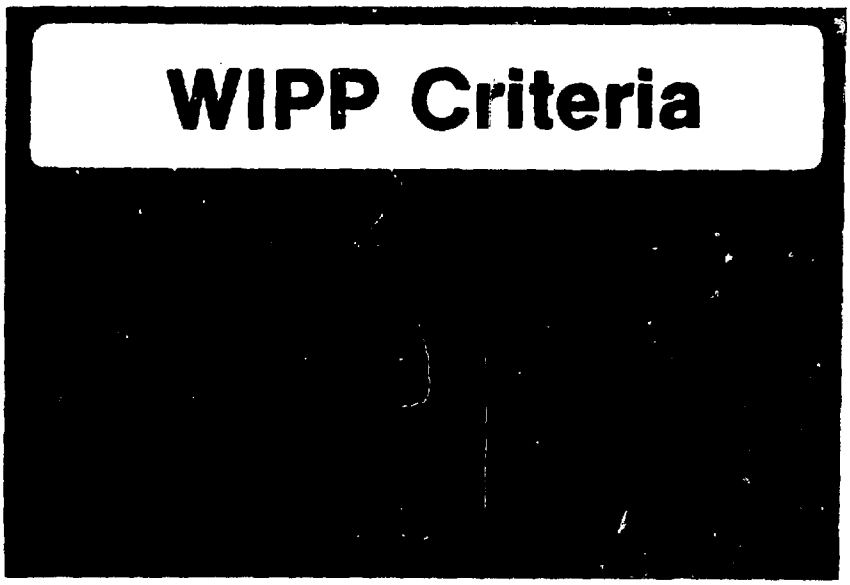


Fig. 14.5. Draft criteria for Waste Isolation Pilot Plant.

operational by 1987 in order to have waste to ship to the proposed respository. (This date has since slipped due to a change in policy and problems with funding, but it was the date in effect at the time of the study.) All the processes must meet the Department of Energy and Environmental Protection Agency guidelines for releases and exposure of personnel to hazards.

The only processes that could meet the repository criteria assumed for the study were the three slagging pyrolysis units. The other processes could meet the criteria only if an additional step was added: vitrification or immobilization in concrete or asphalt (Fig. 14.6). Only the slagging pyrolysis incinerator currently marketed by Andco-Torrax could meet all the constraints (Fig. 14.7).

At this point the results of the study were presented to DOE, and a recommendation was made that R&D be done on the use of the slagging pyrolysis process for the INEL wastes. DOE agreed with the recommendation and asked that a separate task force be established to review our findings and to verify or dispute the results of the study.

The task force that was established consisted of people from other DOE contractors and from one private firm (Fig. 14.8). The task force chose to use the figure-of-merit analysis technique to evaluate ten alternatives, using five types of incinerators. A new set of criteria was established to evaluate the alternatives (Fig. 14.9). The results of the task force evaluation (Fig. 14.10) were virtually identical to the initial study. For processing the INEL waste, the slagging pyrolysis process was the most promising.

The major difference between the slagging pyrolysis incinerator and the other processes evaluated was the operating temperature--1500°C as opposed to 850°C to 1000°C. At the higher temperatures such inerts as dirt, metals, and sludges would be fused into a basalt-like slag.

The Andco-Torrax process is currently being used in several municipalities in Europe for processing municipal and industrial wastes up to

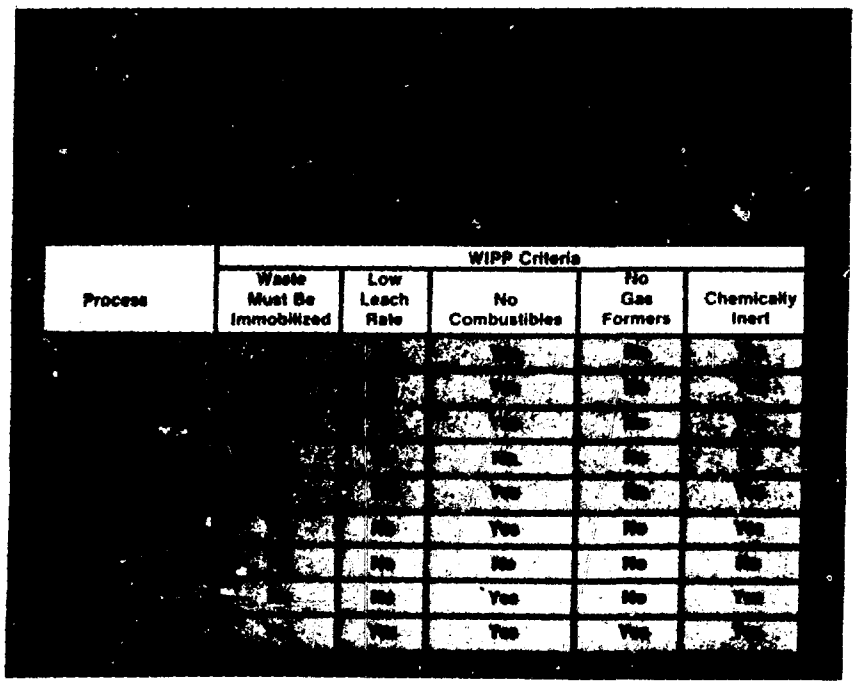


Fig. 14.6. Evaluation of waste incineration processes using WIPP criteria.

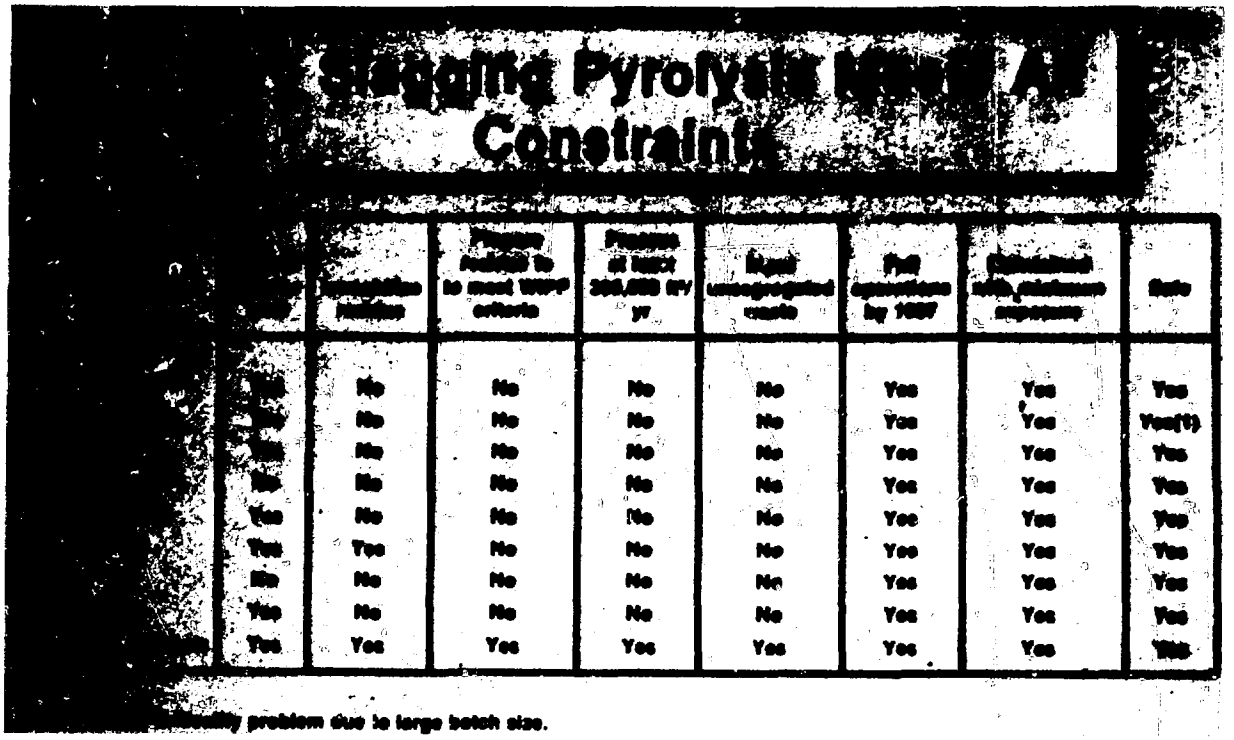


Fig. 14.7. Comparison of slagging pyrolysis with other methods of processing waste.

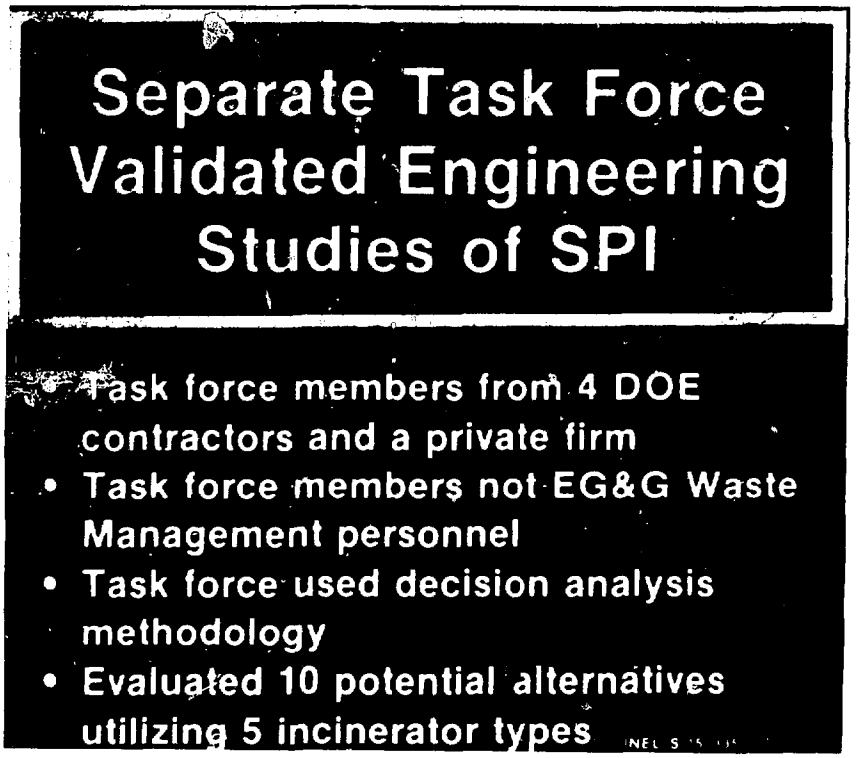


Fig. 14.8. Task force for review of SPI studies.

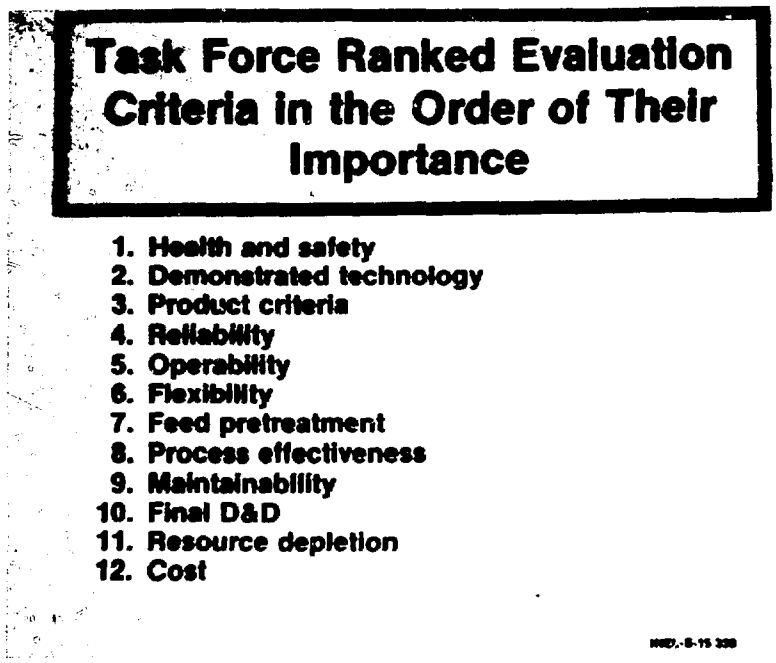


Fig. 14.9. Evaluation criteria ranked for importance.

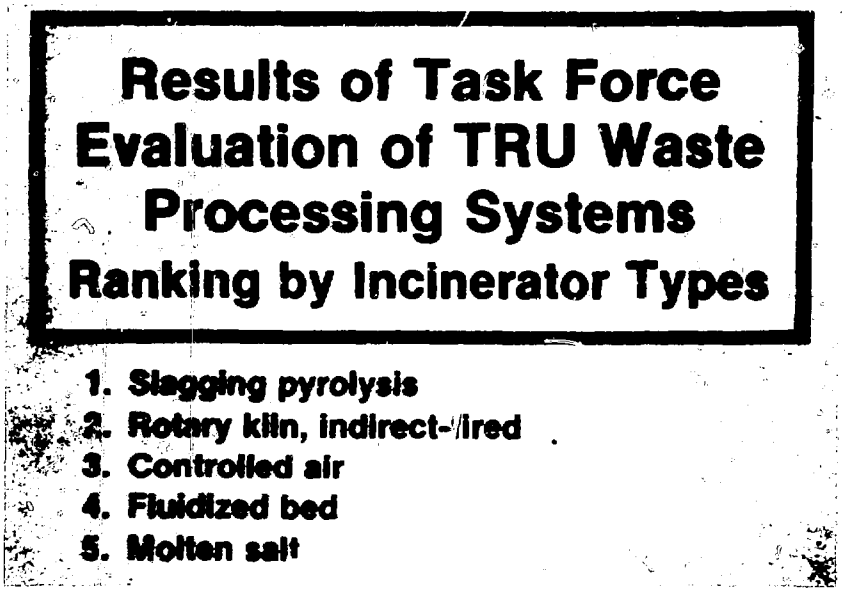


Fig. 14.10. Ranking by incinerator types.

200 metric tons per day. The process is based on blast-furnace technology (Fig. 14.11). The materials are fed into the top of the gasifier, go through a drying zone, then are pyrolyzed. The pyrolysis products and inerts are combusted and melted into a slag (Figs. 14.12, 14.13, and 14.14). The gases produced during pyrolysis are driven off to a secondary combustion chamber where they are burned; the particulate carried over with the gases is melted into a slag similar to that produced in the gasifier. The slag produced in both chambers is dropped into a water quench, and the thermal shock fractures it into small particles which are then transported to a landfill. In the INEL unit, the slag will most likely be cast into a monolith for storage at a federal repository. The gases from the secondary combustion chamber are cooled in a waste-heat boiler and then cleaned, using a variety of gas treatment methods. They are then vented through a stack to the atmosphere.

The Ralph M. Parsons Co. of Pasadena, California is currently under contract for conceptual design of the facility, which is scheduled to be completed in March, 1980. At that time, if funding is available, Title I design will begin.

Figures 14.15, 14.16, 14.17, and 14.18 are artists' concepts of the proposed facility. The current cost estimate is $500 million, based on a 1978 start date.

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Chester: Are there any questions?

Graves: Does your process assume that all the waste going in there will be TRU? There is no separation or attempt to remove any of the TRU in the operation?

McCormack: In the handling section, in the assay portion, we are going to look at possible

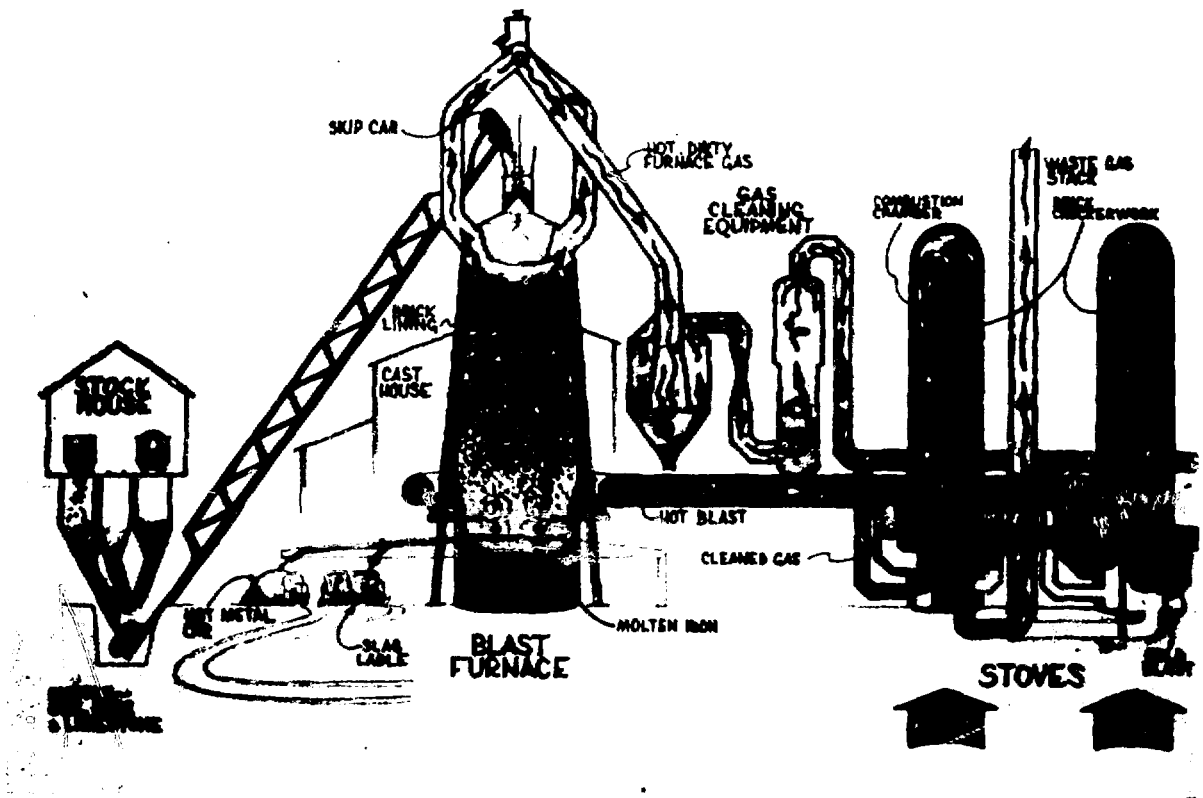


Fig. 14.11. Slagging pyrolysis process.

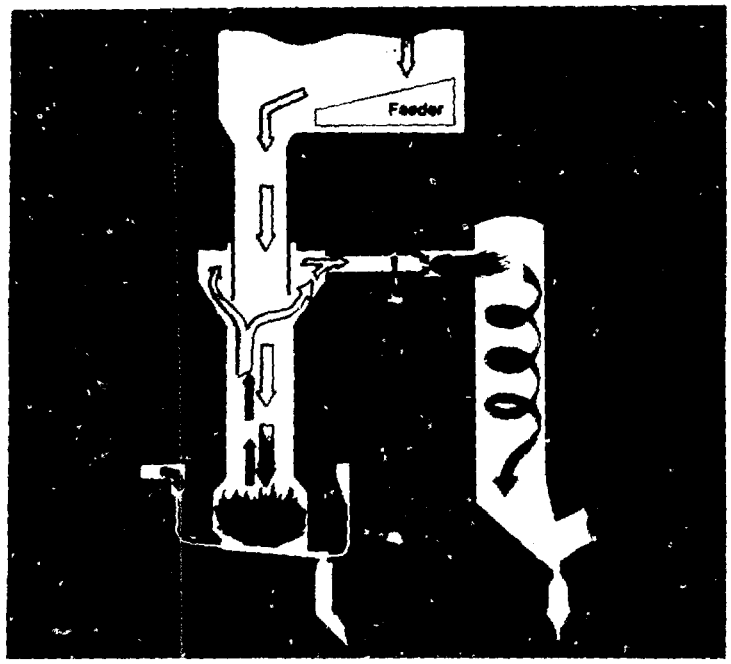


Fig. 14.12. Slagging pyrolysis incinerator unit.

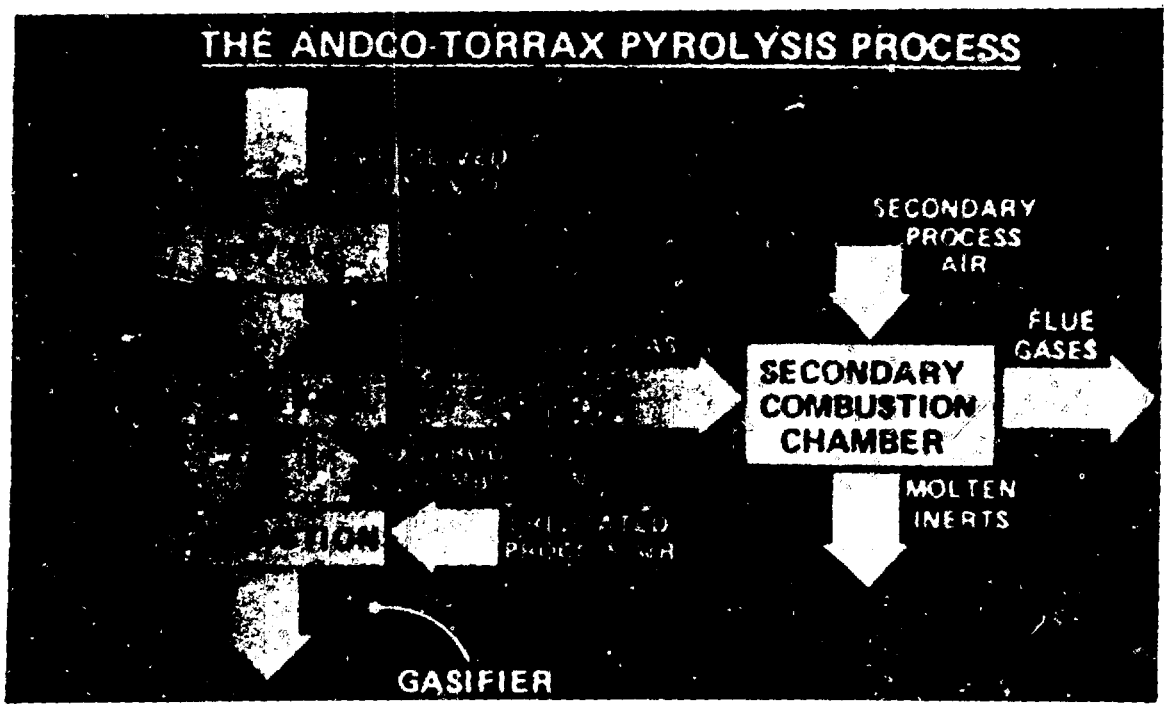


Fig. 14.13. Andco-Torrax process for incineration.

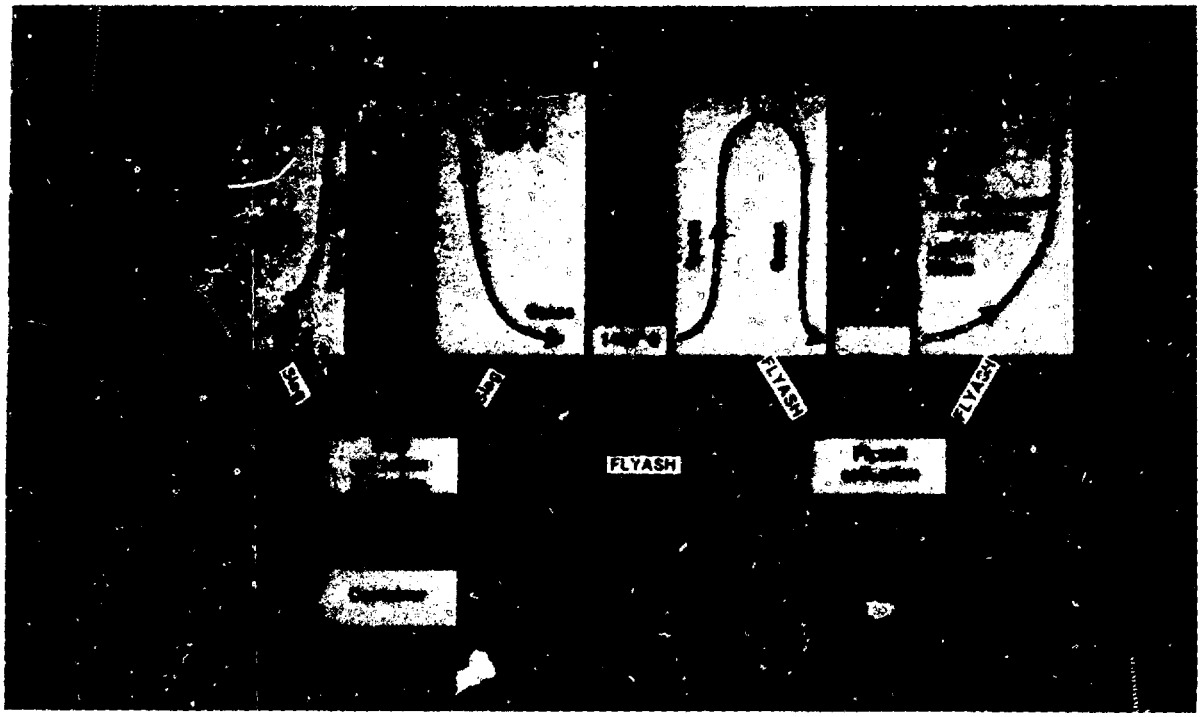


Fig. 14.14. Pyrolysis process.

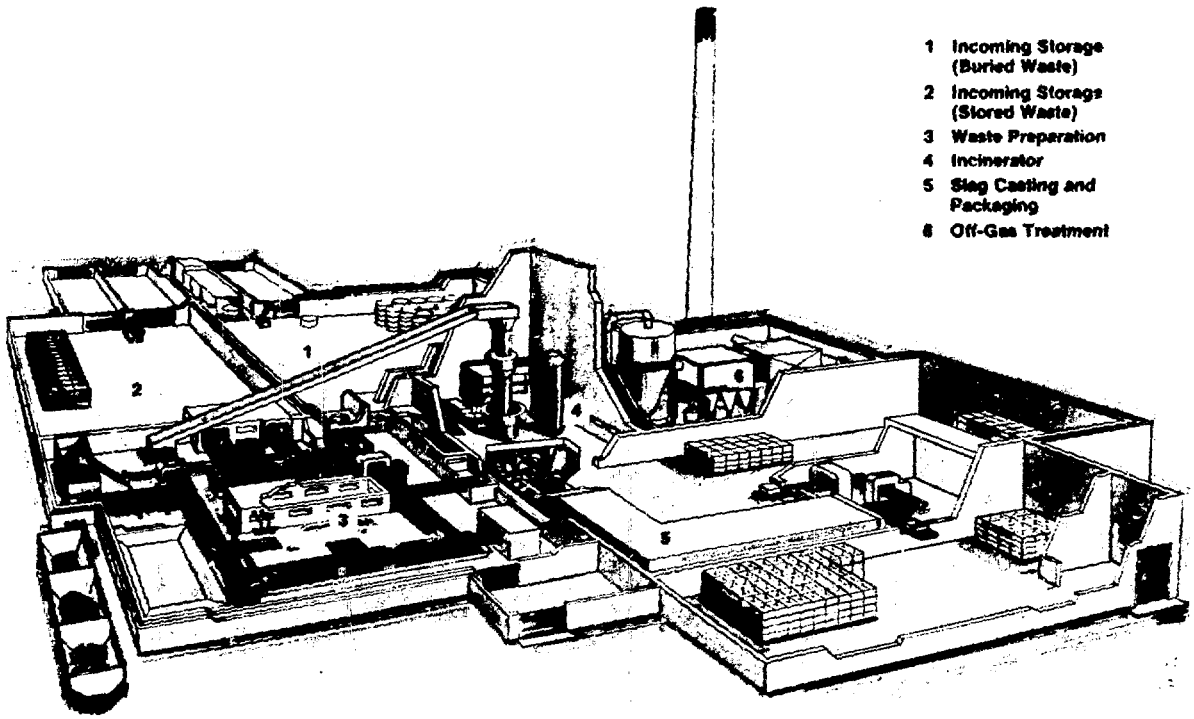


Fig. 14.15. Artist's concept of slagging pyrolysis facility.

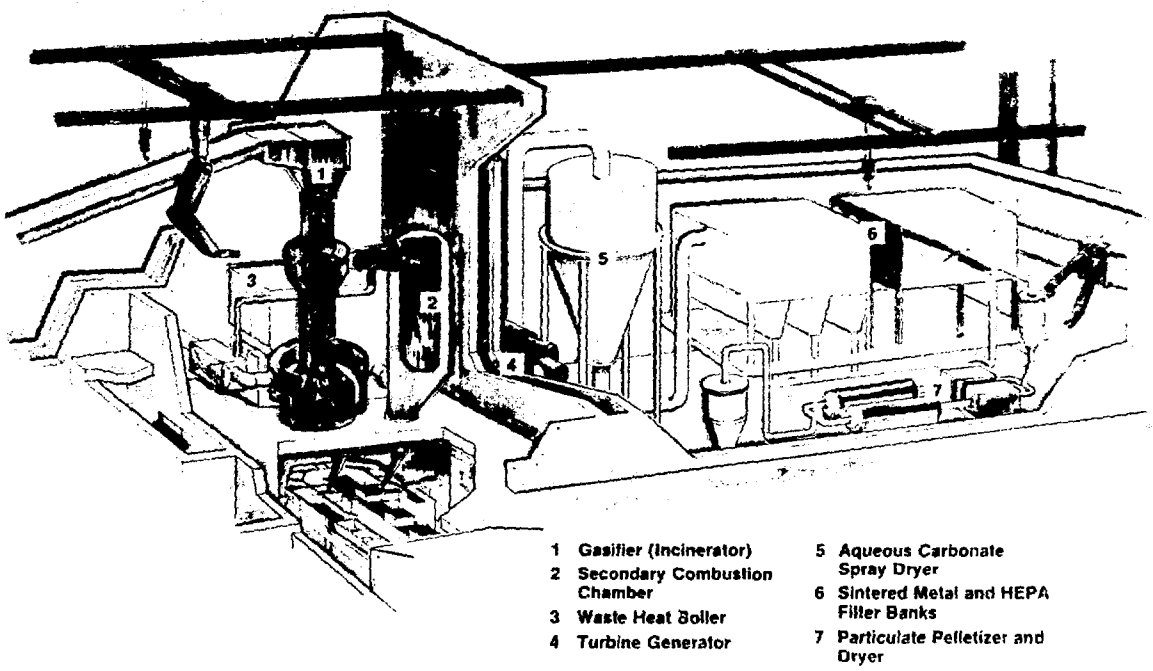


Fig. 14.16. Incinerator and off-gas treatment areas.

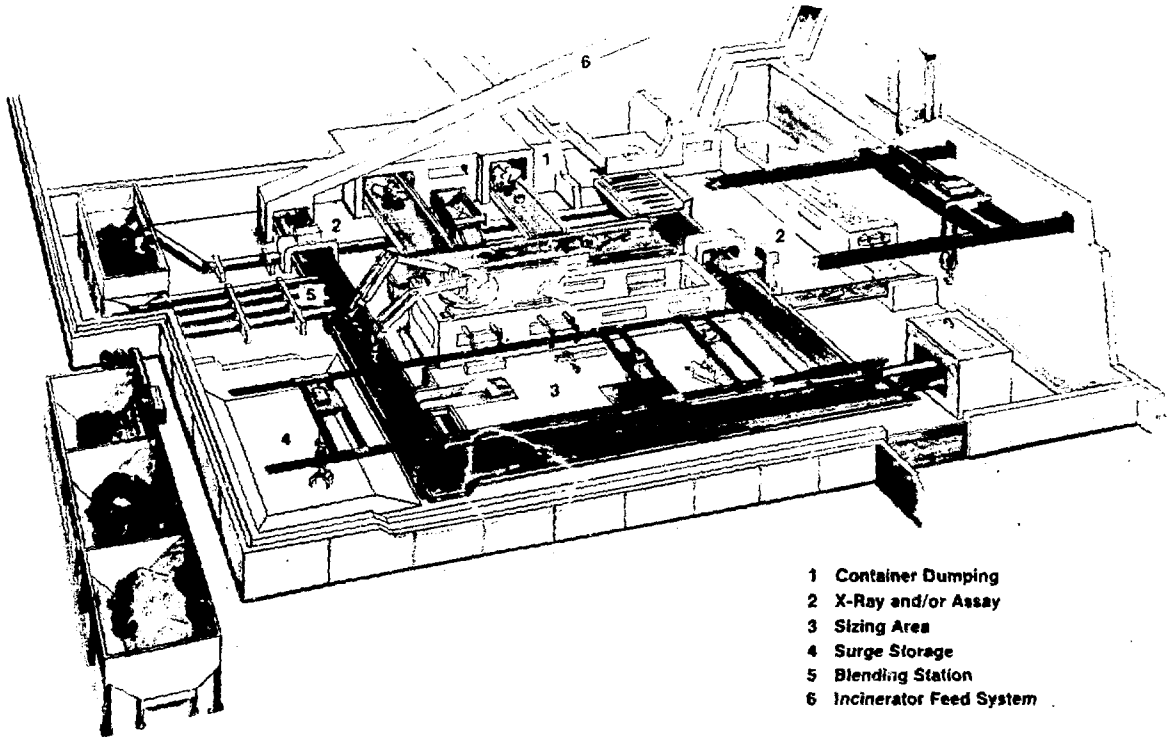


Fig. 14.17. Waste preparation area.

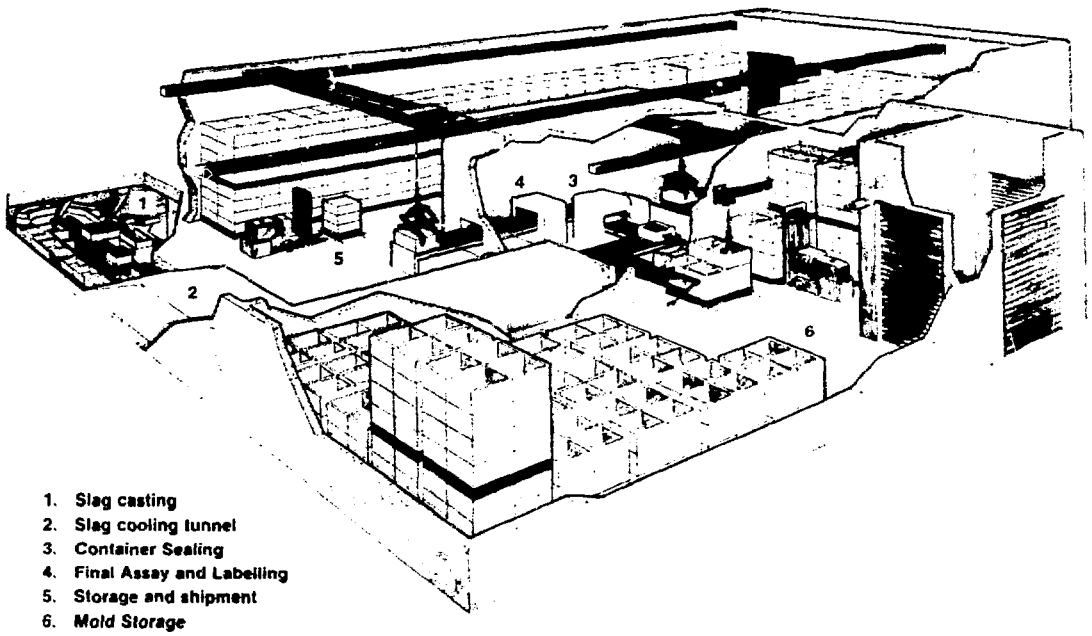


Fig. 14.18. Slag casting and packaging area.

decontamination and separation. For most of the waste that we have--all the stored waste that we are talking of--the process is TRU. The buried waste has about 500,000 cf of beta/gamma intermixed with it that we don't think would be worth trying to separate.

Graves: Well, there are some indications that by slagging operations in metallics you can remove some of the TRU, thus rendering a lot of your melt non-TRU status.

McCormack: Yes, by smelting. And this process just melts it--oxidizes the metals and fuses them in the slag--rather than decontaminating by smelting. We are planning to have a decontamination area in the facility so that large metal objects, such as valves that aren't highly contaminated, can be decontaminated rather than treated as TRU waste, and stored in a federal repository.

From the floor: That means that you wouldn't charge full drums in the as-received condition, and the waste would have to be sorted or segregated.

McCormack: Yes, but segregation is a little different from sorting. When I said "sorting," I meant taking combustibles from noncombustibles, the PVCS from the polyethylenes. Segregation can be done by assay just by checking the level of contamination to determine if it is less than 10 nCi/g. One of the things that we are working on with John Umbarger is the instrumentation that will do that. There is a lot of R&D to be done, but that is the goal right now.

Chester: Art, you were asking some questions about melting this sort of thing. Is anyone going to present a paper on the work that is being done at Rockwell? Could you make a very brief statement? I think you are using an arc melter; am I correct? Is there any comparison that you could make between that and what he is describing here?

Graves: We are looking at contaminated-equipment volume radiation under the Surplus Facilities Management Program (SFMP) through DOE. The first step is size reduction, and the

second step is meltdown. Some lab-scale tests are in the stage now where we are looking at radionuclide separation in the melt itself. And we are looking at kilogram-size melts where we will be contaminating metals with fission products and transuranics and looking at the dispersion of the radionuclides in the matrix after the melt. In addition to that, we will look at slag separation of the contamination process. This would follow initial attempts at surface decontamination. After electrochemical polishing you will have metal items that can't be inspected. Those with suspected TRU contamination will be melted in a furnace for volume reduction. After melting, there is a good possibility that some of the waste can be classified as non-TRU--either by slag separation or by having a diluted matrix with concentrations below 10 nCi/g. We are in that development phase now, and I think perhaps some discussion between us would be worthwhile.

McCormack: Yes, we've tried to keep track of the work you are doing there, as well as Union Carbide's work at Paducah. They have a smelter there that they have been using on nickel; we've been in contact with them for the last few years. We've done some smelting of lead at the INEL for the same purpose, so we want to have some discussions and keep track of what you are doing, because we are very interested in that--especially for our D&D operations. This process is mainly for the buried waste that we have rather than the classical D&D of going in and dismantling a reactor facility. We are going to D&D the burial ground, and it is a little different than the classical D&D waste. It is more like cleaning up the soil in the Marshall Islands.

# 15. CLEANUP OF BUILDING 3019 AND SURROUNDINGS AT ORNL FOLLOWING PLUTONIUM RELEASE OF NOVEMBER 20, 1959

John R. Parrott, Sr.
Oak Ridge National Laboratory
Oak Ridge, Tennessee

A non-nuclear explosion involving an evaporator occurred in a shielded cell in the Radiochemical Processing Pilot Plant at Oak Ridge National Laboratory on November 20, 1959. Plutonium was released, probably as an aerosol of fine particles of plutonium oxide, via three principal routes:

1. Cell ventilation system: collected about 1.5 g, completely removed from the air stream by roughing and absolute filters.
2. The cell door was blown open (but not off) to the outside, releasing approximately 600 mg to a limited area south and east of the building. The Graphite Reactor Building, directly east of Building 3019, was subjected to the highest level of contamination.
3. Pipe passages and service openings through the cell wall resulted in about 70 mg being spread to the building interior.

Building 3019 (Fig. 15.1) was constructed in 1944 to process irradiated uranium "slugs" from the graphite reactor that is located adjacent to the building. The west end of the building contains Analytical Chemistry laboratories and hot cells. The heart of the building is a row of seven remotely operated processing cells, each shielded by either four or five feet of barytes concrete. The explosion occurred in Cell V1, shown in the cutaway view.

Building 3019 is located near the center of ORNL (Fig. 15.2). The building is shown in

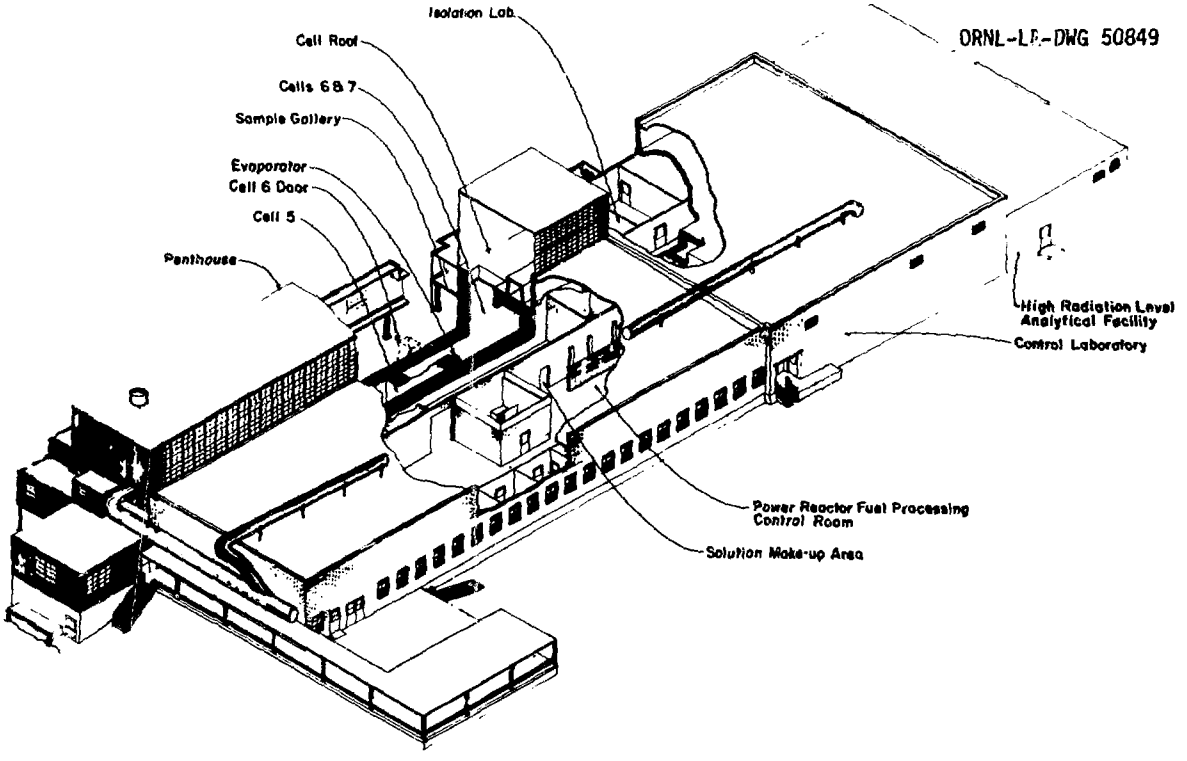


Fig. 15.1. Radiochemical Processing Pilot Plant.

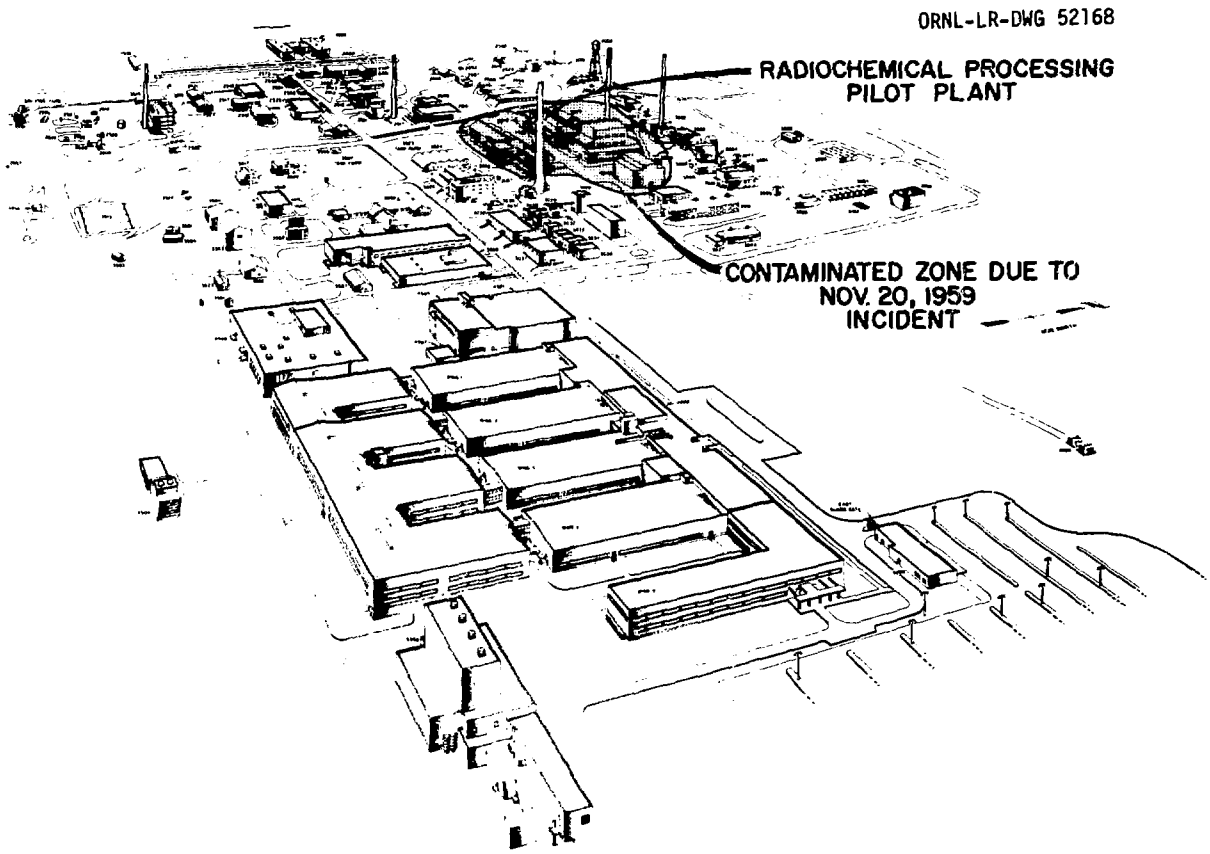


Fig. 15.2. Oak Ridge National Laboratory, X-10 site.

relation to other facilities such as the Building 4500 complex, the Engineering Building, and the Cafeteria. The building we are in now was recently constructed and is located southwest of the Engineering Building. The extent of the contamination to surrounding buildings and areas is shown.

First, I would like to discuss the extent of contamination and the decontamination effort required for resumption of operations.

Figure 15.3 is a cross-section of the facility showing the levels of contamination resulting from the explosion. The distribution of contamination is shown: the highest concentration was inside the cell; the second highest was the area directly above the cell. The level diminished toward the office area.

The required limits for residual decontamination were established as follows:

Table 15.1 Required Limits for Residual Decontamination

| | Direct Reading | Transferable |
|---|---|---|
| Max. | 300 d/m/100 $cm^2$ | 30 d/m/100 $cm^2$ |
| Avg.* | $\leq$30 d/m/100 $cm^2$ | $\leq$3 d/m/100 $cm^2$ |

*Requires a minimum of 10 samples with at least one sample from each square meter of surface.

The only areas which met these limits following decontamination were the office areas.

ORNL-LR-DWG 50851R2

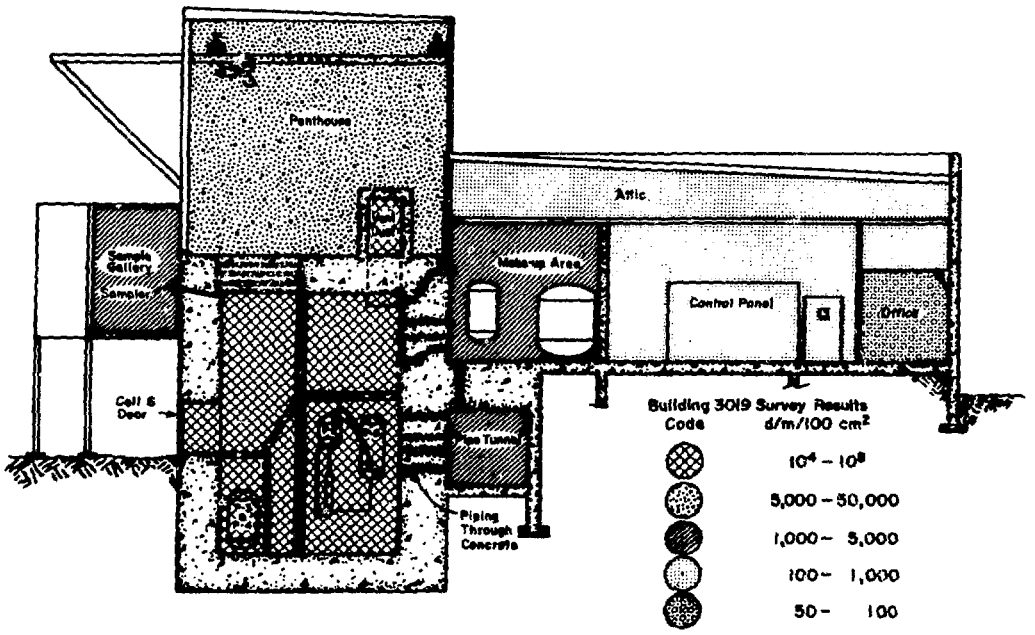


Fig. 15.3. Sectional elevation through cell 6, Radiochemical Processing Pilot Plant, showing inside contamination levels after explosion.

All other areas, except the cells, were decontaminated to a factor of 10 above the limits and repainted with three coats of paint. The first coat fixed the contamination, the second was bright orange in color, and the color of the top coat matched the decor. (When the orange becomes visible, the areas are repainted.)

The most highly contaminated area outside the cells was the area above the cells, an enclosure 165 ft long, 30 ft wide, and 30 ft high. This area was scrubbed numerous times, the existing paint was removed from the ceilings and walls, and abrasives were used on the bare metal walls. After an effort that took 1360 man-days, the area met the limits for painting--using the color-code system. The total effort expended in decontaminating the building, exclusive of in-cell decontamination, was 3000 man-days.

In-cell decontamination was considerably more extensive. The first phase involved the construction of a "greenhouse" or enclosure protruding into the cell directly across from the evaporator. This is the same door which was blown open as a result of the explosion. A view of the greenhouse is shown (Fig. 15.4). Next, a view from inside the cell is shown (Fig. 15.5). From this enclosure, a high-pressure spray jet was directed on the surfaces. Approximately 22,000 liters of a heated detergent solution was applied to the surfaces resulting in the removal of ≈50 g of plutonium; the background in the enclosure was reduced from 400 mR/hr to 60 mR/hr. The solution was collected in an in-cell vessel, sampled for plutonium content, and discharged to the ORNL waste sytem.

The second phase of decontamination involved the removal of debris and concrete blocks from the cell. A view of the cell after the explosion is shown (Fig. 15.6). A different view, taken from a higher elevation, is shown in Fig. 15.7.

The method used to remove the block walls is shown in Fig. 15.8. Two operators in fresh-air suits utilized an elevator to remove the blocks and load them into 55-gal drums. The drums were then wrapped in clean plastic, monitored, and transferred to a truck outside the


Fig. 15.4. "Greenhouse" in 3019 cell.

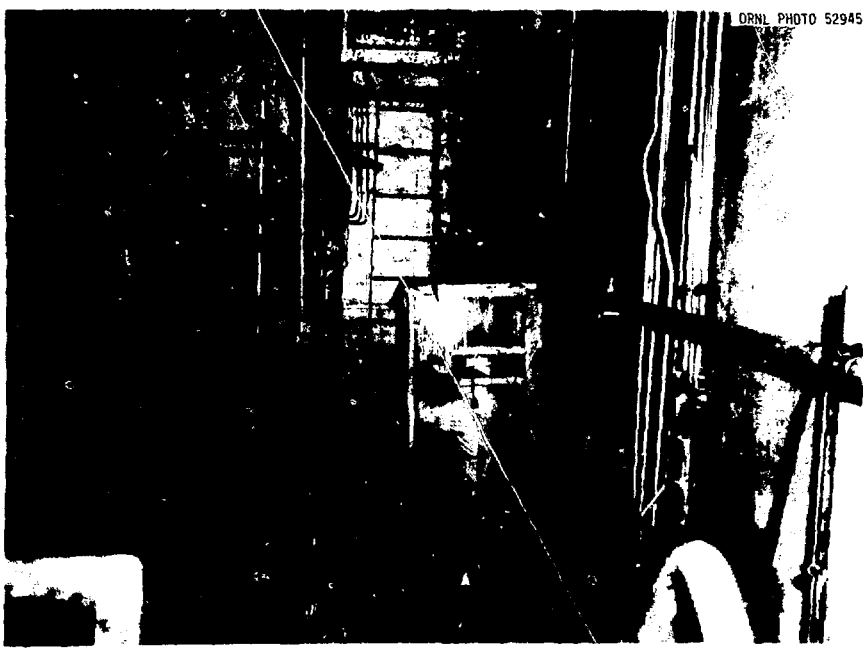


Fig. 15.5. Inside of 3019 cell (during cleanup).


Fig. 15.6. Inside of 3019 cell (immediately after explosion).


Fig. 15.7. Inside of 3019 cell (upper level immediately after explosion).

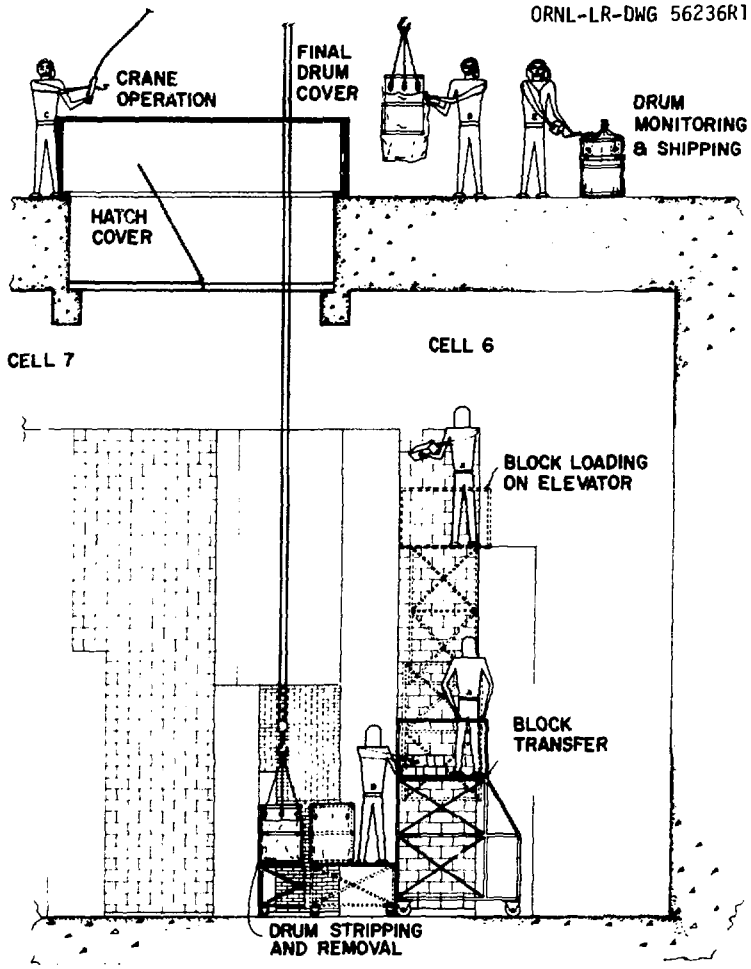


Fig. 15.8. Shielding block removal from cell.

building for transport to the ORNL burial ground.

Following removal of the blocks and debris, the cell was exhaustively flushed from inside by an operator in an air suit, using a high-pressure steam jet. The next figure (Fig. 15.9) shows this operation. The person performing the spray operation was observed by an operator in the greenhouse, and a third operator was standing by to enter the cell in the event of an emergency.

A total of 430,000 liters of solution yielded 141 g of plutonium. The solutions varied from mild detergent to a $HNO_3$-NaF mixture. The final surface contamination, based on selected areas, showed 90% of the smears to contain less than 20,000 dis/min/100 $cm^2$, with the remaining 10% being below 100,000 dis/min/100 $cm^2$. Although the beta-gamma background varied from 50 to 4000 mR/hr with selected areas as high as 20,000 mR/hr, the maximum single exposure received during spraying was 260 mrem, and no individual received more than 1300 mrem in any 13-week period. There were no detectable internal exposures.

The total effort expended in the cell was 3000 man-hours.

The total extent of contamination external to Building 3019 is shown on the next figure (Fig. 15.10). Four other buildings were affected.


Fig. 15.9. Steam jet flushing of 3019 cell.

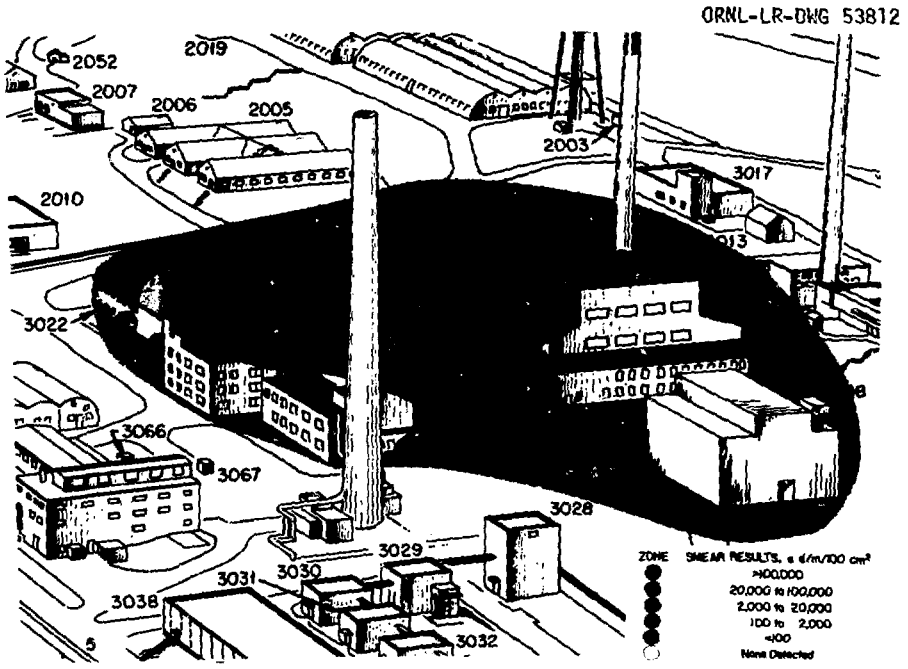


Fig. 15.10. Plutonium fallout zones after explosion.

Building 3022, a wooden Engineering Building, was contaminated on its north side and the roof. These areas were immediately sprayed with enamel paint to fix the contamination. Fourteen window air conditioners were removed from the north side, and a new air supply duct was installed. The building had been scheduled for dismantling before the accident, and later it was razed.

The Solid State Building (3025) roof was coated with aluminum-fiber roofing compound to a depth of 1/4 in. The cooling tower and ductwork atop the building were painted, and the north exterior brick wall was cleaned with detergent and water and sealed with two coats of masonry sealer.

The roof of the Graphite Reactor Building (3001) was coated with aluminum-fiber roofing compound, and all four external walls were repainted the original aluminum color. Approximately 11,000 man-hours were expended in cleaning and repainting the interior of the building to the specifications listed. The Oak Ridge Reactor was immediately shut down, and the building (3042) was cleaned and repainted.

Within two days of the accident, the south side of Building 3019, including the road, ground, two trucks located inside the security fence, and the fence were painted with two coats of white paint. The street and ground were later removed to a 1-in. depth, or to a depth to eliminate any direct-reading alpha contamination, and the material was taken to the burial ground. The streets were later repaved, the white paint was stripped from the building surfaces, and Building 3019 was repainted the original color.

By Monday morning, November 23, 1959, all buildings were open to occupancy except Building 3019. Entry into the Graphite Reactor Building (3001) required shoe covers. Three thousand copies of a printed handout were distributed to incoming personnel on Monday morning. These handouts described the problem and the extent of contamination.

The offices in Building 3019 were reinhabited in six weeks, and complete decontamination was accomplished in nine months--at a cost of approximately $500,000.

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Chester: Are there any questions?

From the floor: Do you have the actual total cost that resulted from the incident?

Parrott: No, the bookkeeping was very poor.

Chester: Or very good.

Parrott: We didn't have the computers running then like we do now. I guess that a half-million dollars is probably right if you rule out the cost of all the operating people who performed the actual decontamination during the year. And that probably would run another half-million. My own guess is that a reasonable number would be about a million dollars. This is the strangest thing in the world: it has been 20 years, and this is the first time we've ever been asked to give a paper or present it. There are some published reports on it. It is nothing that we've covered up--just that there has seemed to be no interest in it.

Chester: This is a common problem. If you are trying to determine decontamination costs, there is no documentation of costs. In fact, it is just the reverse: after an incident like this, everyone tries to hide the cost.

Parrott: We have very detailed costs on man hours to do certain jobs. We did keep very good records of that, but how it affected other operations and what the total cost was, is hard to say.

From the floor: From your diagram, apparently there was a mixture of both asphalt surfaces and grass surfaces. You mentioned what you did with the asphalt surface; but what did you do with the contaminated soils that obviously had to be decontaminated?

Parrott: We actually took off the top inch--or in some places two inches--of soil, grass and topsoil. We took it to our shale burial ground, packaged it up, buried it, and brought in new topsoil.

Chester: John, you didn't mention the dump truck that was parked there.

Parrott: I didn't mention that there were two trucks parked outside. There is a security fence behind the building, and there was an acid truck and a dump truck that were parked outside. They were both painted in this mass painting and were later taken to the burial ground. The acid truck was decontaminated successfully. The dump truck, a couple of years ago, was still out at the burial ground. Still painted white.

From the floor: Do you think you got all the contamination when you removed that one inch of soil? In other words, is there any left?

Parrott: Yes we did; we monitored as we removed it. We had 15 health physicists monitoring continuously as they took the soil up, and we removed it until the monitors registered no detectable activity.

From the floor: Okay, have you monitored recently--with the sophisticated techniques available today?

Parrott: No, we haven't. We have not been able to detect any leaching from the soil.

From the floor: Could you calculate the efficiency of removal by the rainfall? In other words, what was it before it rained and then what level did it get to after it rained?

Parrott: We did not have a good data base before the rain came. It was just hit-and-miss, because we only had one day. It was the second night, on Saturday, when it began drizzling rain. Fortunately, it didn't rain too long, so we do know that the rain did a good job where we hadn't already painted. In fact, we had people painting in the rain--trying to paint before the rain. I'm sure the rain did a pretty good decontamination job for us on what we had missed with our other methods.

Chester: Thank you very much, John. That was a very interesting experience, and it was along the line of a situation you would have in an urban environment if you had an accident that involved a built-up area.

# 16. SURFACE SOIL CONTAMINATION STANDARDS FOR ROCKWELL HANFORD OPERATIONS

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The 200 Areas of the Hanford site contain soils contaminated with levels of radioactivity ranging from fallout concentrations to levels requiring radiological controls. Some contamination is more or less uniformly distributed, and some occurs as discrete specks or spots of activity.

In recent years, there has been a great deal of emphasis on cleaning up the site and decontaminating surface areas. Surface soil contamination limits for radioactive materials are needed--below which posting, restrictions, and environmental controls are not necessary. Contamination standards are also needed to determine if solid waste or other material is contaminated relative to disposal requirements.

The literature was reviewed to determine if standards applicable to the Hanford site have already been developed. Most references on contamination standards deal with surface contamination on equipment or in buildings. The standards contained in the German Radiation Protection Act of October 1976 are examples.[1]

Shiager[2] and others have done a great deal of work relative to radium in soils and contamination associated with uranium mill tailings. The U.S. Environmental Protection Agency (EPA) has proposed a radium standard of 5 pCi/g.[3] Goldsmith[4] contends that a radium-226 concentration of 0.5 pCi/g is acceptable. Standards for transuranics in soil have been developed by the EPA,[5] and Healy[6] has proposed a standard of 100 pCi/g for plutonium. Previous literature on contamination standards is discussed and referenced by Dickson.[7] It is clear from a review of this literature that specific soil standards applicable to Rockwell Hanford Operations (Rockwell) are not available.

## SCOPE

Because of the acute need for standards, the Rockwell Environmental Protection (EP) Group proceeded to develop standards; these were approved by Rockwell in October 1979. It must be emphasized that these standards are only applicable to the 200 Areas of the Hanford site or other areas under Rockwell's jurisdiction. It is assumed that access to these areas will always be restricted and that land-use restrictions will be maintained.

Contamination limits for areas used by the general public would normally be lower than the limits derived in this case. As will be discussed later, it appears that the Rockwell standards divided by a factor of 5 to 10 may be reasonable contamination guidelines for the general environment.

Consideration is given to three types of contamination: (1) average soil contamination, which is contamination generally distributed through a volume of soil, (2) areal contamination, which is contamination confined to a thin area (i.e., less than one centimeter) on the surface, and (3) spot contamination.

## BASES AND CRITERIA FOR STANDARDS

The Surface Soil Contamination Standards developed by Rockwell are intended to give reasonable assurance that current radiation protection standards are not exceeded. Consideration was given to four basic criteria of radiation protection:

External Radiation: The contamination standards are intended to give reasonable assurance that no individual in uncontaminated areas will receive in excess of 500 mrem/yr from external radiation sources.

Ingestion of Radioactivity: The contamination standards are intended to give reasonable assurance that any individual working or digging in uncontaminated areas will not ingest radioactivity that would result in more than 1/10 the maximum permissible body burdens.

Concentrations of Radioactivity in Air: The contamination standards are intended to give reasonable assurance that uncontaminated areas do not produce airborne concentrations of radioactive materials in excess of the limits specified in Department of Energy (DOE) MC 0524 Annex A, Table II.

Concentrations of Radioactivity in Water: The contamination standards are intended to give reasonable assurance that uncontaminated areas would not result in water contamination in excess of the limits specified in DOE MC 0524 Annex A, Table II.

The four criteria above are generally accepted radiation protection standards applicable to the population at large. It is appropriate to base Rockwell standards on external radiation and concentrations of radioactive materials--rather than on dose pathways or health risks--because Hanford is a restricted area and no food crops are grown. Population standards, rather than occupational standards, are used in the development of soil contamination limits, because: (1) no radiological controls for the Hanford population will be imposed on uncontaminated soils, and (2) no restrictions on the migration or use of uncontaminated soils will be imposed.

It is the intent that all of the above criteria be met and that the surface soil contamination standards be based on the most restrictive criterion.

## DERIVATION OF STANDARDS

The four basic radiation protection criteria can be met for each type of contamination by deriving contamination limits in the manner described below and by adopting the most restrictive limit as a standard. Four separate limits for average soil contamination are developed below. These limits are derived from four conditions that may result in human radiation dose: external radiation, ingestion of soil, airborne radioactivity, and radioactivity in water. The most restrictive limit for each radionuclide shall be taken as the average surface soil contamination standard. The average surface soil contamination standard is then used to develop areal contamination standards and spot contamination standards.

### External Radiation

Radionuclide concentrations in soil shall not result in external radiation levels in excess of 50 μR/hr above background anywhere on the contamination. Fifty-seven μR/hr is 500 mR/yr for continuous occupancy, and the 57 was rounded off to 50. It is not necessary to derive specific concentrations of radionuclides that would meet this criteria, provided that a separate external radiation standard of 50 μR/hr be applied simultaneously with other soil contamination standards. Regardless of concentrations of radioactive materials in soils at Hanford, no unrestricted area or uncontaminated area should have radiation levels in excess of this value.

From the floor: Gary, excuse me, would you comment about whether this is above background or is this a gross value?

Boothe: Yes, the intent is that the 50 μR/hr be above background. Background on the Hanford site may run 8 to 10 μR/hr and this is in addition to that.

Concentrations of radioactive material in soil shall not exceed the limit (L) in any of the three equations shown (Fig. 16.1) (i.e., maximum permissible body burden, or concentration of radioactivity in water or in air). Again, you use the most restrictive L as the standard. The rationale and the assumptions used in deriving these relationships will be explained later. In the case of airborne radioactivity, the "R" is a resuspension factor--sort of a measure of the tendency of something to

1. Ingestion (maximum permissible body burden)

$$L = \frac{1/10\ \text{MPBB (pCi)}}{1\ \text{g/day} \times 5\ \text{days/wk} \times 50\ \text{wks/yr} \times 1\ \text{yr} \times 10\%}$$

MPBB = maximum permissible body burden

2. Concentration of Radioactivity in Air

$$L = \frac{\text{MPCa } (\mu\text{Ci/cm}^3)}{\rho\ (\text{g/cm}^3) \times d\ (\text{cm}) \times R\ (\text{cm}^{-1})}$$

MPCa = maximum permissible concentration in air
$\rho$ = density of soil
d = depth from which contamination can become airborne
R = resuspension factor

3. Concentration of Radioactivity in Water

$$L = \text{MPCw } (\mu\text{Ci/cm}^3) \times 10\ (\text{cm}^3/\text{g})$$

MPCw = maximum permissible concentration in water

Fig. 16.1. Limits of radioactive material in soils.

become airborne. I guess it has fallen out of grace recently to use resuspension factors when you are trying to describe a phenomenon or something but for purposes of developing a standard I think it is perfectly all right to use a resuspension factor. In this case, we assumed a resuspension factor of $10^{-8}$ which I think is reasonably conservative.

From the floor: Would you explain the 10 $cm^3$ per gram?

Boothe: What this relationship very simply says is that the concentration of radioactive materials leached out of a soil and in water would be no greater than 1/10 the original concentration of the material in the soil. That is where the 10 comes from. We don't assume a large dilution factor; we are just assuming that water--subsurface water or subsurface water on the Hanford site--could contain as much as 1/10 of the concentrations in soil, where a milliliter of water is equivalent to a gram of solid.

From the floor: What about the factor of 10% in the denominator of the first equation?

Boothe: Well, originally this was 10% retention of the radioactivity, so assume that a man could be working or digging in a contaminated area. He would ingest 1 g of material every day, five days a week, for 50 weeks--for a solid year--and retain 10% of the actual radioactivity that he ingested. That is the 1/10 of the maximum permissible body burden. I think that is a very reasonable, conservative assumption.

From the floor: I think he is asking about the other 1/10.

Boothe: Is that the "ten" you were talking about?

From the floor: No, I was asking about the fact that the second equation has no 10% factor.

Boothe: Why is there no 10% in the airborne equation? Well, why would there be? The reason there is a 10 here [in the first equation] is because we are assuming 10% of the radioactivity is retained. The reason there is a 10 here [the third equation] is because the concentration in water is 1/10 of the concentration in soil, but

there is no reason to use a 10 here [the second equation] anywhere. This equation simply says that the limit for concentration of radioactive materials in soil is a maximum permissible concentration in air divided by the density of soil divided by a distance d (we are assuming d is 1 cm here) and divided also by the resuspension factor of $10^{-8}$.

Maximum Permissible Body Burden (MPBB)

The soil contamination standard shall not exceed L in the following equation:

$$L = \frac{1/10 \text{ MPBB (pCi)}}{1 \text{ g/day} \times 5 \text{ days/wk} \times 50 \text{ wks/yr} \times 1 \text{ yr} \times 10\%}$$

The equation is based on the assumption that an individual may ingest 1 g of contaminated soil each working day for an entire year, and that ten percent of the radioactivity ingested remains in the body. These assumptions are extremely conservative.

Concentration of Radioactivity in Air

The soil contamination standard for a radionuclide generally distributed in soil shall not exceed L in the following equation:

$$L = \frac{\text{MPCa } (\mu\text{Ci/cm}^3)}{\rho \text{ (g/cm}^3) \times \text{d(cm)} \times \text{R (cm}^{-1})}$$

where MPCa is the maximum permissible concentration for the radionuclide specified in DOE MC 0524 Annex A, Table II (Air-insoluble), R is the resuspension factor of the radionuclide, $\rho$ is the density of soil and d is the depth from which radioactivity can become airborne in accordance with the resuspension factor. It shall be assumed that contamination on the Hanford Reservation is insoluble. The resuspension factor shall be assumed to be $10^{-8}$ ($cm^{-1}$). This factor is conservative and is based on the work of Anspaugh and others[8] on the resuspension of plutonium. The density of soil shall be taken as 1.6 g/$cm^3$. The depth, d, shall be taken as 1 cm since it is extremely unlikely that material greater than this depth could become airborne in a short length of time and to the degree indicated by the $10^{-8}$ ($cm^{-1}$) resuspension factor.

It must be emphasized that if resuspension factors are determined to be larger than $10^{-8}$ ($cm^{-1}$) for any 200 Area contamination, the limit derived here must be lowered accordingly. If it is established that the contamination is in soluble form, consideration must be given to the possible increased hazards. This must also be emphasized.

Concentration of Radioactivity in Water

The soil contamination standard shall not exceed L in the equation:

$$L = \text{MPCw } (\mu\text{Ci/cm}^3) \times 10 \text{ (cm}^3\text{/g)}$$

where MPCw is the maximum permissible concentration specified in DOE MC 0524 Annex A, Table II (Water-insoluble). This equation assumes that the concentration of a radionuclide leached out of soil would be no more than 1/10 of the soil concentration and that when the radionuclide is finally imbibed, it is in the insoluble form. This appears to be a reasonably conservative assumption. An alternative procedure would be to assume solubility and a larger dilution factor.

*Areal Contamination*

Much of the contamination in the 200 Areas occurs as thin surface contamination or as specks or spots of radioactivity distributed on the surface. The limits developed for generally distributed contamination are not applicable to such contamination. For example, if contamination were confined to the top millimeter of soil, the average concentration of radioactivity in soil would greatly depend on the depth of the soil sample taken. An areal contamination limit ($pCi/cm^2$) is needed.

Areal contamination standards, rather than average contamination standards, should apply only when concentrations of radioactive materials on a thin surface layer greatly exceed the

concentrations averaged to a depth of one centimeter.

The areal contamination limit must be more restrictive than the average soil contamination limit, because as contamination becomes more concentrated on the surface (higher specific activity), the resuspension factor and relative hazards would increase. The areal limit would also be reasonably consistent and compatible with the average soil contamination limit. That is, for a soil contaminated with the maximum average concentration of a radionuclide uniformly distributed within it, the maximum areal contamination should also be present at some defined depth.

The areal contamination limit can be derived from the average soil contamination limit by multiplying by a suitable safety factor. The actual safety factor should depend on the resuspension factor. As the contamination becomes thinner and thinner, the resuspension factor could get larger and larger. Some average change in the resuspension factor over a given depth is needed.

In view of the above discussion, the areal contamination standard for surface contamination generally confined to less than the top one-centimeter of soil shall not exceed A in the following equation:

$$A = 1/10\ (cm) \times L\ (pCi/g) \times 1.6\ (g/cm^3)$$

where L is the average soil contamination standard, 1.6 ($g/cm^3$) is the density of soil, and 1/10 (cm) is the safety factor. Utilization of this equation is equivalent to the assumption that the resuspension factor for surface contamination could be as high as $10^{-7}$ ($cm^{-1}$). Using the density factor in the equation and defining areal contamination as contamination within the top centimeter of soil makes the areal contamination limit compatible with the average contamination limit. That is, if a soil is contaminated uniformly with L pCi/g, the areal contamination will be L $pCi/cm^2$ down to a depth of one centimeter.

It must be emphasized that if resuspension factors for areal contamination are found to be higher than $10^{-7}$ ($cm^{-1}$) for any 200 Area contamination, the areal contamination limit must be revised.

## Spot Activity

The need for a spot activity standard applicable to the 200 Areas of the Hanford site has been identified. The spot activity standard would reasonably be consistent and compatible with the areal contamination standard. That is, if the maximum areal contamination on a soil was redistributed on the surface as small spots, the maximum spot activity would also be present for some defined area.

Questions arise as to the relative hazards of areal contamination versus spot contamination. Are resuspension factors for both types of contamination the same? Can humans be more easily contaminated from spots or from areal contamination? The answers to these questions appear to be largely unknown, although in the Rockwell Hanford experience spots or specks are generally not easily removable from soils. The answer to the latter questions is inherently linked to the suitable area over which contamination may be averaged. That is, if the spot activity limit was simply the areal limit ($pCi/cm^2$) multiplied by a suitable area, 15 $cm^2$ for example, the assumption would be that 15 $cm^2$ of areal contamination and a small spot of activity represent the same surface hazard relative to potential human exposure. In view of the dimensions of a human being in comparison with the dimensions of 15 $cm^2$, this appears to be a reasonable assumption.

Also, for a probe such as the P-11 (15 $cm^2$ effective area), the areal limit and a single maximum speck under the probe would give about the same readings if a 15 $cm^2$ area is chosen as the suitable area.

In view of the above discussion, the spot activity standards shall not exceed S in the equation:

$$S = A\ (pCi/cm^2) \times 15\ (cm^2)$$

where A is the areal contamination standard. An alternative to the above method of deriving spot

activity limits would be to develop a limit based on the probability of encountering a spot in a given area and the probability of ingesting or inhaling an encountered spot. However, these factors are indeterminate at the present time.

## SURFACE SOIL CONTAMINATION LIMITS

Surface soil contamination limits for selected radionuclides are listed in Table 16.1. The limits listed in the table are the most restrictive limits derived in accordance with the procedures described above. It is the intent that for mixtures of radionuclides, the sum of the fractional limits occurring shall not exceed unity.

It is apparent from the table that the most restrictive criteria for beta and gamma emitters is generally ten times the maximum permissible concentrations listed in DOE MC 0524 Annex A, Table II (Water-insoluble) where a millimeter of water is equivalent to a gram of solid material. The most restrictive criteria for alpha emitters is generally based on Table II (Air-insoluble) values.

It should be emphasized that the external radiation standard of 50 μR/hr (net) must be simultaneously applied with the listed contamination limits to meet all of the radiation-protection criteria specified in this presentation.

Table 16.1. Surface Soil Contamination Limits for Selected Radionuclides

| Isotope | Column I Average Soil Contamination Limits[1] (pCi/g) | Column II Areal Contamination Limits[2] (pCi/cm$^2$) | Column III Spot Activity Limits (pCi) |
|---|---|---|---|
| Cesium-137 | 400 | 60 | 960 |
| Cobalt-60 | 300 | 50 | 720 |
| Hydrogen-3 | 30,000 | 4,800 | 70,000 |
| Iodine-129 | 2,000 | 320 | 4,800 |
| Plutonium-239 | 60 | 10 | 150 |
| Radium-226 | 125 | 20 | 300 |
| Strontium-90 | 400 | 60 | 960 |
| Technetium-99 | 2,000 | 320 | 4,800 |
| Thorium-232 | 60 | 10 | 150 |
| Thorium-230 | 20 | 3 | 45 |
| Uranium-238 | 300 | 50 | 750 |

[1]A suitable mass over which contamination may be averaged must be representative of the contamination (e.g., a 1 kg composite).

[2]A suitable area over which contamination may be averaged shall be 15 cm$^2$.

NOTE: It should be emphasized that regardless of the concentrations of radionuclides in soil, the external radiation rate must not exceed 50 μR/hr anywhere on the contamination.

The soil standards for beta and gamma emitters developed here agree fairly well with the U.S. Nuclear Regulatory Commission's (NRC) exempt concentrations.[9] Although these exempt concentration limits are used for licensing and other regulatory purposes and not as contamination limits, the limits are those below which the NRC has determined no controls are necessary for the protection of the public health and safety.

## WORKING STANDARDS

Working standards can readily be developed from the standards listed in Table 16.2. Time does not allow a discussion of the derivation of working standards. It must suffice to say that the surface soil contamination limits for beta-gamma emitters can be applied using a 200-cpm limit on a GM probe like the P-11 and a uR-meter. The application of alpha standards requires either more sophisticated instrumentation or sampling and analysis.

## COMPARISON OF STANDARDS

It is interesting to compare Rockwell's contamination standards with limits that have been developed by other groups or persons. As emphasized previously, general environmental standards would reasonably be lower than Rockwell standards, since Rockwell standards apply only to Rockwell and the derivation of the standards did not give consideration to foodcrop dose pathways or health risks to the general population.

Assume that general environmental contamination limits could be derived by dividing the Rockwell standard by a factor of 10. Table 16.2 gives a comparison of the reduced Rockwell contamination standards with other recently developed limits. It can be seen that Rockwell's reduced standards for beta-gamma emitters are identical with Texas standards and a little lower than Healy's.[10] Healy assumed various dose pathways in deriving his limits, but Texas and Rockwell did not. Texas did not

Table 16.2. Comparison of Standards

| Isotope | 1/10 Rockwell (pCi/g) | Texas (pCi/g) | Healy (pCi/g) | EPA (pCi/g) |
|---|---|---|---|---|
| Cesium-137 | 40 | 40 | 80 | |
| Cobalt-60 | 30 | 30 | - | |
| Hydrogen-3 | 3000 | 3000 | - | |
| Iodine-129 | 200 | 200 | - | |
| Plutonium-239 | 6 | 30 | 100 | 15 |
| Radium-226 | 12 | 30 | 30 | 5 |
| Strontium-90 | 40 | 40 | 100 | |
| Technetium-99 | 200 | 200 | - | |
| Thorium-232 | 6 | 40 | 20 | |
| Thorium-230 | 2 | 30 | 280 | |
| Uranium-238 | 30 | 40 | 40 | |

consider the airborne hazards of alpha emitters, and this explains why Texas alpha limits are higher than Rockwell's reduced limits.

The Rockwell reduced standard for radium-226 does not consider radon buildup in structures whereas the EPA limit does.

Rockwell's thorium-230 reduced standard is lower than the plutonium-239 and appears to be too restrictive in that it is very close to background concentrations. This suggests that it may be more reasonable to divide general environmental limits. This would make Rockwell's plutonium-239 reduced standard closer to the EPA's plutonium limit and also closer to Healy's alpha limits.

It appears that areal contamination limits and spot contamination limits for the general environs could be identical to the Rockwell standards because these limits already have a safety factor of 1/10 relative to average soil contamination standards.

The external radiation limit for the general environment would reasonably be 1/10 of Rockwell's 50 μR/hr, or 5 μR/hr. This limit would apply regardless of the concentration of radionuclides in soils or on soil surfaces.

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# 17. SOIL SURFACE DECONTAMINATION AND REVEGETATION PROGRESS

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I will discuss briefly the type of work that we are doing at Rockwell Hanford Operations (Rockwell) related to large-area decontamination efforts. We have at Rockwell a Program Office which manages the decontamination and decommissioning (D&D) efforts. Part of the program is involved with large-surface area cleanup in conjunction with surveillance and maintenance of retired sites and facilities. The other part is the decontamination and decommissioning of structures. Today I will talk basically about the large-surface area cleanup work.

There are 322 surplus contaminated sites and facilities for which Rockwell has responsibility on the Hanford Site. There is a total of nearly 400 for all contractors at the Hanford Site; nationally there are over 500. So a good fraction of those are a part of Rockwell's responsibility. Rockwell has set up a Program Office for a disciplined approach to cleanup of these retired sites. There are three major projects: the first is surveillance and maintenance of the sites prior to D&D, the project under which the radiation area cleanup is contained. Another project is for contaminated-equipment volume reduction; we are looking at a size reduction with arc saw cut-up and volume reduction with a vacuum furnace meltdown. The third major project is structural D&D.

I'd like to talk first about the surveillance and maintenance of contaminated inactive facilities (Fig. 17.1). The first objective of this project is to prevent the spread of contained radioactive contamination in the inactive facilities prior to D&D. This includes structures and outdoor sites such as burial grounds, ponds, cribs, and ditches. To stabilize or reduce surface areas of these contaminated, inactive, outdoor sites is the second or sub-objective; this includes our radiation area cleanup project. The third objective is to maintain inactive structures prior to D&D.

OBJECTIVES

- PREVENT SPREAD OF CONTAINED RADIOACTIVE CONTAMINATION IN INACTIVE FACILITIES
- STABILIZE AND REDUCE THE SURFACE AREAS OF THE CONTAMINATED INACTIVE OUTDOOR SITES
- MAINTAIN THE CONTAMINATED INACTIVE STRUCTURES PRIOR TO DECONTAMINATION AND DECOMMISSIONING

Fig. 17.1. Surveillance and maintenance of contaminated inactive facilities.

In addition to the D&D Program, which has responsibility for these 322 retired sites, there are other sites that are currently active which require the same kinds of controls. Rockwell is doing the same type of general cleanup in those. In the Rockwell portion of the Hanford Site, we have about 2500 acres of posted controlled area (Fig. 17.2). There are 260 acres of ponds and ditches and 455 acres of liquid waste disposal sites, comprised of cribs and trenches. There are also 190 acres of solid-waste disposal sites, the burial grounds themselves, for a total of 3405 posted acres under Rockwell surveillance and maintenance control. As stated in the second objective, Rockwell does have a concerted effort to reduce the acreage of posted-surface contamination areas. Within this near-term effort, we are not exhuming the waste per se, so we are not getting rid of the subsurface contamination or the radionuclides, but we are trying to reduce the controls necessary on the surface. After the surface is cleaned to the working limits that Gary Boothe described in the previous talk, the surface is posted as

| | ACRES |
|---|---|
| POSTED CONTROLLED AREA | 2,500 |
| PONDS AND DITCHES | 260 |
| LIQUID DISPOSAL SITES | 455 |
| SOLID DISPOSAL SITES | 190 |
| TOTAL | 3,405 |

Fig. 17.2. Radiologically controlled areas.

"buried radioactive materials" instead of "surface contamination." This posting will then allow limited access to these surface areas.

An example of the terrain in eastern Washington is shown in Fig. 17.3. The climate is semiarid, and we're not concerned with a lot of brush or stands of native vegetation. One of the problems with large-area surface cleanup is that you denude the land and, with the kinds of winds we have in eastern Washington, soil transport results. So in our overall approach, techniques we consider must perform some type of surface stabilization, once we have completed the contamination surface cleanup.

The next figure (Fig. 17.4) shows the projects Rockwell has completed to date. The accomplishments listed have been made over the past 20 years; as long as there has been a nuclear industry, there has been site cleanup.

| | |
|---|---|
| **PAST ACCOMPLISHMENTS** | |
| • FOUR DRY POND SITES | 50 ACRES |
| • MISCELLANEOUS TRENCHES | 200 FEET |
| • MISCELLANEOUS CRIBS | 1 ACRE |
| • THREE SOLID WASTE DISPOSAL SITES | 5 ACRES |
| • MISCELLANEOUS SITES | 10 ACRES |
| **CURRENT ACCOMPLISHMENTS** | |
| • TRENCHES AND BERM | 1,500 FEET |
| • FOURTEEN CRIBS | 4 ACRES |
| • SIX SOLID WASTE DISPOSAL SITES | 60 ACRES |
| • MISCELLANEOUS SITES | 1 ACRE |

Fig. 17.4. Surface cleanup projects completed.

In the past, when situations occurred where contamination was released, the objective was to clean it up and get on with business but not to document what was done. When you review the past cleanups in an attempt to determine what

Fig. 17.3. Example of the terrain in eastern Washington.

was done and how, you must look through notes and logbooks and talk with the old-timers; the information is not archived. I think this is one of the important underlying points this workshop addresses: the fact that you need information. We talked about as-built drawings in a couple of previous discussions. As-builts are essential, but you can't always trust them. As an industry, we should not perpetuate this lack of information by continuing without documentation.

Back to the figure: the best that we can determine from our old records for past accomplishments is that we have gone through surface cleanup and release of about 50 acres in four dry ponds. In miscellaneous trenches that lead to the ponds, we have cleaned up about 200 linear feet. These trenches are anywhere from 5 to 20 feet wide, they have been filled in and have surface contamination. After the surface was cleaned up, we installed a biobarrier (because we didn't exhume the radionuclides), added clean soil, then released the surface.

In the past, we've surface-stabilized an acre of miscellaneous cribs. We have three solid-waste disposal sites that we've cleaned up and released--five acres of surface. The last entry under past accomplishments is for miscellaneous sites, which in our nomenclature are called "unplanned releases." An "unplanned release" is an accidental spill, one that could occur, for example, when a pipe breaks. The area involved is posted and given a site designation number. We've cleaned up ten acres of this kind of surface area and subsequently removed the surface control requirements.

Since 1977 when we established our D&D Program Office, we've accomplished a little more. We have cleaned up 1500 feet of trenches and berms and 14 different crib surface areas totalling four acres; we have released from surface controls six solid-waste disposal sites, a total of 60 acres; and we cleaned up one acre of miscellaneous sites.

Now, I'll present some photographic evidence of what we've been doing in the field. The main purpose is to provide the context from which the next two Rockwell presentations derived information. Jim Toomey will be talking about the specific surface decontamination techniques and the planning approaches we utilize. I'll give you a preview of our depth of experience--the type of work we are doing--which should add some credentials to what we are presenting today.

An example of trench and berm cleanup is shown in the next photograph (Fig. 17.5). The berm runs alongside the ditch that takes outfall

Fig. 17.5. Trench and berm cleanup.

or effluent from the laundry. The trench is mucked out on a periodic basis and the soil is put on the surface, creating a berm. There is contamination in the soil that is put on the berm. The top surface is stabilized, but the berm has radioactivity in it. So we've had a project whereby we removed 1500 feet of the contaminated berm, placed it in trucks, and moved it to a burial ground. All the contaminated soil from the berm is now in an administratively controlled and managed burial ground. Jim Toomey will go into some detail on this in his presentation.

The next three photographs show some work we did on cribs. These cribs took liquid effluent, leached the radionuclides out, and allowed the liquid to go down into the soil. The first photograph (Fig. 17.6) shows the original vent pipes in one of the crib complexes that we cleaned up. We removed all the vent-pipe risers, removed the surface contamination, installed a biobarrier consisting of herbicide and a plastic sheet membrane, put clean fill over the top, then revegetated with cheat grass--one of the native grasses there. The second photograph (Fig. 17.7) shows the stand of grass we had the following year. We have reposted all our sites this past year, and one of the new posting designations is for "buried radioactive material." This new posting is used when the surfaces are clean but there is subsurface contamination or buried radionuclides. The third photograph (Fig. 17.8) shows the good stand of mature vegetation we now have after two years. The purpose (once again) for revegetation is to stabilize the surface so that we're not spreading the soil across the countryside.

The next figure (Fig. 17.9) shows one of the two major burial grounds we've worked on during the last year. We've set up an in-field test parameter study on biobarrier systems using two existing burial grounds. We've worked closely with Battelle Northwest Laboratories in developing these systems. In one burial ground we stabilized the burial-ground trenches, decontaminated the surface, put in clean topsoil, and revegetated. The area of the burial ground is about 20 acres. On the upper left is an aerial view of the burial ground before any cleanup work was done. The upper right shows the burial ground after the trenches were stabilized. (I'll get into that process briefly on the next burial ground.) After we stabilized the trenches, we added clean soil to the burial ground and regraded it. The lower aerial view shows the type of semiarid terrain and the sandy soil in which we work.

The second burial ground has biobarriers installed. We are using the first burial ground as a control and the other one as a biobarrier installation site. We are testing five different parameters on this burial ground: thickness of plastic sheeting, type of herbicide, depth of soil fill over the plastic, and different types

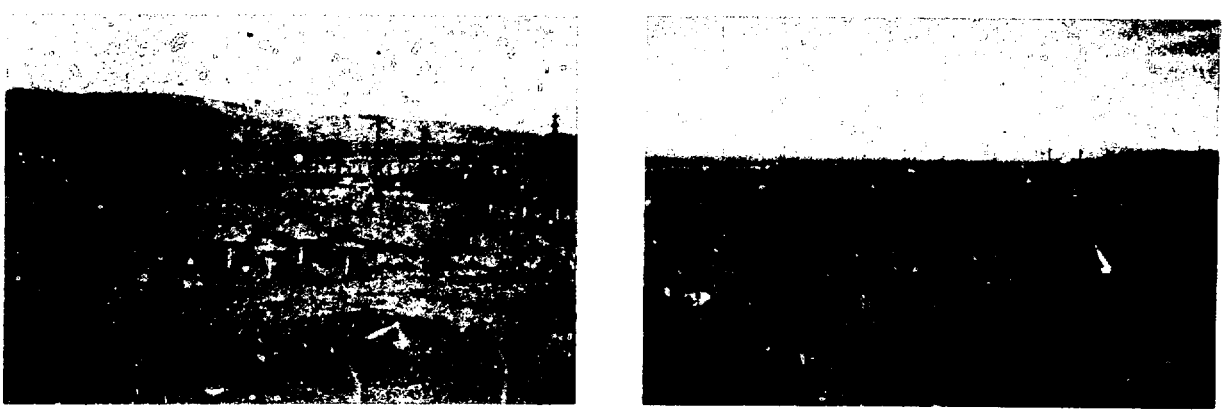

Fig. 17.6. Crib complex before cleanup.

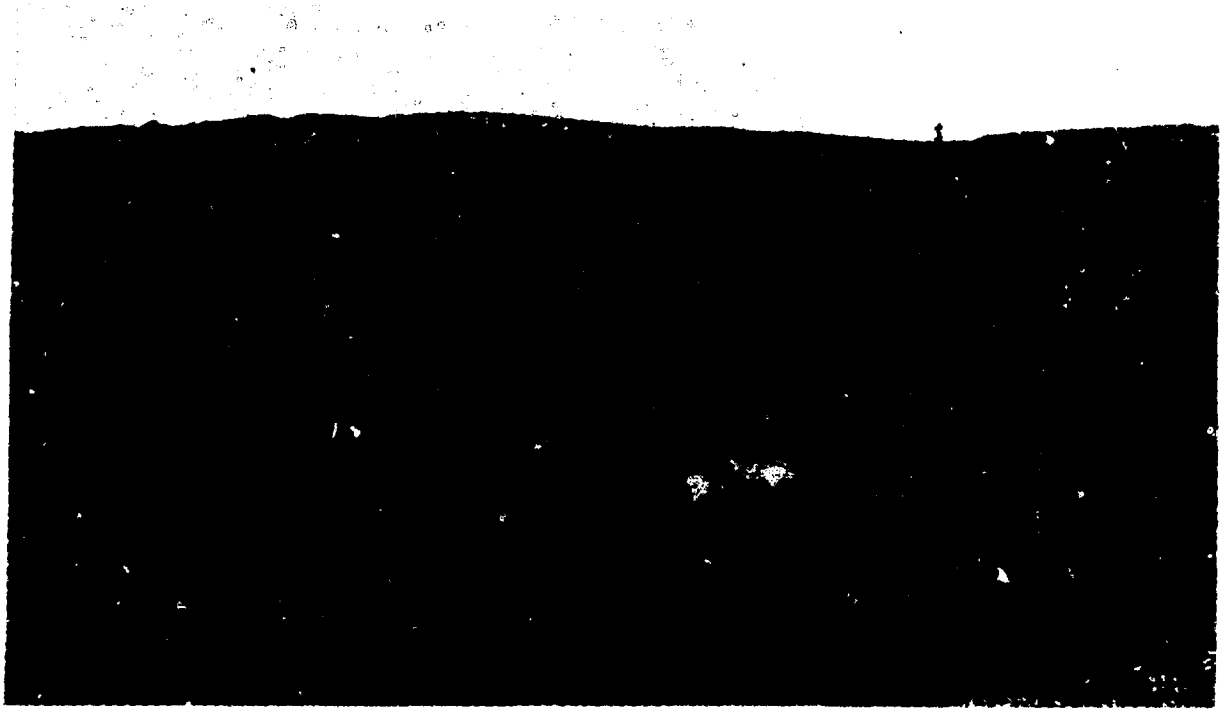

Fig. 17.7. Crib complex one year after cleanup.

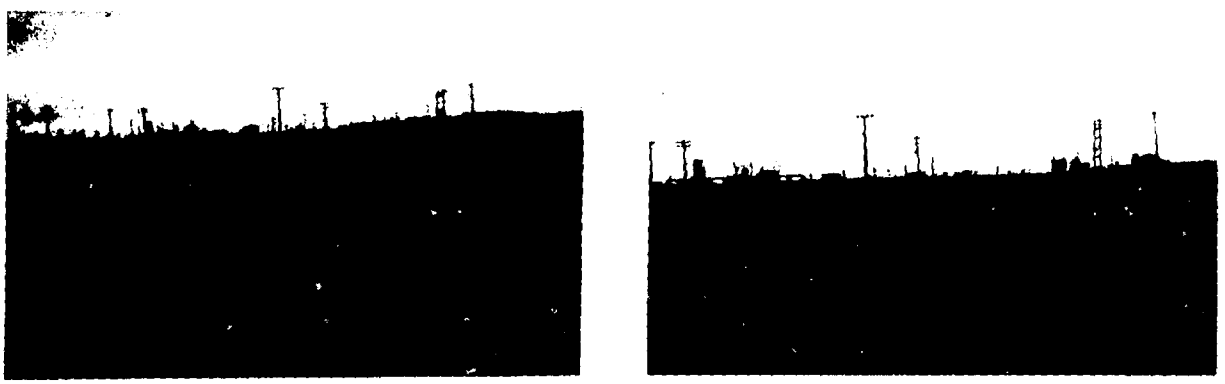

Fig. 17.8. Crib complex two years after cleanup.

of vegetation, as well as different initial watering schedules to get primary vegetation germination.

The first photographs (Figs. 17.3 and 17.10-17.13) in the series for the second burial ground show what we had to do to stabilize the burial ground trenches. Burial ground stabilization became necessary because we were experiencing subsidence (cave-ins). When the waste was buried years ago, the restrictions weren't quite as stringent as they are now. Some of the wooden boxes in which this waste was buried had a lot of void spaces and over the years there were some cave-ins. We first made aerial photos of the site to identify where the access roads were, using old site drawings and data. Then we staked the burial ground to identify access roads between trenches (Fig. 17.3). These are the V-trenches put across the terrain. The narrow staked spacing is the access road or

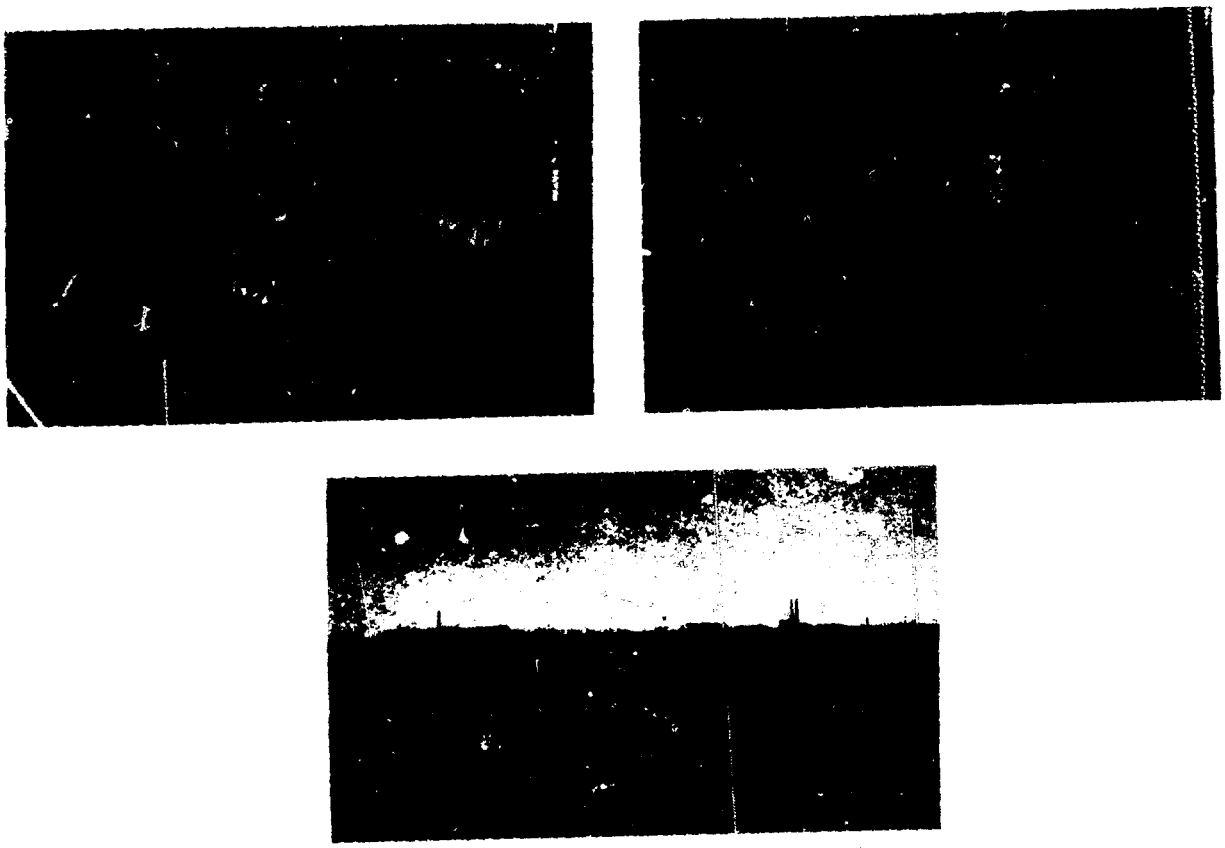

Fig. 17.9. First burial ground operation.

Fig. 17.10. Second burial ground, showing cave-ins.

Fig. 17.11. Earth movers at second burial ground.

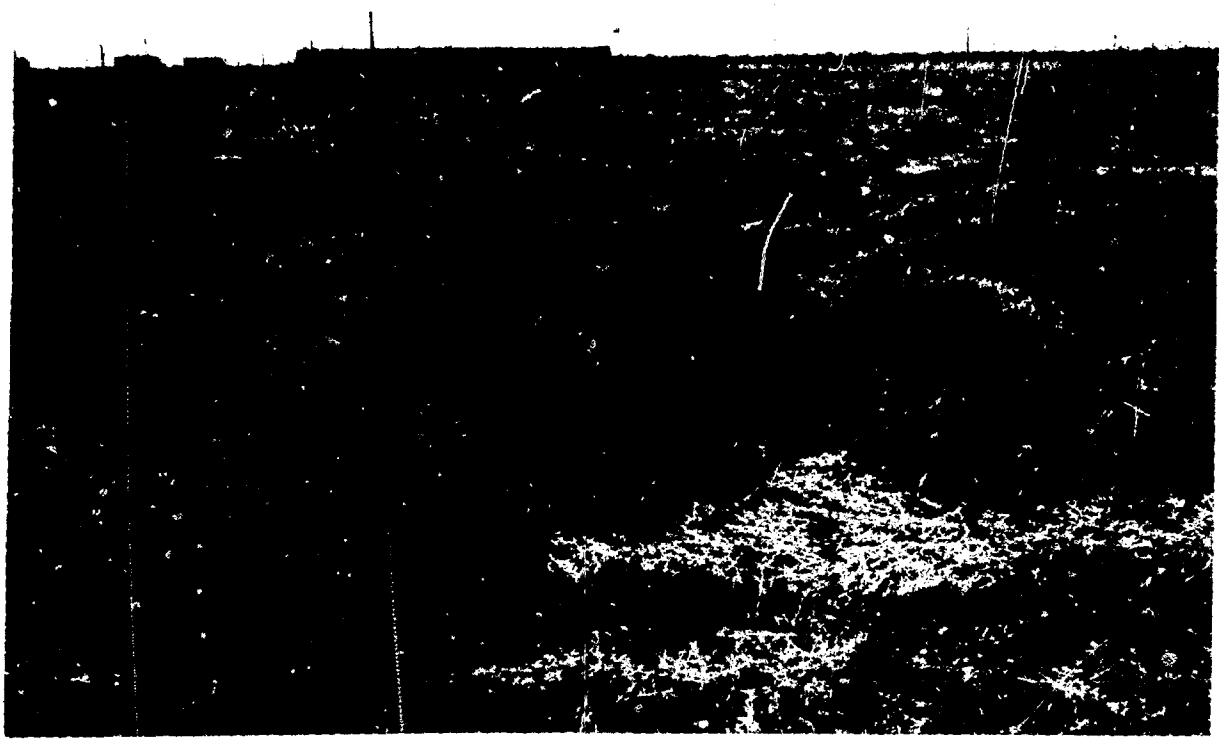

Fig. 17.12. Stabilized surface at second burial ground.

Fig. 17.13. Second burial ground after all trenches have been traversed.

undisturbed soil between the trenches, and the wider staked spacing is the burial V-trench. The access roads between trenches provided for the heavy equipment which supported the burial operations. The next photo of the series (Fig. 17.10) shows the types of subsidence we ran into. With a cave-in, the ground just collapses away. This makes it difficult to do semiannual radiation audits or surveys, because it is dangerous for the people to go onto the burial grounds. That creates a situation where we can't even take current data in some of the burial grounds. The solution is to stabilize these. In the next photo (Fig. 17.11) we take the big scrapers, fill them full of dirt, and traverse all the trenches; cave-ins are triggered by the high surface loading pressure. Once we trigger a cave-in, we then drop the load of dirt from the scraper into the void. After the dirt has been put down, we grade the surface as shown in the next photo (Fig. 17.12). This photograph shows where we have taken the equipment and tamped the filled cave-in. So now the subsidence is filled in and that particular spot is stabilized. The last photograph of this series (Fig. 17.13) shows what the burial ground looked like after the trenches had been completely traversed. We ran the 22-yard scraper filled with dirt traversely across the trenches to trigger all cave-ins and firm up the whole site.

The next series of photos shows the type of operation that would be necessary when there is a large-scale decontamination. If it is large-scale and there is a lot of surface to clean up, heavy construction equipment will be used. This photograph (Fig. 17.14) of the burial ground shows the gravel strips which are over the access roads. We ballasted the access roads with gravel, removed vegetation, and graded over the trench areas with clean fill after they had been stabilized. The next photos show the types of equipment that we are using. This one (Fig. 17.15) shows the big belly loader, the 22-yard scraper, bringing in soil. In soil removal, the operation would be similar. The graders then

Fig. 17.14. Gravel strips between trenches in second burial ground.

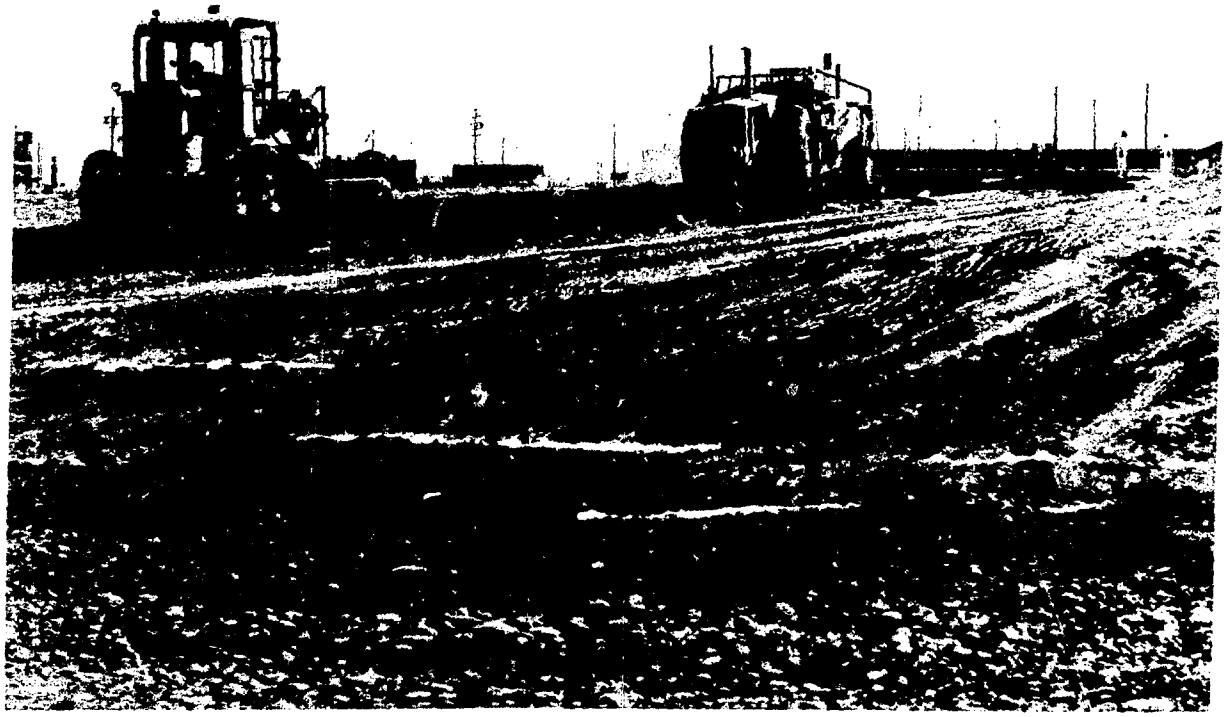

Fig. 17.15. Scraper used in filling burial grounds.

level out the soil. The following photo (Fig. 17.16) shows the intermediate step used where we have put down a herbicide and then have applied a plastic sheet (biobarrier). On top of the plastic film, soil is brought in with the large scraper. The photograph shows the soil being brought in by the scraper and the operators spreading out the plastic.

The next photo (Fig. 17.17) shows the requirement for the use of water. When moving a lot of soil in a semiarid environment you have the airborne dust problem. We have to use the large construction-type equipment: I believe this was a 9000-gallon, road-construction-type water system. We had to continually apply water to the area where we added soil and to the areas where we obtained the soil, to keep the dust levels down.

This photo (Fig. 17.18) shows an agricultural type of operation, applying the seed and a herbicide. The next photo (Fig. 17.19) is a composite of the final operations. The upper left-hand corner shows the burial trenches all brought up to grade with the biobarrier systems installed and the ballasted roadways between. In the upper right photo is the straw mulcher application. After the seed is applied, we put down a straw mulch to prevent weather-caused erosion or dispersion which will remove soil and seed. Once the straw mulch is applied, a crimping operation is performed (in the lower left-hand photo) which is similar to a disking operation using a zero rake angle on the disk. This operation forces the straw down into the soil to give mechanical protection against the wind. The bottom right photo shows a view of a trench with all surface stabilization complete, including the straw crimping. That surface is now stabilized against weather erosion while the seeds germinate. This last photographic group in this series (Fig. 17.20) shows the general system: the upper left-hand corner before we started work, the upper right-hand corner during the process of applying the plastic, the lower left in applying the fertilizer, and, in the lower right, the stabilized site.

Fig. 17.16. Installing biobarrier.

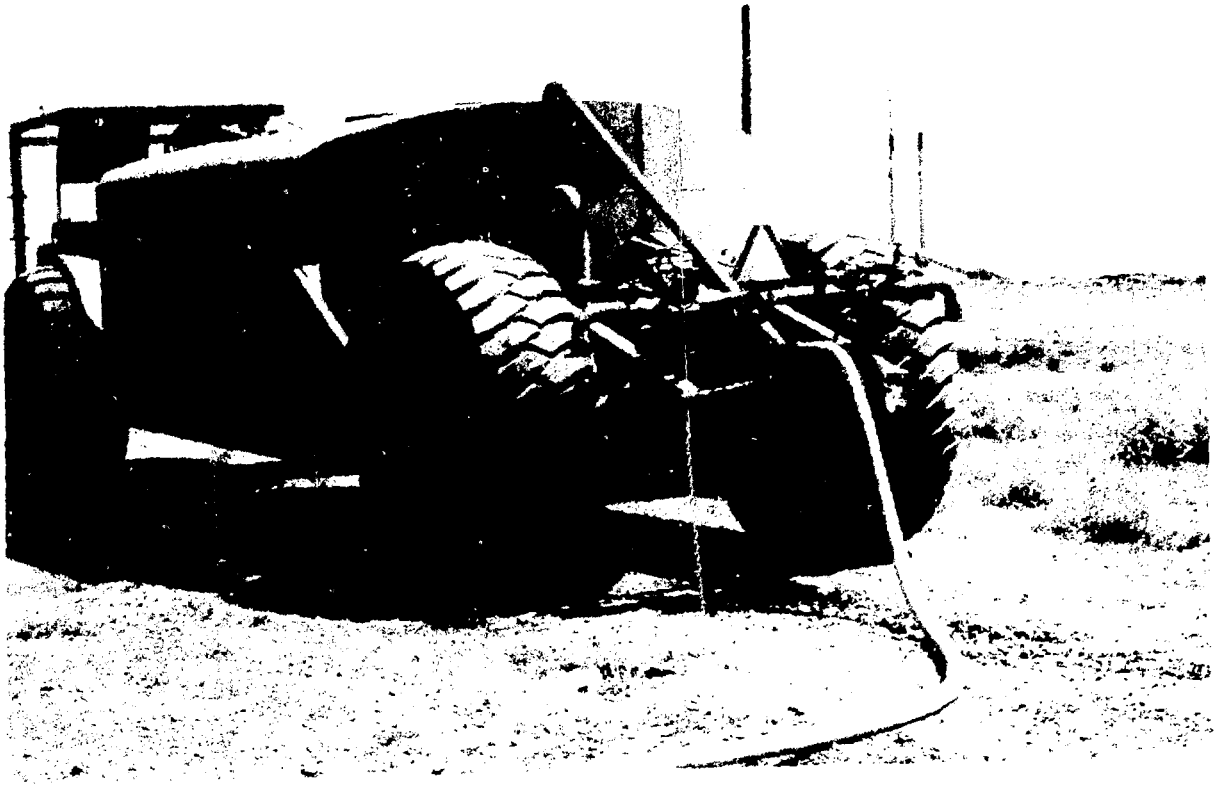

Fig. 17.17. Dust control using 9000-gal water system.

Fig. 17.18. Applying seed and herbicide.

Fig. 17.19. Final operations.

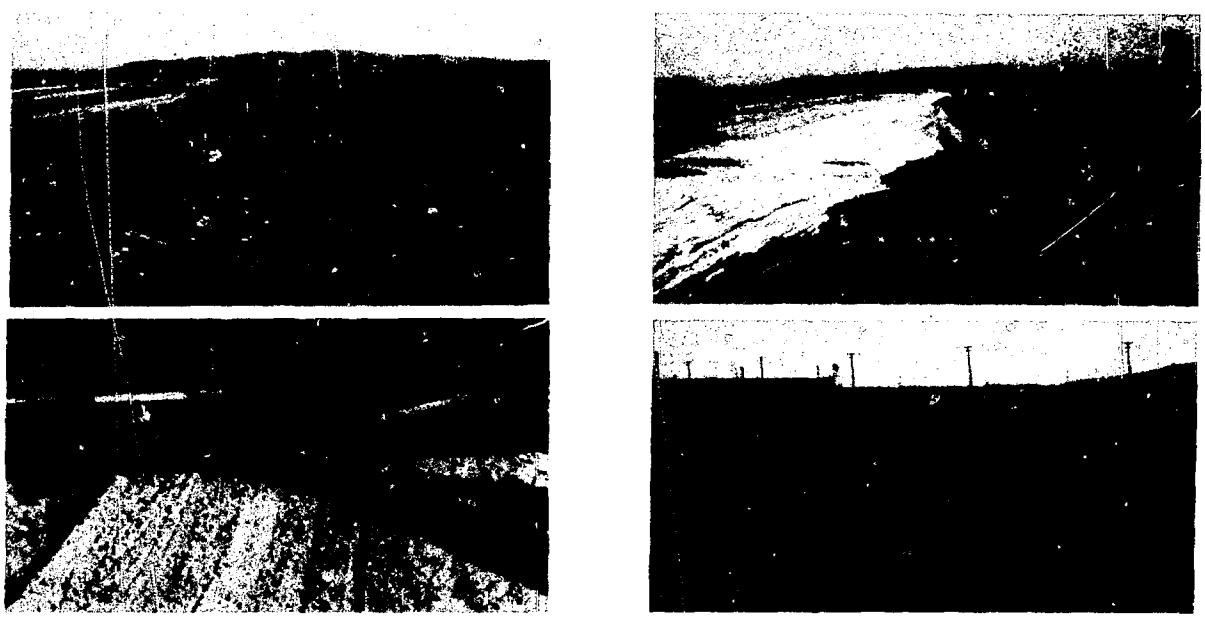

Fig. 17.20. General surface stabilization system.

The following photographs show what we do on a miscellaneous site. This was the site of an unplanned release. We had an underground pipe break, and the contamination in the soil worked up to the surface. We used smaller-scale but still large equipment to decontaminate and stabilize the surface. We used a dump truck and front-loader and excavated down to about two feet (Fig. 17.21). Clean soil was added, and in this case we used gravel to stabilize the surface. We used road graders (large equipment) to spread the gravel (Fig. 17.22). The finished effort is shown in Fig. 17.23. This site is no longer posted for surface contamination: it is now posted as "buried radioactive material." We have stabilized a surface, in this case using gravel instead of vegetation.

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From the floor (Church): Have you fellows considered concrete for surface stabilization?

Graves: Yes, we have, and Rockwell's charter has two facets: one is the long-term stabilization of outdoor radiation areas and the other is a near-term engineering effort for radiation area reduction. My efforts are in looking at the near-term or tens-of-years. We're trying to take an approach that is reversible, in that if our technique for tens-of-years doesn't match exactly the long-term technique, we haven't lost anything: we have bought time. We are trying to buy time as inexpensively as possible but to stabilize the surfaces as well. Concrete, over long periods, will tend to break up; we do have examples of that out in the field.

From the floor: Does Rockwell have standards for identifying burial trench locations?

Graves: Yes, absolutely. We have a Rockwell standard that applies markers after burial trench locations have been surveyed. There is a Hanford specification--they are concrete posts about 8 inches in diameter, and 6 feet long. They are buried 3 feet in the ground. Each has a brass identity placard and also carries the U.S Survey Coordinates on it.

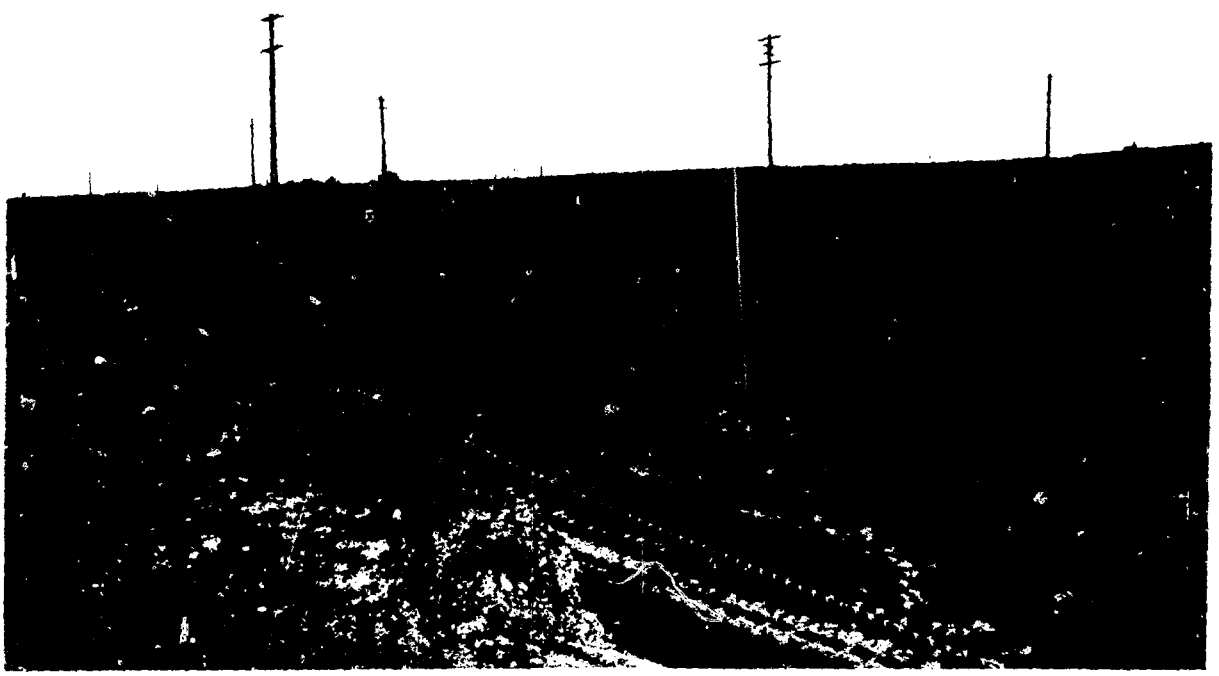

Fig. 17.21. Cleanup of unplanned release.

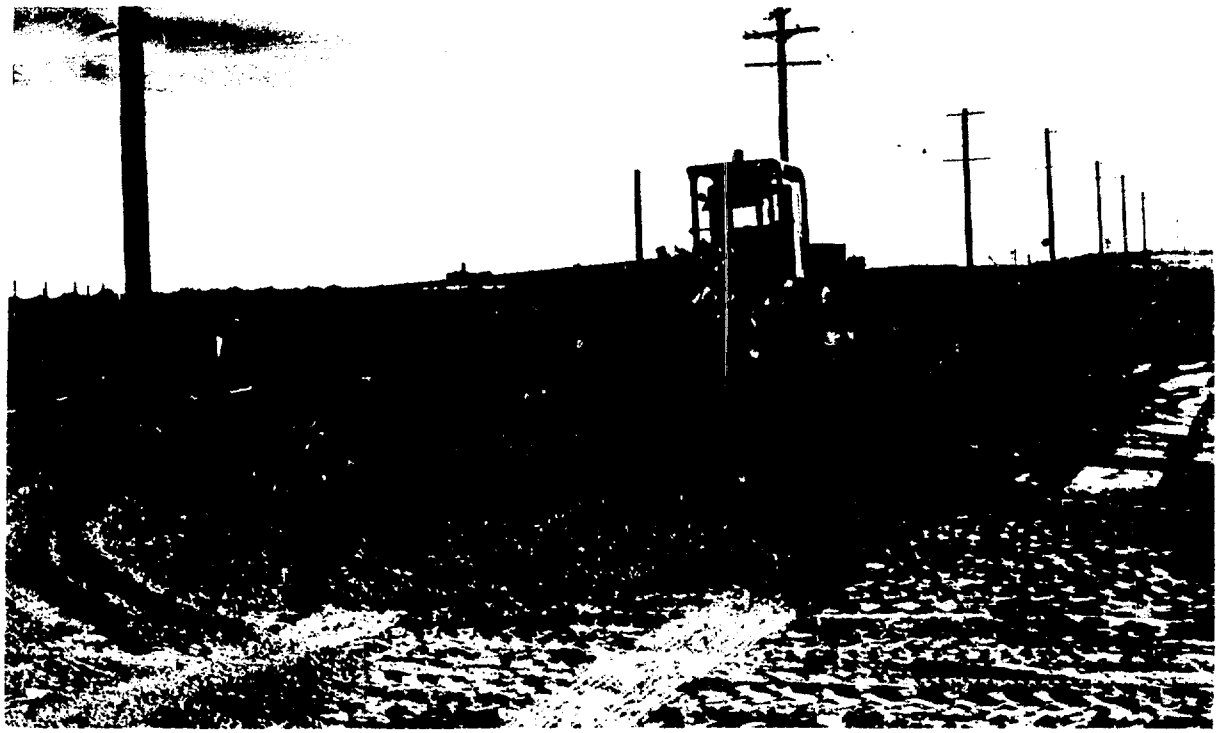

Fig. 17.22. Spreading gravel on soil surface.

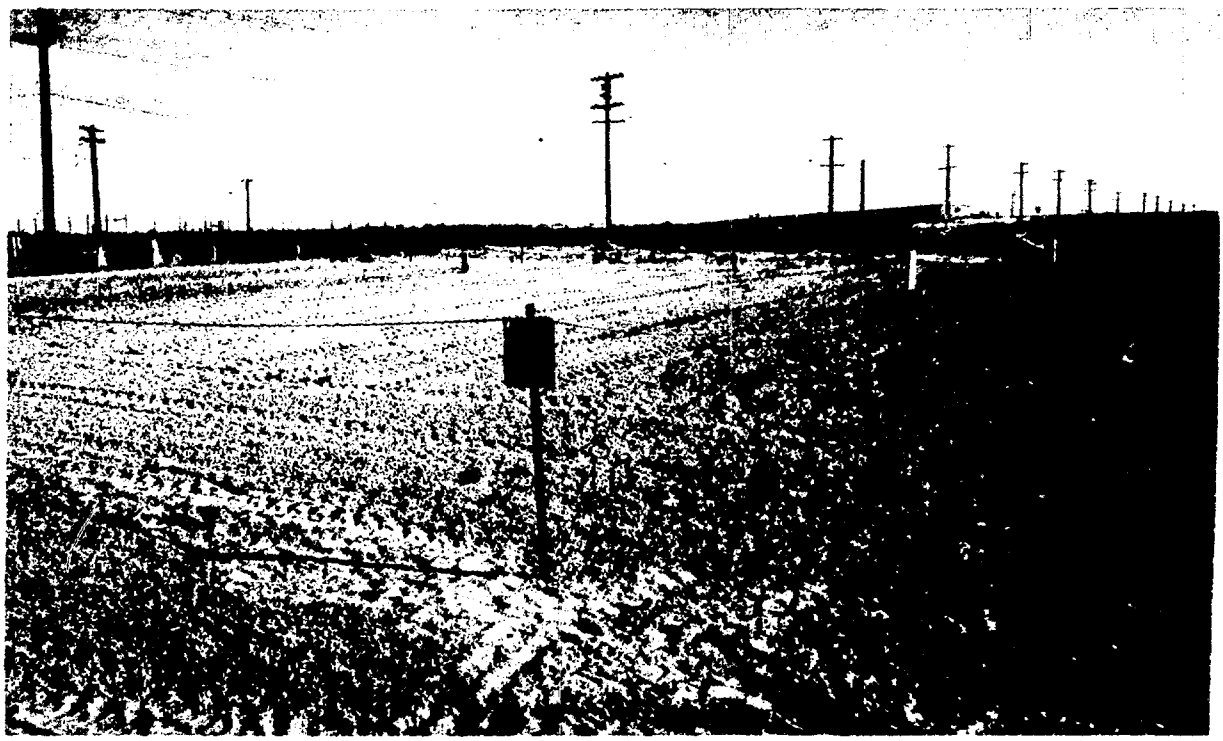

Fig. 17.23. Decontamination and stabilization of surface completed.

The posts are installed on the centerline of all the burial trenches. We have about 5,000 markers to be installed and have started the permanent installation.

From the floor: I think that is an excellent idea.

Graves: One of the things that we are also doing is upgrading as-built site drawings. Archives in the past haven't been too good, but we are not perpetuating [illegible] error.

From the floor (John Jay): When you clean up a large area, to what depth do you go, and what do you do with the soil? Where do you put it? How do you handle the soil that you remove?

Graves: Well, in the major burial ground that we have started right now we had low spots, so we moved the contaminated soil over the low spots. In that particular site we won't have to remove any of the contaminated soil, in that we have buried radioactivity already present. We've added nominally two feet of soil above the plastic-and-herbicide system, that is, six inches of sand above the plastic to give mechanical protection, then 18 inches of soil. We do have, as one of our test parameters, the evaluation of one foot of fill over the plastic sheet versus two feet of fill and how it affects the revegetation success. The soil from the laundry berm was moved to a burial trench, since that area was not intended to be a waste disposal site.

From the floor (Ahlquist): In the picture of the man doing the seeding, it appeared that he was wearing anticontamination clothing. Was he doing that for a reason?

Graves: Yes, because of the toxic nature of the herbicide. The clothing provided respiratory and skin protection against the possible toxic effects of the herbicide itself. That is part of our procedure.

From the floor: Do you input your concrete marker post locations into a central state or other regional coordinate recording system?

Graves: I honestly can't answer that question. Sounds like a good idea; that is one of the things I will follow up on when I get back. We are upgrading the H-4 Hanford Site drawings, though.

# 18. PROJECT PLANNING APPROACH

James E. Toomey
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Richland, Washington

In this presentation I will discuss the project planning approach utilized by Rockwell Hanford Operations in our outdoor cleanup activities (Fig. 18.1). The discussion will address the rationale and requirements, as well as a description of the planning documents. In addition, a recommended adaptation of this approach to a large-scale environmental cleanup process will be described.

ROCKWELL HANFORD OPERATIONS
PROJECT PLANNING APPROACH

* REQUIREMENTS
* DOCUMENT DESCRIPTIONS
* IMPLEMENTATION

Fig. 18.1. Project planning approach.

The three major elements of Rockwell Hanford's project planning approach are assignment of responsibilities, development of applicable criteria, and alternatives identification, assessment and recommendation (Fig. 18.2). Data gathering and data management are also necessary elements to complete the planning.

REQUIREMENTS

* ASSIGN RESPONSIBILITIES
* IDENTIFICATION/DEVELOPMENT OF APPLICABLE CRITERIA
* IDENTIFICATION/SELECTION OF ALTERNATIVES
* DATA GATHERING
* DATA MANAGEMENT

Fig. 18.2. Requirements of project planning approach.

Specific planning documents that are used at Rockwell Hanford are divided into two major areas: control plans and project plans (Fig. 18.3).

The control documents will be discussed first. The next figure (Fig. 18.4) illustrates each specific control document and the content.

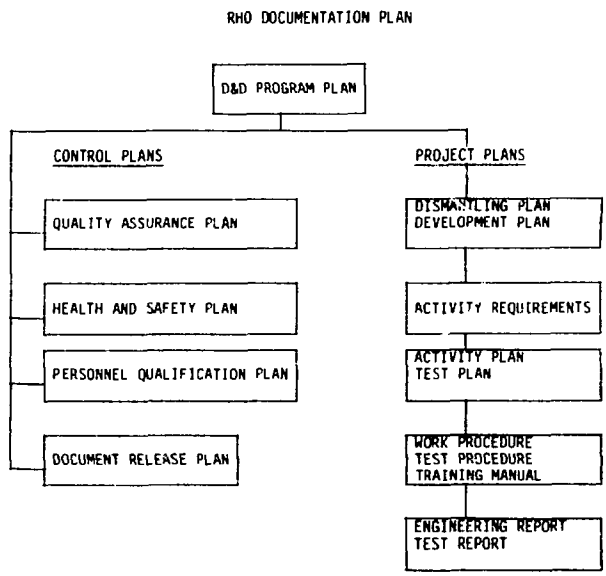


Fig. 18.3. Documentation plan.

* QUALITY ASSURANCE PLAN

  IDENTIFIES THE QUALITY ASSURANCE REQUIREMENTS ASSOCIATED WITH ALL PHASES OF THE DECONTAMINATION AND DECOMMISSIONING PROGRAM

* HEALTH AND SAFETY PLAN

  DESCRIBES THE GENERAL INDUSTRIAL HYGIENE, INDUSTRIAL SAFETY, AND RADIATION SAFETY REQUIREMENTS FOR THE DECONTAMINATION AND DECOMMISSIONING PROGRAM

* PERSONNEL QUALIFICATION PLAN

  ESTABLISHES THE GENERAL PERSONNEL QUALIFICATIONS REQUIRED FOR THE DECONTAMINATION AND DECOMMISSIONING PROGRAM AND THE REQUIREMENT FOR SPECIFIC TRAINING PLANS FOR EACH PROJECT

* DOCUMENT RELEASE PLAN

  ESTABLISHES THE REQUIREMENTS GOVERNING THE PREPARATION, IDENTIFICATION, AND RELEASE OF DECONTAMINATION AND DECOMMISSIONING DRAWINGS, SPECIFICATIONS, AND SUPPORTING DOCUMENTS

Fig. 18.4. Control document requirements.

The quality assurance plan addresses standard quality control requirements. Most important, when coupled with the document release plan, these two control documents address the management of field data. Responsibilities and control for specific pieces of data would be delineated and agreed upon prior to accumulation of the first piece of data.

The health and safety plan delineates the general industrial hygiene and safety requirements for the program; it would take the national standards and criteria and put these into site-specific, working-level criteria. This plan is the primary interfacing document between national and local criteria and standards.

Next, the personnel qualification plan: This delineates the general training required of personnel engaged in a program, as well as the requirements for special training growing out of any unique operations or conditions that will be encountered. In the case of a large-scale decontamination project, this plan may become a generalized requirements document, as opposed to one that addresses specific training. Delineation of training authority would be a minimum requirement of this document.

The next figure (Fig. 18.5) delineates the project documents. The dismantling plan describes the specific facility, or work you are going to accomplish, as well as delineating a tentative sequence. The major function of the dismantling plan is to break the project into major activities or work elements. The next series of documents are the activity requirements and activity plans. Activity requirements fulfill a similar need that is met by functional design criteria in an engineering design. An activity requirements document would be written for all of the major work elements defined in the dismantling or project plan. As in functional design criteria, an activity requirements document states the objectives, or endpoints, and the resources required to accomplish a specific major work element or activity.

* DISMANTLING PLAN

  DESCRIBES THE FACILITY, OVERALL PLAN, TENTATIVE DISMANTLING SEQUENCE, COST AND SCHEDULE, AND IDENTIFIES THE MAJOR ACTIVITIES WITHIN THE PROJECT.

* ACTIVITY REQUIREMENTS

  DEFINES THE GENERAL REQUIREMENTS FOR ACCOMPLISHING A MAJOR TASK OR ACTIVITY, INCLUDING SCOPE AND DESIRED ENDPOINTS. IDENTIFIES KNOWN RESOURCES, REFERENCE DATA, APPLICABLE TECHNOLOGY, AND CANDIDATE PROCESSES, EQUIPMENT OR DEVELOPMENT; PRESENTS REQUIREMENTS FOR A PRELIMINARY ENGINEERING EFFORT.

* ACTIVITY PLAN

  IDENTIFIES THE REQUIRED WORK PROCEDURES, PROCESS DEVELOPMENTS, OR DEVELOPMENT TESTING NECESSARY TO COMPLETE AN ACTIVITY; IDENTIFIES THE SCOPE, ENGINEERING AND SUPPORT, AND THE SCHEDULE AND RESOURCE REQUIREMENTS TO ACCOMPLISH THESE EFFORTS.

* WORK PROCEDURES

  PROVIDES DETAILED INSTRUCTIONS NECESSARY TO PERFORM SPECIFIC TASKS: INCLUDES RADIATION WORK PROCEDURES, PRECAUTIONS, NOTES, AND IDENTIFIES HAZARDS; PROVIDES A CHECKLIST TO INDICATE COMPLETION OF EACH STEP AND IDENTIFIES HOLD-POINTS AS REQUIRED.

Fig. 18.5. Project document requirements.

The planning document that logically follows the activity requirements is the activity planning document. This document starts with what is known and the objectives specified in the requirements document and sets forth what has to be done to reach the stated objective. The end product of an activity plan is a work procedure. This is the piece of paper put into the individual's hand that states in a step-by-step manner what is to be done.

The next figure (Fig. 18.6) identifies initial planning steps that could be accomplished. These are steps to generate management control plans delineating responsibilities. The second step is a breakdown of major tasks, and the third is establishment of endpoint criteria for site cleanup.

RECOMMENDED PRE-PLANNING

* MANAGEMENT AND CONTROL PLANS
* BREAKDOWN OF MAJOR TASKS
* ESTABLISHMENT OF END POINT CRITERIA

Fig. 18.6. Recommended pre-planning for outdoor cleanup activities.

The next figure (Fig. 18.7) shows a planning or readiness checklist that Rockwell Hanford uses for its facility D&D programs. This is the management oversight risk tree (MORT) method. MORT is utilized by the nuclear industry for the purposes of accident investigation. The system provides an extensive list of questions that one asks in the planning phases of a project. MORT is oriented towards construction projects, but adaptations for environmental projects are totally feasible. This particular system may prove to be a beneficial and desirable method to direct planning efforts.

The next figure (Fig. 18.8) presents the steps that would be implemented in the event of an incident. The first response is to implement the management and control systems. The next step is to collect pertinent data, radiological and non-radiological. If data gathering and data management are addresssed as major activ-

* IMPLEMENT MANAGEMENT AND CONTROL SYSTEMS
* DEFINE AND SCOPE IMPACT OF PROBLEM
* COLLECT PERTINENT DATA
* GENERATE WORK PROCEDURE

Fig. 18.8. Incident response.

MANAGEMENT OVERSIGHT AND RISK TREE (MORT) READINESS ANALYSIS

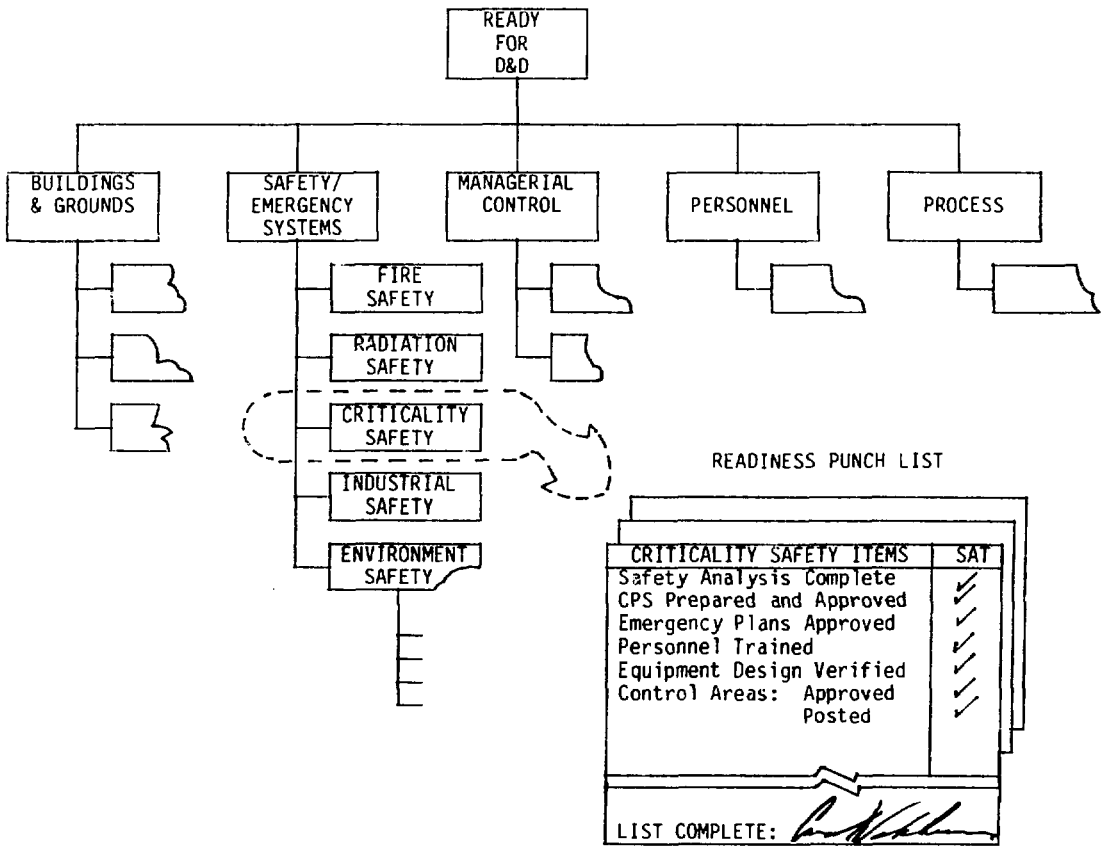


Fig. 18.7. Readiness analysis used.

ities, responsibilities could be fully delineated and understood by the appropriate people. The next step is to fully define the problem and its impacts. This is the decision-making that is accomplished as a direct result of identifying and gathering sufficient data. The final step is the generation of procedures for recovery from the incident.

Dup

# 19. METHODS AND COSTS FOR SOIL REMOVAL

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Rockwell Hanford Operations
Richland, Washington

I represent the engineering organization at Rockwell Hanford; I will discuss methods utilized in the surface stabilization of our outdoor radiation areas. For the purposes of this paper, I have divided the work into three major tasks: soil transport, surface preparation, and surface stabilization.

The first figure (Fig. 19.1) summarizes the methods and equipment utilized for the soil transport task. The first is a shovel-and-box method. The one piece of equipment utilized in this method is a dump truck, which is used to transport the soil (that has been picked up and boxed) to the disposal site. The number of personnel required in this method is listed on Fig. 19.2 and includes the person actually using the shovel, the one packaging the soil in the box, and a supervisor. Excluded from the count is radiation-monitoring coverage. This coverage is required for all of the contaminated soil removal methods discussed in this paper. The second method of soil transport is the dump truck. The first piece of equipment listed on the summary figure (Fig. 19.2) is the water

ROCKWELL HANFORD OPERATIONS

RADIATION AREA REDUCTION METHODOLOGY

SOIL TRANSPORT
- MANUAL
- SCRAPER
- DUMP TRUCK

SURFACE PREPARATION
- HERBICIDE
- SEEDING

SURFACE STABILIZATION
- MULCHER
- CRIMPER

Fig. 19.1. Summary of methods and equipment for soil transport.

SOIL TRANSPORT
EQUIPMENT/PERSONNEL USAGE

| | SHOVEL & BOX | DUMP TRUCK | SCRAPER |
|---|---|---|---|
| WATER TRUCK | | X | X |
| SCRAPER | | | X |
| DUMP TRUCK | X | X | |
| FRONT LOADER | | X | |
| PUSH CAT | | | X |
| PERSONNEL | 2 | 7 | 3 |
| SUPERVISION | 1 | 2 | 2 |
| RADIATION MONITOR REQUIRED | | | |

Fig. 19.2. Equipment and personnel usage for soil transport.

truck: its purpose is dust abatement and control. The soil removal and transport operation is accomplished with the front loader placing dirt in the dump truck. Three persons are required to operate the equipment and four to package the material in the dump truck and to operate water hoses for contamination control. At Rockwell Hanford, there are two crafts involved with this work. Both crafts are required, by labor agreement, to have in-field supervision. This brings the number of personnel involved to a total of nine. Again, radiation monitoring is required, because this work deals with contaminated material.

The third method of soil transport is the scraper. As in the dump-truck method, a water truck is required for dust abatement. The scraper itself moves the dirt to the site, where it will be spread by either a push cat or by a road grader. This method utilizes a total of

three people on the equipment and two supervisors. The multi-craft rule applies in this operation the same as in the dump-truck method. Radiation monitoring is also required if the operation is taking place in an area of known or potential contamination.

The next figure (Fig. 19.3) gives a comparison of the rates of soil transport for the three methods, limitations of the operations, and areas where the methods are applicable. The term "turn-around distance" is the physical distance the scraper or dump truck must travel to deliver its payload and return. The yards of soil removed or delivered during any given day of operation depend on the distance that the equipment must travel. The scraper has a limited capability to transport contaminated soil, due to the physical size and the near impossibility of eliminating loss of contaminated material during transport.

Consequently, a prime use of the scraper is in the transport of clean backfill. The scraper method also requires large areas to be effective, because the piece of equipment is large and has limited maneuverability. The dump truck has a much lower rate of soil transport, but it is a primary method of transporting contaminated material. At Rockwell Hanford, the damp contaminated soil placed in a dump truck is fully enveloped in plastic wrap and covered with canvas to prevent loss of the material enroute to the disposal site. The main use of the dump-truck method at Rockwell Hanford is for area cleanup operations. "Heavy equipment" is listed as a limitation of both the scraper and the dump truck. This is to highlight the absolute requirement for an effective maintenance program to keep operations moving: nothing shuts down operations more quickly than downed equipment. The impacts and costs of this down time cannot be taken lightly. The rate of soil transport by the shovel-and-box method is considerably lower than that of the other two methods. However, if specky contamination can be specifically located

| | SCRAPER | DUMP TRUCK | SHOVEL & BOX |
|---|---|---|---|
| RATE | 600 $YD^3$/DAY/SCRAPER (AVERAGE) | 55 $YD^3$/DAY/TRUCK (MAXIMUM) | 1 $YD^3$/DAY/SHOVEL |
| LIMITATIONS | LIMITED TRANSPORT OF CONTAMINATION | RATE DEPENDENT UPON TURN-AROUND DISTANCE | SLOW<br>LABOR INTENSIVE |
| | RATE DEPENDENT UPON TURN-AROUND DISTANCE | DEPTH ACCURACY, $\pm$ 6 INCHES | |
| | EFFECTIVITY DEPENDENT ON AVAILABLE SPACE | HEAVY EQUIPMENT | |
| | DEPTH ACCURACY $\pm$ 6 INCHES | | |
| | HEAVY EQUIPMENT | | |
| USES | LARGE AREAS | AREAL CONTAMINATION | KNOWN LOCATION OF SPECKY CONTAMINATION |
| | MOST SUITABLE FOR CLEAN BACKFILL | | SMALL AREA WHERE PRECISION IS IMPORTANT |

Fig. 19.3. Comparison of soil transport methods.

or if the area is a small one where precision is important, this method becomes more feasible.

The second major task in the environmental stabilization work at Rockwell Hanford is surface preparation. The elements of surface preparation and the equipment and personnel requirements are listed in the third summary figure (Fig. 19.4). Herbicide application is specific to a technique utilized at Rockwell Hanford.

There are similar equipment requirements for the fertilizing and seeding process. Two specific pieces of equipment, the disc and the drag, would be used if the seeds required burial in the soil as opposed to broadcasting on the surface. There are commercially available seed drills which provide flexibility and assurance of seed depth. The disc/drag method used at Rockwell Hanford performs the same function as the seed drill. The disc is a standard farm disc used to put furrows in the soil for seed burial. The drag is a section of chain link fence that performs quite well as a piece of equipment to cover the seed.

The rates and limitations for the surface preparation processes are listed on the fourth summary figure (Fig. 19.5). Note that the rates of operation are observed rates. These particular elements of the Rockwell soil stabilization process were accomplished during slack periods; consequently, it is felt that the observed rates are far from being maximum values. It is estimated that progress in excess of twenty acres per day is a realistic planning number. The main limitation in the seeding operations is the type of seed. As seed types and shapes vary, the ease with which they can pass through the seed spreader varies. The schedule impact of stuck seed dispensers is minimal. One thing that is mandatory is to insure that the seed type selected is fully compatible with existing environmental and local soil conditions.

The third and final task to be presented is surface stabilization (Fig. 19.6). Work elements and required equipment and personnel are listed. The mulcher is a piece of machinery that "sprays" straw out of a nozzle onto the ground surface. The crimper is a piece of rolling machinery similar to a sheep's foot that physically pushes the straw into the soil. This operation holds the surface of the soil in place until seed germination has taken place. The high number of people (seven) required in the mulching operation is necessary to feed the hay

SURFACE PREPARATION

| | HERBICIDE GRANULAR | HERBICIDE SPRAY | FERTILIZING | SEEDING |
|---|---|---|---|---|
| TRACTOR | X | | X | X |
| SPREADER | X | | X | X |
| SPRAY RIG | | X | | |
| DISC | | | | X |
| DRAG | | | | X |
| PERSONNEL | 2 | 3 | 3 | 3 |
| SUPERVISION | 2 | 2 | 2 | 2 |

Fig. 19.4. Summary of surface preparation process.

SURFACE PREPARATION

| | HERBICIDE GRANULAR | HERBICIDE SPRAY | FERTILIZING | SEEDING |
|---|---|---|---|---|
| RATE* | 4 ACRES/DAY @ 500 LBS/ACRE | 4 ACRES/DAY | 3 ACRES/DAY | 3 ACRES/DAY |

LIMITATIONS - SEEDING RATES WILL VARY WITH SEED TYPES

OPERATIONS WERE CONDUCTED ON AN AS AVAILABLE BASIS
CAN EXPECT RATES ON THE ORDER OF 20+ ACRES/DAY

*OBSERVED RATES

Fig. 19.5. Surface preparation processes, rates and limitations.

SURFACE STABILIZATION

| | MULCHING | CRIMPING |
|---|---|---|
| FLATBED TRUCK | X | |
| MULCHER | X | |
| CRIMPER | | X |
| TOW VEHICLE | | X |
| PERSONNEL | 7 | 1 |
| SUPERVISION | 2 | 1 |

Fig. 19.6. Surface stabilization task.

SURFACE STABILIZATION

| | |
|---|---|
| RATE* | 2.25 ACRES/DAY @ 60 BALES /ACRE |
| LIMITATIONS | MULCH AVAILABILITY/PROXIMITY |
| | NOT GOOD ON STEEP HILLSIDES |
| | HIGH WINDS WILL DISPERSE MULCH MATERIAL |
| USES | HOLD SOIL PENDING SEED GERMINATION |

*OBSERVED RATES

Fig. 19.7. Surface stabilization, rate and limitations.

to the mulcher. The last figure (Fig. 19.7) delineates the rate and limitations of this task. The main limitations are availability of mulch material and difficulty of dispersing in high-wind conditions. Approximately 60 bales of mulch material per acre were required at Rockwell Hanford, and the specific truck used to feed the mulcher was stacked with only 10 bales per load. The main consumer of time became the loading of the truck with the bales of material.

---

Chester: We have time for a minute's worth of questions.

From the floor (Henningson): Have you made any provision in these decontamination procedures for discouraging burrowing animals from getting in and disturbing the surface cover? Have you devised a way to eliminate that as a

way of opening up these areas to future exposure?

Toomey: Yes, there are some ways which are effective: one of them is to put cobbles on the surface. That is a particularly expensive one and it has some poor spinoffs. One thing we do is to generate what we call a monoculture. If cheat grass is the only thing that is on the surface, who wants it? So it is sort of a spin-off of our particular operations. It was discussed with our biological people beforehand, because burrowing animals are a very definite and critical pathway to get things to man and we found this to be a spinoff benefit from our particular stabilization approach.

From the floor (Church): You are right; that is a real problem. One way that we have tried to combat that is through depth of over-burden, so that you have plenty of room for the burrowing animals. We don't have to have any vegetation on our desert to get them. But I was going to ask you, is there any pesticide barrier that you put down?

Toomey: It has been considered and there was a rodent control program. But if you will look at what we are dealing with--essentially with Mother Nature--you can see that you are never going to win. If you start a pesticide program, it has to continue forever. Because if you go after rodents, something else is going to be affected. I am not smart enough to say what is going to be effective, and I'm not sure that anything short of a $5 million project is going to determine what is going to be effective. So we're trying to limit the maintenance require-ments after our stabilization is completed. I wouldn't say that pesticides are ruled out, but they have been downgraded as a solution.

# 20. ATOMICS INTERNATIONAL'S RECENT DECOMMISSIONING EXPERIENCE*

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A program for decommissioning eight nuclear facilities has been underway by the Atomics International (AI) Division of Rockwell International during the past five years. The facilities are located at the Rockwell Santa Susana Field Laboratory, approximately 30 miles from the center of Los Angeles. The facilities served experimental and development programs for space nuclear power, liquid metal technology, and commercial power generation. The land involved is under lease to the Federal government and may revert to private ownership. The programs conducted in these facilities were terminated in the 1960s, and the facilities were placed in a layaway status. They were designated as being surplus to programmatic needs in the early 1970s, and decommissioning project authorization was received from the government in 1974.

Prior to placing the eight facilities in a layaway status, reactor fuels were removed, the small Systems for Nuclear Auxiliary Power (SNAP) reactor structures were removed, loose surface contamination was placed under control, useful equipment was salvaged and, as appropriate, measures were taken to control access and prevent contamination spread.

The eight facilities constituting the current decommissioning program were:

1. Engineering Test Building 003 (Hot Cave)
2. Kinetics Experiment Water Boiler Reactor (KEWB)
3. Shield Test Irradiation Reactor Building 028 (STIR)
4. SNAP 8 Experimental Reactor Building 010 (S8ER)
5. SNAP Ground Prototype Test Facility Building 059
6. SNAP Environmental Test Facility Building 024 (SETF)
7. Radioactive Materials Disposal Facility (RMDF)
8. Sodium Reactor Experiment (SRE)

Decommissioning, acccording to guidelines jointly agreed upon by AI and DOE, has been completed for the first four facilities listed. Major activities have been completed for the remaining four.

Functional objectives of the program were:

1. To remove radioactive materials which significantly exceeded background from these facilities and sites
2. To remove chemical or toxic material hazards
3. To restore the facility or site to unrestricted use status

Corollary performance objectives required:

1. Actions to minimize contaminated waste volume
2. Approaches to meet ALARA exposure principles
3. Approaches to maintain a safe work environment
4. Actions to optimize cost effectiveness
5. Approaches to minimize potentials for detrimental environmental impact

General guidelines for acceptable surface contamination and concentrations in soil and concrete were established early in the program. The limits reflect an understanding reached jointly by AI and DOE-SAN and interfaced with the California State Department of Health. The guideline concentration for soil and concrete is

*Work performed under DOE contract DE-AT03-765F75008.

currently the subject of an environmental analysis which will supplement the initial environmental assessment. The surface contamination limits and specific activity guidelines for soil and structural materials are shown in Table 20.1.

Table 20.1. Surface Contamination Limits for Decontamination and Disposition

| | Total | Removable |
|---|---|---|
| Beta Gamma Emitters | 0.1 mrad/h at 1 cm through 7 mg/cm$^2$ absorber | 100 dis/min/100 cm$^2$ |
| Alpha Emitters | 100 dis/min/100 cm$^2$ | 20 dis/min/100 cm$^2$ |

The surface contamination limits are somewhat more conservative than those in NRC Regulatory Guide 1.86 and the proposed ANSI Standard (N328). The guideline for distributed fission or activation products in soil, concrete, and structural materials is a gross beta value of 100 pCi/g and includes the background activity. It is a guideline value based on several considerations:

1. The local gross beta background in soil was found to range from 11 to 48 pCi/g.
2. The predominant isotopes resulting from these operations and after this elapsed decay period are strontium-90, cesium-137, and cobalt-60.
3. The expected statistical deviations in sampling results.
4. The factual case that operating to below-guideline values usually results in levels considerably lower than the guideline values.

## DECOMMISSIONING ACTIVITIES

A description of the decommissioning activities performed in this program follows.

### Building 003--Hot Cave

Decommissioning of the hot cave, which was composed of examination hot cells, entailed total dismantling and removal of all radioactive materials including those found in exhaust systems, liquid waste-handling systems, and fume hoods. A plastic enclosure was constructed at the entry to the cell doors, and a negative air pressure was maintained. Initial personnel entry into the cells removed remains of experiments and radioactive (~25 rad/h) residues in containers. The cell interiors were decontaminated, using a foamer with a decontamination agent to loosen contamination and a vacuum system to pick up the contamination. The interiors of the cells were finally scrubbed with a light caustic solvent. The above-grade block structure was dismantled, and below-grade concrete structures, drain lines, and holdup tanks were excavated. Contaminated materials were packaged and shipped for burial offsite. Upon completion of the decommissioning of the hot cave, the area was used as a tooling development laboratory. A 35-ft-deep simulation of the SRE reactor vessel was constructed. During excavation, soil samples and ground water were analyzed, but nothing above background levels was found.

### Kinetics Experiment Water Boiler Reactor Decommissioning

The KEWB facility is shown in Fig. 20.1 prior to dismantling. Reactor fuel had been removed earlier in a deactivation program. The reactor vessel, reactor enclosure, fuel handling system, controls, and a radioactive waste handling system remained. These were disassembled, packaged, and shipped to burial. A

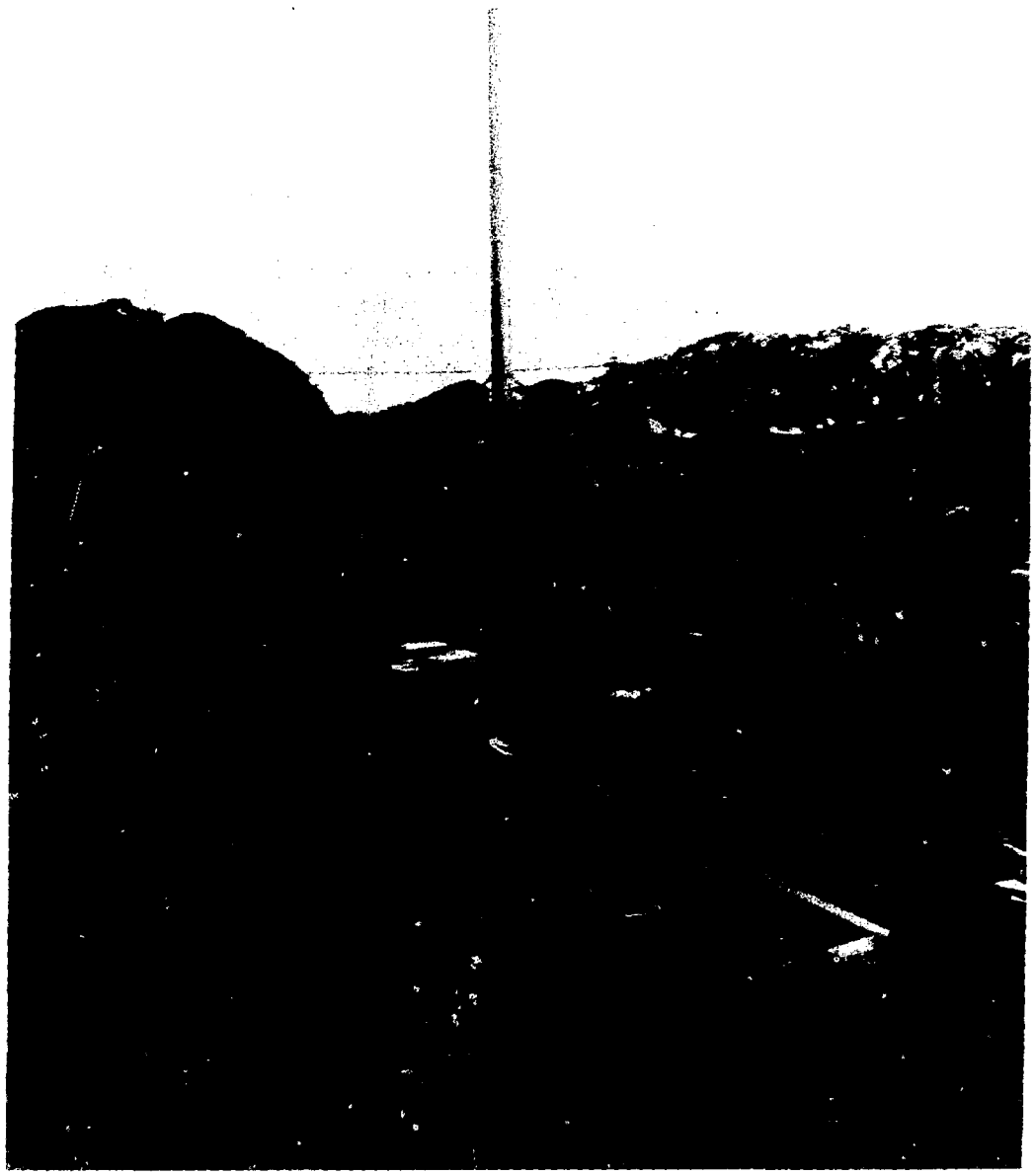

Fig. 20.1. KEWB prior to decommissioning.

section of concrete wall with an area of 3 ft by 6 ft had been activated by the reactor neutron flux. This section of wall was demolished, using jack hammers. Airborne contamination was minimized with a water spray and by exhausting the air through a portable blower and particulate filter system. The site after removal of the facility is shown in Fig. 20.2.

### Shield Test Irradiation Reactor Decommissioning

The STIR facility contained a 1-MW pool-type reactor, used primarily to conduct basic shielding experiments. Dismantling of the facility began in 1975. Contaminated and irradiated components and structures associated with the reactor, water-cooling system, thermal

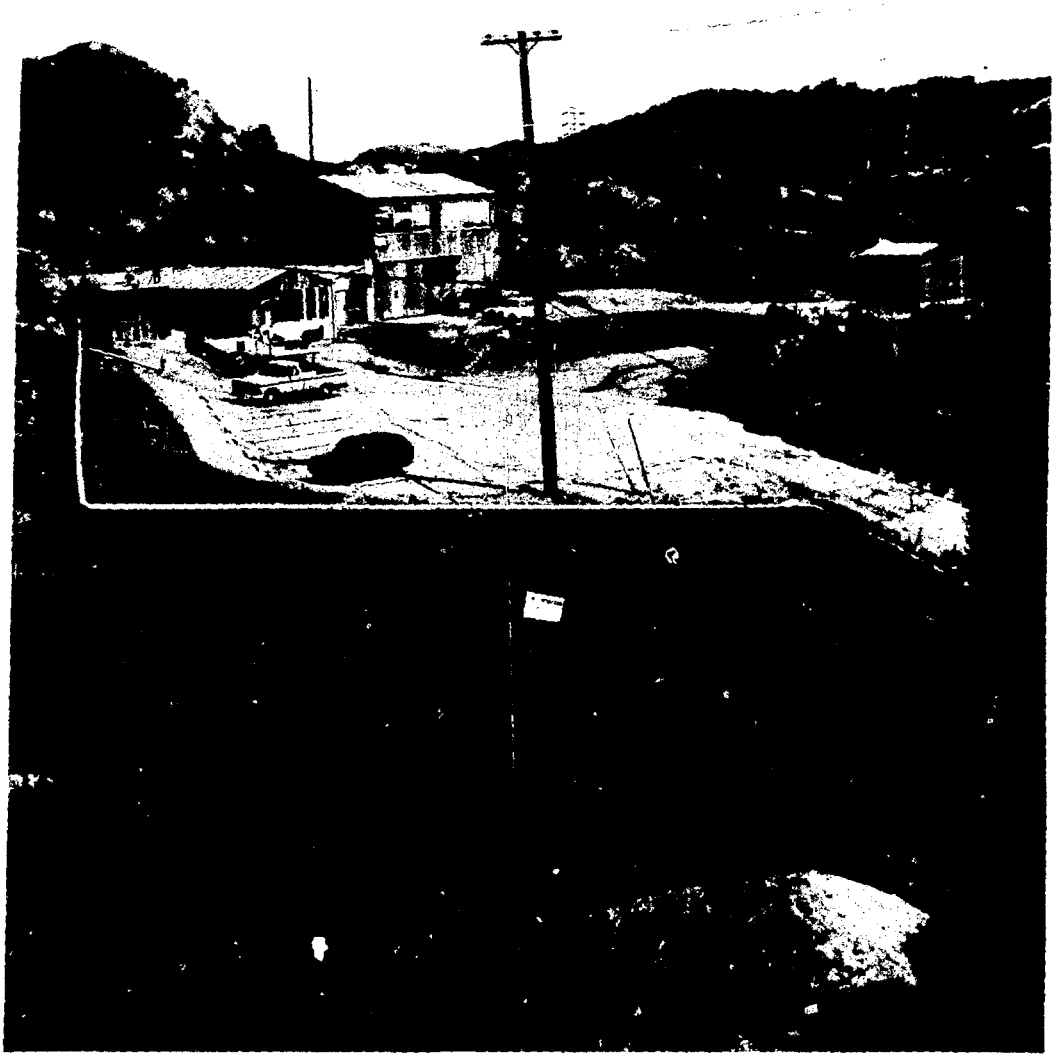

Fig. 20.2. KEWB after decommissioning.

column, test carriage, and facility exhaust systems were removed. These were then packaged and shipped to a licensed commercial burial site at Beatty, Nevada, for disposal. The reactor containment was segmented by plasma torch. Nonradioactive peripheral equipment, such as the cooling tower, shield door, and photographic film conveyor, were removed as salvage. Floor and wall openings resulting from the D&D operations were filled and covered with concrete as required to restore the facility to a safe conditon.

Excavation of the activated concrete reactor enclosure was an important operation in this decommissioning project. A hoe ram equipped with a hydraulic chisel tool was used for concrete demolition. This activity was performed inside the sealed, shield test room so that airborne contamination was contained. Equipment used in the operation was decontaminated in the shield test room upon completion of concrete removal.

### SNAP 8 Experimental Reactor Building 010 Decommissioning

The S8ER facility was used to test space reactors. The optimum economic decommissioning

of this facility entailed complete removal of all structures and a repaving of the area. Decontamination of concrete vaults was accomplished with foam. The principal component in the facility was the reactor vessel: although cutting of the vessel was considered in the planning, it was removed intact with its biological shield and shipped as a unit to Beatty, Nevada, for burial (Fig. 20.3). After the removal of contaminated systems and materials, the excavation was filled with clean rubble and repaved.

### Radioactive Materials Disposal Facility (RMDF) Decommissioning

The RMDF is currently being used to decontaminate equipment and materials, to process liquid wastes, and to package and ship radioactive waste to burial. Decommissioning of this facility will not begin until all others are completed. However, an abandoned sewage-leach field, associated in the past with the RMDF operations, was opened and found to be locally contaminated. Test holes were bored into the leach field to define the scope of the effort. Heavy rains early in 1978 required the construction of a retention sump and pumping of the slightly contaminated water into storage tanks and drums. The stored water was later processed in the RMDF evaporator. The entire leach field was excavated and placed into 1485 shipping cartons for burial. The limited access of the leach field required the use of a crane to hoist the boxes of soil to the RMDF. The leach field

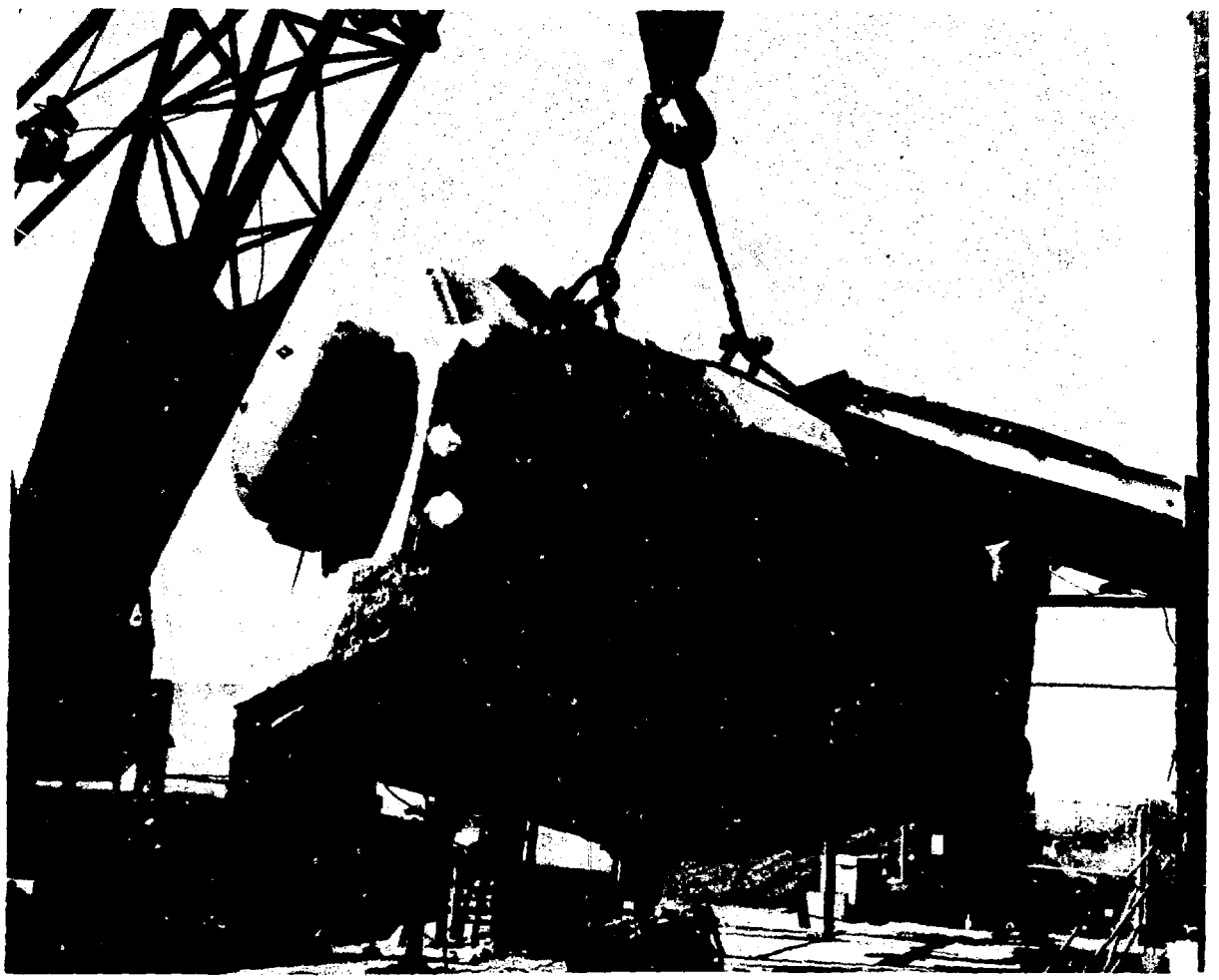

Fig. 20.3. S8ER vessel and biological shield.

area now is decontaminated to guideline levels except for a small area in a separation of bedrock where contamination above 100 pCi/g exists. This area has been sealed, and the total leach field area has been graded to direct rain runoff away from the area. A summary of the remaining radiological condition and an analysis of implications is in progress.

### Sodium Reactor Experiment (SRE) Decommissioning

The sodium reactor experiment (Fig. 20.4) was designed and constructed to demonstrate the feasibility of a high-temperature sodium-cooled reactor as the heat source for a central station power plant. The facility was deactivated in 1967. Primary sodium was drained into the fill tank, and the secondary sodium was drained into drums and removed from the site. Fuel was removed to storage at the RMDF.

Dismantling of the SRE began with the removal of peripheral nonradioactive systems. The kerosene cooling system, secondary sodium systems, inert gas, vault-cooling systems, air blast heat exchangers, and the supporting structures for these systems were removed.

A major portion of the operation involved the disposal of the sodium stored in the primary fill tank, removal of sodium system components, and the reaction of residual sodium in the removed components and in the reactor vessel. Components containing bulk sodium were placed in a melt tank and drained of sodium. Large components, such as the main heat exchangers, hot and cold traps, and pumps, were connected to an alcohol-sodium passivation system for sodium

Fig. 20.4. SRE prior to decommissioning.

removal. The reactor vessel residual sodium was similarly passivated. The reactor vessel was filled with water upon completion of the sodium passivation to ensure completion of the passivation and to provide shielding for subsequent operations. A significant amount of radioactively contaminated alcohol (6000 gal) resulted from the sodium passivation process. Since liquid wastes burial was not allowed, the alcohol was absorbed in diatomaceous earth and cellulose fiber, contained in drums, and shipped to burial.

The reactor vessel was opened by removing the shield plug. This 50-ton shield plug and the 70-ton ring shield were surface-decontaminated, painted to ensure immobilization of subsurface contamination, and shipped intact for burial. Because of the size and weight, special shipping permits were required. Disposal of these large masses by cutting and breaking into small pieces was considered, but it was not economical and not in agreement with the principle of limiting personnel exposure to radiation levels as low as reasonably achievable. A similar disposal approach was taken in shipping and burying intact large contaminated support systems, such as the fuel-handling machines and the moderator-element-handling machine.

While the sodium disposal activities were in progress, two tooling development tasks were being performed: the first for explosive cutting of the reactor vessel internals and the second for remote cutting of the vessel, using a plasma torch manipulator. A simulation of the SRE reactor containment vessel was provided, as described earlier, and greatly aided the development of tooling and techniques.

The manipulator was installed over the reactor vessels. An important feature of the manipulator was a TV camera which allowed viewing of explosive charge installation and positioning for cutting. The reactor sodium system contained single- and double-walled pipe which, beacuse of their geometry and inaccessible location, were best cut by explosive charge. The explosive cutting development program demonstrated that the pipe could be cut safely under water. During the explosive cutting in the reactor vessel, no significant water plumes or gas releases were evident. The gases that were generated were exhausted through an 18-in.-diameter venting duct connected to the facility's radioactive gas filtering system.

The plasma torch manipulator system (Fig. 20.5) was used to cut the reactor vessels into sections which could be placed in a cask liner for shipment to burial. Transfer of the cut segments from the reactor vessel to the water storage tanks was made remotely in air. The more radioactive segments (100 rad/h) transfers were performed during off-shift hours and with specially erected shields for operating personnel. The 5-1/2-in.-thick thermal rings were positioned outside the cavity and segmented by oxy-acetylene torch with localized ventilation control.

After removal of the reactor vessels, the principal remaining activities in the SRE decommissioning were the removal of contamination from the concrete floors, walls, ceilings, vaults, trenches, hot cells, and the exhaust system; the removal of contaminated soil, rock, and structural concrete; and the removal of the activated concrete in the biological shield. Plans were prepared for excavations in the SRE facility high bay down to bedrock, a depth of 40 ft at the reactor location. Excavation is in progress (Fig. 20.6). The fuel storage cells, pipe trenches, and portions of the wash cells have been removed. (In removal of contaminated soil by backhoe, the scoop design of the backhoe was found to be critical.) The SRE basic structure will remain because it affords containment for the operations and its facility exhaust system can be utilized for control of airborne contamination.

Several techniques were employed for the removal of contamination from concrete surfaces. Initial cleaning was done with application of, and later removal of, decontaminating agents held in a foam carrier. Sandblasting was tried in the fuel-handling machine storage pit, with some success. Sandblasting primarily removed

Fig. 20.5. Plasma torch system in operation.

paint and a little of the concrete surface. Contamination embedded in the pores of the concrete or at expansion joints was not effectively removed by sandblasting.

A number of power-driven abrading tools were tried. The tool which gave good results was a "scabbler," which is a ganged concrete spalling tool that has tungsten carbide points on an air-driven head. This was equipped with a vacuum and air-cleaning system. This not only collected the dust generated but made the tool more effective because it removed the contamination from the area, preventing the tool from impacting contaminated particles back into the concrete surface.

The use of jackhammers, with operators properly suited and working in a vented enclosure, was effective where the contamination depth was inches below the surface.

A gross approach to cleaning walls and floors of contamination was the use of the hoe ram, which was used for stripping a 4-in. thickness of concrete from 2-ft-thick walls in the gaseous waste vaults. This technique somewhat increases the volume of waste, which is costly to bury. However, when weighed against the labor involved in other techniques, it can be an economical method.

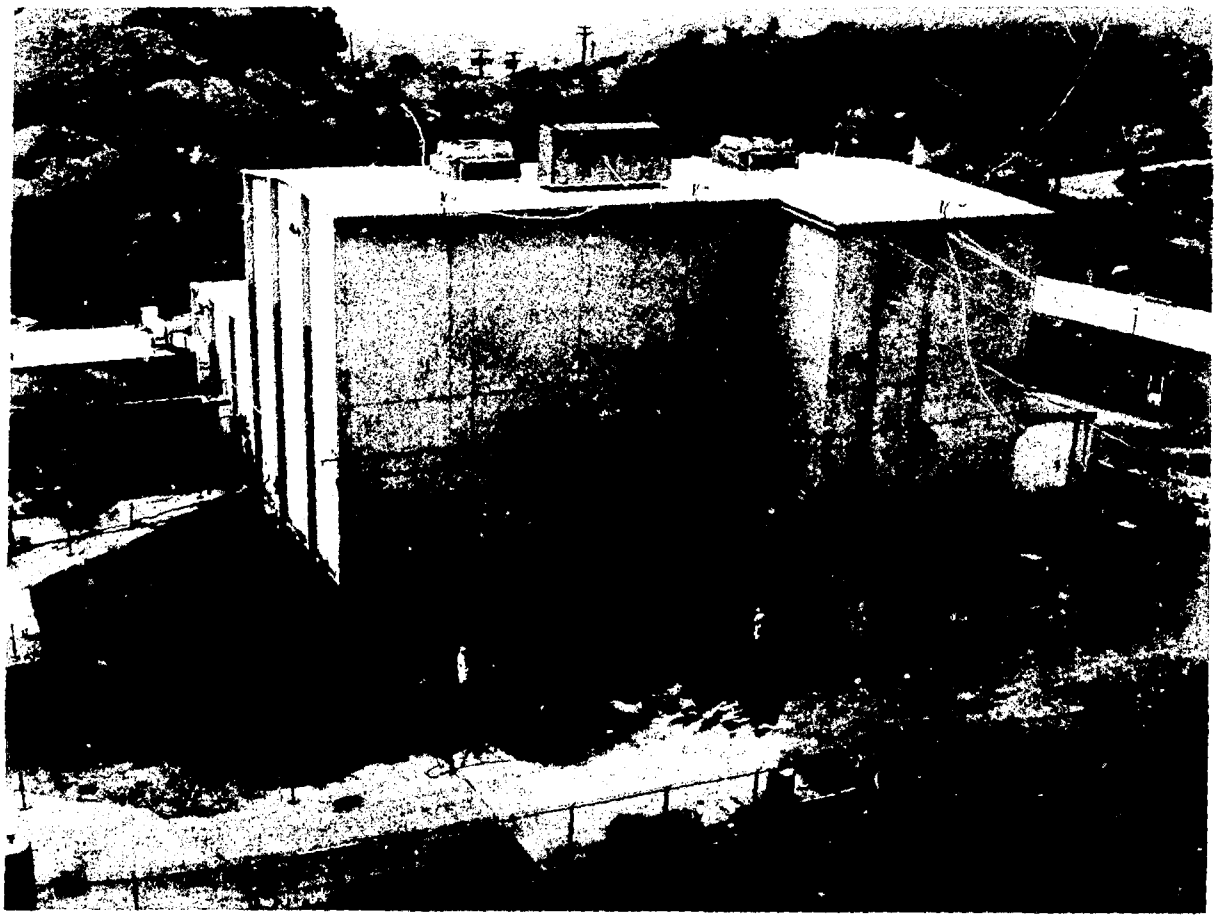

Fig. 20.6. SRE during excavation of soil.

## SUMMARY

In summary, it is believed that the most noteworthy accomplishments in the SRE dismantling project are:

1. Proving and refining the technology for remote cutting of highly radioactive structures by plasma arc torch.
2. Proving and developing the technology for remote explosive cutting of radioactive components.
3. Increasing the experience base and technology for removing and reacting large amounts of contaminated sodium.
4. Showing and applying concepts for economic removal of large items of equipment.
5. Developing and applying concepts which dismantle a nuclear facility and yet preserve the site and superstructure for immediate alternate use.
6. Dismantling a major nuclear facility with minimal radiation exposures to the workers and without adverse impact on the environment.
7. Providing a data base of information for worldwide use on other decommissioning projects.
8. Demonstrating that there are no insurmountable technical problems to decommissioning—possibly the most important accomplishment.

# 21. TECHNIQUES FOR REMOVING CONTAMINATED CONCRETE SURFACES*

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Accidental spills, vapor releases, and fine particles of various substances have contaminated concrete surfaces, necessitating development of methods to remove these surfaces. Ideally, these methods should:

- reduce the contaminated waste volume that has to be placed into controlled storage,
- provide a convenient method for cleaning surfaces (such as those contaminated by a small spill), and
- remove surfaces quickly.

This discussion compares various techniques that have been used to clean concrete surfaces by removing the surface. Three techniques which have been investigated by the Pacific Northwest Laboratory (PNL) for removing surfaces are also described: the water cannon, the concrete spaller, and high-pressure water jet.

The equipment was developed with the assumption that removal of the top 1/8 to 1/4 in. of surface would remove most of the contamination. If the contamination has gone into cracks or deep voids in the surface, the removal processes can be repeated until the surface is acceptable.

## COMPARISON OF VARIOUS TECHNIQUES

A comparison of these various surface-removal techniques can be found in Table 21.1. Sandblasting is a technique that is used to remove some surface contamination. It is a slow technique, and it is effective only if the contamination is only on the surface. The sandblasting medium becomes contaminated, adding to the material to be placed in controlled storage. A blasting technique using dry ice pellets has been evaluated, but this is even slower than sandblasting.

Flame spalling has not been tried because handling the by-products of combustion, which may be contaminated, would be more difficult.

Explosives also have been used to remove surfaces. Although the technique is fast, the structures need to be sturdy, the surfaces must be large, and explosives experts are needed.

Jackhammers are fairly effective but are awkward to use on walls and ceilings and in tight, constrained areas. An impactor, a large jackhammer-like device which must be mounted on a backhoe (Fig. 21.1), is limited to large, accessible areas. Operators can easily remove complete walls but find it difficult to remove only 1/4 to 1/2 in. of wall surface.

The scrubber, or scabbler, works well on floors, but it is slow by comparison to other techniques. In its present configuration, the scrubber would be difficult to use on walls and ceilings.

Two types of water cannons have been evaluated. One is a 458-magnum gun which is fairly slow, requiring 5 to 6 min to remove 1 $ft^2$ of concrete surface. The second technique is a rapid-fire model: it will fire at a rate of 4 to 5 shots per second, but it must be picked up and placed between each shot. Besides the disadvantage of having to reposition every time, the spall has a diameter of only 1 to 2 in., which means the rapid-fire model is only slightly faster than the manual water cannon.

The concrete spaller has proven to be a fast, effective technique. When the drill and spaller are handheld, about 1 $ft^2$ of surface per minute can be removed. When the drill is mounted on a platform, the speed can be increased to 1-2/3 $ft^2$ per minute.

A technique using very high-pressure water was fast, removing 4 to 6 $ft^2$ per minute, but

*This paper was prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO-1830.

Table 21.1. Comparison of Various Concrete Surface Removal Techniques

| Technique | Limitation | Estimated Relative Speed at which a Unit of Surface Area Can Be Removed |
|---|---|---|
| Sandblasting | Grit adds volume to the contamination | Slow |
| Dry-Ice Blasting | Very slow penetration | Slow |
| Flame Spalling | Heat may cause undesirable chemical reactions | Slow |
| Explosives | Generates moderate quantities of dust which must be controlled | Fast |
| Jackhammer | Awkward to use on walls | Medium fast |
| Impactor Powered by Air or Hydraulics | Limited to large accessible facilities | Fast |
| Scrubber | Awkward to use on walls | Slow |
| Water Cannon | | |
| Handheld modified 458-*Magnum Rifle* | Gunpowder combustion products are produced | Slow (5-6 min/ft$^2$) |
| Rapid-fire Model | Limited to large accessible facilities | Slow (3-4 min/ft$^2$) |
| Concrete Spaller with 38-Pound Air Drill to Make Holes | | |
| Handheld | | Medium fast (50-60 sec/ft$^2$) |
| Semi-automated on Platform | | Medium fast (35-40 sec/ft$^2$) |
| High-pressure Water (40,000 to 60,000 psi) | Produces contaminated water | Fast (10-15 sec/ft$^2$) |

Fig. 21.1. Impactor mounted on a backhoe linkage.

the water used must be treated afterwards to remove the contamination.

## WATER CANNON

The water cannon, shown in schematic form in Fig. 21.2, is a modified 458-magnum rifle with a nozzle on the end. Suppositories were melted down and made into 2-in.-long glycerine sticks (0.45 in. in diameter), which were propelled with gun powder. The nozzle forms the glycerine into a high-velocity stream which then spalls the concrete surface on contact. A shield was placed around the nozzle to collect the rubble and the by-products of combustion. It makes a spall approximately 2 to 3 inches in diameter (Fig. 21.3). The spall is about 3/4 in. deep at the center. Figure 21.4 shows a 1-ft$^2$ sample wall which was spalled in about 6 min with 24 shots. Figure 21.5 shows the gun being operated without the vacuum cleaner attached. The glycerine tends to capture or encapsulate all the dust; therefore, there is no airborne dust contamination.

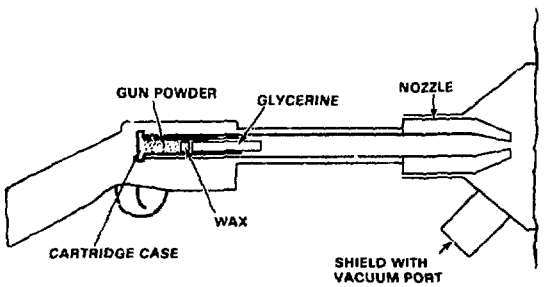


Fig. 21.2. 458-magnum water cannon schematic.

Fig. 21.3. Water cannon spall.

Fig. 21.4. One square foot of surface removed by the water cannon.

Fig. 21.5. Water cannon being operated without a vacuum.

## CONCRETE SPALLER

The concrete spaller is a device developed by PNL specifically for removing concrete surfaces.* The concrete spaller consists of three basic parts: a hydraulic cylinder, a push rod, and a bit with expanding wedges. The schematic is shown in Fig. 21.6. The bit is made of steel tubing, tapered at one end. The tapered end is machined into a circular wedge which is split into four equally spaced segments parallel to its central axis. A push rod with a tapered end to match the tapered tubing is inserted into the bit. The spaller is inserted into a predrilled hole, approximately 2 in. deep and 1 in. in diameter. The hydraulic cylinder is then activated, causing the wedges of the bit to be embedded into the wall. As the tip of the push rod pushes against the bottom of the hole, it forces the wedges away from the bottom, causing an average 8-in.-diameter spall. The holes are drilled 8 in. apart in a triangular pattern. A dust shield placed around the drill and used in conjunction with a vacuum cleaner collects the drilling chips (Fig. 21.7). Figure 21.8 shows the spaller being inserted into the predrilled holes; the resultant spalls are shown in Fig. 21.9. The spaller and a spalled panel are shown in Fig. 21.10. Ocassionally, small areas of surface were left intact. These areas were then redrilled and spalled again. Note that the rubble produced by spalling is conveniently sized so that handling is easy and much of the surface layer remains intact. The thickness of the surface removed is nominally 1 in.; if at that depth contamination is still found, the spalled surface can be redrilled and spalled as many times as necessary.

Spalling done on concrete with reinforcing steel (rebar) is shown in Fig. 21.11. The outer layers of concrete can be removed down to the rebar. If contamination is still deeper, spalling can be done around the rebar so that it can be removed also.

*The concept for the concrete spaller was patented by C. H. Allen.[2]

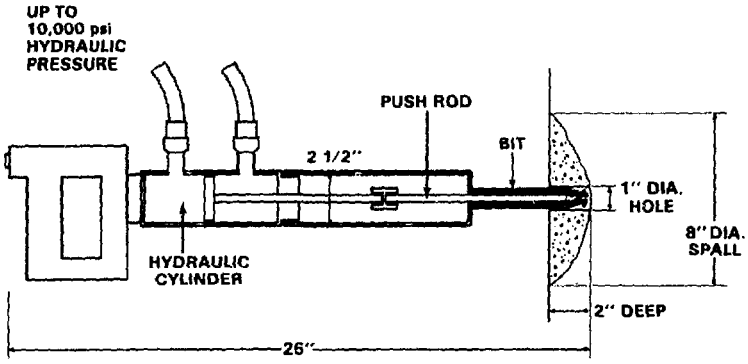


Fig. 21.6. Concrete spaller schematic.

Fig. 21.7. Air drill with dust shield and vacuum hose.

Fig. 21.8. Concrete spaller being operated.


Fig. 21.9. Typical spall made with concrete spaller.

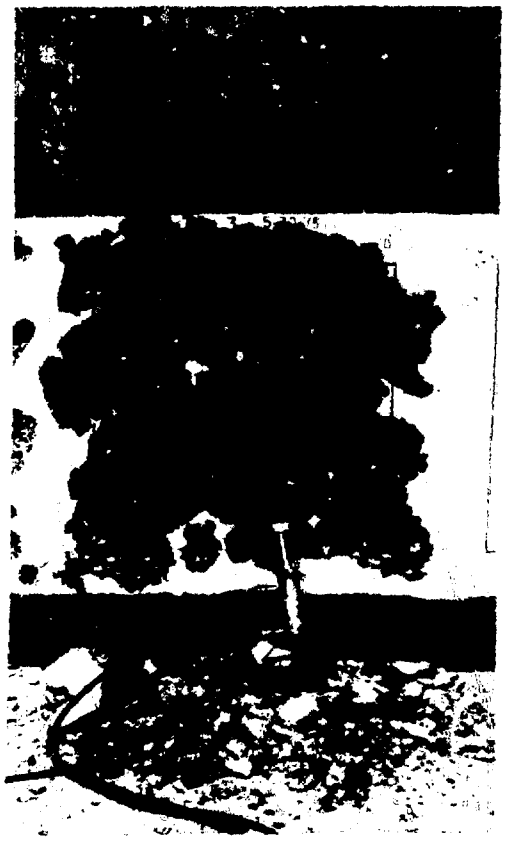

Fig. 21.10. Concrete spaller next to spalled test panel.

Fig. 21.11. Spalling done around rebar.

To simplify the overall operation, the spaller was suspended (on a cord) from a pivoting arm beside the operator. To increase the hole-drilling rate, the drill was mounted on a track on a platform. The drill was positioned horizontally and moved in and out for operation. Later, motors and a control system were added to the drilling unit in an effort to further increase the drilling rate. The width of the track was also increased, so that an 8-ft-wide strip could be covered each time the platform was positioned. Figure 21.12 shows the drill in operation. Figure 21.13 shows the wall being

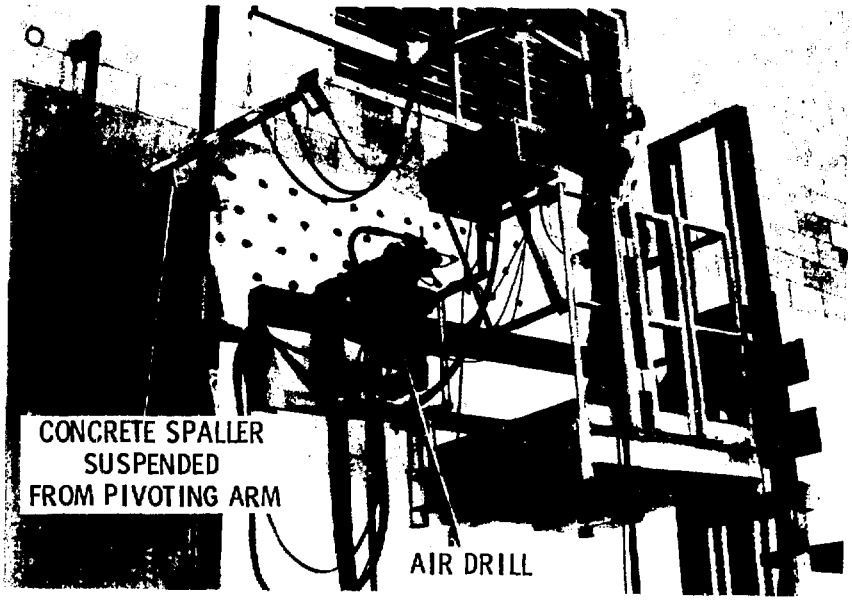


Fig. 21.12. Automated air drill in operation.

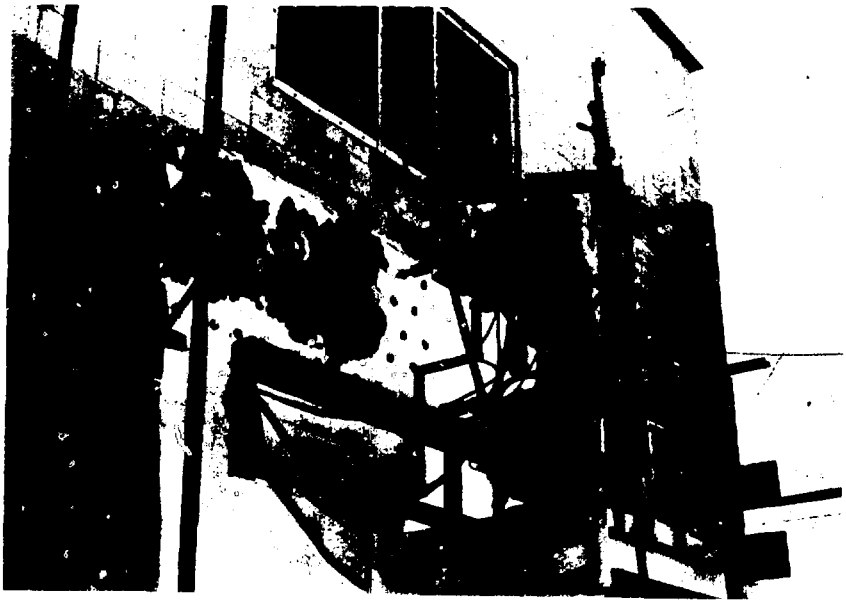

Fig. 21.13. Concrete spaller in operation.

spalled. Motorizing the drill added some problems, the most important being that the drill has to be backed up and repositioned manually when it hits a rebar. Because of the need to reposition the drill manually, the plan to automate the drill and let it work its way across the wall while the operator was spalling had to be abandoned.

The platform and the supporting equipment are shown in Fig. 21.14.

## HIGH-PRESSURE WATER

The high-pressure-water technique for surface removal was developed by Flow Industries Inc. of Kent, Washington. The system consists of two pressure intensifiers powered by hydraulics. They generate a water pressure of 50,000 psi, which is transmitted by a small-diameter pipe to three nozzles in the hooded unit (Fig. 21.15). These nozzles move back and forth across the surface being removed, eliminating 1/8 to 1/4 in. of the surface. Figure 21.16 shows two of the nozzles and a slab of concrete with part of the surface removed.

The system can remove approximately 6 $ft^2$ of surface per minute. It is also very powerful: it not only blasted the grout from between the aggregate but it removed the tops of the aggregate, as well. The technique produces a lot of mist and small-size rubble which shoots out everywhere. To be used for decontamination, the rubble must be contained and all the water treated to remove any contamination.

Fig. 21.14. Spaller platform and supporting equipment.

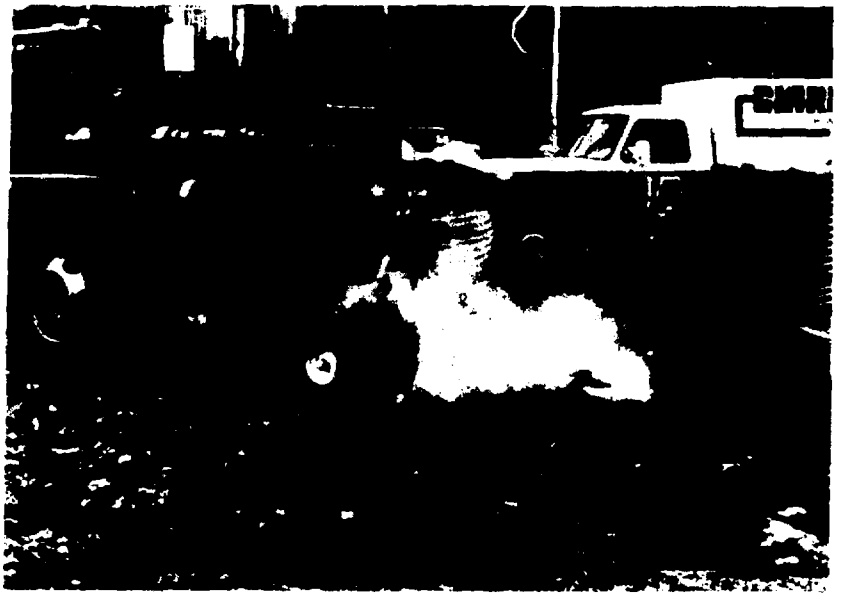

Fig. 21.15. High-pressure water surface removal equipment in operation.

Fig. 21.16. High-pressure water nozzles and a slab of concrete with part of the surface removed.

Chester: Thank you. That is very interesting. I'd like to know what kind of a swivel they used inside their hood that would handle that 50,000 psi.

Halter: They used a lot of extra pipe, and they just let the pipe bend.

REFERENCES

1. Halter, J. M. and R. G. Sullivan, "Contaminated Concrete Surface Layer Removal," Surface Contamination, Vol. 1, R. L. Mittal, ed., Plenum Publishing Corp., New York, N.Y., pp. 443-455 (1979).

2. United States Department of Energy, "Expansible Apparatus for Removing the Surface Layer From a Concrete Object," U.S. Patent No. 4152028, United States Patent Office, Washington, D.C. (1979).

# 22. DECONTAMINATION OF WATER BODIES

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In September of 1975, the governor of the State of Virginia ordered the closure of the James River to the taking of sport and commercial fishes. This dramatic action reflected deep concern for the health implications of preliminary data revealing contamination from the chlorinated organic pesticide Kepone. Subsequent studies revealed potentially hazardous levels of Kepone over a 243-mile stretch of the river from the fall line at Richmond to the outlet into Chesapeake Bay. The immediate economic implications of such a closure and the possibility that migration downstream could threaten the Chesapeake fishery itself prompted a government-funded evaluation of technology to decontaminate the James River. That effort, coupled with ongoing research and development and the experience gained from attempts to mitigate numerous smaller spills of oil and hazardous chemicals throughout the nation, forms the current technological base for decontamination of water bodies.

Spills into water continue to frustrate those who would ameliorate them. The dynamic features of water bodies serve both as boon and bane to restoration efforts. Currents and diverse microbiological communities can provide rapid dilution and natural degradation to minimize impacts. Conversely, the mobility of the waters and the presence of a heterogeneous population of flora and fauna threaten exposure to a wide range of sensitive receptors which can be damaged. For those contaminants which are hazardous at very low levels, accelerated dilution only results in much larger volumes of material to be cleansed. Mobility also complicates efforts to locate and track the contaminant plume requiring remedial action. Hence, while a considerable R&D program has been undertaken in the 1970s to provide better tools for decontaminating water bodies, the challenge of the mission remains very much intact.

Alternatives for decontamination efforts are best reviewed in the context of the physical location of the contaminant after it enters the water body. This defines three scenarios, each of which requires a different approach for mitigation:

1) the contaminant is insoluble and floats on the surface of the water,

2) the contaminant is relatively soluble and mixes into the water column, and

3) the contaminant is insoluble and sinks or has a high affinity for particulate matter residing on the bed of the water body.

The following is a review of technology available to address each of these possibilities reflecting both the state-of-the-art and practical experience gained in actual cleanup efforts.

## FLOATING CONTAMINANTS

A discussion of floating contaminants is, in essence, a discussion of spilled oils. Of the estimated 15,000 spills per year in the U.S., some 12,000 involve oil-like materials. While there is still a great debate as to the toxicological implications of spilled oils, aesthetic considerations have focused attention on removal of the visible slick involved. Impetus for the development of cleanup technology came from the Torrey Canyon incident in 1967 and was spurred on by the Santa Barbara oil leaks of 1969. As a result, extensive research and testing were conducted in the late 1960s and early 1970s on candidate oil-removal systems. While many approaches were evaluated, all can be categorized into three groupings based on the final disposition of the oil. One can:

1) contain and remove the oil,

2) destroy the oil, or

3) disperse the oil.

## CONTAINMENT AND REMOVAL

The bulk of all oil-spill-mitigation equipment development was directed to equipment for the containment and removal of oils. A number of manufacturers offer a variety of boom configurations which can be displayed around a slick to "fence in" the oil until it can be removed. While boom technology has improved in the last decade, it still cannot adequately address rough water conditions; therefore, it is ineffective in high wind and seas.

Skimmers are often used in conjunction with booms as the means of removal and separation. These devices are designed to skim off the top layer of water and subject it to mechanical separation operations that store concentrated oil and discharge residual water. Skimmers have been effective on thicker slicks in calm waters, but performance declines rapidly with rough weather.

Gelling agents have been used as an alternative to mechanical containment. Additives such as molten wax, lanolin, and synthetic polymers are applied to oil slicks so that the oil congeals into a gel-like mass. While appealing in concept, this approach is both costly and difficult to implement. Gelled oils have proven difficult to harvest, either mechanically or manually.

One of the oldest available methods for removal of oil is the use of physical absorption. Materials with a high affinity and capacity for sorbing oil are spread over the slick and subsequently harvested. Candidate agents include talc, vermiculite, Fuller's earth, straw, sawdust, peat and polymeric materials such as polyurethane. As with gelling agents, application and collection steps must be refined to improve the competitiveness of this approach.

## DESTRUCTION

Two means of destruction have been developed for mitigating oil spills: combustion and biodegradation. In the late 1960s, several attempts were made to ignite and burn oil slicks as a means of spill cleanup. First-hand experience and subsequent laboratory experimentation have revealed that most crude oils and many heavy refined products will not sustain combustion in a pool-fire configuration. With sufficient weathering (12-24 hours), the more volatile components have vaporized--leaving residuals that are heavy and more difficult to burn. These complications, coupled with aesthetic and safety objections to large-scale incendiary programs, have diminished interest in this approach except in arctic areas where colder temperatures inhibit the loss of volatiles.

Biochemical degradation has received a similar level of limited attention. The presence of significant concentrations of toxic aromatic fractions severely inhibits natural microbial attack of oils. However, several commercial interests have pursued the isolation of acclimated strains of bacteria which will preferentially attack aromatic hydrocarbons. Success to date has been extremely limited and has not shown the promise of being able to address very large spills in a short time frame.

## DISPERSAL

The final means of mitigating oil spills involves the dispersal of the oil throughout the water column so that it is not concentrated in a surface slick. This can be achieved physically or chemically. Physical dispersal is accomplished with sinking agents which bond themselves to the oil and then carry it to the bottom. Unfortunately, the bonding mechanisms involved are not permanent and oil is often subsequently re-released.

Chemical dispersal is accomplished with surfactant materials capable of forming stable

oil-in-water emulsions. The soap-like agent is sprayed onto the slick, where agitation of natural turbulence accelerates the spread of the emulsion to levels dilute enough to allow natural forces to degrade the oil.

## CURRENT STATUS

From the above discussion, it is apparent that many alternative approaches to oil spill cleanup have been evaluated. As a matter of practice, however, the majority of all spill responses have utilized booms and skimmers or chemical dispersants. In the early 1970s, concern for potentially increased toxicity of dispersed oils and an overriding philosophy that residuals should not be left in the receiving water prompted most response teams to invest heavily in booms and skimming devices. As a consequence, the bulk of all spills are addressed in that manner. However, recent events appear to be modifying that situation. Rising costs and the manpower-intensive character of mechanical containment have rekindled interest in the use of dispersants. This is particularly true in cases of large oil spills such as the recent well blowout in the Gulf of Mexico. The strengths and weaknesses of specific response methods are compared in Table 22.1.

Table 22.1. Relative Advantages and Disadvantages of Oil Spill Mitigation Alternatives

| Alternative | Advantages | Disadvantages |
|---|---|---|
| Containment and Removal | | |
| Booms and Skimmers | Effective in calm waters, easy to stockpile, low associated impacts, removes oil | Costly, not effective in high seas or rough weather |
| Gelling Agents | Can facilitate clean-up under adverse conditions | Difficult to apply and harvest |
| Physical Sorbents | Low cost | Difficult to apply and harvest, create associated disposal problem |
| Destruction | | |
| Combustion | Amenable to large spills; low cost | Effective only on unweathered crudes, light oils or spills in arctic conditions |
| Biodegradation | Low cost | Not shown to be effective on large spills |
| Dispersal | | |
| Sinking Agents | Low cost, can apply in rough weather | May re-release oil, may cause impacts on benthos |
| Chemical Dispersants | Applicable in rough weather, competitive costs | May be more toxic to aquatic life |

## SOLUBLE CONTAMINANTS

Alternatives for the mitigation of spills of soluble contaminants are the least developed of all spill-response techniques. By their nature, these contaminants spread through the receiving waters making it difficult first to find the contaminant plume and then to treat it, since large volumes of water become involved. Technology for addressing spills of soluble materials has been evaluated and developed for the most part by the Environmental Protection Agency (EPA) as a part of its hazardous-materials spill research program. Some of the more promising approaches have subsequently been tested on spills that have occurred during the last decade. In general, approaches fall into two major categories: in situ and ex situ.

## EX SITU TREATMENT

The first and most simple approaches taken to mitigate spills of soluble materials involved the removal and subsequent treatment of contaminated waters. Once waters were isolated from the receiving body, they could be subjected to virtually any treatment scheme available on-scene. Development has therefore focused on two features:

1) a means of segregating and removing contaminated waters, and

2) equipment with a broad range of treatment capabilities that could be quickly mobilized.

With respect to the former, EPA contractors have developed stream diversion devices which can be applied to channelized flow, to divert contaminated water to a treatment facility. These devices are limited to small streams and canals and therefore are of no use in major waterways or impoundments. For the latter waters, mobile vans are available; the unit is brought to the nearby shoreline and used to pump contaminated waters directly to treatment facilities or into inflatable storage bladders.

The mobile treatment facilities utilized for spill response consist of transportable units containing equipment required to perform an array of separation processes, including coagulation, sedimentation, adsorption, ion exchange, and neutralization. If mobile plants cannot be activated, temporary treatment facilities can be constructed onsite. Such an approach was taken for the restoration of Pond Lick in Ohio when the shallow five-acre reservoir was contaminated with endrin. Water was pumped from the lake to barrels filled with activated carbon, then released. Analysis confirmed the system's effectiveness, but costs were estimated at some $125,000. Mobile units have been similarly employed in areas such as the Little Menomenee River where creosote residuals were removed and treated and the Duwamish Waterway where PCBs were extracted from dredge spoil elutriate.

## IN SITU TREATMENT

The large volumes of contaminated water associated with spills of soluble materials provide significant incentives for the development of in situ treatment alternatives. Few efforts have been successful, however. Essentially, in situ treatment utilizes the same physical and chemical processes employed in ex situ treatment, but the water body itself becomes the contact vessel. As a consequence, approaches must be tailored to accommodate the lack of finite boundaries and an inability to readily manipulate the waters for stirring the separation processes.

The first in situ treatment approaches considered are those involving chemicals which can be neutralized, degraded or otherwise chemically altered to reduce subsequent impacts. In these cases, reactants are merely introduced into the contaminated waters. Mixing can be left to natural forces or stimulated through means of pumps or outboard motors. The major problems associated with this approach stem from potential additional impacts. Treatment agents such as acids, bases, and oxidizers are hazardous in their own right. Overdosing or underdosing can, therefore, continue to exacerbate

impacts. Achieving correct dosage in the open environment is difficult, at best. Further, the products of chemical treatment are often solid precipitates which create turbidity and bottom deposits and hence aesthetic and environmental impacts. Similar approaches with biochemical treatment have been suggested utilizing acclimated cultures of bacteria. For the most part, however, this technology has not proven satisfactory for use on large spills.

As an alternative to in situ chemical treatment, research efforts have focused on approaches utilizing mass transfer media such as solid sorbents and ion exchangers. One of the first attempts at this involved the application of commercially available activated carbon to contaminated waters. With a modest amount of mixing from an outboard motor, the granulated sorbent could be readily spread throughout the water column and allowed to sink with the contaminant. However, the reversible nature of the sorption process and the concomitant loading of the benthos with large quantities of particulate matter creates concern over the long-term effectiveness of this aproach. Therefore, subsequent efforts have focused on the use of retrievable media.

Two types of retrievable media have been tested for application to spills. The first involves the entrapment of active media in porous fiber bags analagous to tea bags. These sorbent pillows are then attached to floats and applied to contaminated waters. The second type of media was a buoyant sorbent or ion exchanger which floated as a result of is low density. In this case, individual media are applied to the contaminated plume and allowed to rise through the water column while being dispersed by natural turbulence. Slowly, the spent media rise to the surface and are removed with booms and skimming devices. In parallel evaluations, the buoyant media were found superior to the tea bags. The latter approach was inhibited by poor contact between media and contaminated waters resulting in low removal capabilities. The buoyant-media approach currently suffers from a lack of commercially available media. The original stocks of floating activated carbon employed during development are no longer produced by the supplier. Several other industrial concerns have demonstrated the ability to produce a comparable media, but are not currently offering it as a product. Buoyant ion exchangers have been produced as a specialty item and can be obtained.

## CURRENT STATUS

Because of the problems associated with in situ treatment, physical removal and ex situ treatment of contaminated water remains the sole alternative presently utilized for spills of soluble materials. A synopsis of the advantages and disadvantages to technical alternatives is provided in Table 22.2.

## BOTTOM-SEEKING CONTAMINANTS

The third and final group of contaminants is that representing materials which will reside on the bottom of the receiving water. This encompasses heavy, insoluble solids and liquids and materials with a strong affinity for particulate matter. These latter materials are of the greatest importance. They include many of the more toxic hazardous materials such as heavy metals, transuranics, and chlorinated hydrocarbons. They have been associated with such incidents as the contamination of the James River (Kepone), the Hudson River (PCBs), Lake St. Clair (mercury), and Indian Creek (DDT).

Mitigation of spills of these materials differs from that of floating and soluble materials since the media of primary concern is now solid rather than liquid. It is the sediments which must be decontaminated. If only the water is addressed, the contaminated sediments will act as a continuing source of material maintaining low levels of the contaminant. Once again, there are three types of approaches which have been evaluated for spill mitigation:

1) in-place destruction;

2) in-place fixation; and

3) removal and disposal.

Table 22.2. Relative Advantages and Disadvantages of Alternatives for Mitigation of Spills of Soluble Materials

| Alternative | Advantages | Disadvantages |
|---|---|---|
| Ex Situ Treatment | Only proven, available technique | Most handle large volumes of water, required materials may not be readily available, may be costly |
| In Situ Treatment | | |
| Chemical Addition | Inexpensive, simplified logistics; no disposal requirements | Hazards associated with improper dosing and by-products |
| Biochemical Degradation | No hazardous reactants involved | Requires extensive inventory of specific cultures; may create significant DO problems |
| Tea bags | Easily deployed and collected | Low effectiveness due to poor contact |
| Buoyant Media | Effective and adaptable to a variety of water bodies and conditions | No current source of floating activated carbon; buoyant exchangers are expensive, specialty products |

## IN-PLACE DESTRUCTION

When organic-based contaminants are involved, one has the option of attempting to destroy the contaminant in place. Five alternatives were identified for evaluation during the studies on the James River: ultra-violet radiation/ozonalysis, biodegradation, chemical oxidation, gamma radiation, and electron beam radiation. None of these alternatives have been applied in the field; however, each was originally developed for use in enclosed treatment systems and therefore would require modification prior to use in situ. Furthermore, several are not likely to be effective. Most of the more toxic bottom-seeking hazardous materials of concern are refractory and therefore highly resistant to chemical and biochemical attack. The combined ozone/uv oxidation process required good contact/mixing and would be difficult to operate in situ. Safety considerations militate against use of radiation.

## IN-PLACE FIXATION

Technology has been available for many years to stabilize wastes in low solubility forms which would reduce the risk of leaching. With growing concern over the disposal of chemical wastes, there has been a proliferation of products to this end. Most are silicate-based, using Portland cement and additives to produce a dissolution-resistent matrix into which the waste form is incorporated. Other candidates are gypsum, sulfur- or polymer-based. Since the early 1970s, Takenaka Komuten Co. Ltd. of Japan has been developing techniques and equipment to apply their own proprietary stabilization agent in situ. This technology has now been successfully applied to marine sediments. The silicate-based agents are intimately mixed with the sediments in a tubular contact chamber inserted into the floor of the water body. The treated sediments are then allowed to cure, much as in the case with marine applications of cement

foundations. Limited data are available on heavy metal and PCB leach rates from the stabilized sediments. No data are available on long-term stability or subsequent releases. As a consequence, officials have been reluctant to approve use of this approach in the United States. In-place fixation was specifically rejected in the case of the James River when it was found that available stabilization agents required the use of lime as an additive which solubilized the Kepone contaminant and thereby rendered the fixed mass less leach-resistant than the original sediments.

In an approach related to in-place fixation, some workers have suggested the use of sorbents which can be added to the sediments to decrease the re-release of contaminants to the water. Since the sorption processes involved are typically reversible, this approach offers no long- term solution.

A third approach to immobilization was developed to assist the EPA in stabilizing mercury-laden sediments. The technique involves the placement of impermeable covers such as polypropylene sheets over the affected sediments. This prevents solubilization and transport from the sediments to the water column. The finite life of such covers, susceptibility to tears and displacement by currents, and adverse impacts to benthic life have precluded use of this alternative. However, it may serve as a temporary measure for short-lived contaminants or in cases where a more permanent solution will take time to implement.

## REMOVAL AND DISPOSAL

While technology for in-place fixation of contaminated sediments is relatively new, the primary approach to removal predates concern for toxic deposits. Dredging technology has been developed over the years to create and maintain navigational channels and to mine geologic resources. With growing concern for in-place toxic residues, dredging has been viewed as the most economic and feasible alternative currently available for mitigation. Specific types of dredges are as numerous as the conditions under which they may be called upon to operate. In addition to differences in efficiency and cost, alternate designs offer differing levels of control and impact on the environment. These two features are of particular importance in dealing with in-place toxics.

The goal is to remove the maximum amount of contaminant possible--not just a given amount of solids--with a minimum amount of resuspension. The dredge should cover the affected zone areally, as opposed to greater depth over part of the area. A characterization of dredge types is provided in Table 22.3. From recent evaluation efforts it is concluded that hydraulic suction dredges are the best available means for removing in-place toxics. Additional development is still needed to provide better control and reduced turbidity. Two pneumatic dredges developed to provide cleaner operations have yet to be proven. The Italian-designed pneuma dredge was tested by the U.S. Corps of Engineers and found to be more costly than estimated, with much lower solids concentrations in the yield than claimed. The oozer dredge is highly touted in Japan but has not been tested in the U.S. Current law prevents the use of foreign dredge equipment in the U.S.

The major disadvantage of dredging for removal stems from the large volumes of materials which must be handled and ultimately disposed of. The same concerns which motivate removal of the contaminated sediments preclude many of the traditional disposal options such as ocean dumping and impoundment. Recent research has been directed to the development of innovative alternatives to dredging which would eliminate these drawbacks. The thrust of such research is to allow selective removal of contaminants or, at a minimum, a smaller volume of sediments with the contaminants concentrated therein. One approach involves the use of sorbents on ion-exchange media containing magnetite. These magnetically retrievable particles are spread over the contaminated sediments and allowed to concentrate contaminant over a period of days. A magnetic device is

Table 22.3. Characteristics of Existing Dredge Types

| Mode of operation | Availability | Advantages/Disadvantages | Estimated Costs |
|---|---|---|---|
| Mechanical and Wireline Dredges | | | |
| Clamshell Dredge | Common, sealed bucket type not available in U.S. however | Difficult to provide even coverage, highly turbid | $2.50/yd$^3$ |
| Dragline dredge | Common | Difficult to control cut, highly turbid | $2.94/yd$^3$ |
| Dipper dredge | Common | Turbidity augmented by violent digging action, difficult to control cut | $2.50/yd$^3$ |
| Bucket Ladder Dredge | Only a few private units in U.S. used for mining | Disperses sediments widely | |
| Hydraulic Dredges | | | |
| Hopper Dredge | Most units owned by U.S. COE, some private units now available | Elutriate and fines discharged overboard, prohibitions to discharge have resulted in high water-to-solids ratio and hence lower productivity, hard to manipulate in confined areas | |
| Cutterhead Pipeline Suction Dredge | Common | Reduced turbidity, releases can be minimized if cutterhead is not required. Required disposal area of hopper dredge within piping distance | $1.50/yd$^3$ mobilization-demobilization could raise to $4.00/yd$^3$ |
| Dustpan Dredge | All units owned by U.S. COE, not available in Great Lakes area | Reduced turbidity | |
| Mud Cat Dredge | Available on rental basis from National Car Rental System, Inc. | Small units, mobile, and tailored to site, cut depths up to 10-15 feet, can't work in water over 15 feet deep | $2.40/yd$^3$ depends on length of rental period |
| Sidecaster Dredge | Three units in U.S., all are owned by COE | Required hopper dredge in tandem or produces highly turbid discharge, use is highly restricted and not well suited to in-place toxics | |
| Pneumatic Dredges | | | |
| Airlift Dredge | Constructed as needed | Susceptible to cratering in one location, would require support of hydraulic dredge-type equipment | |
| Pneuma Dredge | One unit in U.S. | High noise levels, low solids ratio in discharge, poor cut control, limited data available | $0.70/yd$^3$ |
| Oozer Dredge | Units in Japan only | Law prevents use in U.S. at this time, good turbidity control, high solids ratio in spoils | |

then worked across the bed to selectively retrieve the now-spent media. Recovered toxics are removed for disposal while the sorbent/exchanger is regenerated. This patented approach was found to be effective when tested on a laboratory-scale with Kepone-laden sediments. While the reduced cost of disposal made it preferable to the dredge-and-dispose option, no field-scale work has been performed nor has prototypical equipment been designed for application. Similar use of oil-soaked mats (for organic toxics), in-place solvent extraction, and bioharvesting have been proposed, but no testing has been performed.

## CURRENT STATUS

Growing concern over the effects of in-place toxics has stimulated development efforts in the area of technology for mitigation. While several of the new approaches appear promising, dredging and disposal remain the only proven alternatives available at this time. Similarly, the use of standard hydraulic dredges is still preferred to minimize the dispersal of contaminated spoils, although the newer pneumatic dredges show sufficient promise to justify evaluation in the field.

Disposal remains the major stumbling block to this mitigation alternative. It is becoming increasingly difficult to site dredge material disposal facilities, let alone those for contaminated spoils. Hence, costs are rising rapidly and the incentives are increasing for demonstration of more selective removal or fixation techniques. A summary of the advantages and disadvantages of alternatives for contaminated sediment mitigation is presented in Table 22.4.

## POSTSCRIPT

While the current status of mitigation alternatives for spills into water suggests a relatively static technology over the last decade, it should be noted that promising advances are under study. In some instances, new approaches lack only field-testing before they are accepted as a part of the spill-response arsenal. The urgent atmosphere surrounding most spill incidents and the high visibility of response actions has inhibited the testing of newer approaches. Hence, field certification awaits a well-planned testing program or a unique spill opportunity. Given such circumstances, several new concepts warrant evaluation. These include plume capture for soluble spills, pneumatic dredges, and retrievable sorbents. The two latter approaches have been discussed previously. The first approach is at the conceptual stage only. It involves the physical in-stream entrapment of the contaminant plume within the confines of an impermeable envelope. The captured plume is then towed shoreside to be processed and released.

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Chester: Thank you. A very interesting paper. Of course, we at ORNL use ion exchange for our decontamination.

Table 22.4. Relative Advantages and Disadvantages of Alternatives for Contaminated Sediments

| Alternative | Advantages | Disadvantages |
|---|---|---|
| In-place Destruction | | |
| UV/Ozone | No residuals management | Never attempted in situ; limited to organics |
| Biodegradation | No residuals management | Limited applicability; unknown consequences |
| Chemical Oxidation | No residuals management | Very limited applicability; adverse side effects |
| Radiation | No residuals management | Safety and public reaction problems; untested |
| In-place Fixation | | |
| Sorbents | Simple process, no residuals management | Reversible process, merely postpones problems |
| Stabilization | No residuals management | Inadequate understanding of long-term performance, legal problems with creating a disposal site |
| Polymer Film Seal | Low cost | Temporary measure only |
| Remove and Dispose | | |
| Retrievable Sorbents | Minimizes disposal requirements | No prototype equipment available; no field tests to date |
| Bioharvesting | Low cost | Limited applicability, does not concentrate contaminants sufficiently |
| Oil-soaked Mats | Low cost | Limited to organics; untested |
| Solvent Extraction | Low residuals management | Potential adverse effects from solvent; untested |
| Dredging | Only proven alternative; equipment available | Major residuals management problem, cost and siting |

# 23. HUDSON RIVER CLEANUP

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Malcolm Pirnie, Inc.
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Although Malcolm Pirnie, Inc. (MPI) has not been historically involved with nuclear facilities, we have been serving industrial and government agency clients for approximately 70 years. MPI is one of the larger firms specializing only in environmental engineering including water supply, wastewater treatment, solid waste management, and air pollution control. Industrial operations have resulted in considerable experience in dealing with what are now classified as hazardous wastes. In the past, many of the materials involved, including organic chemicals and heavy metals, were simply considered industrial wastes. The techniques that were utilized have included concentration, recycling within process streams, treatment, thermal destruction, and land burial.

Since 1975, Malcolm Pirnie has been providing consulting services to the New York State Department of Environmental Conservation (DEC) with respect to the problem of contamination by polychlorinated biphenyls (PCB) in the bed materials of portions of the upper Hudson River. The scope of this effort has involved determining the feasibility of removing PCB-contaminated bed material (while minimizing the loss of the contaminant) and placing the material in a secure area until an ultimate destruction method becomes feasible. Such a method must be feasible from both a technical and--perhaps more important--an economic standpoint. The evaluations were integrated with a number of related studies including extensive sampling of the river system, sediment sampling, biological sampling, water-quality sampling, laboratory analysis of the various materials, treatability studies, and landfill studies.

The study area (Fig. 23.1) is the upper 40-mile reach of the Hudson River from Albany to Ft. Edward. The primary source of the PCB was

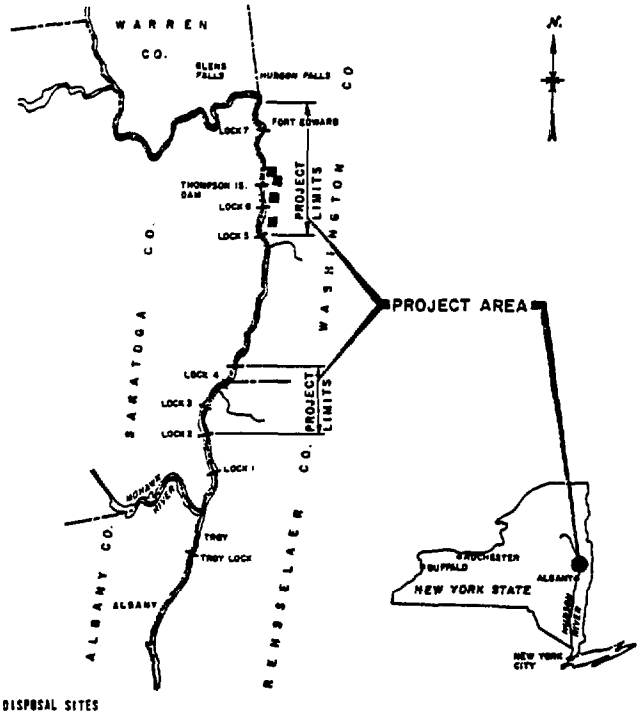


Fig. 23.1. Location map for dredging of PCB-contaminated "hot spot" areas in the Hudson River.

the General Electric Company's operation in the Ft. Edward-Hudson Falls area. The material was discharged directly via an effluent stream to the river, and contaminated solid waste and drums were put in a number of landfills throughout the study area. Some initial dredging of PCB-contaminated bed materials has been undertaken to maintain the navigation channel in this part of the river. Approximately 200,000 cubic yards of material was removed in 1977 and 1978, using State funds and funds from a settlement with General Electric. This has provided significant experience with regard to dredging equipment capabilities and sediment/contaminant loss rates. These losses had been estimated in several cases, but this dredging project provided the opportunity to monitor and test specific containment methods.

The Hudson River from New York to Albany, about 140 miles, is a tidal estuary and is a significant fishery or nursery area for striped bass and shad. The 40-mile upper reach above Albany to Ft. Edward is a series of pools formed by eight dams and locks. The pools facilitate navigation of the Champlain Barge Canal, and several of the dams provide hydroelectric power. In the past, the river has been used extensively for the transportation of timber and bankside processing of wood products in local lumber mills. The PCB problem first came to light after an additional dam was removed at Ft. Edward in 1973. This was a timber crib dam in imminent danger of failure. After removal and subsequent flooding in late 1973 and 1974, several hundred thousand cubic yards of material scoured downstream. At the time the dam was removed, no one realized that the sediment in the former pool behind this dam was heavily contaminated with PCB. The PCBs ranged from several thousand micrograms per gram (µg/g) in the pool deposits on the eastern bank near the former discharge to a few µg/g in the sediment along the western bank. This contaminated material was eroded and redeposited in the downstream pools.

The principal concern for PCB is that it is a carcinogen. Although not clearly demonstrated in people, this property has been demonstrated in other animals. It also causes skin effects and other acute symptoms in people who are exposed to the material. It has demonstrated environmental effects on biota. In Michigan PCB-contaminated fish were unknowingly fed to mink, with subsequent destruction of portions of the mink industry. It has also been shown to have an effect on plankton productivity and reproduction of other organisms in aquatic systems.

The bed material in the river is highly variable. It ranges in size from very coarse wood fragments through sand and shale to fine-grained silt or clay materials. It is interesting to note that the PCB concentrations seem to be related to the two ends of the spectrum. PCB seems to have a high affinity for the wood with a large surface area and also for fine-grain silt materials. The highest concentrations are found in these two types of material.

The depositional pattern within the river is quite variable--both along the length of this reach and the river width. It seems to be concentrated in patches or hot spots. The identification of these hot spots is based on a data base including over 600 cores and surface grabs throughout this reach of river. It would have been nice to have more samples, to determine more precisely where these materials might be located, but costs are prohibitive. As indicated in Fig. 23.2, hot spots are not necessarily related to depth; they are more related to the hydraulic conditions in the river as altered by the dam systems. With respect to the occurrence of PCB with depth in the sediment, the highest levels seem to occur at approximately 10 inches. Very little seems to occur below 24 inches in depth.

The current project proposes to remove selected hot spots in several major areas in the upper pools. Most of the material is still concentrated in the upper pools and is not yet flushed out. The highest levels have been found in the Thompson Island pool, the first below where the dam was removed. The hot spots are defined by places where the PCB exceeds 50 µg/g.

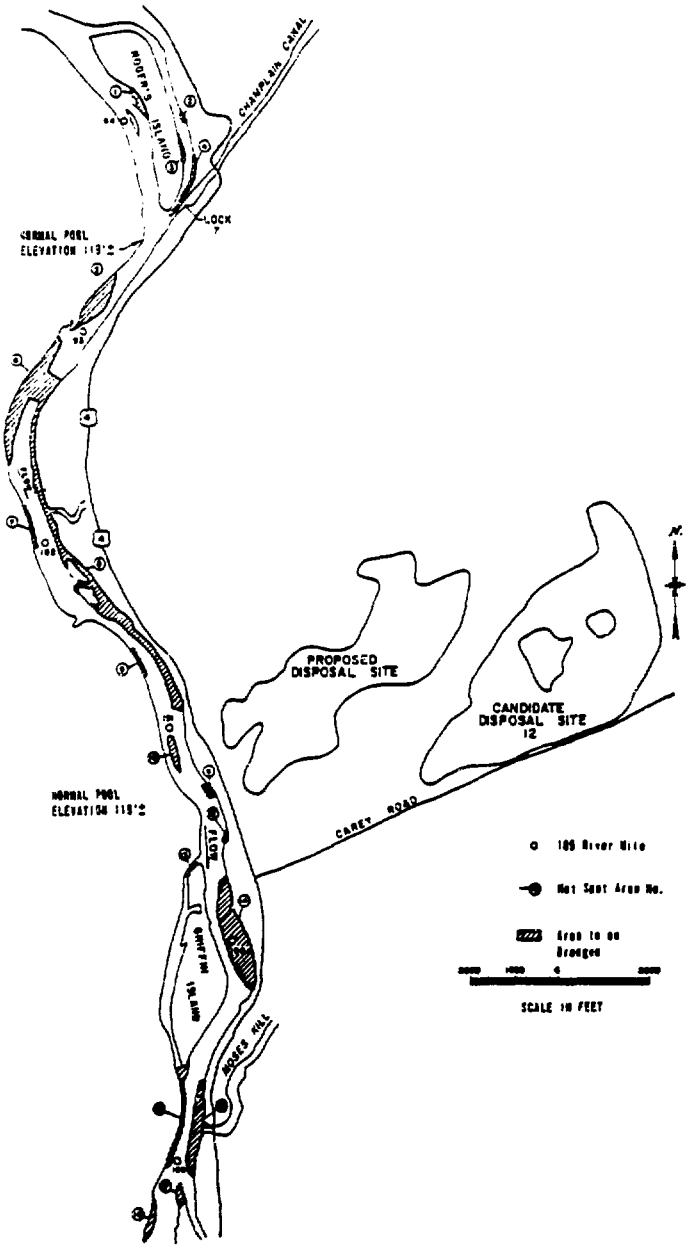


Fig. 23.2. Location of PCB "hot spot" areas to be dredged in the Thompson Island pool.

In the Thompson Island pool, the average concentration is approximately 125 ug/g and there are levels as high as 3000 ug/g.

Several alternatives have been evaluated for reclaiming this reach of river. A "no action" policy is unacceptable, because as long as the PCBs are in the sediment, they are subject to movement and flushing downstream. There is enough PCB--more than 400,000 pounds in this reach of river--so that it could act as a source of PCB in contamination of fish in the lower river virtually forever. As long as it is

there, there will be an uptake into the fish resulting in levels in the flesh of over the FDA limit of 2.0 µg/g. Dredging seems to be the only practical remedial action. In the review of the feasibility of dredging, a number of factors were considered: the technology that is currently available, emerging dredging technologies, the costs of various dredging systems, the environmental effects associated with various systems, and the factors that would bear on whether a remedial program could in fact be implemented--including financing and management of the system.

There are several components to any dredging system: the dredging plant, transport, and disposal. For instance, in a hydraulic dredge there would be a cutterhead dredge, and a pipeline transport system to a disposal site. With a hydraulic dredge, there is a substantial return flow to the river which must be treated. Each of these components was evaluated for its cost-effectiveness. Some of the factors to consider in looking at performance are the nature of the material to be dredged, the amount of material to be dredged, the concentration of PCB, and various losses associated with the operation. Return flow considerations include reduction of losses to the river from the disposal site and reduction of the long-term loss of PCB to ground water. The nature of the material is very important. Eighty percent of the material in the upper Hudson is very coarse, which enhances removal efficiencies.

Three principal dredge systems were evaluated (Fig. 23.3): hydraulic dredge and transport system, clamshell dredge with barge transport and mechanical unloading off the barge, and clamshell dredging with hydraulic pumpout. The hydraulic systems are limited by the distance to a disposal site. Because a 40-mile reach is involved, the pumping requirements for a hydraulic dredge would result in a need for multiple disposal areas. These sites must be relatively large, because they must act as settling basins. It is undesirable to build a number of contained land burial sites. Although in certain parts of the upper pools it may be feasible to use hydraulic dredging, mechanical dredging seems preferable. Mechanical dredging involves digging the material out of the bottom, putting it on a barge, bringing the barge to a shoreline site, unloading it mechanically, and transporting it on trucks to a disposal area. The return flow is substantially reduced because the material removed is essentially at its *in situ* density. A single smaller disposal site would be required. The clamshell with hydraulic pumpout would be similar except that the barge would be unloaded hydraulically and flushed to a disposal site, and the return flow must be treated.

There may be some accuracy advantages to hydraulic versus clamshell dredging. This is important where hot spots are of relatively small size. However, this advantage may be overcome by the tendency to lose more material through the return flow. The differences in efficiency of overall PCB removal are on the order of 95 or 96 percent for a clamshell versus 93 or 94 percent using a hydraulic dredge. These are small differences; therefore the cost becomes a big factor in determining which method is to be employed.

There are also some advanced dredging systems manufactured in Japan and Italy. These systems are classified as pneumatic dredges using hydrostatic pressure and pneumatic pressure to fill and evacuate the dredge head. Although these dredges have been used in contaminated environments, the sediments have been very fine grained. They would seem to have very little application in the Hudson River where the material is variable and coarse. Since much U.S. dredging equipment is available, the importation of foreign equipment is undoubtedly going to have a lot of opposition. In addition, it has not been clearly demonstrated that the losses from pneumatic dredges are significantly lower than from a conventional hydraulic dredge or even a clamshell dredge. The efficiency and loss at the cutterhead is a very small proportion of the material to be removed. Monitoring downstream from hydraulic and cutterhead dredges indicated that the turbidity plume was not

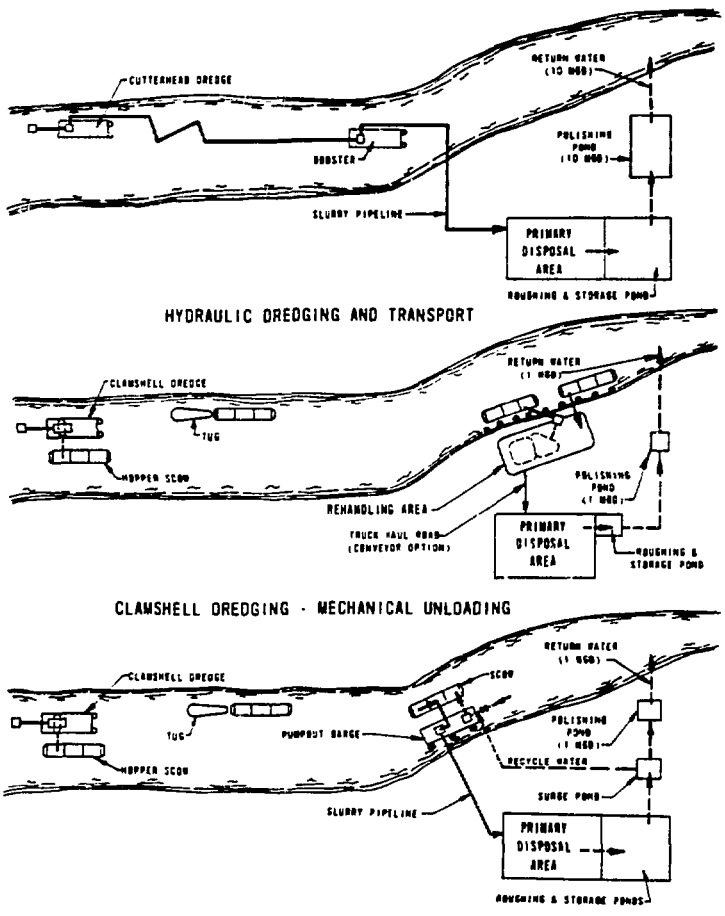


Fig. 23.3. Alternative dredging systems considered for removal of PCB-contaminated riverbed materials from the Hudson River.

measurable a short distance from the dredge. The Corps of Engineer Waterways Experiment Station's research on monitoring turbidity plumes indicate that the extent of such plumes is not really a significant factor in dredging.

These are the main reasons why conventional types of equipment seem preferable in removing contaminated sediments from the Hudson River. Modifications are being evaluated; they include more refined positioning equipment and greater control over the handling process.

The cost bases of hydraulic and clamshell dredging have been compared. The alternative of dealing with the whole 40-mile reach of the river as opposed to dredging hot spots was also considered. The results are shown in Fig. 23.4. The most cost-effective approach is to use a clamshell dredge with mechanical unloading to get about 36 percent of the PCB out of the upper river by dredging only the hot spots. The hot-spot cost would be around $20 million, as opposed to $200 million to dredge the whole 40-mile upper reach of the river.

One of the key concerns in this project has been where to put the dredged material and what criteria are necessary to assure that the land burial site is secure. A site-screening process was undertaken, considering key siting factors

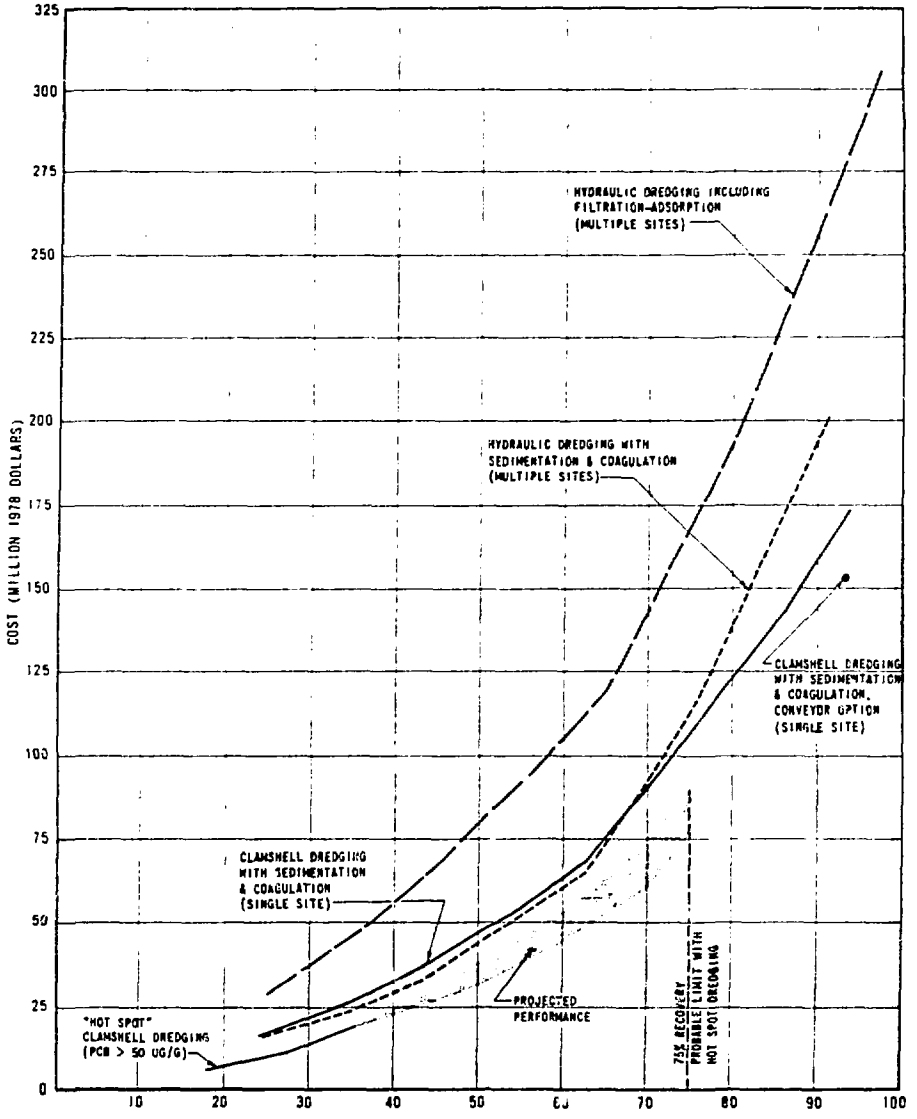


Fig. 23.4. Ratio PCB recovered to total PCB in situ, present dredging cost/performance.

such as wetlands, slopes, and surface water classifications. A complete list of the factors is provided in Table 23.1. The most important factor is whether a site has very low natural soil permeability. An acceptable site would have clay soils with a permeability of $10^{-7}$ cm/sec. The available data were plotted for the 40-mile reach of the river, two miles on either side, and an overlay process was used to identify potential sites. The end result, after taking all those factors into consideration, was a collage of overlapping colors leaving "windows" that indicated acceptable areas for disposal of the contaminated bed materials.

The potentially acceptable sites were examined in more detail, and several sites were selected as being best. One site in particular was attractive because it is held by a single private owner who purchased the land for an investment. This means that the state wouldn't

Table 23.1. Site Screening Criteria

| Parameter | Unacceptable | Ideal |
|---|---|---|
| Soil | Permeability greater than 1 x $10^{-5}$ cm/sec, less than 3 ft thick in situ. (<1.4 x $10^{-4}$ cm/sec overlaid) Class I or II agricultural soils | <1 x $10^{-7}$ cm/sec, % soil passing # 200 sieve >30, in situ thickness >10 ft, liquid limit >30, plasticity index >15 |
| Slope | Deep gullies, slope over 15% | <10% |
| Surface Water | Closer than 300 ft to any pond or lake used for recreational or livestock purposes, or any surface water body officially classified under state law. In special flood hazard areas or recognized wetlands | >1000 ft from any surface water body<br>>200 ft from intermittent streams |
| Bedrock | Closer than 30 ft to highly fractured rock or carbonates, closer than 10 ft to all other rock | >50 ft deep |
| Groundwater | Closer than 10 ft to groundwater, wells tapping shallow aquifers, closer than 1000 ft to any water supply well. Flow towards site | >50 ft, deep bedrock wells or no wells within 2000 ft radius |
| Committed Land | Closer than 1000 ft to parks, cemeteries, residential areas, historic sites, etc. | >1500 ft away |
| Biologically Sensitive Areas | Endangered plant or animal habitats, unique or regionally significant environments | No woodlands, no locally significant features |

have to deal with multiple owners. MPI is currently working with the DEC to initiate a program of detailed site studies involving backhoe test pits, wells and infiltrometer tests for verification of the low permeability. Figures 23.5 and 23.6 illustrate the conceptual design for a facility to be built for containment of the hot spot dredging material until a long-term disposal method can be defined. Existing clay material will be used as a base, and the excavated material as a clay cap. There would be gravel over the cap and ten inches of top dressing for seed. There would be sufficient slope for surface drainage control, and gutters would carry runoff to reduce the infiltration by rainwater. An underdrain system for ground water will also be provided.

About 200,000 cubic yards have been removed from the river, using the funds that were available. This material was readily available as it was exposed in the river bed when the dam came out, and it was relatively easy to excavate most of it in the dry. The PCB in this bed material ranged from a high of 1,500 down to 200 µg/g. The surface was scraped down by about two feet. Some of the material had already washed down into a navigation channel, and that had to be removed by dragline and backhoe. The material was placed in a specially constructed secure land burial site.

This site was not one of those that was identified in the site evaluation. In order to expedite this initial work, it was necessary to work with a site that did not involve ownership

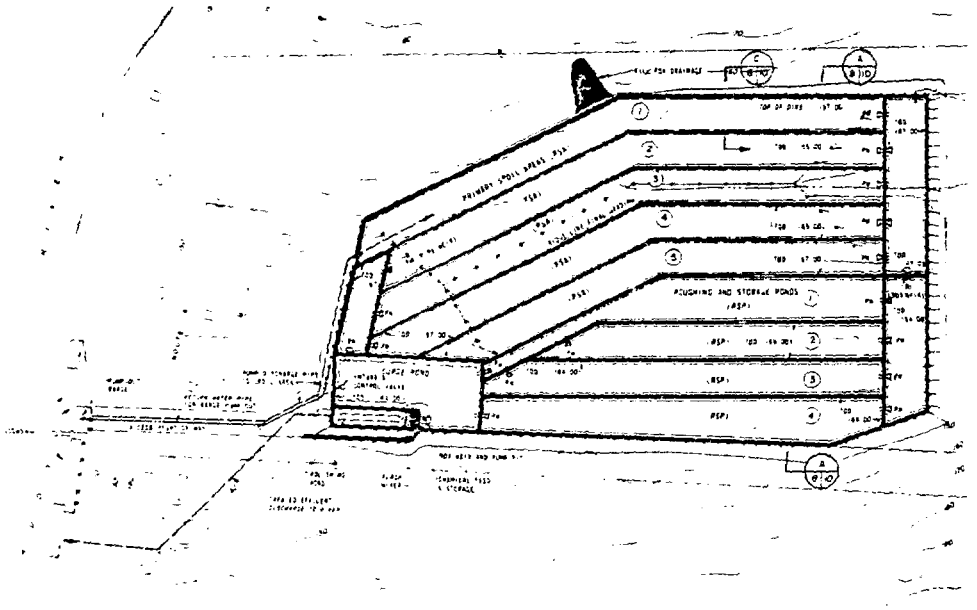

Fig. 23.5. Conceptual design for disposal site using clamshell dredging with hydraulic pumpout, showing possible use of interior dikes for material segregation.

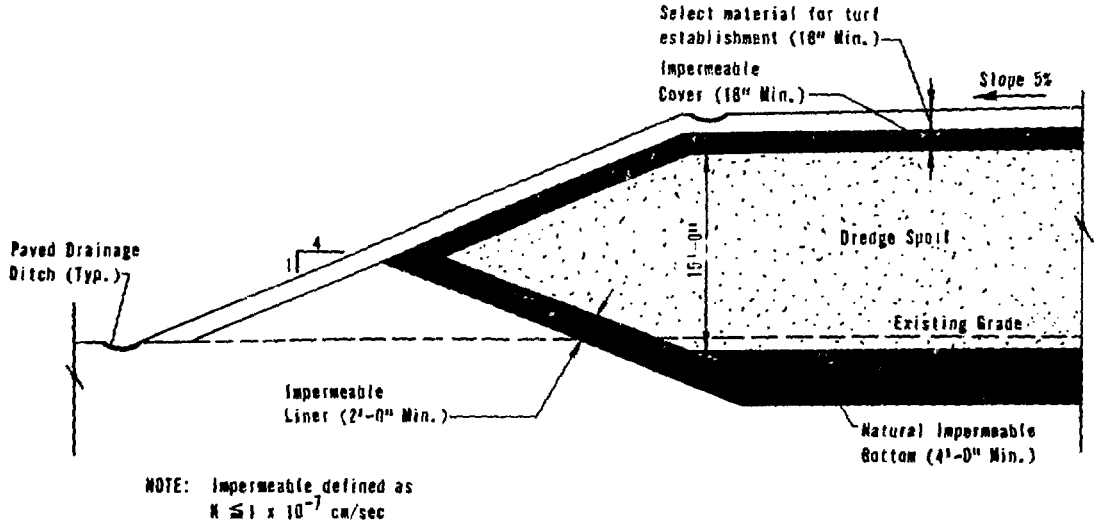


Fig. 23.6. Typical disposal site construction with clamshell excavation and mechanical unloading.

acquisition. The site belonged to the Department of Transportation, and it had been previously used for dredged material disposal. The surrounding material was previously dredged material, some of it contaminated, but not as highly as the new material. Detailed field investigations revealed that about 2/3 of the site did not have clay of sufficient impermeability to meet key soil criteria. Suitable clay was brought in, and the basin was lined to

a depth of about 18 inches. A peripheral drainage system was constructed to control ground water. The sides were sloped to maximize runoff and the surface runoff was collected. The site has now been stabilized, and there are no problems with it.

An environmental assessment was done as a part of the project. There were a number of environmental groups that questioned whether it could be demonstrated that it was better to remove the material than to leave it in place. The only possible answer is that this is a highly concentrated contaminant readily available for removal, and every season that it was there, the river washed more downstream. As the material washed away, it spread out and dispersed more and more so that the cost of removal would increase. Therefore, the benefits of immediate removal are quite apparent. The potentially negative environmental effects of removing the material were evaluated in considerable detail. From this came identification of the mitigating measures that could go into the plans and specifications to reduce the impacts. Key concerns during dredging were whether material would be released which would effect water quality downstream, since the lower end of this reach was used as a water supply. It was determined that the amount of contamination was minor and that any increase would probably not be measurable. Generally it was found that the long-term benefits far outweighed the short-term impacts of dredging. It is important to realize that the project was evaluated in the context of a highly polluted environment. The EPA-proposed ambient limit for PCB in fresh water is one part per trillion; the proposed effluent standard is one part per billion. The river-bed material of the upper Hudson contains from several hundred to several thousands parts per million of PCB, and aquatic organisms such as fish have several hundred parts per million. The river water may contain as much as 10 or 20 parts per billion. The leachate from the Moreau disposal site is on the order of one part per billion, in the range of what the EPA has proposed as an effluent criteria.

In implementing the proposed program, there are a number of things that have to be considered. It is important to make sure that the contractors are qualified, have the appropriate type of equipment, and employ the proper approach. There should be preconstruction conferences to make sure the bidders and contractors understand the significance of this action. Wherever possible, conventional equipment should be used to expedite the action, but the equipment or techniques also may be improved with modifications such as accurate positioning systems. It is important to monitor the dredging and return flow. The monitoring done in the preliminary work to open the navigation channel and remove the readily available materials has been helpful in demonstrating the feasibility of further remedial action. The monitoring has been a big factor in the determination to use conventional equipment rather than improved dredging equipment.

Another major concern is the need for long-term management of a disposal site. The people in the radioactive waste management business are well aware of this need. However, there are a lot of people in the world who are horrified by the whole thought of managing chemical contaminants, and it is disturbing that there has been little interaction between the people who have been doing this for several decades with radioactive waste and the people who are now trying to think of how to deal with chemical contaminants. There should be a lot more interaction, because a lot may be learned from the people who have been dealing with radioactive wastes.

A major factor in whether this project will ever be completed is the availability of Federal funds. There are approximately 15,000,000 yards of material, involving over 400,000 pounds of PCB, remaining in the upper reach of the river. To do the whole river and remove all the contaminants in the upper 40-mile reach, approximately $200 million would be needed. It appears most cost-effective to remove the material initially only from the upper three pools. The State would prefer to remove all of it, but to remove only about 140,000 pounds of PCB (2 million

yards) costs $22 million. Obviously, this can't be done without some aid. The State alone just does not have that much money. They have already removed over 200,000 cubic yards of material at a cost of $3 million. The State of New York has applied for a Federal Clean Water Act grant, but so far they have been unsuccessful. There are some indications that they may be able to get some assistance. The State is hopeful that it will be possible to start work sometime in 1980.

The work which has been done already has demonstrated the technical feasibility. Detailed site studies are currently being initiated including test pits, borings, and wells on the disposal area. The preparation of detailed plans and specifications will be initiated soon.

It is clear that this is not a routine project. The PCB levels are probably the highest in the country. It will be under close scrutiny by government groups and many environmental groups, but it is a challenging demonstration of what can be done to clean up an aquatic environment.

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From the floor: What I did not notice was a study of the effectiveness of the removal versus the remaining concentrations in the water. You had this $20 million proposal that could get the hot spots and 30% removal. Yet you are talking about three or more orders of magnitude difference and concentration between ambient and proposed EPA dream standards. If you can remove only 1/3, that is not going to lower the levels in the fish enough.

Henningson: I understand exactly what you are saying. Even if you were to remove the bed material down to 10 parts per million, it is unlikely that the levels in the fish would get down to the FDA standard of two parts per million. As long as you have two parts per million in the bed it will contaminate the water to the level that you would still have over two parts per million in the fish. Is the two parts per million level in the fish reasonable? Certainly 300 is not. If you could get the fish level down to 2, 5, 10 . . . is that a reasonable accomplishment, and is that a reasonable level to have in fish? We know that PCB is not something that you want to leave and have throughout the river system. We have material that we can get out easily rather than letting it distribute itself throughout the whole river system. The thought is, while you can get at it, get the highest spots out and do something with it. Why let it spread throughout the whole environment? No, it isn't going to improve the fish situation so that it is within FDA limits, but it certainly is going to make it better.

From the floor: Will there be any hydrological reconcentrations behind downstream dams in the future? In other words, it was all trapped behind a dam, and now that you have taken that dam out, it will go on downstream. Will it be trapped again behind the next dam? Or could you wait for a while and get it to reconcentrate for you naturally?

Henningson: It appears to have reconcentrated in certain spots. That concentration pattern varies from pool to pool depending on the hydraulic characteristics. What will happen is that every time there is a flood it is going to move from pool to pool and gradually work its way downstream. They have found that the levels of PCB in the water column during flooding are much higher than during low-flow periods. So it moves during a flood situation and will move downstream. It will constantly be repositioning itself, and eventually it will reach the estuary. At that point it becomes very difficult to deal with.

# 24. IDAHO NATIONAL ENGINEERING LABORATORY DECONTAMINATION AND DECOMMISSIONING SUMMARY

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Idaho National Engineering Laboratory
Idaho Falls, Idaho

The topics I would like to cover today concern the D&D work performed at the Idaho National Engineering Laboratory (INEL) during FY 1979 and include both operations and development projects (Fig. 24.1). I would like briefly to present the different types of D&D projects planned and the D&D projects we have completed. I will then discuss the problems we encountered on these projects and the development program that we recommend.

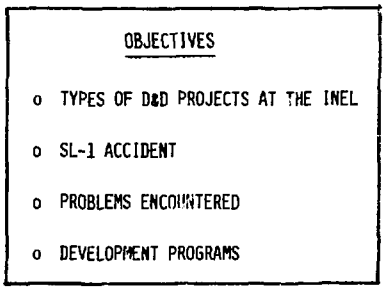


Fig. 24.1. Program objectives.

Contaminated areas at the INEL consist of test reactors, reactor support facilities, a fuel reprocessing facility, and various soil areas (Fig. 24.2). I want to emphasize that the reactors requiring D&D at the INEL are test reactors. Most are considerably smaller than commmercial power plants. In the past, these reactors provided a unique service in the field of reactor safety development. Because of this uniqueness, when a series of tests were completed the reactor was shut down and was of no use in further tests. As a result of this, 52 reactors have been built at the INEL, many of which are currently inoperative.

However, because they are small and have relatively low radiological fields, these facilities do provide an excellent opportunity to develop D&D technology. They allow personnel to

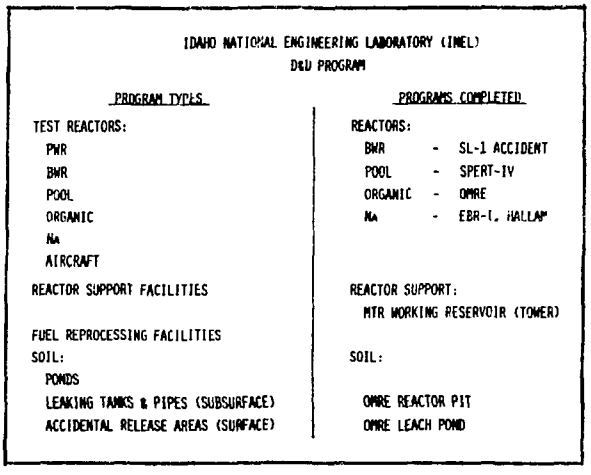


Fig. 24.2. D&D program, INEL.

learn D&D techniques and to develop planning methods without the risk of high radiological fields or accident conditions. (We have the opportunity to learn to walk before we have to run.) The programs we have completed include those shown on the right-hand column in Fig. 24.2.

The first D&D project at the INEL occurred as a result of an accident. The Army Stationary Low-power Reactor (SL-1) experienced a violent power excursion when the control rods were removed. The reactor went super-critical and over-pressurized. The resultant explosion destroyed the reactor and containment building, contaminated large areas of land, and killed three people. A summary of the SL-1 accident parameters is shown in Fig. 24.3. Approximately 500,000 Ci of fission product inventory were released; approximately 5% of the core breached the containment vessel.

The D&D task began immediately and was divided into three phases: (1) to recover the three bodies; (2) to determine the nuclear status of the reactor core; and (3) to gather

SL-1 ACCIDENT CLEAN-UP

PHASE I - RECOVERY OF THREE BODIES

PHASE II - DETERMINE NUCLEAR STATUS OF REACTOR CORE

PHASE III - GATHER DATA, REMOVE HARDWARE, DECONTAMINATE

| PHASE | FIELD | MAX EXPOSURE | NO. PEOPLE USED |
|---|---|---|---|
| I | >1000 R/HR | 27 R | 15 |
| II | 300 - 800 R/HR | 5 R | 800 |
| III | 200 DOWN | | |

FISSION PRODUCT INVENTORY 500,000 CURIES

5% OF CORE OUTSIDE CONTAINMENT VESSEL

Fig. 24.3. Summary, SL-1 accident parameters.

data, remove hardware, and decontaminate. The highest fields encountered were in excess of 1000 R/hr. These fields were found during Phase 1, and the highest exposure recorded to a single person was 27 R. Exposures dropped to 5 R per person during Phases 2 and 3, because shielding was used for protection and the fields naturally dropped as contaminated hardware was removed from the area. Today there is still a large land area at SL-1 which is contaminated (Fig. 24.4). A shallow burial ground is located behind the ARA II area, and the buildings at ARA II remain contaminated.

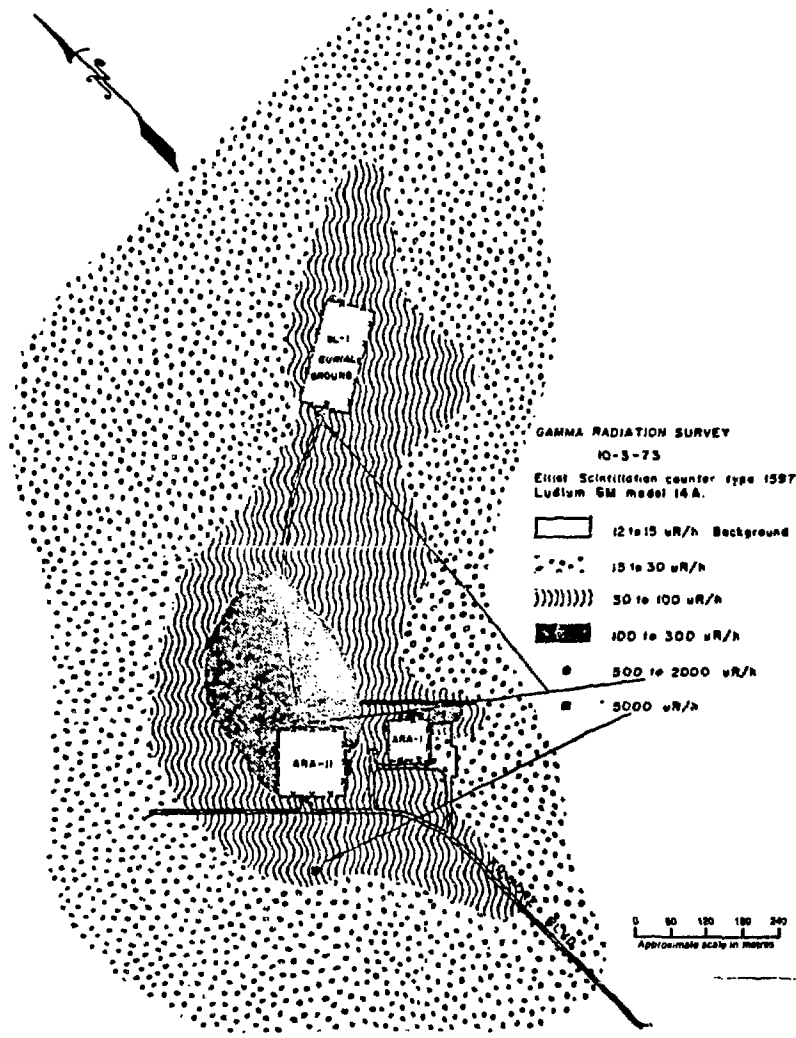


Fig. 24.4. Gamma survey of contaminated area outside ARA-I and ARA-II fence.

As one compares D&D activities today with those during SL-1, 19 years ago, it is discouraging to find that there has been very little technology development in the field of D&D. Some kinds of equipment, such as TV cameras, have greatly improved; however, equipment for handling and cutting, remote measurement, and portable shielding have effectively stood still. I believe much of the needed technology exists in other fields. It is a matter of getting the right people thinking about D&D and applying existing technology to this field. Some inventions may also be required, and this can only be done through adequate funding. The D&D lead lab has an excellent opportunity to ascertain the areas requiring development and to dispense funding accordingly. D&D has been looked upon as an engineering job--a garbage collector. This must change if we are to bring other members of the scientific community into the fields of research and development. With the development of special tools, the costs to D&D a facility should be reduced.

Figures 24.5 through 24.8 are before-and-after views of two D&D projects. The problems we encountered during the D&D operations in FY 1979 are listed (Fig. 24.9). In general, the materials handling/cutting problems were typical of any demolition program, and our solutions were the obvious ones which would be used in typical demolition activities. The only non-typical problem is that of radiation. In general, we dealt with relatively low fields, so personnel exposures were relatively low. Additional shielding precautions were taken when removing the OMRE vessel, because these fields were in the order of 350 R/hr. This shielding consisted of filling the reactor vessel with

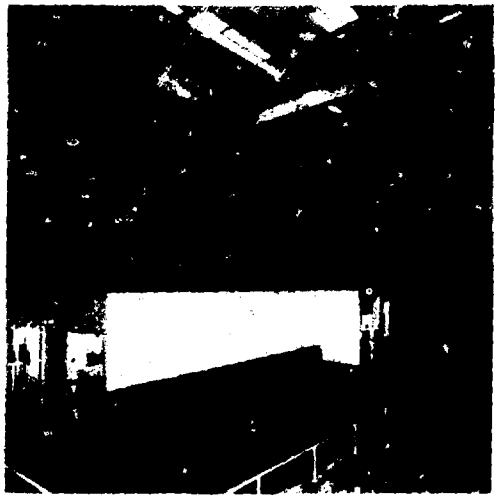

Fig. 24.6. After D&D.

Fig. 24.5. Before D&D.

Fig. 24.7. Before D&D.

Fig. 24.8. After D&D.

PROBLEM AREAS

- o MATERIALS HANDLING & CUTTING
- o VOLUME REDUCTION
- o CHARACTERIZATION
- o SOIL RELEASE CRITERIA

Fig. 24.9. Problems encountered during 1979 D&D operations.

concrete to a level above the core location and placing lead shielding around the vessel during cutting operations.

Exposures, although below guidelines, could be further reduced through the use of remote cutting and handling equipment. This is an area we feel requires further development; however, we have not pursued this task. In cutting open the Hallam components for inspection (Fig. 24.10) after processing the Na, we did employ a semi-remote saw. This was used as an experiment to compare the saw with standard flame-cutting techniques. It was necessary for personnel to strap the saw on the vessel and begin the cut. Once the cut was begun, the saw operated remotely to cut the remaining circumference of the vessel (approximately 12 ft diameter by 3 in. thick). In general, the operators much preferred the saw to flame cutting, because it was faster, cleaner, and much less work on their part. This also provided an additional safety factor during opening for inspection, since we anticipated the possibility of residual sodium being inside the vessel.

Because the remaining storage volume at the RWMC is small, we are quite sensitive to volume reduction, particularly in the case of large tanks and pipes. The only tanks we have attempted to cut apart were the pool reactor tanks in SPERT IV; we accomplished this with a plasma-arc cutter. This provided a unique problem of its own, because the plasma-arc torch requires carbon dioxide gas which reacted with the nickel in the stainless steel to produce nickel-carbonyl and carbon monoxide, which are poisonous gases. Air samplers were placed in the cutting

Fig. 24.10. Hallam components were cut open for inspection.

area, and the operators were required to wear respirators.

A study was completed last year comparing various techniques to reduce the volume of large tanks, pipes, and irregular shaped objects. We decided to develop or purchase a smelter to handle beta/gamma-contaminated wastes. One alternative was to increase the size of our burial site, but this was not acceptable to the State of Idaho.

Lack of characterization of a facility prior to actual D&D has been one of the most severe problems we have encountered. We have tried to turn this around by thoroughly characterizing the site one year prior to the actual D&D operations. The facility is characterized radiologically for volumes of various materials, both contaminated and noncontaminated, and for physical locations of components. Any peculiar problems regarding removal of hardware or other programmatic impacts are also identified. Without accurate characterization, problems are encountered which slip schedule and cause cost overruns.

Characterization has not totally eliminated operational problems. In the case where high radiation fields exist, it has not been possible to take accurate physical measurements, because allowable personnel exposure times are too short. Remote equipment needs to be developed to record these fields. We are proposing the development of a remotely operated gamma-sensitive camera, to be discussed later. The French have developed robots which can either be pre-programmed or remotely operated to enter high radiation fields and perform rather complex operations. This needs to be looked into further.

The most difficult problem we have encountered is the lack of criteria for release of soil areas (Fig. 24.11). We have attempted to define a relatively liberal set of criteria based on (1) the fact that we are a nuclear site with operational reactors adjacent to areas we are cleaning up, and (2) natural radiological backgrounds throughout the world. We feel the 1-nCi/g-beta/gamma release criterion is acceptable as this is equivalent to approximately 20

| INEL SOIL RELEASE CRITERIA ($\beta$-$\gamma$) | |
|---|---|
| PROPOSED | 1 nCi/g |
| EBR-I | 10 pCi/g |
| TRITIUM (EBR-I) | $1 \times 10^{-3}$ $\mu$Ci/g |
| BACKGROUND | 0.5 TO 1 pCi/g |
| OMRE | < 0.2 pCi/g<br>< 0.1 mR/h |

Fig. 24.11. Soil release criteria.

mrem/yr--comparable to the natural background found in the Colorado mountains (Fig. 24.12). This criterion has been proposed by EG&G but has not been acepted by DOE-ID.

If we are to attempt to clean up sites and release them between now and FY-1982, we must develop some acceptable interim standards. EPA is scheduled to release criteria for soils in a draft form during FY-1980 and an approved set of criteria during FY-1981. It is essential that individuals such as those here today provide input to this study, or we may find ourselves decontaminating soil to existing local background levels. In most cases, this is certainly not cost-effective nor warranted, based upon a risk/benefits analysis.

Measurement accuracies and the confidence one has in the data are of great concern. When dealing with large soil areas, the number of samples to be analyzed can become astronomical; the resulting expense can be prohibitive. The results are not better than the sampling techniques employed. Additionally, the accuracy of the data should be dependent on how the data are used. In the case of D&D at the INEL, we are interested in determining the area and depth of contamination and the isotopes in that area. We simply want to know how much soil do we dig up and store, what nuclides are present, and whether the area is clean when we finish. We therefore accept a factor of two in accuracy for characterization steps. Samples taken to determine

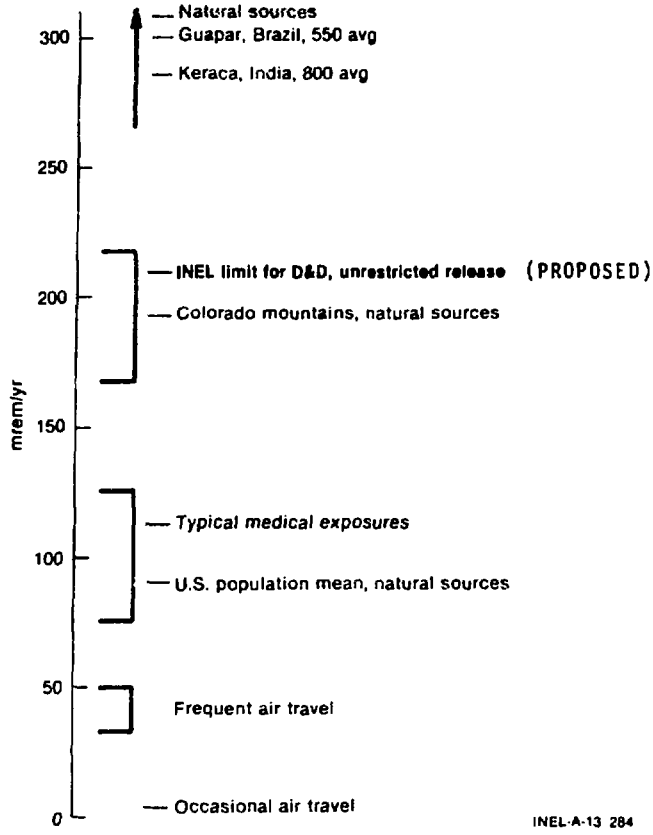


Fig. 24.12. Radiation exposures.

release will have to be much better than this and will be determined once the release criteria are established. We feel the factor of two is consistent with our sampling procedure.

When accepting an absolute measurement for releasing a soil area, one needs to consider what confidence he has in the laboratory which analyzed the soil samples. Some time ago, DOE-ID's Radiological and Environmental Sciences Lab sent doped samples of contaminated mice and soil to 11 labs, including their own, for analysis. Only two of the 11 results agreed, with others varying by orders of magnitude. This points out a need to standardize sampling techniques, reference standards, and measurement techniques.

This brief summary completes the first portion of my discussion. I would now like to address the development programs we are pursuing or recommending. These include volume reduction, characterization using remote measuring equipment, soil decontamination, and soil release criteria.

We investigated various methods to reduce the volume of our contaminated materials (Fig. 24.13). We considered compactors, smelters, shredders, and electrochemical techniques. The majority, by volume, of contaminated material consists of heavy-walled, stainless-steel items. The strength of the heavy-walled, stainless-steel pipe rivals the strength of the shredders and most compactors. One compactor was found that would suit our purpose. Based upon the cost trade-off (Fig. 24.14), we have selected a smelter as being the best choice for our purposes. Electrochemical techniques look quite

| VOLUME REDUCTION |
|---|
| CONSIDER METALLIC ITEMS ONLY - STEEL MOST VOLUME |
| COMPACTOR - 400T (8 - 10 TONS/HR) |
| SMELTER - 5 TONS/HR |
| ELECTROCHEMICAL - NOT FEASIBLE FOR COMPLEX SHAPES (AT PRESENT TIME) |

Fig. 24.13. Comparisons, methods of reducing volume of contaminated materials.

CONTAMINATED METALS HANDLING COST COMPARISON

| | | |
|---|---|---|
| PRESENT HANDLING: | | |
| CAPITAL COST | : | $0 |
| HANDLING COST | : | $0.35/LB |
| CONTAMINATED VOLUME REDUCTION: | | NONE |
| MECHANICAL COMPACTION: | | |
| CAPITAL COST | : | $650,000 |
| HANDLING COST | : | $0.22/LB |
| CONTAMINATED VOLUME REDUCTION: | | 20% TO 70% |
| SMELTING DECONTAMINATION: | | |
| CAPITAL COST | : | $1,775,000 |
| HANDLING COST | : | $0.23/LB* |
| | | $0.13/LB** |
| CONTAMINATED VOLUME REDUCTION: | | 90% TO 93% |

* No recycling of smelted steel.
** Decontaminated steel sold for scrap at $0.095/lb.

RECOVER INITIAL COSTS

| | | |
|---|---|---|
| COMPACTOR: | 1.5 | MONTHS |
| SMELTER: | 9 | MONTHS - NO METAL RESALE |
| | 5 | MONTHS - WITH METAL RESALE |

Fig. 24.14. Cost comparison of methods for handling contaminated metals.

promising, but based upon current release criteria and measurement techniques, we do not feel the approach feasible at this time. We may decontaminate the material only to find we can't release it and then still have to face burial of the material. This process also generates liquid wastes which would have to be processed at added cost.

Remote characterization does not appear to have a simple or inexpensive solution. We are proposing an idea, not a design, of a gamma-sensitive camera (Fig. 24.15). Basically, the gamma ray is incident on a scintillator surface which converts gamma energy to light photons. For image quality this surface should probably be quite thin, to avoid multiple scintillations and scattering. The result is picked up by a coherent-fiber optic bundle, to preserve the spatial image, and then amplified. This amplified image is then incident upon a photon-to-electron converter and read out as an analog video signal which can be viewed in real time or converted to digital readout for storage. The system is presented in a very simplified form. In addition to the components shown, a collimator with shielded aperture and visible filter may also be required on the front end.

Several ideas have been investigated regarding soil decontamination (Fig. 24.16). At this point, none of these techniques have proved to be completely effective in decontaminating soil. If we are allowed protective storage, the biobarrier would appear to be the most cost-effective solution. All of these processes have inherent problems (Fig. 24.17).

I would like to discuss two of the ideas for soil decontamination that we are considering at the INEL. These are (1) chemical extraction and (2) removal of nuclides by plants, namely

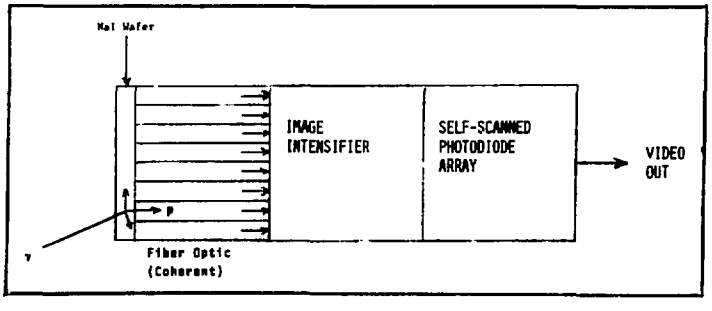


Fig. 24.15. Gamma-sensitive camera.

SOIL DECONTAMINATION TECHNOLOGY

- o CHEMICAL EXTRACTION
- o TERRESTRIAL AND AQUATIC PLANTS
- o BOX AND BURY
- o FRIT FOR GLASSIFICATION PROCESS
- o MECHANICAL SEPARATION - ROCKWELL, ROCKY FLATS
- o PROTECTIVE STORAGE - BATTELLE, PNL

Fig. 24.16. Techniques for decontaminating soil.

PROBLEMS RELATED TO SOIL D&D TECHNIQUES

| | |
|---|---|
| AQUACULTURE: | HANDLING COSTS<br>SUPPLY OF NONCONTAMINATED PLANTS<br>ION EXCHANGE TO SOIL |
| MECHANICAL: SEPARATION | DEWATERING OF FINE SOIL FRACTION<br>SOLUBILITY OF Cs, Sr<br>SOIL CHEMISTRY MAY REQUIRE SEPARATE PROCESSES<br>HANDLING COSTS |
| BIO BARRIERS: | UPWARD MIGRATION DUE TO PLANTS, ANIMALS, GROUNDWATER.<br>SURVEILLANCE GREATER THAN 50-100 YEARS QUESTIONABLE<br>PUBLIC OPINION |
| BOX & BURY: | HANDLING COSTS ARE PROHIBITIVE<br>LACK OF BURIAL SPACE |
| CHEMICAL: | INITIAL CAPITAL OUTLAY GREATEST<br>HANDLING COSTS MAY BE PROHIBITIVE |
| GLASSIFICATION: | SOIL VOLUMES AVAILABLE ARE MUCH GREATER THAN REQUIRED FOR GLASS MAKING |
| BULK BURIAL: (NTS) | DEVELOP TRANSPORTATION SYSTEM<br>PUBLIC & LOCAL GOVERNMENTAL OBJECTIONS |

Fig. 24.17. Inherent problems of soil decontamination processes.

the water hyacinth. The chemical extraction technique is shown (Figs. 24.18, 24.19, and 24.20). This technique is similar to the screening separation scheme proposed by Rockwell at Rocky Flats but differs in the following areas:

(1) In addition to size separation, we are performing both a surface leach and a leach of the ore.

(2) We feel we have a chance in volume reduction by a ratio of 100 to 1.

(3) Our technique is more complex and probably more costly than other similar processes.

The process consists of collecting the contaminated soil and hauling it to the processing site where plant materials are separated from the soil and rock (Fig. 24.18). The plant materials may be used as an energy source or returned to the desert for mulching the decontaminated soil. The soil and rock fraction is separated according to size, with rocks larger than about 15.2 cm (6 in.) being separated on a grizzly, and the materials larger than 2.5 cm (1 in.) being separated by a coarse screen. If the rocks are significantly contaminated internally they will be crushed to expose the contaminated surfaces for subsequent leaching and washing. Material smaller than 2.5 cm (1 in.) will be further classified to separate the fine soil fractions from the small rocks; this will be done with the leachate present, and some decontamination will be accomplished here. (As a first approximation, one would expect the finest fractions to retain most of the radioisotope contamination.) The materials are now sent to the leaching section where most of the decontamination will be done. Some classification will occur in the after sections of the leaching processors. The solids will be sent to a settling pond where they will be dewatered and returned to the desert for revegetation. The leachate from the leaching section and settling ponds will be treated for isolation and consolidation of the radioisotope contamination.

Two methods are suggested for isolation and consolidation of the contaminants. One involves evaporation of the leach liquor, the other depends on precipitation, co-precipitation, and ion exchange (or reverse osmosis) for isolation and consolidation.

The first process accepts the finest solids fractions from the classifier/reactor (these are suspended solids) and the leachate from the countercurrent contactor. The solids are separated from the leachate in a settling pond and the leachate is evaporated (Fig. 24.19). The solids from these two steps are calcined, then sent to long-term storage facilities.

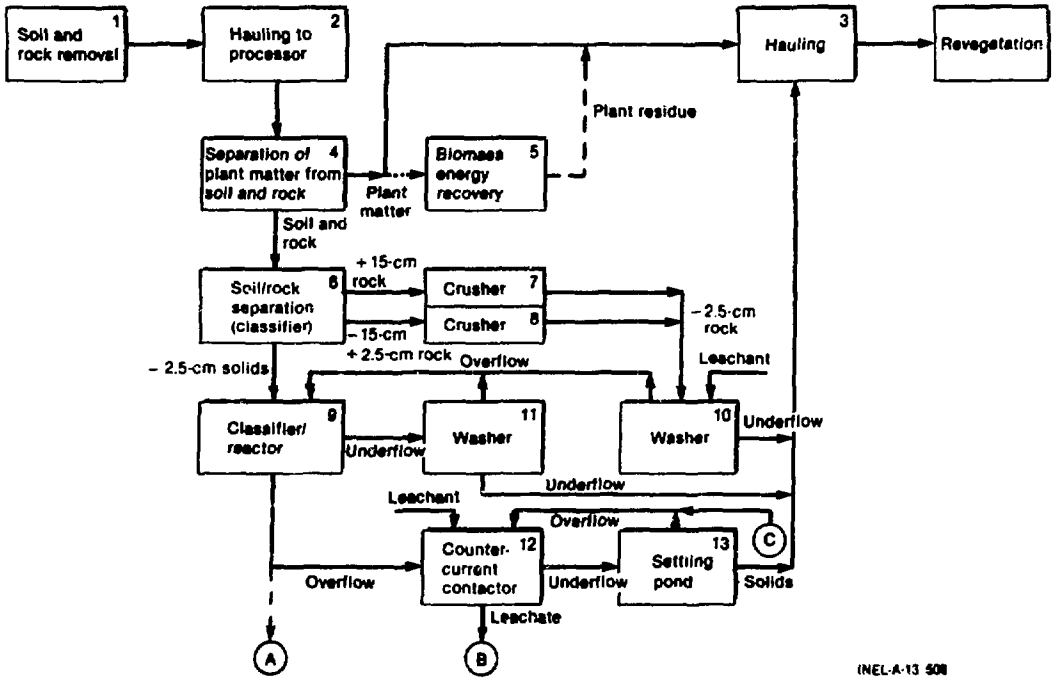


Fig. 24.18. Chemical extraction flow sheet (No. 1).

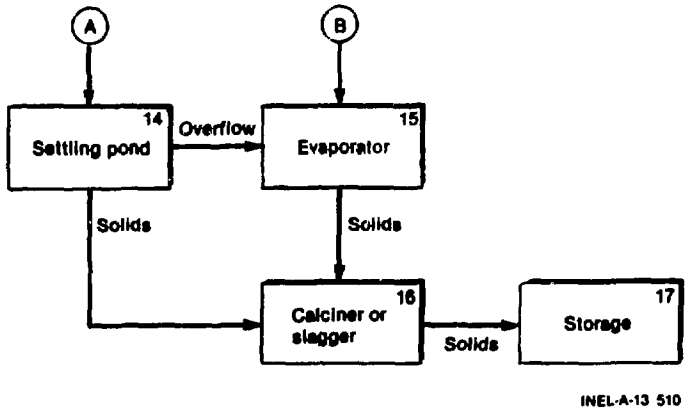


Fig. 24.19. Chemical extraction flow sheet (No. 2).

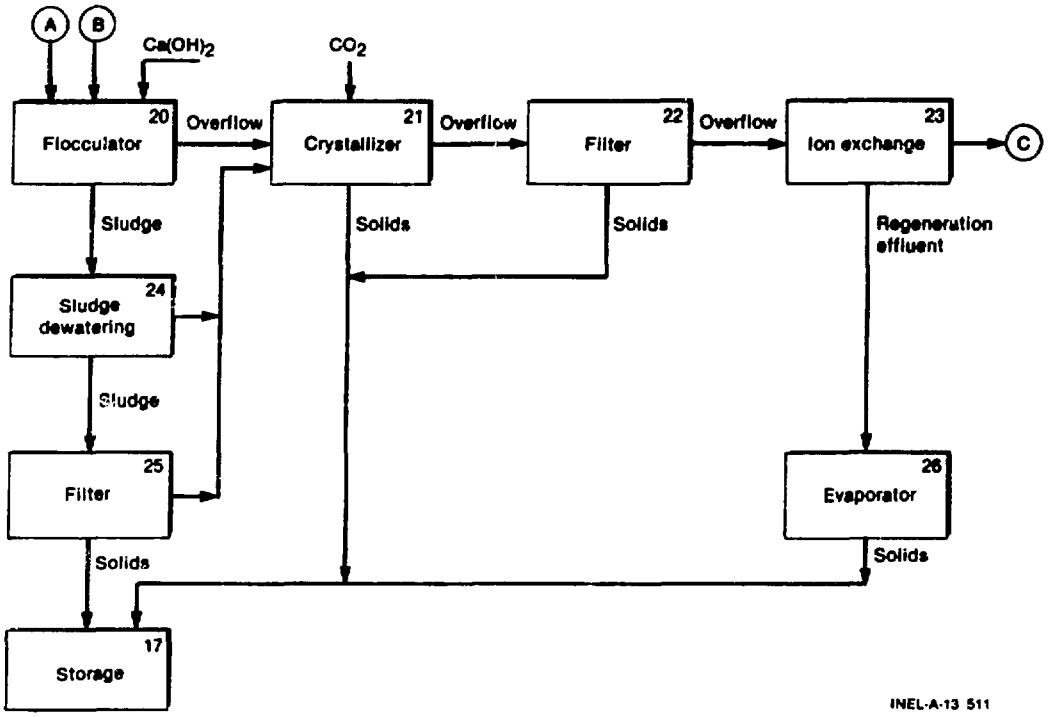


Fig. 24.20. Chemical extraction flow sheet (No. 3).

The second process appears to be more complicated than the first but has the potential of being substantially less energy intensive. The finest (suspended) solids from the classifier/reactor are sent to a flocculator. Lime, for example, is added there to agglomerate the solids, to precipitate most of the strontium, and to co-precipitate portions of the cesium and cobalt (Fig. 24.20). The water fraction from the flocculator is sent to a crystallizer, where carbon dioxide gas is used to precipitate the soluble portion of the calcium added as lime in the flocculator. This will precipitate as calcium carbonate and should co- precipitate the remaining strontium and part of the cesium and cobalt. The liquid from the crystallizer is filtered and sent to an ion exchange (or reverse osmosis) system, where the remaining cesium and cobalt are extracted. The water from the ion exchanger is sent to the countercurrent contactor as makeup water.

The solids (as a sludge) from the flocculator are filtered and sent to storage (Fig. 24.19). The filtrate is sent to the crystallizer. Solids from the crystallizer and the filter are also sent to storage.

The ion-exchange system will require periodic regeneration to return it to normal operating capacity and to remove the retained radioactive contamination. The effluent (liquid) from the regeneration operation will be evaporated, with the solids being sent to storage.

As I mentioned earlier, there is no obvious solution to the soil decontamination problem. For this reason, I believe we need to look into areas that are not obvious: nonconventional and non-nuclear methods. We have looked at one such area and that is recovery of radionuclides using nature, or plant extraction. Tests performed at NASA/NSTL have shown the water hyacinth to be capable of absorbing large quantities of heavy metal ions from waste effluent streams. We

rationalized that if this was possible, why not use plants to extract radioactive elements from soil?

A feasibility study was completed that proposes the use of plants to remove radionuclides from soils. The approach taken was to (a) delineate methods that increase radionuclide uptake, (b) find climatically adapted plants that absorb the largest quantities of radionuclides, (c) develop cultural management practices that permit their optimum growth but do not allow contamination of air or of water tables, and (d) investigate plants that could be adapted to the INEL climate under natural and greenhouse (controlled) conditions.

The most significant finding of this study was that use of aquatic plants for soil decontamination appears to be feasible using plants such as water hyacinths, alligator weeds, water willows, or the common cattail, which can be grown in a greenhouse environment. The fact that aquatic plants can absorb heavy metals such as mercury, cadmium, and lead may be the most promising result of this study. This may indicate a method for decontamination of mill tailings that contain other heavy metals, such as uranium, americium, and radium.

A very simple experiment was conducted at the INEL under what were probably worst-case conditions (Figs. 24.21 and 24.22). Although

WATER HYACINTH TEST DATA

- 9 PLANTS RECOVERED 8% OF NUCLIDES BETWEEN 1 AND 6 DAYS
- VOLUME REDUCTION - 22%
- BEST PLANT UPTAKE
  - $^{137}Cs$ - 10 TIMES AN EQUAL WEIGHT OF SOIL
  - $^{60}Co$ - 2 TIMES
  - $^{90}Sr$ - 2 TIMES

Fig. 24.21. Data, water hyacinth experiment.

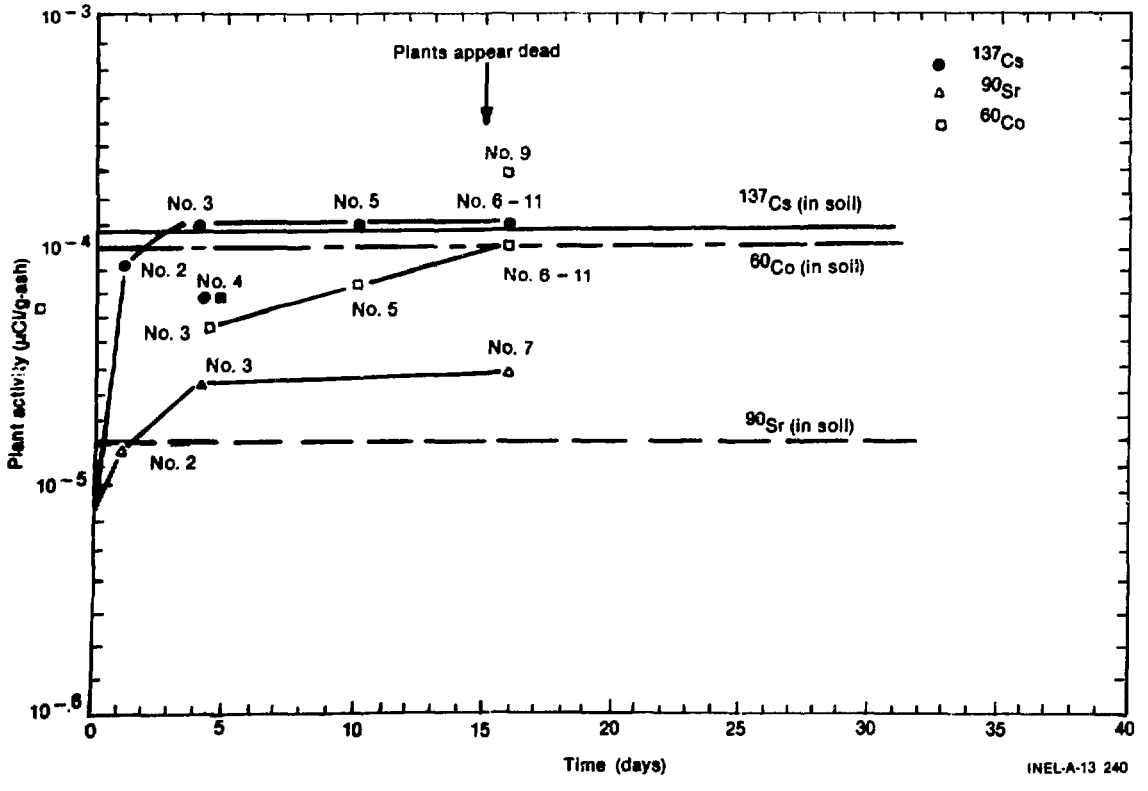


Fig. 24.22. Data, water hyacinth experiment.

the results of this test were not conclusive, they do indicate a possibility of soil decontamination utilizing the water hyacinth. We feel that further testing under controlled conditions is warranted; however, there is no funding this year to proceed. This technique may also have application in the purification of geothermal waters prior to reuse. This is being evaluated at our Raft River Geothermal Site beginning in the Spring of 1980. It may also have use in decontaminating nuclear reactor waste-water leach ponds prior to ion exchange on the fine soil fractions.

A conceptual design of a proposed Aqua-Processor for the decontamination of soil is shown in Fig. 24.23. The major problems to be resolved are soil handling costs and releasing the nuclides from the fine soil fractions to the water in ionic form. A very rough order-of-magnitude cost estimate comparision for the five methods we considered is given (Fig. 24.24). The $10^7$ $m^3$ of soil is the estimate of the contaminated soil volume at the INEL.

SOIL DECONTAMINATION
COST COMPARISONS (ROM)

| TECHNIQUES | CAPITAL OUTLAY | OPERATING | TOTAL FOR $10^7 m^3$ OF SOIL |
|---|---|---|---|
| (1) BOX & BURY | $130 TO $160 PER BOX | $30/$m^3$ | +2 BILLION |
| (2) CHEMICAL | $10 TO $25 MILLION + | | |
| (3) MECHANICAL | $5 TO $7 MILLION | $17/$m^3$ | 190 MILLION |
| (4) AQUACULTURE | $3 TO $5 MILLION | | |
| (5) PROTECTIVE STORAGE | $500K TO $1 MILLION | MINIMAL | 5 MILLION |

Fig. 24.24. Cost estimate comparison of methods considered.

It appears that three approaches must be followed prior to accepting or rejecting this technique as a viable process. These approaches are: (1) to investigate techniques to place the nuclides into solution, (2) to determine plant toxicity levels for nuclides resulting from high-level spills, and (3) to maximize plant growth and nuclide uptake by optimizing lighting conditions.

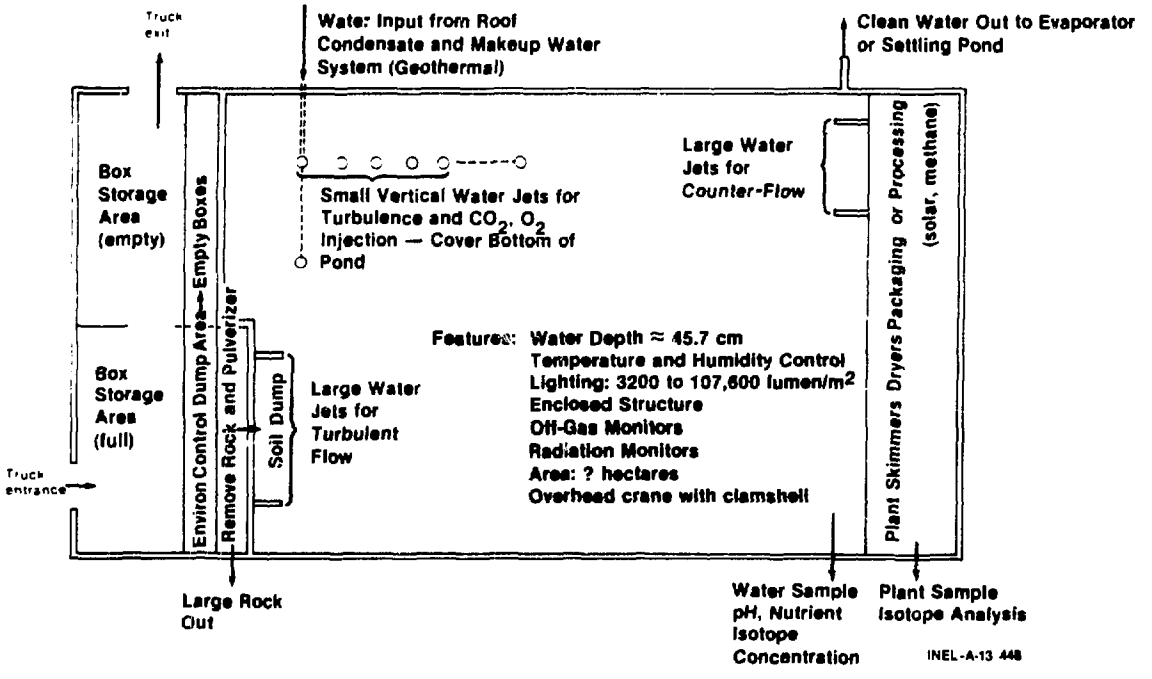


Fig. 24.23. Aqua-processor concept.

If the nuclides can successfully be released from the soil fraction, there is a potential for an 80-90% volume reduction. If this can be done, further testing should be undertaken, using large numbers of plants (several hundred). Light levels should be optimized by establishing a controlled greenhouse environment.

Figure 24.25 summarizes the development program at the INEL.

SUMMARY

- INEL D&D PROGRAM COVERS MANY FACETS OF D&D DISCIPLINE
  - MANY DIFFERENT TYPES OF REACTOR FACILITIES
  - COMPLEX FACILITY CHARACTERIZATION
  - PERSONNEL EXPOSURE CONTROL
- INEL PROGRAM HAS DEFINED D&D PROBLEM AREAS
  - SOIL DECONTAMINATION OR HANDLING
  - VOLUME REDUCTION
  - NEED FOR D&D RESEARCH (INSTRUMENTS, TOOLS)
  - NEED FOR UNIVERSALLY ACCEPTED CRITERIA

Fig. 24.25. Summary of INEL development program.

Chester: We have time for one question.

From the floor: What cutting techniques do you prefer for metal and concrete?

Chapin: We haven't cut any concrete. For metal, we've used the plasma arc torch on the large tanks, which was quite successful. On small pipes, very small pipes, we've used just hand tools. There we had another problem: we thought we had xylene in the tubes, and we couldn't use flame for that.

From the floor: In the volume-reduction techniques for soil, what would you propose to do with the waste solutions--or with the plant matter or whatever? Where would you put it, what would you do with it, and what volumes would you have?

Chapin: If we were to go to the water hyacinths, as an example, you've got about 95% volume reduction by drying the plant, and you can reduce that by another 18% by ashing the plant. The plant also could be used for methane production--because a very large biomass produces quite a substantial amount of methane. You could then recover the methane. Dry the plant, incinerate the plant. We would look to eventual incineration.

From the floor: Then you will put the ash in disposal areas?

Chapin: Yes.

# 25. A CRITERIA DEVELOPMENT METHODOLOGY FOR DOE DECOMMISSIONING OPERATIONS

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Pacific Northwest Laboratory
Richland, Washington

In this presentation, I will briefly outline the study currently in progress at the Pacific Northwest Laboratory (PNL) entitled "Criteria Development for DOE Decommissioning Operations." Our project is not one to develop specific release criteria, but rather to use radiation standards agreed upon with our sponsor, the U.S. Department of Energy, Division of Operational and Environmental Safety, in developing a Radiological Guide for use by DOE and its contractors in conducting decommissioning operations. In addition to agreeing upon radiation standards (or Annual Dose Criteria), the work to be performed at PNL includes the following tasks:

- Site Characterization. Recommend methods for establishing or confirming radioactivity levels prior to, during, and subsequent to decommissioning operations--including statistical design, sampling techniques, and instrumentation performance criteria (to include review and evaluation of methods currently being developed at Oak Ridge under NRC contract).
- Estimation of Occupational Radiation Exposures. Recommend methods for estimating occupational radiation exposures during decommissioning operations.
- Estimation of Environmental Radiation Exposures. Recommend methods for estimating environmental exposures prior to, during, and subsequent to decommissioning operations, including unplanned releases.
- Determination of Numerical Guidance. Develop simplified methods for determining specific numerical guidance for decontamination and/or release, for both exterior and interior surfaces and for bulk materials.
- Documentation and Quality Assurance. Recommend overall documentation and QA requirements for decommissioning, from written procedures and agreed-upon goals prior to initiating decommissioning to the generation of records and their storage requirements.

The methods recommended in this project must be applicable to all DOE (and its predecessor organizations) facilities and sites, to the extent possible. The Guides developed in this project will provide a uniform basis within DOE for assessing hazards, will promote more uniform contractual requirements for decommissioning contractors, and will provide a consistent basis for certification of decommissioned sites.

## BACKGROUND

The Department of Energy is faced with the need to dispose of equipment, structures, and real estate known or believed to be contaminated with radioactivity. And as we have seen at this meeting, decommissioning guidance to date has usually been defined by the local contractor or field office for the specific site, based on one or more of the factors listed below.

- Measurement capability
- Some multiple of background
- As low as reasonably achievable (ALARA)
- Some fraction of applicable limits

Unconditional release has been based most commonly on the first factor, measurement capabilities of available instrumentation. However, with respect to impact on people, such site-specific guidance has resulted in inconsistent release criteria. It may also have resulted in unnecessary disposal of materials as contaminated wastes or in unnecessary restrictions on reuse. From these potential inconsistencies, we concluded that there is need for a general method for deriving acceptable residual contamination levels that can be applied in the release of any decommissioned nuclear site.

Our proposed approach is to determine acceptable environmental contamination levels based on the maximum annual dose to an individual from the residual contamination via all environmental pathways. In Fig. 25.1 we have illustrated the approach by comparing the maximum individual dose rate with a set of "limits"--Maximum, Design Objective, and de Minimis. The Maximum Limit is the current DOE standard of 500 mrem/yr for individuals in uncontrolled areas. At the other extreme we define a "de Minimis" level as the minimum dose of concern. In this example we have used 1 mrem/yr to the maximum individual as the de Minimis level. This is consistent with that suggested by the Great Lakes Water Quality Agreement[1] and by ERDA 77-24[2] as the minimum level for environment surveillance programs. However, it is well to point out that "de Minimis" does not mean ignorance, but rather ignore-ance. De Minimis levels are those that would, at worst, result in incremental radiation doses at the "so what" level.

In between the Maximum Dose Limit and the de Minimis level is the Design Objective level, defined as the maximum acceptable dose for designing a decommissioning program. We have deliberately not shown a specific value for the Design Objective level, but rather a range from several to tens of mrem/yr, typical of those currently being discussed for decommissioning activities.[3] It is anticipated that the Design Objective level will be site-specific based on the ALARA concept. As noted in Fig. 25.1, uncontrolled sites or facilities are those in which residual contamination levels have been reduced to below the Design Objective level and hence fall into the ALARA region. Controlled sites would then be those in which residual contamination levels exceed the respective Design Objective dose rates. Increased exposure potential for those sites would be prevented through the institution of appropriate controls on the continued use of the site or facilities.

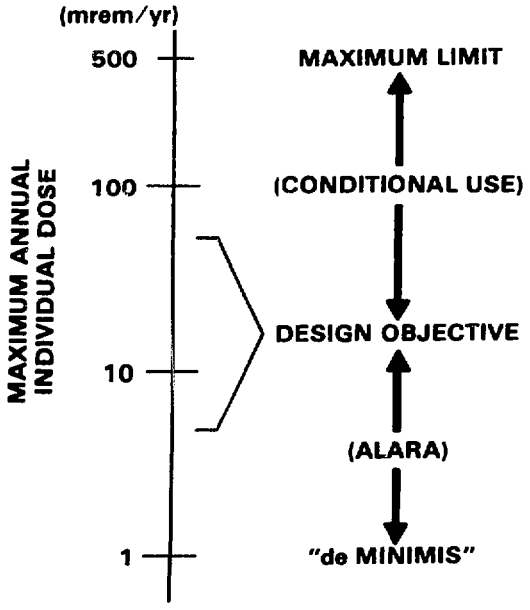


Fig. 25.1. Comparison of maximum individual dose rate with a set of limits.

## DISPOSITION CRITERIA METHODOLOGY

Once acceptable dose criteria (Design Objective and de Minimis levels) are established, it is possible to calculate target residual contamination levels for a given site or facility using appropriate environmental pathway models. This, in turn, will permit one to design a sampling program and to choose appropriate monitoring methods to detect contamination at those levels.

A general method has been developed at PNL[4] for deriving acceptable radioactive contamination levels. This method can be applied to any decommissioned nuclear site; it is capable of accommodating all radionuclide mixtures and site-specific features. It is based on limiting the annual doses to members of the general public and has been used for the past several years for Nuclear Regulatory Commission studies.[5-7] This method compares annual dose limits with calculated annual doses to members of the public (Fig. 25.2).

Initially, site-specific source terms and environmental parameters are needed for pathway analyses as shown in the circles at the top of

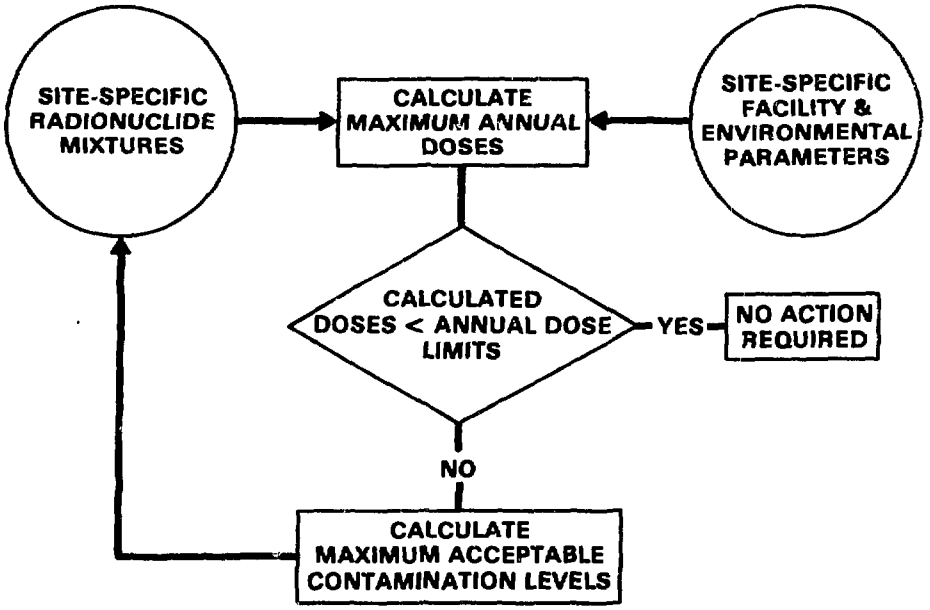


Fig. 25.2. Methodology for disposition criteria.

Fig. 25.2. These become the input parameters for the three-step methodology shown:

1. Calculate the maximum annual doses to the organs of reference resulting from the site-specific residual radioactive inventory using the methodology of Soldat[8] and others[9] at PNL.

2. Compare the maximum annual doses calculated above with the Design Objective dose rates. If the maximum doses are: (1) less than the Design Objective, no further calculations are required; (2) greater than the Design Objective, calculate the residual contamination levels that produce the Design Objective dose rates. (Note: The residual contamination may include such media as structures, soil, or water.)

3. Determine the maximum acceptable contamination levels at the Design Objective dose rates by selecting the most restrictive combination of exposure pathways and organ doses. These values, here referred to as disposition criteria, are dependent on the composition of the radionuclide inventory and the site-specific exposure pathways.

An example of using pathway methodology to relate soil contamination to dose is given in Fig. 25.3, based on the calculations of Healy.[10] This particular example is for strontium-90, assuming that all food sources and residences are on soil contaminated to those levels. The specific concentrations chosen were those corresponding to (1) minimum sensitivities by environmental monitoring (Environmental MDL: soil sampling followed by lab analysis) and in situ monitoring (portable instrument survey in field), (2) typical fallout levels (from past nuclear weapons testing), and (3) those proposed by the American National Standards Institute.[11]

Similar charts could be produced for other nuclides or nuclide combinations, giving the relative ranking of such factors as environmental or in situ MDL, natural background, and surface contamination standards. For comparison, such values were calculated for plutonium-239 based on the proposed EPA environmental limit of 200 $mCi/km^2$.[12] The annual dose to lungs for a person residing on soil contaminated to that degree is 30 mrem. Using a soil density of 1.5 $g/cm^3$ and a contamination depth of 1 cm, the EPA limit corresponds to 10-15 pCi/g. The relationships so derived for $^{239}Pu$ are given in Table 25.1.

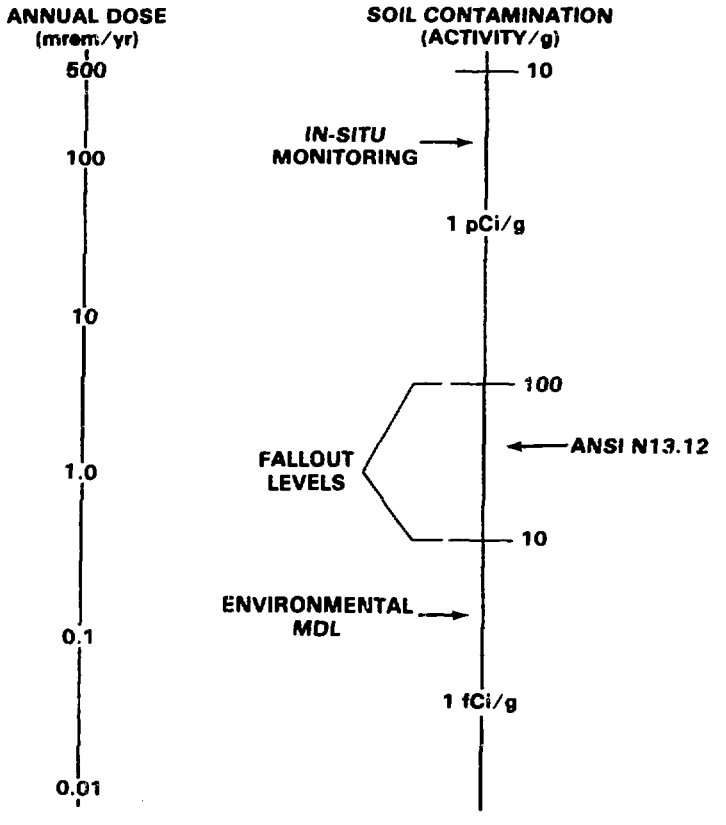


Fig. 25.3. Example of pathway methodology to relate soil decontamination to dose.[10]

Table 25.1. Annual Lung Dose from $^{239}Pu$ vs Soil Contamination Levels

| Annual Dose (mrem/yr) | Soil Contamination |
|---|---|
| 0.01 | 3 fCi/g (environmental MDL) |
| 0.3-1 | 0.1-0.3 pCi/g (fallout levels) |
| 30 | 10-15 pCi/g (EPA Guide, 200 mCi/km$^2$) |
| 3000 | 1 nCi/g (LASL in-situ Phoswich[13]) |

As noted from Fig. 25.3 and the comparative data for $^{239}Pu$, the capability of measuring the maximum acceptable residual contamination levels (at the Design Objective dose rate) may not be achievable at the present time. That capability is dependent in part on the sensitivity of the instrumentation utilized, the nuclide inventory, and the time available for surveying.

Another perspective on the relative importance of pathway analysis and soil contamination is shown in Table 25.2, also from Healy.[10] Here the fission products, strontium-239 and cesium-137, and the natural emitters, thorium and uranium, are compared with plutonium-239. In this example the soil is assumed to be uniformly contaminated to a depth of 20 cm. Each nuclide is treated separately and assumed to be deposited to a level of 5 pCi/g, a level which has been suggested for some cleanup criteria. From Table 25.2 it is clear that a single concentration limit would not result in the same dose to persons exposed, even for the same nuclide.

Table 25.2. Maximum Annual Individual Dose (mrem/yr) at 5 pCi/g Soil Contamination for Several Radionuclides

| | Inhalation | Ingestion | External Radiation | All Pathways |
|---|---|---|---|---|
| $^{90}Sr$ | 0 | 100 | -- | 100 |
| $^{137}Cs$ | 0 | 2000 | 30 | 2000 |
| $^{232}Th$ | 60 | 20 | 60 | 100 |
| $^{238}U$ | 3 | 300 | 0.4 | 300 |
| $^{239}Pu$ | 10 | -- | -- | 10 |

PROJECT SCHEDULE AND SUMMARY

A first draft of the Radiological Guide for DOE Decommissioning Operations is planned for fall, 1980. This Guide will provide a uniform basis for assessing hazard inventories, making risk analyses, performing site characterizations, and certifying decommissioning operations. While initially addressed to radioactive contaminants, in all likelihood it will be extended to include other contaminants.

We will continue to participate in workshops such as this one, including one we plan to conduct in April, 1980. That workshop will emphasize site characterization methodology and will include an overview of the Radiological Guide.

In the Radiological Guide, we expect to use potential maximum annual dose as the controlling factor in determining the acceptability of a residual contamination level or of a decontamination method. This method is site specific, radionuclide-mix specific, and is compatible with an annual dose limit. While the assignment of specific annual doses is not a part of this study, we have proposed a three-level set of criteria: Maximum, Design Objective, and de Minimis for DOE decommissioning operations. In conclusion, we believe that acceptable residual contamination levels can be determined by pathway analyses in which the calculated maximum individual dose is compared with an established annual dose limit (Fig 25.2). Such a method results in defensible, acceptable residual contamination levels that can be related to risk. Of course, an important proviso is that the pathway models (including their underlying assumptions) result in reasonably accurate estimates of dose.

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From the floor (Church): Dale, can you briefly tell us how you arrived at that cesium level? Two rem/yr for 5 pCi/g $^{137}Cs$ seemed awfully high.

Denham: That table was from Healy's food pathway calculations. His cesium and strontium calculations were based on $^{137}Cs/K$ and $^{90}Sr/Ca$ ratios. Because his $^{137}Cs/K$ ratio for meat is very large compared to other dietary sources, he obtained a high dose from that pathway. I'm not sure that I necessarily agree with his value, but we did not perform similar calculations, so I only reported the values as provided. These data were taken from a study Healy did for interim guidance for the New Brunswick Lab in New Jersey; I simply took his numbers and showed them, since they were all done the same way.

Church: Maybe I need to ask you then, how are you going to derive those kinds of numbers? Are you going to do your own pathway analysis?

Are you going to look at the suite of numbers available? I'm thinking particularly about work done by Bill Robinson (LLL) and others in real-life settings.

*Denham:* We will use the latest and best factors available to our staff. I realize this is an avenue of discrepancy or potential discrepancy. I don't know if that really answers your questions other than, yes, we will attempt to use pathway analyses that are as realistic as possible.

From the floor: Dale, I am still concerned about the values for plutonium; apparently Healy used 0 for ingestion. Some time ago he was still assuming a $10^{-5}$ transfer factor in the food chain from soil to plants and plants to animals, but more recent information tells us clearly that there is significant transfer to the food chain from ingestion of soil and particles themselves. Do you happen to know if this model still considers the food chain, or is he interested in the ingestion of soil itself on leafy vegetables and so on?

Denham: I'm sorry the values for $^{239}Pu$ were misleading. They should not have been attributed to Healy, but to EPA. The EPA only considered the inhalation pathway shown in Table 25.2. I did not present this particular table for the specific values shown (actually they were rounded to only one significant figure) but rather to emphasize that choosing a value of so many pCi/g as an across-the-board contamination standard does not result in an equal impact. Our plan is to determine acceptable contamination levels through site-specific environmental pathway dose calculations based on comparable dose impacts, not on equal contamination levels.

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# 26. FUSRAP EQUIPMENT CONCEPT DEVELOPMENT STUDY

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Washington, D.C.

The United States Government has instituted a program entitled Formerly Utilized MED/AEC Sites Remedial Action Program, or FUSRAP. This remedial action program is managed by the Department of Energy (DOE) Oak Ridge Operations (ORO). The objectives of this DOE program include the development of equipment concepts for nuclear waste retrieval, packaging, storing, and for transporting contaminated soil and other debris to a DOE-selected waste repository. The principal objective in the study is to specifically examine equipment requirements for the Middlesex Sampling Plant, VITRO Rare Metals Plant, and VITRO Uranium Mill Tailings Pile. Currently on-going, the study will include an investigation of equipment systems at both Port Hope and Grand Junction to determine applicability to current DOE needs. Based upon data gathered from site visits, three equipment concepts were developed for retrieval, packaging, storing, and transporting of waste materials.

The purpose of this engineering evaluation study is to present equipment concepts that could be used to provide remedial action to these three selected FUSRAP sites and to estimate the associated costs for each concept. Each concept recommends the removal of the contaminated material from the site to a long-term storage area.

The volume and weight of material to be removed from each site is based upon returning the site to natural background levels of radium ($^{226}Ra$) concentration.

City, county, and state regulations were reviewed for the transfer of low-level radioactive waste material over streets, roads, highways, and rail. The three states containing the FUSRAP sites included in this study were analyzed and they are "nonagreement" states with the United States Nuclear Regulatory Commission. These states apply U.S. Department of Transportation regulations for the transfer of low-specific activity materials.

## PURPOSE

Under DOE contract, Dalton·Dalton·Newport, Inc. is performing an engineering evaluation of three selected FUSRAP sites in an effort to generate equipment concepts to perform remedial action for retrieval, packaging, storing, and transporting contaminated soil and other debris. Along with this engineering evaluation, an analysis of state and federal regulations was made which had significant impact on the selected equipment and costs for each remedial action concept.

## DESCRIPTION OF THE THREE SELECTED SITES

Each site selected for inclusion in this remedial action study has unique features which make the requirements for remedial action significantly different from the other two sites. The current status of the three FUSRAP sites is as follows: The VITRO Uranium Mill Tailings Pile is essentially unused; the Middlesex Sampling Plant is vacant and unoccupied; the VITRO Rare Metals Plant is partially occupied by the Canon Development Company which leases the buildings located on the site to tenant companies.

### VITRO Uranium Mill Tailings, Salt Lake City, Utah

The tailings pile (Fig. 26.1) is located on a 128-acre tract approximately four miles southwest of the Salt Lake City, Utah downtown area. The tailings pile is uncovered and exposed to both wind and water erosion. It is fenced by a six-foot chain link fence and warning signs are

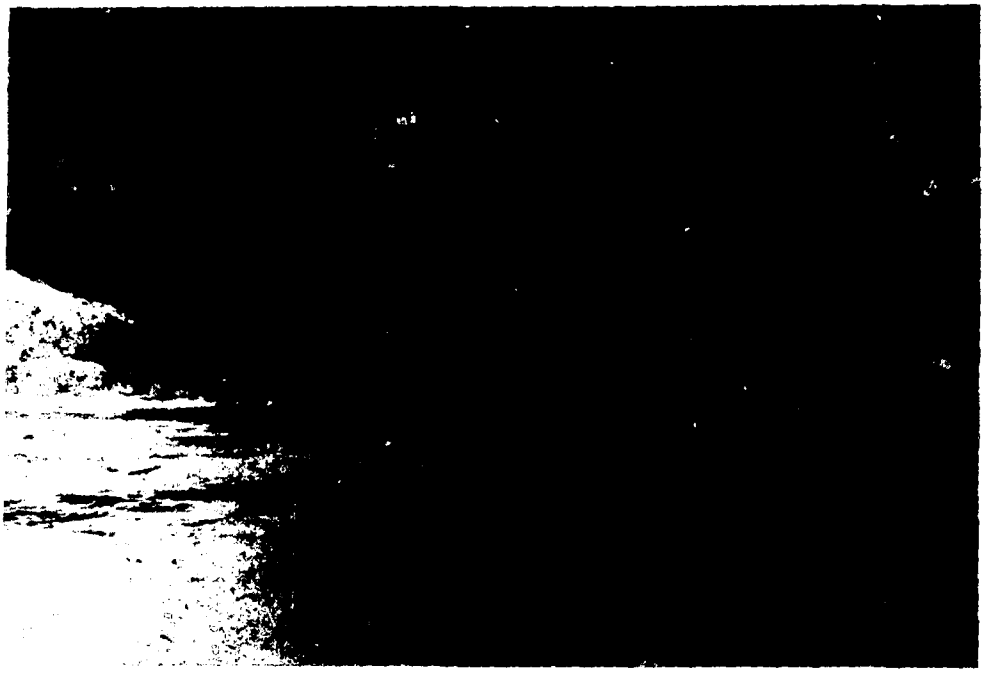

Fig. 26.1. VITRO Uranium Mill Tailings Pile at Salt Lake City, Utah.

posted, but this site is still accessible to the public. Some ore is being reclaimed on the site around the foundations of the removed VITRO Uranium Mill building. The Salt Lake City Surburban Sanitation District Number 1 Treatment Plant is located on a portion of the property.

The property was used by VITRO Chemical Company for processing uranium ores from 1951 to 1964. During this period 1.7 million dry tons of $U_3O_8$ were milled to yield approximately 4800 tons of $U_3O_8$ concentrate. The mill was then converted to produce vanadium in 1965 through 1968 and approximately 106,000 dry tons of vanadium-bearing material were processed. The mill and associated facilities were dismantled in 1970 except for a 450-foot stack, a water tower, and railroad spur. The tailings consist of fine sands, clays and slimes. The environmental impact and associated health effects arise from the thorium-230, radium-226, radon-220 and radon-222 progeny contained in the uranium tailings.

The volume of contaminated material is approximately two million cubic feet which will weigh about 2.8 million tons (moisture included). The average depth of contamination is, for the mill and ore-storage areas respectively, three feet and six feet. Removal of this quantity of material will restore the VITRO uranium mill tailings site to a natural background level of about 0.6 pCi/l of radon concentration. The $^{222}Rn$ is approximately 9 pCi/l for the site.

### VITRO Rare Metals Plant, Canonsburg, Pennsylvania

The Canonsburg site (Fig. 26.2) is located on approximately 18.6 acres within the corporate limits of Canonsburg, Pennsylvania. There are three contaminated areas of land designated as areas A, B, and C. Buildings located at the Canonsburg site are on Parcel A which contains 11 acres of land. This area is serviced by Conrail railroad spurlines which are operable but

inactive. The area is covered with building debris and the residue from manufacturing operations. Areas around the buildings contain a gravel cover material.

Buildings located on Area A are being used to house metal fabrication operations, chemical packaging, a trucking company, a laundry company, warehousing, and a wholesaling company. The area is enclosd by a six-foot chain-link fence topped with three strands of barbed wire. Radiological conditions of Area A indicate that it has a mean value of 85 pCi/g for all three sources of radiation. The quantity of material that would be removed to restore Areas A, B, and C to natural background level is approximately 146,000 cubic yards, which weighs about 200,000 tons.

Middlesex Sampling Plant
and Associated Properties,
Middlesex, New Jersey

The contaminated properties include the Middlesex Sampling Plant (Fig. 26.3), the Rectory of the Church of Our Lady of Mount Virgin located at the corner of Harris and Drake Streets, and a residence at 432 William Street, Piscataway.

The Middlesex Sampling Plant, located on about 9.6 acres, was a storage depot and sampling plant for uranium and thorium ores from 1943 to 1955. The plant is located in the Borough of Middlesex in north Middlesex County, New Jersey. The site, owned by the federal government, was occupied until recently by the Sixth Motor Transport Battalion of the U.S.

Fig. 26.2. VITRO Rare Metals Plant, Canonsburg, Pennsylvania.

Fig. 26.3. Middlesex Sampling Plant, Middlesex, New Jersey.

Marine Corps and served as a reserve training center. All seven buildings and the soil on the site are contaminated, and radiation measurements indicated radioactivity levels exceeding guidelines published by the United States Surgeon General for radium in soil and radon daughter concentrations.

A major portion of the site is covered by an asphalt surface and surrounded by a six-foot-high chain-link fence. Properties adjacent to or near the Sampling Plant site where contamination has been located include residences, commercial buildings, and vacant lots. Measurements indicate this radioactivity is near the surface of the property. The church rectory is a three-story structure aboveground with a basement belowground. Concentrations of radium and external gamma radiation levels were found in the soil surrounding this building, and elevated $^{222}Rn$ radiations were measured inside the structure. The residence located at 432 William Street, in Piscataway Township, is a one-story private residence with a partial basement and a detached garage. Soil surrounding the residence is contaminated and the gamma radiation/radium concentrations exceed normal background level for the areas (1.0 to 1.7 pCi/g). The recorded measurement of radon concentration in the rectory was 31.4 pCi/l in the number nine room located in the basement; at the street level the measurement diminished to 0.9 pCi/l.

## DISCUSSION OF REMEDIAL ACTION

City, county, and state requirements for handling and transferring inactive uranium mill tailings were analyzed for the three areas included in this study. The states of Utah, Pennsylvania, and New Jersey are "nonagreement" states with the Nuclear Regulatory Commission and apply the Federal Department of Transportation regulations for the movement of low-specific-activity materials over streets, roads, highways and rail. The results of the regulations study were used in the remedial action recommendations to avoid violation of a state's regulations for the transfer of mill tailings.

The remedial action recommendations are based on returning the area containing the contaminated materials to natural background levels of radiation and radium content. The United States Surgeon General's guidelines have established natural background level to be equal to or less than 1.7 pCi/g. To achieve this for the three sites, contaminated material must be excavated and loaded into containers for shipment or loaded directly into carriers and transported to a long-time storage site. Contaminated slabs of concrete must be reduced in size and loaded into containers of transport carriers. Contaminated structures, buildings, foundations, stacks, and other support facilities must be razed and reduced in size so they can be loaded

into containers or in carriers and transported to a long-term storage area for radioactive contaminated materials.

The three sites reviewed as part of this study contained contaminated soil, concrete slabs and foundations, brick, concrete blocks, wood structures, reinforcing steel bars, buildings, water towers, stacks, and other contaminated debris deposited on the property. This material will have to be reduced in size and loaded in containers or in carriers for transport to a long-term storage area. Contaminated materials were found under slab floors of homes, businesses, around and under building foundations, and on vacant lots adjacent to and in the vicinity of the contaminated sites. The most cost-effective way to provide remedial action for the three sites would be to clean up the areas adjacent to and in the vicinity of sites by stockpiling contaminated materials on the site or by transporting them directly to a long-term storage area. If a rail transport mode is selected for the movement of the low-level radioactive waste materials, a stockpiling technique would be recommended to reduce the down time of the hopper cars.

VITRO Site, Salt Lake City, Utah

The recommended remedial action for the Salt Lake City area and the VITRO Uranium Mill Tailings Pile is to stockpile contaminated materials retrieved from the 22 contaminated areas on the VITRO site. When this work is completed, the tailings and all contaminated materials will be transported to a long-term storage area away from the Salt Lake City metropolitan area.

Remedial action for businesses and residences will require that all contaminated material be removed from open areas around and under foundations and under slab floors. Construction materials such as concrete, bricks, and cement blocks containing radioactive materials must also be removed from residential and business areas. The remedial action program will be monitored as work progresses and material will be removed until natural background levels of radiation are achieved.

Important considerations for site remedial action are: (1) maximum equipment flexibility is required and (2) equipment should not be operated both on and off the site. At the completion of the remedial action, all equipment must be washed down and completely decontaminated before leaving the site. The property will be backfilled, leveled, and planted with grass seed to provide a ground cover to minimize wind and water erosion.

VITRO Rare Metals Plant,
Canonsburg, Pennsylvania

The contaminated site is divided into three areas containing 11, 4.5, and 3.1 acres, respectively. The site contains approximately 146,000 cubic yards (about 200,000 tons) of contaminated soil, manufacturing debris, buildings, and other rubble. Two areas contain contaminated soil only and the third and largest area contains contaminated soil, buildings, and other discarded debris.

The recommended remedial action for the Canonsburg site is to raze the contaminated buildings and reduce the resulting brick and concrete rubble into manageable sizes by using a concrete crusher. Contaminated wood will be reduced in size by using a portable skill saw, then loaded with brick and concrete debris into hopper rail cars or dump trucks for short haulage distance and transported to a long-term storage location. Contaminated building foundations will be exposed by using a hydraulic excavator and reduced in size by using pneumatic jackhammers and concrete crushers. Uncontaminated soil will be stockpiled on the site and used for backfill at the conclusion of the decontamination operation. Contaminated concrete slabs and supports must be reduced in size by using pneumatic jackhammers and concrete crushers and will be loaded into either dump trucks or hopper cars. A portable hopper assembly will be used at the Canonsburg site to prevent dump trucks from traversing the site and

picking up contaminated material in tire treads and around the running gear. The device could easily be relocated around the perimeter of the three areas and used in the decontamination activities for the entire Canonsburg site.

All equipment used for decontamination activities must operate strictly either onsite or offsite to eliminate the possibilities of spreading contaminated material. At the completion of the remedial action all equipment must be washed down and completely decontaminated before leaving the site.

Protective clothing and masks will be provided for workers involved in the remedial action. All vehicles and material handling equipment used in the decontamination operation will be thoroughly washed before leaving the site. Wash waters will be treated before being discharged.

### Middlesex Sampling Plant and Associated Properties, Middlesex, New Jersey

The Sampling Plant is located on approximately 9.6 acres in the Borough of Middlesex in north Middlesex County, New Jersey. The area contains approximately 77,000 cubic yards (about 113,200 tons) of contaminated material composed of soil, building materials, and surface asphalt.

The recommended remedial action for the Middlesex Sampling Plant and associated properties is to remove contaminated materials from the residence and church property. When these properties are restored to natural background levels, decontamination activities will be provided for the Sampling Plant. This remedial action program recommends the residence located at 432 William Street in Piscataway, New Jersey, be provided remedial action first and that the contaminated material be stockpiled on the Sampling Plant site. Contaminated materials are on approximately 80% of the property and have been used as fill. Radiation measurements after material excavation will determine if further decontamination of residential structures will be necessary. A hydraulic excavator would be used to remove soil, shrubs, and groundcover around the residence foundation if necessary. Material removed will be placed into a covered portable hopper assembly which will be used to load dump trucks. The contaminated material will be hauled to the Sampling Plant site. The residence, after decontamination, will be restored as nearly as practical to its existing condition.

All decontaminated areas will be backfilled, topsoiled, and replanted with erosion control grasses. The original drainage patterns will be completely restored.

Elevated levels of external gamma have been recorded in the basement and the first floor of the rectory. The source of this radiation appears to be outside the building, and the removal of this source is expected to reduce the radiation to natural background. Contaminated materials removed from the rectory will be loaded into the portable hopper assembly which will load the material into dump trucks. This material will be hauled and stockpiled on the Sampling Plant site property.

Decontaminated areas at the rectory will be backfilled, plants replaced, topsoil added, the lawn replanted and completely restored to its original condition.

Buildings located on the Sampling Plant site consist of an administration building, warehouse and process building, garage, boiler shop, vehicle and equipment storage shop, thaw house and oil drum storage. The buildings are old, with considerable amounts of deferred maintenance that make decontamination efforts inadvisable.

Recommended remedial action for the Sampling Plant would be to raze all the buildings. Mill tailings located on the open areas of the property can be removed by using an excavator and loading the material into the storage hopper. The Sampling Plant site will be backfilled with clean material. (If it should prove to be cost-effective, the site would be resurfaced later and the buildings would be restored).

Protective clothing and masks will be provided for workers involved in the remedial

action. All vehicles and material handling equipment used in the decontamination operation will be thoroughly washed before being removed from the Sampling Plant site. Wash waters will be treated before being discharged.

*Radiological monitoring, sampling, and* radiochemical analyses will be performed during the decontamination and restoration activities.

Wind erosion can be controlled by using covered conveyors and storage hoppers. It is recommended that remedial action be stopped during periods of excessive wind. Water sprinklers also can be employed in open, flat areas to reduce the generation of contaminated dust.

The covered storage hopper located off the property will prevent trucks from picking up contaminated material in the tire tread and on the truck exterior. The truck running gear will not come into contact with material located on the site being decontaminated. The hopper storage assembly will serve as a queue for storing contaminated material, and a hopper will allow the material to be dumped into trucks by using a gravity feed. The trucks should be covered by a canvas material to prevent wind erosion and the spread of contaminated material.

After completion of the decontamination operation the property will be restored to its original condition. Concrete slabs and other structures will be replaced and all excavated areas backfilled and vegetation replaced.

Uranium mill tailings, contaminated debris, and material reclaimed from residences, businesses, and lots stockpiled on the VITRO site will be loaded into hopper rail cars and transported to a long-term storage area.

# 27. MACHINE TECHNOLOGY: A SURVEY

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What I have tried to do is to find existing machines throughout the industry--machines that have been upgraded and that could be used for large-scale decontamination operations outdoors. For this I have looked at the building industry, the mining industry, and the road construction industry. It is mainly the road construction industry that has yielded the machines in this presentation.

The kinds of operations we can do with the machines available now are shown (Table 27.1).

Wire brushing can be effective for removing thin layers of soil and is used even on asphalt and concrete. I don't know how far one can go and to what depth one can remove asphalt and concrete--at least one can clean it. There are wire-brush sweepers that are commonly used to clean city streets.

The next thing of interest is a force-feed loader, a kind of shovel th.. can be used to take out debris, windrows, and cut material. It has been used in North Carolina to remove PCB from shoulders of roads and to remove soil containing PCB.

Then there is the vacuum-cleaning equipment. To pick up the material a recycle air system is

Table 27.1. Existing Machines for Decontamination

| Method | Device | Manufacturer | Application |
|---|---|---|---|
| Wire Brushing | Mobile Sweeper | Athey<br>FMC | Thin-layer removal of soil, asphalt, concrete |
| Shoveling | Force-Feed Loader | Athey | Removal of cut material |
| Vacuum Cleaning | Recycle Air System (Air Blast and Suction) | TYMCO | Sub-micron to half-brick soil removal if scarified |
| | Filtered Air Sweeper | FMC | Removal of earth, debris |
| | Vac/All | Central Engineering | Removes concrete debris behind road planer |
| Road Planing | Hot Planing | Unknown | Asphalt removal |
| | 200-Tooth Auger Scarifier | Galion | Cold removal of concrete, asphalt |
| | Rotomill Pavement Profiler | CMI | Cold planing and direct truck loading |
| Forest Clearing | Tree Extractor | Rome | Pulls tap root out, no stump left |
| | Tree Crusher/Chipper | Marathon-Letourneau | Clears wide swath, drums chop branches and undergrowth into mat |

used, working with air blast and suction. Even an object as heavy as half a brick can be picked up. The equipment uses air filters for purifying the recycled air.

The "Vac-All" is another kind of equipment based on the same principle. It can remove debris and can be used behind other machines which break the soil or cut the concrete or remove a layer of asphalt. These latter machines are used for road planing. In the past, one used hot planing, meaning that the asphalt was melted with flames. This method has been abandoned because of the hazard represented by the fumes and by the combustible materials that were used to produce the flames. The method used now is cold planing: surface layers of roads are removed with automated machines. Galion and CMI manufacture these machines; they are called scarifiers or pavement profilers.

In the last category are machines used for forest clearing. One of these machines is a tree extractor which removes the stump of the tree at the same time. Because the stump can be a hindrance for subsequent operations, it is best to pull it out with the rest of the tree. Finally, if one has to employ brute force--as is necessary in the virgin forests--tree crushers and chippers are available. These are very powerful machines; they simply destroy everything, and after that one has to remove the litter that is left.

Figure 27.1 shows an Athey road sweeper. There are two small rotating wire brushes called gutter brooms, and another large horizontal brush and hopper behind that brings everything up into the box. Loose objects and dirt can be removed with the wire brush, if it is strong enough, and as much as four cubic yards of material can be picked up.

The FMC machinery shown in Fig. 27.2 can be seen in every city in this country. It is equipped with wire brushes and a cylindrical brush that brings the dirt to a mechanical elevator, which in turn dumps it into a box. Figure 27.3 shows the geometry: all the material is brought in by the rotating brushes and then swept into the hopper by the cylindrical horizontal brush. Figure 27.4 shows a front view of one of the small FMC machines.


Fig. 27.1. Athey Mobil sweeper, equipped with steel-wire gutter and pick-up brooms.

Figure 27.5 shows the Athey force-feed loader: it has shovels that can bring up any material. It can also pick up large windrows on the ground surface. The loader works in conjunction with a truck; it can dump on a truck. It has been used in North Carolina to remove a layer of soil contaminated with PCB.

Another way to pick up debris is the air-blast-and-suction mechanism (Fig. 27.6). A fan blasts air on the ground; there is a turbulent motion, and the air is sucked up again, entraining the debris. The debris remains in the box, and the air goes through a filter and back again to the ground. This is rather safe environmentally, because it is the same air that is recycled; the air is practically not released or exhausted into the environment. Figure 27.7 shows the same kind of system developed by another manufacturer (FMC). There is ample room in the box to hold the dirt picked up. Filters are also used. One of the FMC filtered air sweepers is shown in Fig. 27.8. The pneumatic equipment is visible. There is no mechanical

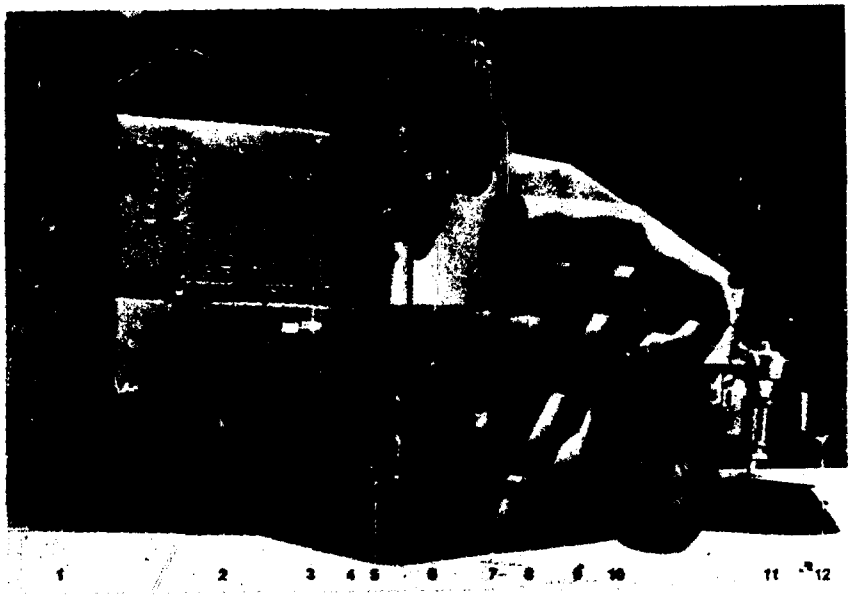

Fig. 27.2. Cutaway view of FMC three-wheel sweeper with 4-cubic-yard box.

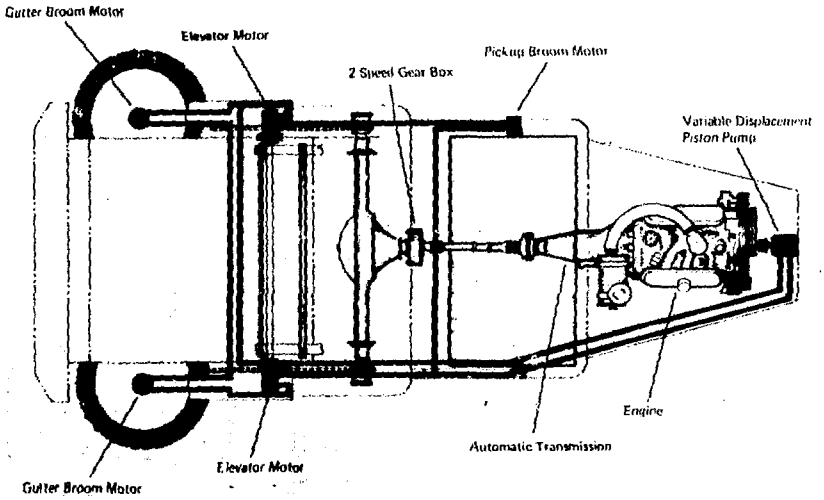


Fig. 27.3. Broom geometry on FMC sweeper.


Fig. 27.4. Front view of FMC sweeper.

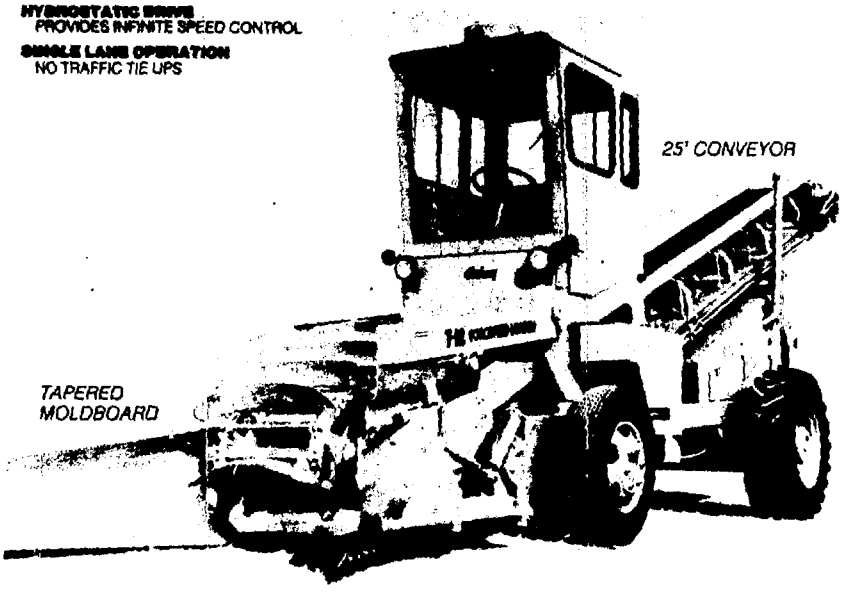


Fig. 27.5. Athey force-feed loader with conveyor.

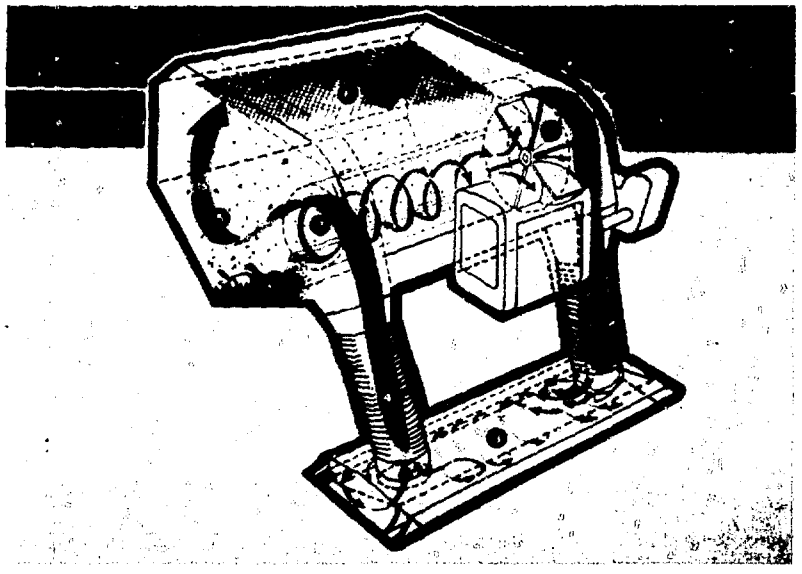

Fig. 27.6. Schematics of Tymco airblast and suction regenerative air system.

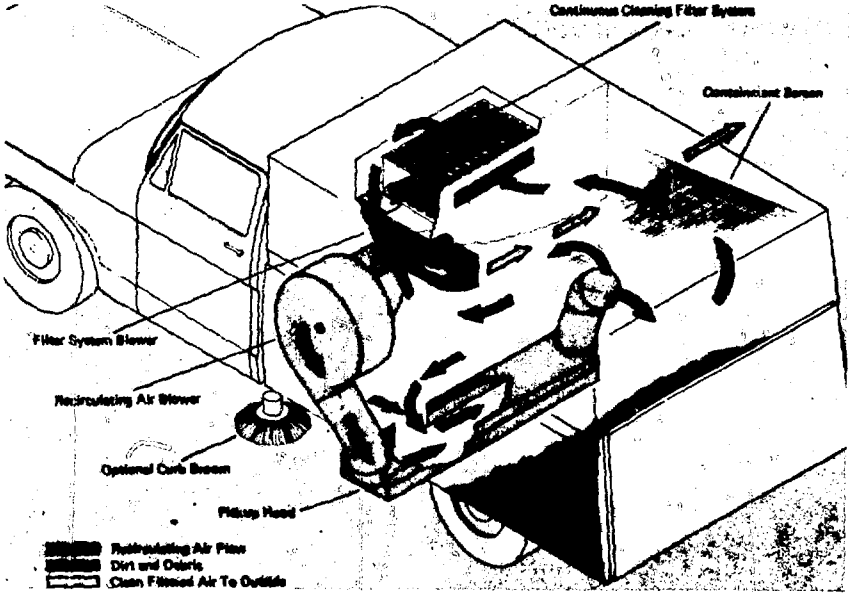


Fig. 27.7. Schematics of FMC filtered air-sweeping system.

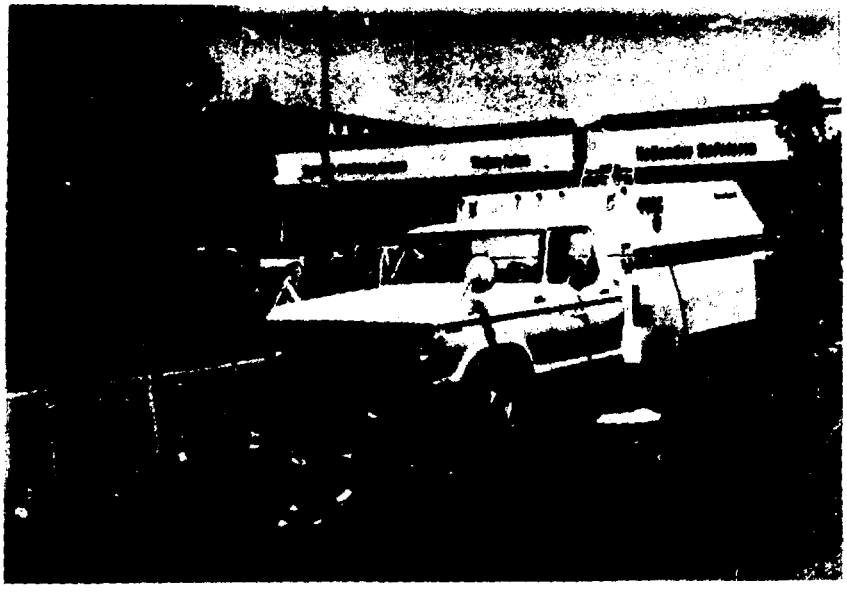

Fig. 27.8. FMC-filtered air sweeper with 4.5-cubic yard hopper.

elevator for the debris; one is only vacuum-cleaning what can be sucked in. This equipment is used extensively in cities. Another brand of the same kind of equipment (Fig. 27.9) is sold under the trade name "Vac-All" for municipal and industrial uses. This is a stronger model; very large models of these are made for industrial users (Fig. 27.10).

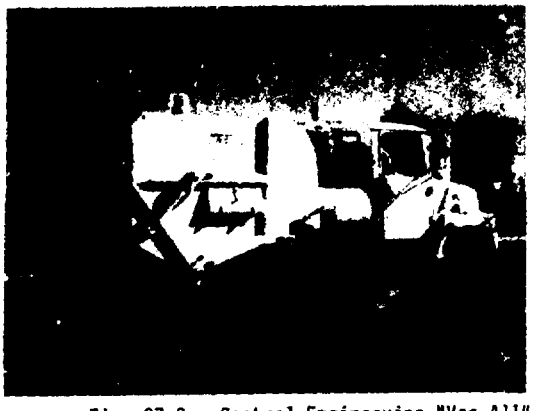

Fig. 27.9. Central Engineering "Vac-All" municipal street sweeper.

An additional feature of this model is a hose that can be used manually to pick up things that have not been reached by the machines. This type of heavy industrial system has been used in conjunction with road planers to pick up the cut debris or material from the road. As an example, Fig. 27.11 shows a Galion road planer; behind it the vacuum-cleaning truck is picking up all the debris that has been cut by the teeth of the planer.

Now we will examine road-planing machinery. The old way of doing the road planing (Fig. 27.12) used flames for removing a layer of asphalt. (Note the flames and release of fumes.) There were many explosions in the fuel tanks of these machines; currently there is a shift towards cold road planing. The Galion machine (Fig. 27.13) I showed you earlier in the photograph with the Vac-All (Fig. 27.11) is equipped with a cylinder that has 200 teeth that attack the pavement.

Another cold planer (Fig. 27.14), manufactured by the CMI Company, is very heavy; it is designed to avoid irregularities in the cutting

Fig. 27.10. Central Engineering "Vac-All" industrial sweeper.

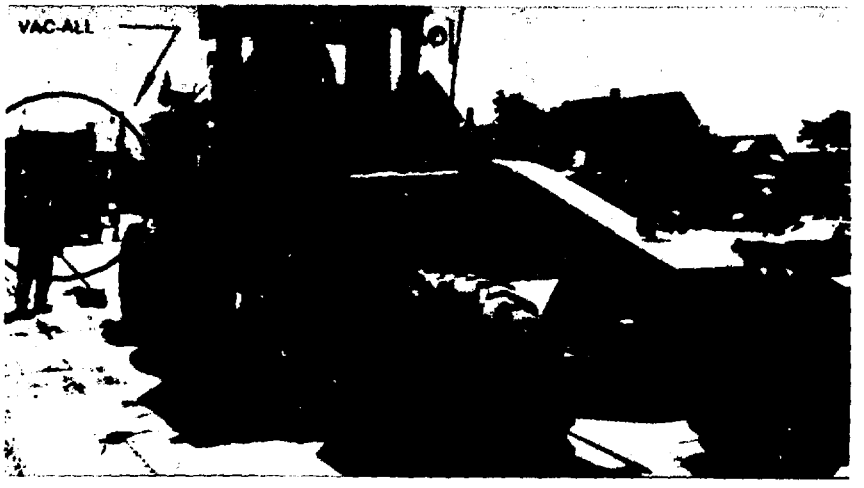


Fig. 27.11. "Vac-All" street sweeper following Galion road scarifier to pick up cut material.

Fig. 27.12. "Hot" method for removal of asphalt layer by road planer.

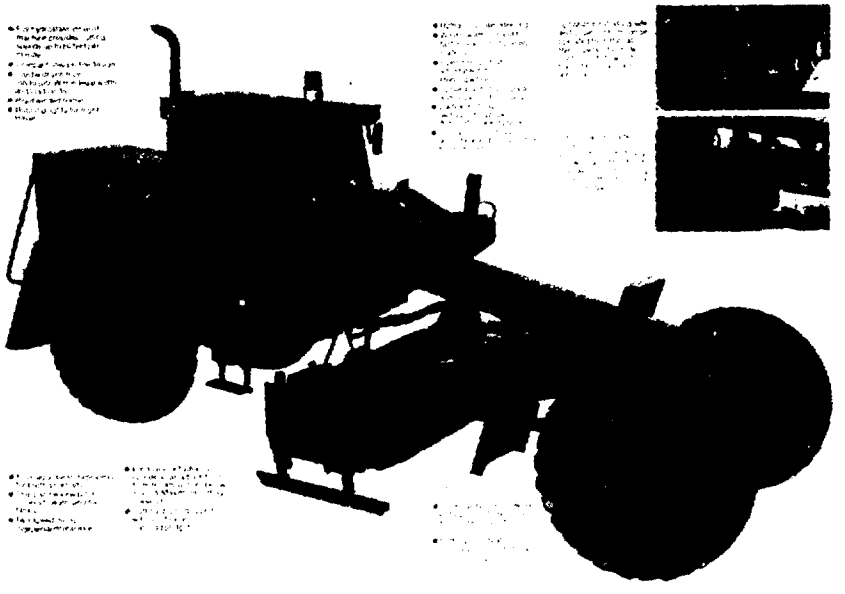

Fig. 27.13. Galion "cold" road planer. The 42-inch-wide cutting drum has a maximum cutting depth of 4 inches.

Fig. 27.14. CMI Rotomill pavement profiler with 80-inch-wide cutter.

level. This company also manufactures an even larger model that can cut up to 12 feet (half a highway) in one pass (Fig. 27.15). It is equipped with a mechanical system to carry the debris up and to dump it into a truck. This is the largest road planer that can be found. It can remove down to 6 inches of concrete but can also remove a layer as thin as 1/4 inch.

Fig. 27.15. CMI Rotomill pavement profiler with 12 ft-6 in. wide cutter.

Now we come to the forestry operation. If the trees are cut with the usual felling equipment, there are stumps that stay in the way of all subsequent operations. Fortunately, a machine has been developed that will pull up the entire tree, with the stump. Vertical blades (Fig. 27.16) go around the stump and cut all the horizontal roots, then the tree is clamped, and the vertical roots are pulled out with the tree. This machine is widely used for cutting pine trees throughout the southeastern United States. It has the advantage of leaving the surface in rather good condition for subsequent cleaning operations. Figure 27.17 shows a tree harvested with the bark and the stump. You can see that this machine is very powerful.

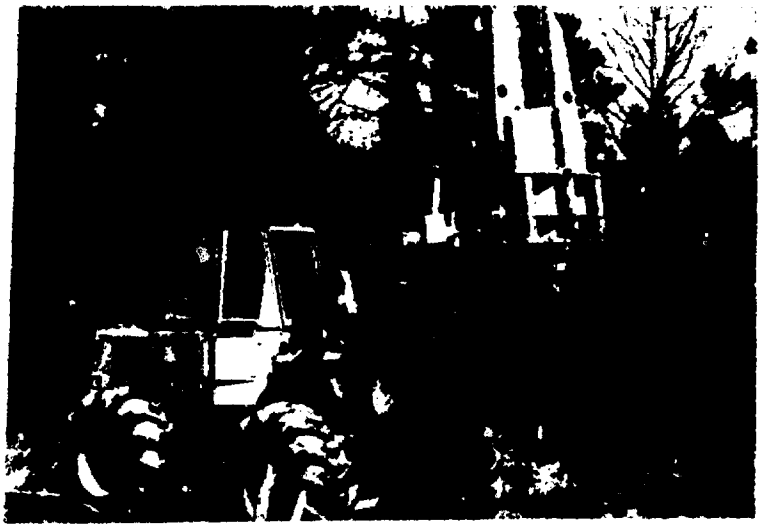

Fig. 27.16. Rome tree extractor harvesting whole tree with stump and taproot.

Fig. 27.17. Tree harvested by Rome tree extractor.

Figure 27.18 shows a machine that is used in the Amazon region in Brazil. This bar simply pushes down the trees that it encounters. On the wheels there are cutting blades that chop and destroy the undergrowth, brush, and the side branches of the trees. This is about the most powerful equipment that can be found: it will crush anything that is in the way. This machine cuts wide swaths in the forest, and after it has passed there is rather little to do; the whole forest is reduced to a litter.

In conclusion, we can say that these machines represent a starting point for the development of the technology required for decontamination. A few additional things are needed as well. First, we need to monitor the radiation field coming from the place decontaminated, so directional radiation counters are needed that will signal when the layer removed is sufficient. There is also a need to investigate shielded cabs, because in some cases radiation levels can be much higher than 2.5 millirem/hour, and a shielded cab can permit working with normal manual control in areas where radiation levels are 10 or 100 times higher than tolerance. Then, because much higher levels can still occur, we need to investigate remote controlled operation of all these machines. Cost and time estimates for the decontamination operations are needed, and the following information will be developed for each machine: the capital cost, the manpower requirements, the maintenance cost (including spare parts and fuel), and the productivity in square meters cleaned per hour. From there we will try to derive estimated costs per unit of area cleaned. It is hoped that this can be done for three models of each machine: the normal manned operation of the current model, the model equipped with the shielded cab, and the model equipped for remote control and completely unmanned operation. In this way, too, we hope to arrive at a better definition of the equipment that is needed and at the real cost of decontaminating.

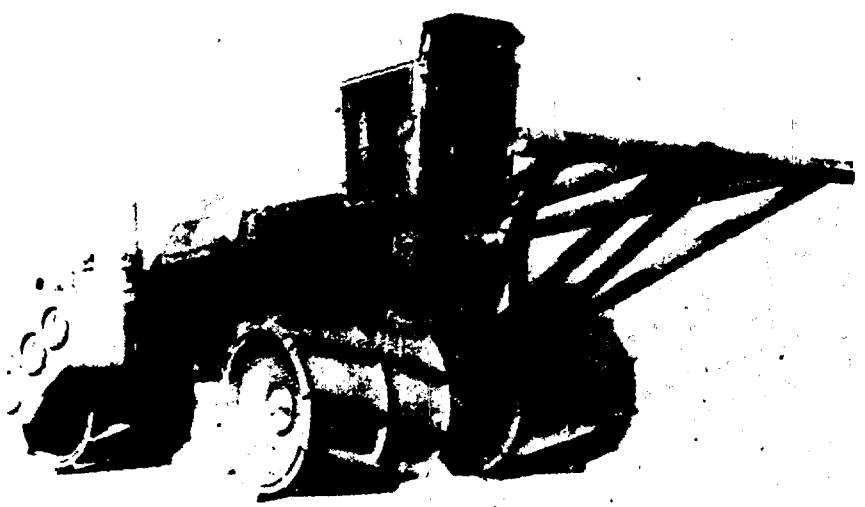

Fig. 27.18. Marathon-Letourneau tree crusher with cutting blades for chopping branches and undergrowth.

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