INSTITUTE FOR ENERGY AND ENVIRONMENTAL RESEARCH

6935 Laurel Avenue, Suite 204
Takoma Park, MD 20912

Phone: (301) 270-5500
FAX: (301) 270-3029
e-mail: ieer@ieer.org
http://www.ieer.org

Poison in the Vadose Zone:

An examination of the threats to the Snake River Plain aquifer from the Idaho National Engineering and Environmental Laboratory

Arjun Makhijani, Ph.D.
Michele Boyd

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A very special thanks is due to the Snake River Alliance. When IEER's work involves a specific site, it is generally done in partnership with a local activist group. The experience and expertise of the Snake River Alliance not only helped us in the review process, but also in informing us of the history of the site and of much literature that it would have taken far more effort to find and analyze than it did.

As is always the case, the authors of this report remain solely responsible for the contents of the report, its conclusions and recommendations, and any omissions or errors. We would also like to thank IEER staff members, especially Staff Scientist Sriram Gopal for his extensive help in preparing some of the tables and in fact-checking the final report and Librarian Lois Chalmers for her extensive bibliographic research and fact-checking.

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Arjun Makhijani
Michele Boyd
September 2001

Preface

Water resources in many parts of the United States have been polluted and continue to be threatened with contamination from wastes dumped at sites used for nuclear weapons production.[1] Some of these water resources are of immense regional and national importance. Ironically, it was the presence of plentiful water resources that was one of the primary reasons for building nuclear weapons facilities at these locations.

Water resources are particularly scarce in the West, where the value of the land itself and its habitability depend on the availability of water. For example, much of the prolific agriculture in Idaho, on which its economy is largely built, would not be possible without irrigation water.

Idaho's Snake River Plain aquifer is among the water resources most threatened by a nuclear weapons site. The Idaho National Engineering and Environmental Laboratory (INEEL) sits directly above this aquifer. We chose to study it as our first case study on water issues for several reasons:

- The Snake River Plain aquifer is a sole source aquifer – that is, a large number of people have no alternative local source of water.[2]
- The U.S. Department of Energy buried more plutonium and other long-lived radionuclides (by curies) at INEEL than at any other U.S. site. More than a metric ton of plutonium was buried in flimsy containers for about two decades. This waste is leaking and traveling much faster than anticipated towards the aquifer; some plutonium has already reached it.
- The vadose zone (the unsaturated zone between the ground surface and the water table) is contaminated, and contaminants are continuing to migrate through the vadose zone to the aquifer.[3] Yet, there appears to be time, through well-designed remedial action, to protect the aquifer from the most serious problems that threaten it.
- The conclusions about INEEL could be qualitatively applied to other nuclear sites in the arid West.

Fortunately, the importance of the vadose zone has begun to be appreciated in some parts of the U.S. Department of Energy (DOE), which recently published a complex-wide vadose zone science and technology roadmap. The purpose of the roadmap is to determine the research needed for characterizing, monitoring, and modeling subsurface contaminant fate and transport. The roadmap report clearly states that current knowledge about the vadose zone and contaminant transport is extremely limited.[4]

This gap is one more reflection of the low priority given to scientific issues relating to environmental protection compared to nuclear weapons production within the DOE

[1] This includes research, development, and testing of nuclear weapons.
[2] Designated by the US Environmental Protection Agency (56 FR 50634) on October 7, 1991 under the Safe Drinking Water Act [PHSA § 1424].
[3] DOE, August 2001, page 1
[4] DOE, August 2001, page v-vi

system. Furthermore, the DOE is using ignorance of the problems and the real difficulties of clean up as an excuse to leave most, possibly the vast majority, of these wastes in the ground even as it makes huge claims on the public purse in the name of clean-up.

Removing buried wastes, stopping current and future dumping, and remediating the vadose zone to the extent possible should be the central technical and policy approaches to water resource protection. A more vigorous research and development program for vadose zone remediation and a better technology selection process are also needed. We hope that this case study will be useful to the U.S. Department of Energy, the state of Idaho, the U.S. Environmental Protection Agency, and the elected representatives and their staffs in their efforts to protect a vital local, state, and national resource. The problems have been allowed to fester for so long that we have concluded that the situation calls for a fundamental institutional restructuring of the DOE's clean-up program.

This report shows that the bill for nuclear weapons production in terms of environmental and resource costs is far from being paid. The present course is likely to foist these costs on future generations in the worst way – by depriving them of clean water. We hope that this report will help inform an open, constructive, and long-overdue public debate that will lead to action to protect water resources.

Arjun Makhijani
Michele Boyd
Takoma Park, Maryland
September 2001

Executive Summary

The Snake River Plain aquifer is the most important underground water resource in the northwestern United States. The U.S. Environmental Protection Agency (EPA) has designated this aquifer as a sole source aquifer, because it is the only source of drinking water for 200,000 people in southern Idaho. It is also a major source of irrigation water for regional crops, notably potatoes, and for fisheries. The produce grown in Idaho is eaten throughout the United States and in many other countries, including Japan, Canada, and Mexico.[5] Idaho's trout farms, which rely on the groundwater at Thousand Springs, produce 75 percent of the commercial rainbow trout eaten in the United States.[6]

The Idaho National Engineering and Environmental Laboratory (INEEL) sits directly above 2,300 square kilometers (890 square miles) of this aquifer. For the second half of the twentieth century, large quantities of radioactive waste, including plutonium-bearing waste, were dumped into shallow pits and trenches or directly injected into the aquifer at INEEL from nuclear weapons production operations there and from other sites around the United States. The existing base of information does not permit a thorough assessment of the risks posed by these wastes. But there is enough evidence of current contamination of the aquifer under the site, and of the potential for rapid migration of very long-lived radionuclides like plutonium, to establish that remedial action is urgently needed if the Snake River Plain aquifer is to be protected for future generations.

Main findings

1. The Snake River Plain aquifer and the vadose zone under the INEEL site are contaminated with plutonium, americium, and other radionuclides as well as non-radioactive and hazardous chemicals.

Direct injection of radioactive and hazardous substances into the Snake River Plain aquifer and the discharging of wastes into percolation ponds have resulted in contamination plumes in the aquifer, including plumes of tritium, strontium-90, iodine-129, and trichloroethylene (TCE).[7] These contaminants have areas of their plumes that are above the maximum contaminant level (MCL) set by the U.S. EPA under the Safe Drinking Water Act. Plutonium and americium have also been found in the vadose zone (the unsaturated zone between the ground surface and the water table) and in the aquifer.

2. The Snake River Plain aquifer is threatened with further contamination by buried wastes at INEEL.

From the 1950s to the 1970s, an enormous amount of radioactive and hazardous waste was dumped in cardboard and wooden boxes and 55-gallon steel drums in shallow dumps

[5] Idaho State Department of Agriculture, 2001
[6] USDA, March 2001
[7] Hazardous chemicals are toxic, corrosive, flammable, or reactive. A contaminant plume is the zone of polluted groundwater down-gradient from a point source of pollution.

at INEEL. This waste contains more than a metric ton of plutonium-239/240, which is enough to make about 200 nuclear bombs. The total amounts of some individual long-lived radionuclides, including plutonium and americium, are so large that each one by itself could pose a major threat to the Snake River Plain aquifer. There are also large amounts of hazardous chemicals in the buried wastes, some of which have traveled rapidly into the aquifer. The DOE is continuing to dump low-level radioactive wastes, which can contain long-lived radionuclides, into these pits and trenches. The combined threat from the radioactive and hazardous chemicals in the buried wastes is enormous.

3. Some constituents of the wastes, notably plutonium and americium, are migrating far faster than previously anticipated.

The best available evidence indicates that the rate of migration of some of the most dangerous constituents of the waste, such as plutonium and americium, is much faster than anticipated. Several mechanisms of rapid waste transport have been identified through a combination of field, laboratory, and theoretical work in the last three decades. The evidence of rapid migration of transuranic radionuclides at INEEL is given further support by research at other U.S. Department of Energy sites, where plutonium has also been found to migrate more rapidly than anticipated under a variety of circumstances.

While there is some controversy about the validity of the positive findings of plutonium in water samples from the Snake River Plain aquifer, detections of plutonium deep in the vadose zone further verify that plutonium is rapidly migrating.

4. Sound scientific work indicating threats to the Snake River Plain aquifer has long been largely ignored by the U.S. Department of Energy (DOE).

Despite some very good scientific work on the transport of radioactive and hazardous materials through the vadose zone, the DOE has failed to act on it to protect the Snake River Plain aquifer. For instance, a 1976 report of the U.S. Geological Survey (USGS) presented extensive evidence of rapid contaminant transport at INEEL. Yet, the problem of buried wastes has been inadequately addressed during the twenty-five years since its publication.

5. Some drinking water wells on the INEEL site are contaminated in excess of safe drinking water limits if all hazardous chemical contaminants are taken into account.

While each of the pollutants for which data are available is below the allowable limits in the drinking water wells on the INEEL site, the combined burden of hazardous chemicals exceeds the allowable level of contamination in one of the workers' water supply systems. The level of carbon tetrachloride alone in one of the drinking water wells is 95 percent of the maximum contaminant level. Although the drinking water limits for non-radioactive contaminants are set individually and not considered on an additive basis, as is done in regulations involving radionuclides, it is a prudent public health practice to consider these cumulative risks. These regulations also do not apply to private water

wells. The drinking water supply of workers is currently treated so as to conform to safe drinking water limits.

6. The area of contamination in the aquifer is currently limited, but urgent action is needed in order to protect the aquifer from long-term irreversible damage.

Contamination in the Snake River Plain aquifer is still largely under the INEEL site. Two contaminant plumes have migrated the farthest: tritium and strontium-90. The off site radioactivity for these two radionuclides is less than allowable drinking water limits. Available evidence indicates that the most long-lived radionuclides, notably the transuranics such as plutonium, may not have migrated very far. Therefore, it is still possible, through a proper waste retrieval and processing program, to protect the aquifer. However, the rapid migration of radioactive and hazardous chemicals, the large amounts of these materials in the pits and trenches at INEEL, the substantial uncertainties in migration rates under various conditions, and the current contamination of the Snake River Plain aquifer with transuranic radionuclides under the site point to the need for urgent action to protect the aquifer.

Once the aquifer becomes contaminated at levels that exceed drinking water standards for long-lived radionuclides, the problem will be essentially irreparable. The technology for cleaning up large amounts of water contaminated with mixtures of volatile organic compounds and long-lived radionuclides to safe drinking water standards does not exist today.

7. Americium-241, several plutonium isotopes, iodine-129, and other long-lived radionuclides present the main long-term threats from radioactive materials to the Snake River Plain aquifer.

Americium-241 is one of the most important of the alpha-emitting radionuclides in terms of its potential to pollute the Snake River Plain aquifer. It is relatively soluble in water, and hence, moves with the groundwater. Americium-241 has a half-life of 432 years. Water in the aquifer travels from under INEEL to the Magic Valley, southern Idaho's most productive agricultural region, in about half that time. Some americium-241 has already migrated through the vadose zone into the aquifer. The highest concentration of americium-241 found in the groundwater was 1.97 picocuries per liter in 1997. The levels of americium-241 are still below allowable drinking water limits (15 picocuries per liter), and no plume has as been identified. But considering that the amount of time that has elapsed since the waste was buried is far shorter than a single half-life of americium-241, and that knowledge about transuranic radionuclide migration has many gaps, it is not possible to predict the fate of the americium-241 with confidence. Preventing pollution of the aquifer depends mainly on limiting the amount of americium available for transport by recovering transuranic buried wastes from the pits and trenches into which they were dumped.

Iodine-129 is more soluble than americium and there is already a plume of it in the aquifer. The most contaminated well with iodine-129 had a concentration of 3.82

picocuries per liter in 1991 (its maximum contaminant level is 1 picocurie per liter). In 1991, iodine-129 from waste disposal at INEEL was detected in an off-site well at levels much less than the allowable drinking water standards. However, even though discharges of iodine-129 to the environment have stopped, the current source of iodine-129 in buried waste presents a serious problem because iodine-129 has a half-life of 17 million years. Despite the fact that there is a known plume of iodine-129, DOE rates its own monitoring of iodine-129 as 'poor.'[8]

8. Plutonium-239 in buried wastes presents long-term security and environmental threats, possibly including an accidental nuclear criticality.

More than a metric ton of plutonium-239/240 is buried at INEEL. It presents a security concern should control of the site be lost, because that amount is enough to make more than 200 nuclear bombs. In other words, the pits and trenches at INEEL are potential plutonium mines.

The proliferation and environmental risks arising from so much plutonium in the buried wastes are illustrated by a controversy as to whether an accidental nuclear criticality gave rise to a fire in a waste barrel in 1970. The report on that fire is still classified. It is not well established whether any of the containers originally had enough plutonium to go critical (a spontaneous uncontrolled nuclear reaction) if they fill up with water. But plutonium in the buried wastes could leak and accumulate in a small volume of soil, which could lead to an accidental criticality in times of heavy rainfall or flooding.

The evidence from groundwater sampling so far indicates that plutonium migrates far more slowly than americium. Nonetheless, although plutonium does not appear to have migrated far and has not formed a plume, its migration rate through the vadose zone to the aquifer has been orders of magnitude faster than those assumed by the policy of shallow-land dumping. The half-life of plutonium-239 – more than 24,000 years – is far longer than that of americium-241. How the migration of plutonium will unfold, and how the climatic conditions of the site will change over such long periods, is unknown. Therefore, the long-term risks of leaving plutonium in the buried wastes are substantial from the environmental as well as the security point of view.

9. Continued storage of liquid high-level wastes at the Tank Farm also poses risks of spills and other accidents.

While most highly radioactive wastes at INEEL arising from reprocessing have been calcined and put into stable solid form for storage, 6,740 cubic meters of liquid waste, containing 2.6 million curies of radioactivity, were still stored at INEEL in 1997.[9] Given the large amount of radioactivity involved, this waste poses a threat to the groundwater in cases of spills or other accidents.

[8] DOE, July 2000. Book 1, page 4-77.
[9] ORNL, December 1997, page 2-23

10. The recovery of buried wastes will be difficult, risky, and complex.

The variety, combination, and amounts of wastes, the poor records, the deterioration of containers over time and the presence of combined flammable, explosive, and radioactive materials are factors that make the recovery of buried wastes difficult and complex. A large part of the difficulty arises from the fact that no existing technology can characterize the wastes fully before retrieval due to their complexity and heterogeneity. The safety risks to workers associated with this lack of knowledge need to be factored into the approaches that will be used for retrieval and processing (see recommendations).

11. DOE has initiated programs for the removal of some organic contaminants from the vadose zone at INEEL and from the Snake River Plain aquifer, but DOE continues to rely on "natural attenuation" to an unacceptable extent.

Remediation programs are important for reducing the burden of hazardous non-radioactive materials in the vadose zone. For example, DOE is operating a vapor-vacuum extraction program to remove some of the volatile organic chemicals in the vadose zone below the Radioactive Waste Management Complex. A pump-and-treat program to remove trichloroethylene (TCE) from the Snake River Plain aquifer beneath the Test Area North has operated since 1996. In November 2000, DOE proposed using bioremediation to remove TCE from the most contaminated area (hot spot) under Test Area North. However, the proposed program changes would lower the clean-up goals for removal of contaminants, leaving a larger amount to "natural attenuation," which is the reduction of contaminant concentrations in the aquifer through radioactive decay, dilution, and dispersion. This will take an unacceptably long time. Organic contaminant removal is not only important in itself, but may also help to reduce the rate of transuranic radionuclide migration through the vadose zone.

12. New institutional arrangements are needed in order to create and implement a sound clean-up program.

The DOE Environmental Management program has not established the right priorities for waste management and instead has wasted enormous sums of money on poorly designed projects. A culture of denial seems deeply embedded with regard to major environmental problems, notably the threat posed by buried wastes. Insufficient resources are being devoted to clean-up of the dumped buried transuranic wastes, while far greater priority is being given to shipping the stored transuranic wastes, which are kept in relatively secure conditions indoors, to the Waste Isolation Pilot Project (WIPP) in New Mexico.

There is little prospect that the right priorities will be set and clean-up accomplished under the present institutional arrangements. On the contrary, the renewed emphasis on nuclear weapons will likely further decrease the priority given to clean-up and the quality and quantity of effective resources devoted to it.[9]

[9] See IEER's report *Containing the Cold War Mess: Restructuring the Environmental Management of the U.S. Nuclear Weapons Complex* (Fioravanti and Makhijani, 1997) for more information about the extensive and systemic institutional problems with DOE's Environmental Management program.

Recommendations

There are four urgent priorities for the protection of the Snake River Plain aquifer:

- ***Discontinue dumping waste into pits and trenches and percolation ponds***
- ***Recover and stabilize buried wastes***
- ***Solidify liquid high-level waste and store the resultant solid products***
- ***Remediate the vadose zone***

These priorities are needed to ensure that the Snake River Plain aquifer will remain usable and not be threatened by the wastes dumped in pits and trenches, released into percolation ponds, or leaked from waste tanks and pipelines.

A thorough, site-wide remediation of the vadose zone, expanding on and improving current programs as well as making greater use of innovative technology, is needed. Hazardous organic materials, such as carbon tetrachloride and trichloroethylene (TCE), are highly toxic pollutants that could mobilize faster transport of radionuclides through the vadose zone.[11] The remediation of highly contaminated vadose zone areas at INEEL should, therefore, be a high priority. The DOE should not use the limited understanding of contaminant transport as an excuse to leave the buried waste in the ground. On the contrary, the limited understanding and the difficulty of the problems should be a spur to make the recovery of buried waste and the remediation of the vadose zone among its highest priorities. The stakes are very high. Doing nothing or simply monitoring the growing problem may result in irreversible damage to the Snake River Plain aquifer.

Our other recommendations are as follows:

1. A thorough and comprehensive program of groundwater monitoring, contaminant transport research, and analysis should be created.

While there is a substantial amount of groundwater monitoring already conducted, it is inadequate for the purpose of analyzing the migration of transuranic radionuclides, notably plutonium, which have not formed plumes. A more focused and open effort needs to be carried out to ensure that a thorough, rigorous, and effective program of measurements and analysis is conducted. Such a program can probably be conducted

[11] Laboratory experiments show that iodine is very soluble in carbon tetrachloride (Bender, 2002) and that the addition of carbon tetrachloride to tributyl phosphate enhances the ability of the latter to extract plutonium from an aqueous solution. (Wick, 1980, p. 464). Observations in the field have found that transuranics are transported by colloids (Kersting, *et al.*, January 1999) or natural organic matter (McCarthy, *et al.*, 1998) and can migrate much faster than previously believed. At INEEL, organic materials, including tributyl phosphate and carbon tetrachloride as well as radionuclides, including transuranics radionuclides, were dumped in the shallow pits and trenches of the RWMC (Lockheed, August 1995, Vol. 1, pp. 3-36 to 3-39).

Although the transport of radionuclides in the environment is a question that involves many parameters and, in some cases, is not very well understood, it is reasonable to conclude, based on the laboratory and field evidence cited above, that organic materials could enhance the migration of a variety of radionuclides through the vadose zone.

within existing resources by rethinking goals of the program and hiring contractors according to their ability to meet the goals of the program.

Recent work on the transport of contaminants has revealed that long-standing simple assumptions about the transport of radionuclides were wrong, that the phenomena are very complex, and that there are serious gaps in knowledge of contaminant transport. The existing research on this issue needs to be expanded into a comprehensive and sound program of scientific research. The future health of a large portion of U.S. water resources depends on it.

2. More open, thorough and frank disclosure of measurements, analyses of those measurements, and discussion of their implications for the health of the Snake River Plain aquifer are needed.

DOE has tended to minimize findings of contamination and obscure the need for remedial action by suggesting that the results may be due to factors in the measurement process, such as cross-contamination, rather than to actual pollution in the aquifer. A more frank disclosure, noting the uncertainties but also the policy implications of those uncertainties, is needed. When measurements of trace quantities of pollutants are involved, there can be and often are real uncertainties about the interpretation of the results. But policy needs to be made in light of these uncertainties, and should favor clean up. Moreover, there should be far broader public disclosure and far more thorough monitoring programs when there are uncertainties concerning plutonium and other pollutants. More thorough discussion with the public that involves fewer unwarranted reassurances that there are no problems in the face of indeterminate results would add much needed accountability and would contribute to improving clean-up performance.

3. The recovery of wastes should take due account of the lack of adequate knowledge of waste composition in the waste recovery and processing plans.

Since it will be impossible to fully characterize the wastes prior to retrieval and processing, the approach that is used to carry out these tasks should take that fact into account. Specifically, the approach should learn lessons from past failures at INEEL and elsewhere. Some of these failures, including INEEL's Pit 9 project, are documented in IEER's 1997 report, *Containing the Cold War Mess.*[12] Our suggested approach has the following elements:

- DOE should use highly modular and small-scale processing lines, each with some flexibility as to the waste composition it could handle;
- DOE should use remote recovery and processing techniques;
- The recovery of waste should be conducted in an inert environment if possible;
- The processing of waste should be done in explosion-proof structures that would protect workers and the environment in case of fires or explosions; and

[12] Fioravanti and Makhijani, 1997

- DOE should process waste remotely in relatively small batches so that explosions and fires can be contained within structures where no workers are present.

4. Buried wastes should be recovered both for environmental and security reasons.

Some of the wastes containing significant amounts of plutonium need to be recovered for security reasons, while the rest need to be recovered in order to protect the Snake River Plain aquifer. Since accurate characterization is not possible prior to recovery, the goal of as complete recovery of buried wastes as possible would be a prudent one. Due attention will have to be paid to preventing accidental criticalities during processing of recovered buried wastes.

5. New institutional arrangements for carrying out clean-up need to be considered and implemented.

Despite the availability of much sound science and growing understanding of the nature of the threats posed by the environmental legacy of the Cold War, the DOE and its contractors have proved unable to carry out a sound clean-up program. The DOE's process for creating clean-up projects and selecting contractors has not measured up to the importance of the endeavor. Contractors for clean-up should be selected according to the task at hand, with strict criteria for expertise and experience relevant to the specific job, as well as for accountability and openness. At sites where production-related activities are still going on, there is a conflict between the goal of environmental cleanup and nuclear weapons-related goals. This is a more complex problem that requires more comprehensive institutional restructuring. Some options are mentioned in Chapter IV.

6. The clean-up should be carried out under stringent national standards enforced by the U.S. Environmental Protection Agency.

We recommend that these clean-up standards should include:

- a guideline involving doses "as low as reasonably achievable" (ALARA) of up to 2 millirem per year to the maximally exposed person; [13]
- a standard of a maximum exposure of 10 millirem per year to the maximally exposed person from all pathways arising from the INEEL site, including the food pathway;
- sub-limits to the maximum dose involving the safe drinking water standards, which limit dose to 4 millirem to the critical organ from drinking water alone from most radionuclides;
- inclusion of consideration of cancer risks from hazardous materials and reduction of maximum permissible radiation exposure when exposure to hazardous materials is also present; and
- consideration of non-cancer risks and risks due to synergisms between various hazardous and radioactive materials.

[13] The ALARA limit has been a general approach to radiation protection that mandates reduction of exposures below the standards that must be met. The ALARA limit is a guideline conditional on technological and economic factors.

Chapter I: Introduction to INEEL and the water resources of the region

A. Introduction to the Site

The Idaho National Engineering and Environmental Laboratory (INEEL), originally called the National Reactor Testing Station, was established in 1949 as a testing laboratory for nuclear reactors.[12] The first reactor in the United States to generate electricity, the Experimental Breeder Reactor I (EBR I), was built there. INEEL is particularly associated with naval propulsion reactors, including their development. INEEL has also been a center for research on reactor safety, and reactor prototypes were built at the site for that purpose. In all, 52 nuclear reactors have been built at INEEL. Of these, three reactors are still used and one reactor is on standby.[13]

The primary mission of INEEL in terms of funding, however, has been nuclear weapons related activities, notably the reprocessing of spent fuel from naval reactors to recover highly enriched uranium.[14] (See box below.) Such reprocessing was halted in 1992; INEEL now accepts and stores naval spent fuel.[15]

INEEL also accepted large amounts of plutonium-contaminated wastes from the Rocky Flats Plant, near Denver, where most of the plutonium triggers for U.S. nuclear weapons were manufactured.[16]

At 2,300 square kilometers (890 square miles), INEEL is one of the largest sites in the nuclear weapons complex (see Figure 1).

The Nuclear Weapons Mission at INEEL

The Idaho Chemical Processing Plant (ICPP, now INTEC) was used for reprocessing spent fuel from naval nuclear reactors (used for submarines and aircraft carriers) and other reactors containing highly enriched uranium (HEU). The extracted uranium was then used as fuel in tritium and plutonium production reactors at the Savannah River Site (SRS) in South Carolina after first being shipped to the Y-12 plant in Oak Ridge, Tennessee, where it was fabricated into the driver rods for the reactors. The tritium and plutonium-239 produced in the SRS reactors were used to make nuclear weapons. Historically, the ICPP (INTEC) provided less than 10 percent of the highly enriched uranium used by the Savannah River reactors, because the Savannah River Site operated its own reprocessing plant to recover HEU on site.[17]

[12] The site was called the National Reactor Testing Station (NRTS) until 1974, when it was changed to the Idaho National Engineering Laboratory (INEL). In 1997, the site was renamed the Idaho National Engineering and Environmental Laboratory (INEEL). Stacy, 2000, pages 218 and 244

[13] Bradley Bugger (DOE-Idaho media relations), email communication to Michele Boyd, May 2, 2001

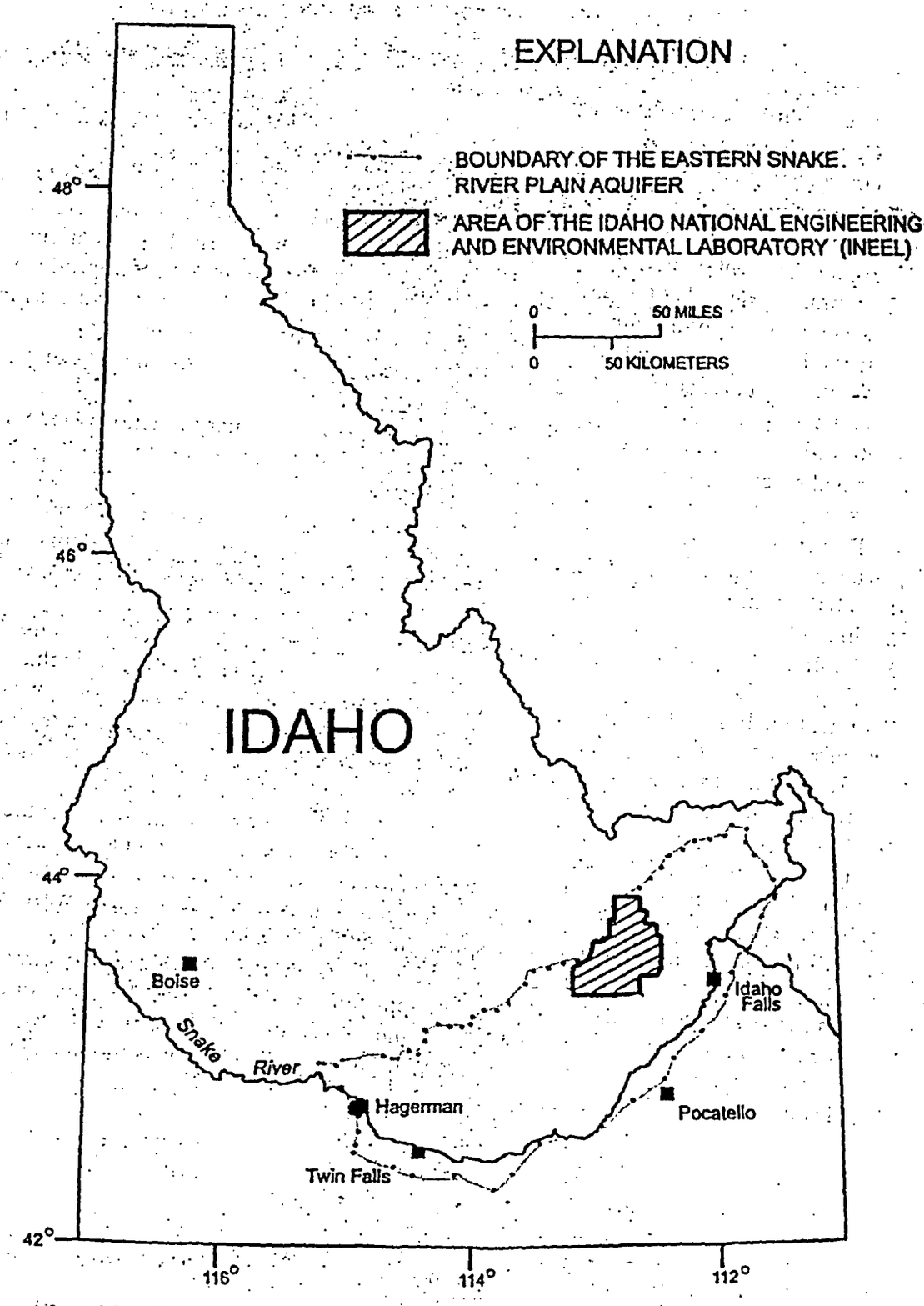
[14] In 1997, 87.9 percent of INEEL's budget was nuclear weapons related. Schwartz (ed), 1998, page 591

[15] DOE, January 1997, page 209

[16] DOE, January 1997, page 187; The Rocky Flats plutonium trigger production ceased in 1989. DOE, January 1997, page 26

[17] DOE, January 1997

Figure 1: Map of Idaho



Source: Adapted from USGS, 1999, page 2

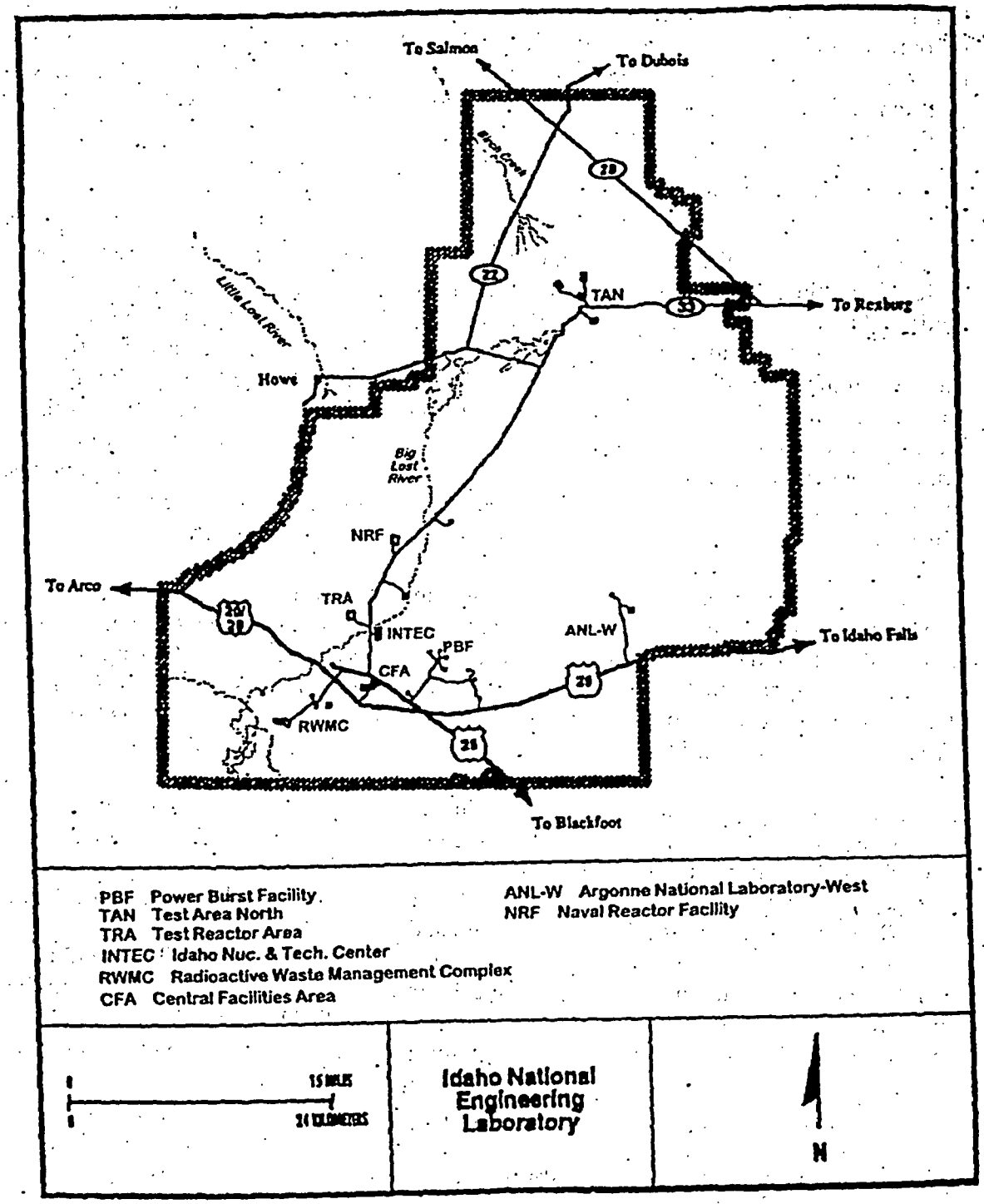
Figure 2 shows a map of INEEL. There are eight main operating areas at INEEL, most of which are currently managed by Bechtel B&W (BBWI):[18]

- **Auxiliary Reactor Area** (ARA): ARA was built to develop a compact power reactor. The facility is essentially no longer used.
- **Central Facilities Area** (CFA): CFA is the headquarters for services, such as fire and emergency medical facilities, and administration at INEEL.
- **Idaho Nuclear Technology and Engineering Center** (INTEC): INTEC (also known as the Idaho Chemical Processing Plant [ICPP], or Chem Plant) was constructed to reprocess spent nuclear fuel from naval and research reactors. The highly enriched uranium was used at the Savannah River Site in driver rods for reactors to produce weapons-grade plutonium and tritium. It currently is used to store spent nuclear fuel from the U.S. Navy and other sources and to store and treat high-level waste. Contaminant releases originate from waste in the percolation ponds, the tank farm, and a deep injection well, which is no longer used.
- **Naval Reactors Facility** (NRF): From 1953 to 1995, its primary function was to train naval reactor operators. NRF continues to be used for naval reactor fuel research. It is part of the DOE-Pittsburgh Naval Reactors Office.
- **Power Burst Facility** (PBF): PBF was constructed for testing reactor transient behavior and for safety studies on light-water-moderated enriched fuel systems. Its most recent mission, compacting and incinerating mixed and low-level wastes, ended in 2000.
- **Radioactive Waste Management Complex** (RWMC): Currently, RWMC is used to dispose of low-level waste. The Subsurface Disposal Area of the RWMC includes pits, trenches, and soil vaults in which mixed low-level and transuranic waste was buried, and Pad A, which received nitrate salts, depleted uranium, and sewage sludge from Rocky Flats.[19] The Transuranic Storage Area of the RWMC is used to store retrievable transuranic waste.
- **Test Area North** (TAN): The TAN facilities were built in the 1950s to house the research program to develop a nuclear-powered airplane and for conducting research on reactor performance. The largest program currently at TAN produces armor for U.S. Army tanks. Sources of groundwater contamination at TAN include waste water infiltration ponds, injection wells, spills, and underground tanks.
- **Test Reactor Area** (TRA): TRA was originally established to conduct experiments on materials used in nuclear and reactor applications. Ninety percent of the work at the Advanced Test Reactor at TRA is for the nuclear navy, but it also produces medical and industrial isotopes. Sources of groundwater contamination include disposal ponds and an injection well.

[18] Until 1998, INEEL was managed by multiple contractors. INTEC was managed by WINCO and the rest of INEEL was managed by EG&G. Stacy, 2000, page 258.

[19] Kathleen Trever (Idaho Department of Environmental Quality), email communication to Snake River Alliance, August 30, 2001

Figure 2: INEEL site map



Source: Adapted from DOE, June 1996, page Idaho-19

The University of Chicago operates the Argonne National Laboratory-West (ANL-W), which is located within INEEL boundaries. Argonne National Laboratory-West was constructed to research liquid metal fast breeder reactor technology. It is currently used to research reactor decommissioning technologies and a reprocessing technology called pyroprocessing or electrometallurgical processing. This technique was a part of the research for a sodium-cooled breeder reactor, the Integral Fast Reactor (IFR). The IFR research program was cancelled in 1994. In 1999, INEEL was named as the lead DOE facility for nuclear reactor research.

B. Water Resources at the Site

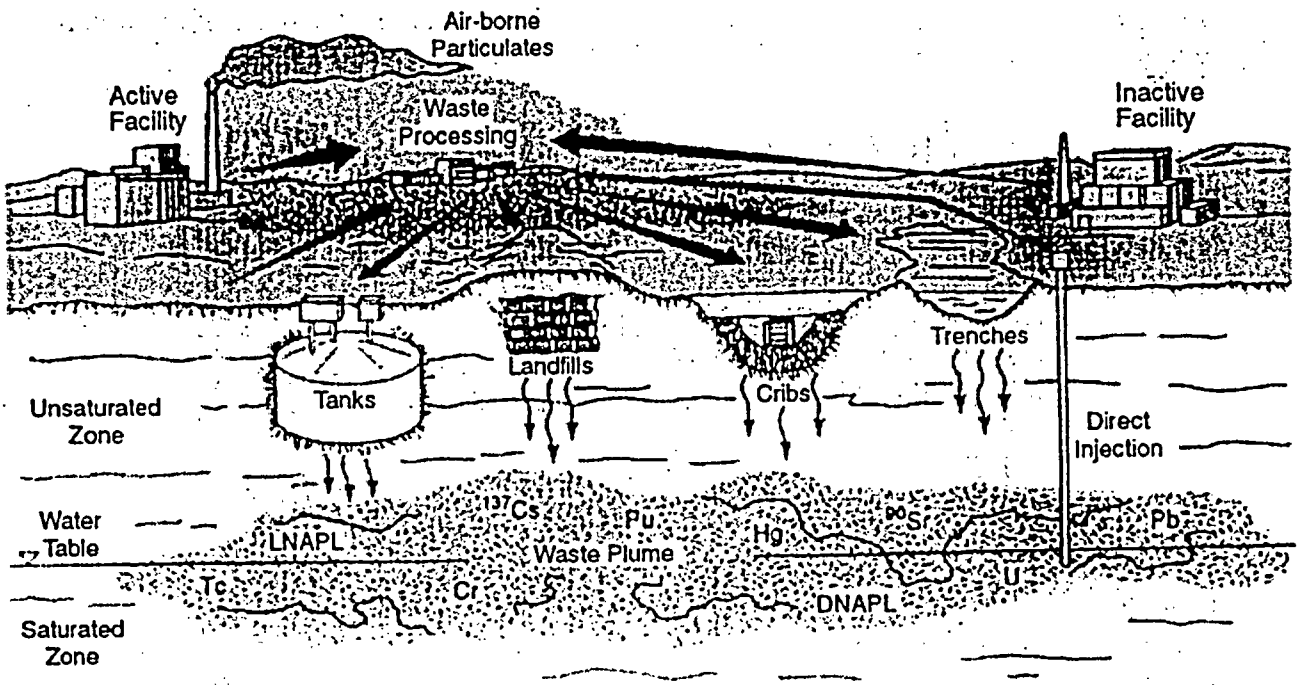
INEEL is situated on the north-central edge of the Eastern Snake River Plain, which is underlain by the second largest unified aquifer in North America, the Snake River Plain aquifer.[20] Operations at INEEL have affected the quality of groundwater in the aquifer. Most of the contamination from radioactive and non-radioactive sources is currently in the portion of the aquifer that is under the site. There continue to be large potential sources of contamination of the water from the radioactive and hazardous materials that were dumped into unlined trenches and pits on site in containers such as 55-gallon steel drums, wooden boxes, and cardboard boxes,[21] as well as from shallow percolation ponds, underground storage tanks, and contaminated soil. See Figure 3 for a schematic illustration of DOE waste management practices and contaminant pathways.

The Snake River Plain aquifer is one of the most important water sources in North America. It is approximately 325 kilometers (200 miles) long, 65 to 95 kilometers (40 to 60 miles) wide, and covers an area of about 25,000 square kilometers (9,600 square miles).[22] The approximate flow of the groundwater through the Eastern Snake River Plain aquifer is shown in Figure 4. With about 2 billion acre-feet of water, it is the largest unified aquifer in Idaho and the second largest in North America.[23]

The dominant use of the groundwater of the Snake River Plain is for crop irrigation. Food grown in the region, including potatoes, sugar beets, and barley, is consumed throughout the country and the world. Nearly one-third of Idaho's agricultural products is exported to foreign markets, including Japan, Canada, and Mexico.[24] The Eastern Snake River Plain is a cool, semi-arid sagebrush plain and receives only 8 inches of precipitation annually.[25] Without tapping the aquifer, it would be impossible to cultivate such large tracts of land in the region. Of the 3.1 million acres that were irrigated on the Snake River Plain in 1980, about 1 million acres was supplied by groundwater.[26] Idaho's trout farms, which produce 75% of the commercial rainbow trout eaten in the United

[20] An aquifer is underground porous rock that is saturated with water and is sufficiently permeable to conduct groundwater so as to enable its extraction.
[21] Hazardous chemicals are toxic, corrosive, flammable, or reactive.; EG&G, August 1991, page 3
[22] DOE, December 1993, page 2-58
[23] DOE, December 1999, page 4-58; USGS, 1995, page 2. The largest aquifer in North America is the Ogallala.
[24] Idaho State Department of Agriculture, 2001.
[25] ESRF, August 1998, page 1-4; DOE, December 1993, page 2-4
[26] Goodell, 1988, pages E23 and E48

Figure 3: Waste management practices in the DOE complex and contaminant pathways



Source: DOE (As shown in NAS-NRC, 2000b, page 26)

States, also depend on water from the aquifer.[27] Therefore, the contamination of the aquifer from operations at INEEL is a major issue not only for the Northwestern United States, but also for the entire country.

The second largest use of the Snake River Plain aquifer is for domestic water supplies, including drinking water. The aquifer provides 20 percent of the drinking water in Idaho, supplying over 200,000 people.[28] As the only viable source of drinking water for many communities on the Eastern Snake River Plain, the aquifer has been designated a Sole Source Aquifer by the U.S. Environmental Protection Agency (EPA).[29] The decision to site the National Reactor Testing Station (NRTS) in Idaho depended on having a plentiful water source, as well as sufficient fuel and electricity supplies.[30] In 1949, the Atomic Energy Commission (AEC) tapped the aquifer for the first time, and it continues to be the source of all water used at INEEL. See Table 1 for the total amount and use of the water withdrawn from the aquifer in 1980.[31]

Table 1: Water use from the Snake River Plain aquifer

Use	Water withdrawal, 1980 (acre-feet)
Irrigation	2,300,000
Aquaculture	1,906,000
Non-industrial public supply	102,400
Industrial withdrawals	71,300
Rural	23,000
INEEL	7,400
Total	**4,410,100**

Source: Goodell, 1988

In addition to the main aquifer, groundwater "perches" in the vadose zone when sediments or dense basalt impede the downward flow of water to the aquifer.[32] The vadose zone is the subsurface region that contains both air and water in soil and rock pores and extends down from the ground surface to the surface of the water table. The vadose zone at INEEL varies in thickness from 200 feet in the northern part of the site to about 900 feet in the southern part. Water in the aquifer generally flows from the northeast to the southwest, though there are local deviations from this overall pattern (see Figure 4). Movement of contamination through the vadose zone depends on the specific

[27] USDA, March 2001
[28] USGS, 1995b
[29] 56 FR 50634, Designated on October 7, 1991; DOE, December 1999, page 4-58; Under the Safe Drinking Water Act, the US EPA can determine that an area has an aquifer that is the sole or principal drinking water source for the area and, if contaminated, would create a significant hazard to public health. Thereafter, no Federal financial assistance can be used for any project that would contaminate the aquifer through a recharge zone so as to create a significant hazard to public health [PHSA § 1424]. DOE, November 1997a, page 2-1
[30] Stacy, 2000, pages 27 and 40
[31] The most recent study that reported specifically on withdrawals from the Snake River Plain aquifer was done in 1980.
[32] DOE, December 1999, page 4-60

contaminant involved and its chemical form, the direction of the water flow through the vadose zone, and the biogeochemistry of the subsurface materials that the contaminant encounters as it makes its way throughout the vadose zone. In other words, assessing the speed and direction of migration of contaminants is a complex matter that requires an understanding of the interactions of the various factors involved. Predicting future migration is even more complex, since there are considerable uncertainties in how the factors affecting the transport of contaminants might change in the long-term.[33]

Besides rain and snow, contaminants on the INEEL site can also be mobilized by surface water flow patterns. INEEL is located in a closed drainage basin, the Pioneer Basin, which includes three main surface-water bodies: the Big Lost River, Little Lost River, and Birch Creek. These streams drain mountain watersheds to the north and west of the site (see Figure 5). However, the surface-water flow is often depleted before reaching INEEL boundaries, especially in the summer months, by irrigation diversions, hydropower diversions, and infiltration losses along the channel bed. During dry years, there is little or no surface water flow on INEEL. Since the basin is closed, surface water does not naturally flow from INEEL, but rather infiltrates the ground surface to recharge the aquifer or is removed by evapotranspiration.[34]

When flow in the Big Lost River actually reaches INEEL, it is first diverted by a dam, located near the southwestern boundary of the site, to a series of natural depressions or spreading areas (A through D, see Figure 6). The diversion dam was built in 1958 (and enlarged in 1984) to prevent the recurrence of flooding in downstream areas during periods of heavy runoff. Water in the spreading areas quickly infiltrates to the aquifer in the vicinity of the Radioactive Waste Management Complex (RWMC), which can potentially mobilize contaminates in the buried waste.[35] See Chapter III for a discussion of contaminant mobilization.

Historically, there has been flooding at several INEEL facilities, including the Idaho Nuclear Technology and Engineering Center (INTEC), Radioactive Waste Management Complex (RWMC), and Test Area North (TAN). During periods of high flow or low irrigation demand, the Big Lost River passes within 61 meters of INTEC and within 3 kilometers of the RWMC. After INTEC was flooded in 1952, a stormwater drainage ditch system was built around the facility. The Subsurface Disposal Area at the Radioactive Waste Management Complex (RWMC), which is located in a topographic depression near the Big Lost River, was flooded in 1962, 1969, and 1982.[36] A perimeter dike and drainage channel was built around the facility, but ponding still occurs in small depressions.[37]

When flow in the Big Lost River is very heavy, some water is allowed to continue past the dam northeastward across INEEL along the natural channel of the Big Lost River to

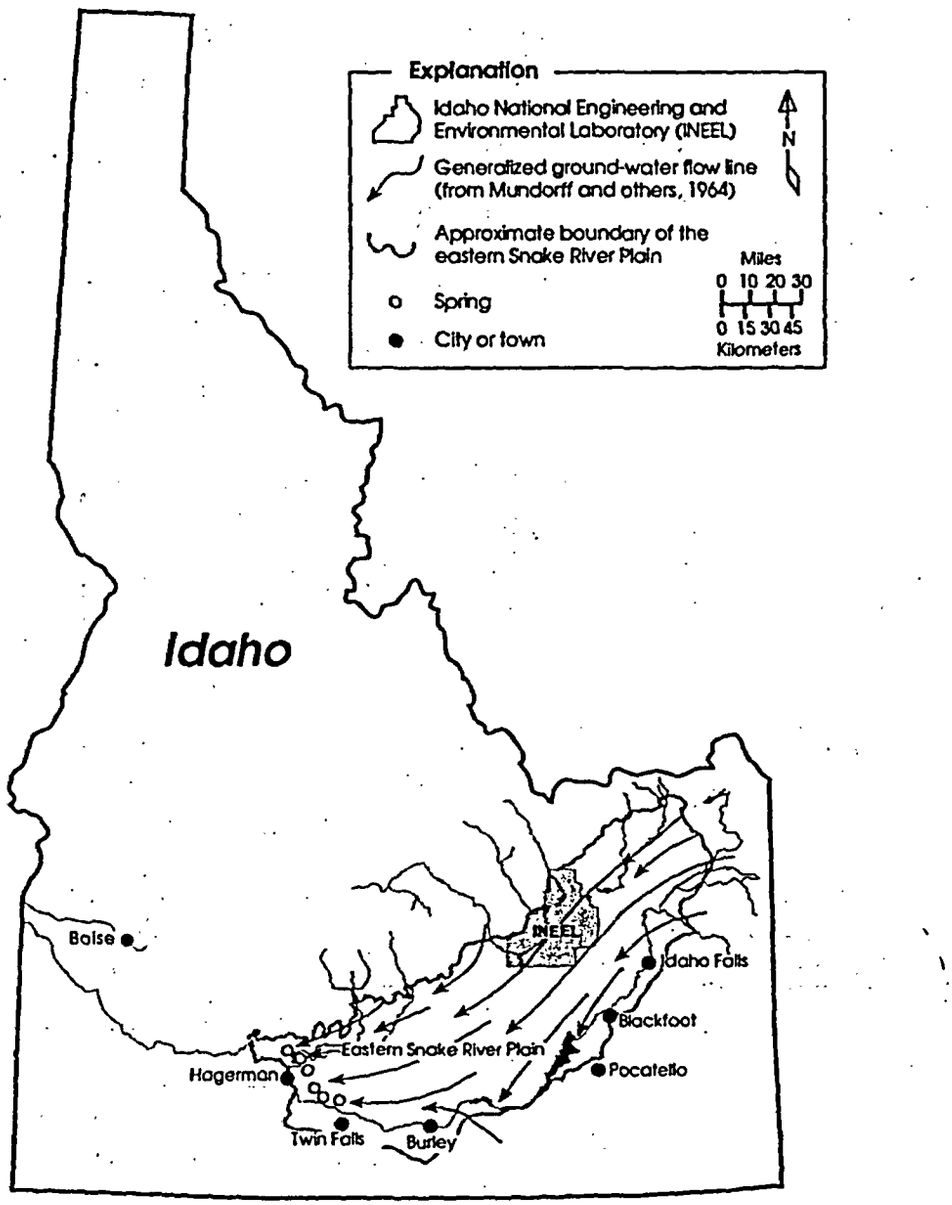
[33] DOE, December 1999, pages 4-49 to 4-54
[34] Due to the diversion dam on the Big Lost River, water can flow from INEEL at spreading area D in the southwest portion of INEEL. DOE, December 1999, pages 4-49 to 4-54, Figures 4-10 to 4-15
[35] USGS, August 1976, pages 68-73
[36] DOE, June 1993, page 8-49
[37] DOE, June 1993, page 2-27

its terminus at the Big Lost River playas (desert lakes that are dry most of the year), where it infiltrates into the ground or evaporates. The playa area covers several hundred acres in the northeast part of INEEL near Test Area North.[38] The Big Lost River can have a very pronounced effect on the recharge of the Snake River Plain aquifer and in the perched water beneath the river.[39]

See Appendix A for a more detailed description of the geology and water resources at INEEL.

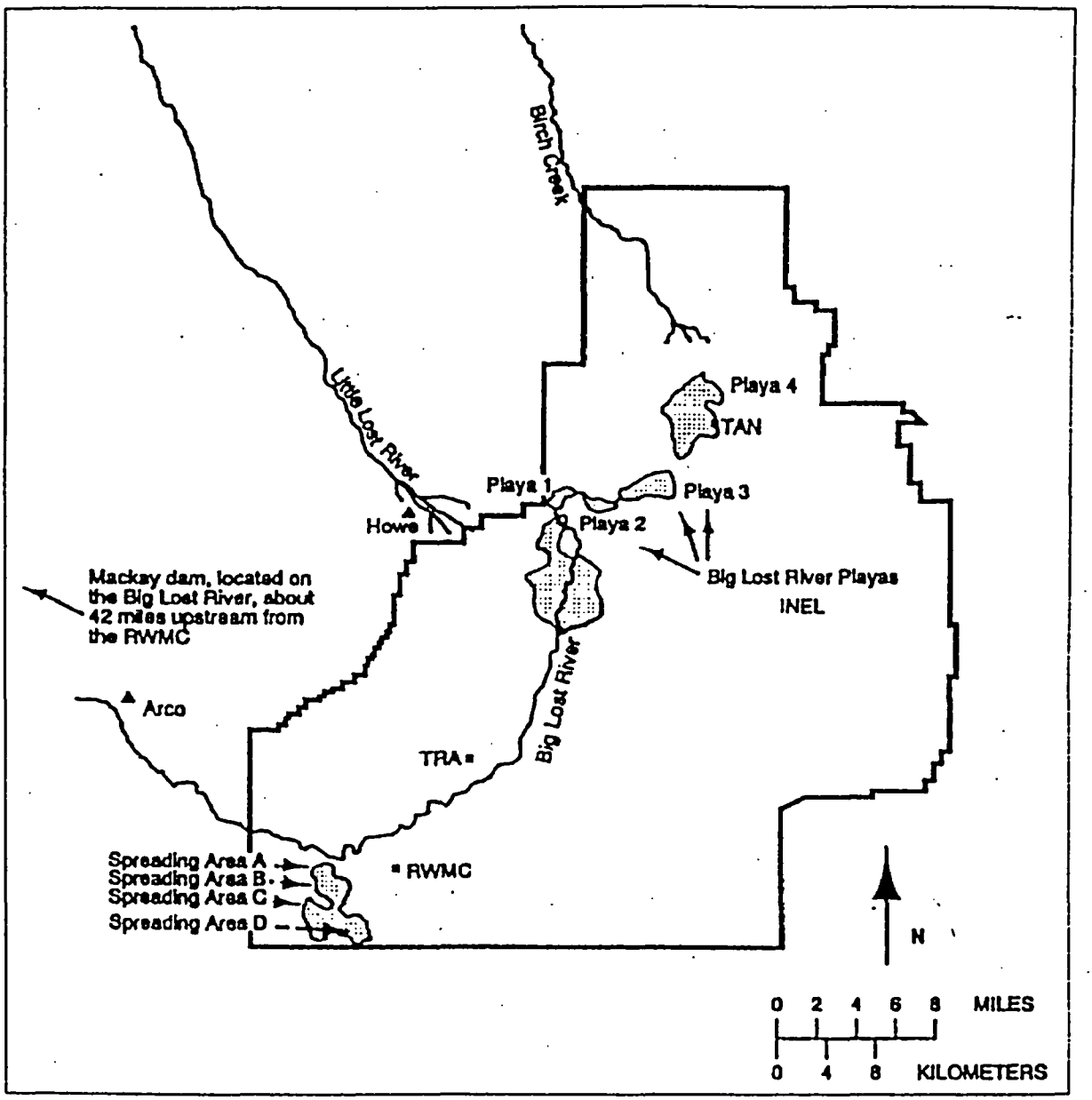
[38] DOE, December 1993, page 2-7
[39] ESRF, 1998, page 1-3; USGS, February 1999, page 7

Figure 4: Flow of the groundwater through the Eastern Snake River Plain



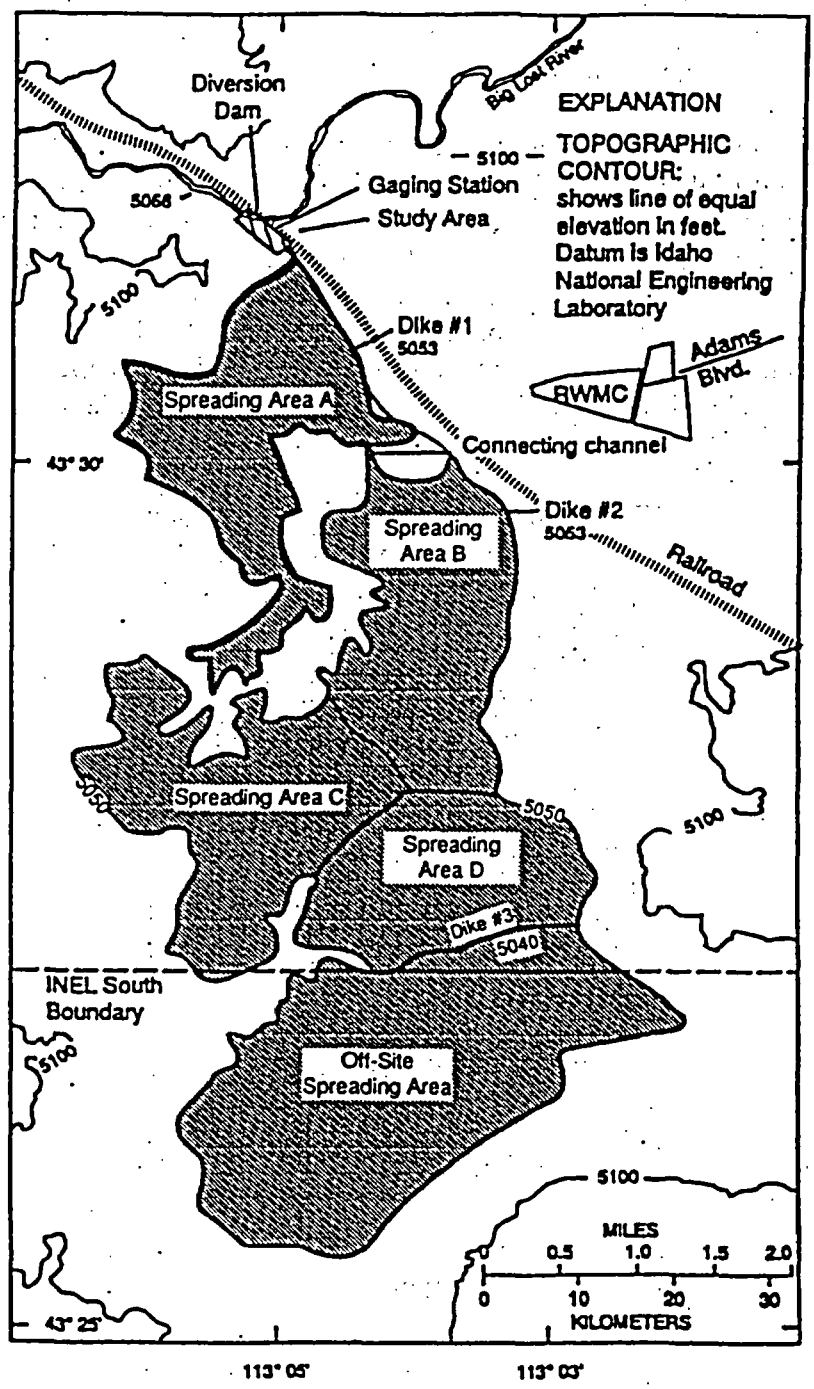
Source: INEEL OP

Figure 5: INEEL surface water drainage features



Source: DOE, June 1993, page 2-26

Figure 6: Big Lost River diversion and spreading areas



Source: DOE, June 1993, page 2-28 (From Bennett, C.M. *Capacity of the Diversion Channel Below the Flood Control Dam on the Big Lost River at the Idaho National Engineering Laboratory, Idaho.* U.S. Geological Survey Water Resources Investigations Report 86-4204, DOE/ID-22071. 1986.)

Chapter II: Current Contamination of Aquifer

Water monitoring at and near INEEL is conducted by the U.S. Geological Survey (USGS), the Stoller Corporation,[40] the U.S. Department of Energy and its site contractors, and the State of Idaho.

The USGS has conducted groundwater monitoring of the Snake River Plain Aquifer on and off site since 1949. The USGS maintains about 125 groundwater monitoring wells, 45 wells for sampling perched water, and about 120 auger holes to monitor shallow perched water.[41] Sampling sites are located on INEEL and beyond the southern and western boundaries.[42] The USGS analyses water samples for certain contaminants and natural parameters on a quarterly, monthly, or annual basis (see list below).[43] A large variety of contaminants, directly attributable to cumulative INEEL operations, are already present in the perched water bodies as well as in the Snake River Plain aquifer.

Contaminants and natural parameters measured in groundwater by USGS

tritium
strontium-90
cobalt-60
cesium-137
plutonium-238
plutonium-239/240 (undivided)
americium-241
gross alpha-radioactivity
gross beta-radioactivity
dissolved chromium
hexavalent chromium
sodium
chloride
sulfate
nitrate
purgeable organic compounds
specific conductance
pH
temperature

Source: USGS, April 1997, page 4

[40] Until 2001, the DOE contracted the Environmental Science and Research Foundation to do off-site monitoring and write the quarterly and annual site environmental reports.
[41] ESRF, June 2000a, page 8
[42] ESRF, August 1998, page 6-3
[43] ESRF, August 1998, page 3-32, schedule Table 3-3

A. Major sources of direct contamination of the Snake River Plain aquifer

Current contamination of the Snake River Plain aquifer is attributable both to direct waste injection as well as to migration of radionuclides and hazardous materials from surface disposal through the vadose zone.

1. Injection Wells

Between 1953 and 1986, injection wells at INEEL were used to inject organic and inorganic chemicals, low-level radioactive waste, and industrial and sanitary waste water directly into the Snake River Plain aquifer. The injection of these wastes into the aquifer is one of the major sources of the current contamination of the aquifer.[44] As early as 1952, a USGS report had recommended that radioactive waste liquid not be injected into disposal wells either into the vadose zone or directly into the aquifer.[45]

> "The chief disadvantages would be (1) relatively little adsorptive action; movement of water through the basalt may be channelized and the walls of the channels soon might become saturated with adsorbed solids; (2) unknown degree of dilution of waste liquids with pure water in the aquifer; (3) unknown path and ultimate destination of waste liquids in the aquifer."[46]

There were six deep injection wells at INEEL, three of which have been shown to be the source of contamination plumes (see Table 2 for a summary of these wells). Numerous shallow injection wells and gravel-lined pits a few meters deep were also used throughout the site to inject waste water into the vadose zone. The pits are still in use for "clean steam condensates."[47] However, these sources of contamination are a small portion of the potential total source term at INEEL and we will not discuss these sources in this report.

a. INTEC (Chem Plant) injection well

From 1953 to 1984, DOE injected liquid radioactive wastes directly into the Snake River Plain aquifer.[48] The liquid radioactive wastes came from a variety of operations at INEEL. The largest volume came from the reprocessing operations at INTEC (formerly called the Chem Plant). The average volume of waste injected annually was 363 million gallons per year for a total of over 11 billion gallons during the period of INTEC injection well operation.[49] This liquid waste contained both hazardous and radioactive chemicals.

The injection of wastes at INTEC primarily resulted in tritium and strontium-90 plumes in the aquifer. The total amount of radioactivity released is estimated to be 22,200

[44] DOE, November 1997a, page 4-1
[45] Deutsch, Nace and Vogeli, December 1952, pages 24 and 25
[46] Deutsch, Nace and Vogeli, December 1952, page 24
[47] Bradley Bugger (DOE-Idaho media relations), email communication to Michele Boyd, May 1, 2001
[48] Humphrey and Hill, January 1990, Appendix 5
[49] DOE, November 1997a, page 1-14 and 4-3

curies.[50] About 96 percent of the discharged radioactivity has been attributed to tritium.[51] The remaining radioactivity is from americium-241, technetium-99, strontium-90, cesium-137, cobalt-60, iodine-129, and plutonium.[52] As of January 1, 1995, the estimated total activity remaining was 3,920 curies.[53]

The injection well also contributed to contamination of the vadose zone. In 1967 or early 1968, the well collapsed at a depth of 68.9 meters (226 feet), resulting in the injection of waste water into the unsaturated zone. The collapse was not discovered until 1970. While the well was being redrilled to its original depth, waste water was disposed at a nearby well, USGS-50 (360 to 405 feet deep). At some point after these operations, the well collapsed again, but was not discovered and reopened to the aquifer until 1982. The collapses resulted in contamination of the vadose zone and perched water bodies with cesium-137, strontium-90, plutonium, iodine-129, technetium-99, and mercury.[54]

In 1984, the well was taken out of routine service and waste water was then routed to two infiltration ponds (see section on "Infiltration Ponds" in this chapter).[55] The injection well was kept open until 1986 in case of problems with the infiltration ponds (i.e. overflow). Available records do not indicate whether the injection well was used between 1984 and 1986. In 1989, the well was permanently sealed from the basalt layer (145 meters below ground surface) to the land surface with cement (pressure grouting). The reason given for sealing the well was to prevent water from flowing from the land surface down the well to the perched water and aquifer.[56] However, the well remains a source of contamination because of leaching from the sediment plug at its bottom.

b. Test Area North (TAN) injection well

A 310-foot deep direct injection well was also operated at the Test Area North (TAN) from 1953 to 1972.[57] The total radioactivity released to the injection well from 1959 through August 1972 is estimated to be 53.53 curies. However, this figure is questionable because there are no records of the radioactivity released before 1971 – that is, for almost the entire period of injection well operation – and no distribution by radionuclide is available until 1971.[58] The main radionuclides were identified as tritium, strontium-90, cesium-137, and uranium-234.[59]

[50] DOE, November 1997a, page 4-4
[51] DOE, November 1997a, page 9-5
[52] DOE, December 1999, page 4-63
[53] DOE, November 1997a, page 4-4
[54] DOE, November 1997a, page 4-3
[55] Between 1984 and 1986, the injection well was used for emergency overflow, but no records are available as to what, if anything, was injected during this time. Injection after 1984 would have violated the Underground Injection Control regulations under the Safe Drinking Water Act. (See 40 CFR 144.)
[56] DOE, November 1997a, page 4-3
[57] The water table at TAN is approximately 63 meters (206 feet) below land surface.
[58] DOE, December 1993, page 3-11
[59] DOE, November 2000, page 7

Toxic heavy metals probably were also injected, including mercury, potassium chromate, and lead.[60] The TAN injection well has been identified as the primary source of the volatile organic compound (VOC) plume in the Snake River Plain aquifer. The main organic compound is trichloroethylene (TCE), but the plume also includes tetrachloroethene (PCE), and dichloroethene (DCE).[61] Although records provide little information on the types and volumes of organic wastes disposed to the injection well, it is estimated that as much as 132,475 liters (35,000 gallons) of TCE were disposed to the well.[62] In 1987, the USGS found up to 35,000 micrograms per liter of TCE in the injection well.[63] The EPA's maximum contaminant level for TCE under the Safe Drinking Water Act is 5 micrograms per liter.

The highly contaminated sludges at the bottom of the TAN injection well continue to be a source of volatile organic compounds to the groundwater. The concentrated sludges were injected into the well from the late 1950s to the early 1960s from an evaporator that processed low-level radioactive waste water to reduce waste volume. In 1990, some of the sludge was removed from the bottom 17 meters (55 feet) of the injection well. The sludge contained approximately 30,000 micrograms per liter TCE and high levels of radionuclides.[64] This removal reduced the TCE concentration at the injection well to 4,100 micrograms per liter.[65]

c. Test Reactor Area (TRA) injection well

The 1,275-feet-deep disposal well at the Test Reactor Area, which currently is used as an observation well, was used from 1964 to 1982 to inject non-radioactive wastewater from cooling-tower operations at TRA into the aquifer. Since 1982, this wastewater has been discharged to the cold water, or non-radioactive, infiltration ponds at TRA.[66] Approximately 3.9 billion gallons of wastewater containing 14,120 kilograms (31,130 pounds) of chromium were injected into the aquifer through the well. This is equivalent to an average of about 1 milligram per liter of chromium in the wastewater. The EPA's maximum contaminant level for chromium is 0.1 milligrams per liter. Based on water sampling, the DOE does not consider the well a source of contamination.[67]

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[60] DOE, December 1993, page 3-10
[61] See Appendix C for information on the properties and health effects of the main contaminants at INEEL.
[62] DOE, December 1993, page 3-12
[63] DOE, December 1993, page 3-31
[64] DOE, December 1993, pages 3-31 and 3-33
[65] DOE, December 1993, page 5-5
[66] USGS, April 1997, page 14
[67] DOE, June 1992, page 4-5

Table 2: Deep injection wells at INEEL

Location of injection well	Use	Wastes	Contaminants of Concern	Volume (billion gallons)	Curies
Idaho Nuclear Technology and Engineering Center (INTEC)/ Chem Plant (ICPP)	1953-84: 598-feet-deep	Service waste water	Estimated 22,000 curies of radioactivity, 96% tritium; remaining from: americium-241, technetium-99, strontium-90, cesium-137, cobalt-60, iodine-129, plutonium	11	22,200
Test Area North (TAN)	1953-72: 310-feet-deep	Organic and inorganic compounds and low-level waste combined with industrial and sanitary waste water	In plume: Trichloroethylene (TCE), tetrachloroethylene (PCE), 1,2-dichloroethylene (DCE), cesium-137, tritium, strontium-90, uranium-234	?	53.53*
Test Reactor Area (TRA)	1964-82:1,271-feet-deep	Non-radioactive waste water from cooling-tower operations	Chromium (hexavalent)	3.9	?

? = Unknown
* = Questionable data

Sources: ERSF, 1998; DOE, October 1999; USGS, November 1999; DOE, June 1993b; and DOE, December 1999

2. Infiltration ponds

Infiltration (or percolation) ponds have also been used at INEEL for waste disposal, especially since the discontinuation of injection wells. Infiltration ponds are designed to allow the waste water that is discharged into them to percolate through the vadose zone to the aquifer. Radioactive and hazardous materials have been discharged into most of these ponds. Table 4 at the end of this section summarizes the characteristics of the main infiltration ponds at INEEL.

In terms of protecting the groundwater from contamination, there is not a significant difference between injecting contaminants directly into the groundwater and letting them percolate through the vadose zone to the aquifer. Percolation ponds delay water from reaching the aquifer only on the order of days to months.[68] As contaminated pond water moves through the vadose zone, it can carry dissolved chemicals to the aquifer. Releases of uncontaminated water can also facilitate the transport of contaminants to the aquifer by remobilizing vadose zone contamination from prior releases, or driving contaminated groundwater in the perched water bodies into the aquifer.

Groundwater "perches" in the vadose zone when sediments or dense basalt impede the downward flow of water to the aquifer.[69] The liquid waste discharged to infiltration ponds creates an additional source of surface water that percolates through the vadose zone and can form perched water bodies if there are subsurface areas of low permeability. Eventually, the water in these perched water bodies continues to migrate downward to the main aquifer, facilitating the movement of contaminants to the aquifer. Depending on the geology, perched water bodies can form below other perched water in the vadose zone.[70]

a. INTEC (Chem Plant) ponds

When the INTEC injection well was taken out of service in 1984, waste water was then pumped to percolation ponds. Two unlined pits (4.5 acres each) continue to receive approximately 1.5 to 2.5 million gallons of service wastewater per day.[71]

Two main perched water bodies have formed in the INTEC vadose zone, which extends 460 to 480 feet below ground surface. The perched water body at the northern end of INTEC is located beneath the sewage treatment ponds and extends towards the west under the Tank Farm. The perched water body in the southern area of INTEC has resulted primarily from discharge to the percolation ponds.[72] Other sources of recharge to the perched water bodies are from precipitation, the Big Lost River, lawn irrigation, leaking fire water lines, steam condensate dry wells, and other miscellaneous INTEC water sources. See Figure 7 for a conceptual model of the groundwater and perched

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[68] For example, a USGS tracer test at the spreading areas in the 1990's found that the water reached the aquifer in 7 days. The average vertical flow rate was about 30 feet per day. Nimmo *et al.*, 2001
[69] USGS, December 1999, page 4-60
[70] DOE, November 1999a, page 1, 2, and 5
[71] DOE, December 1999a, page 4-51
[72] DOE, December 1999a, page 4-60

water body recharge, contaminant sources, and exposure pathways at INTEC. Figure 8 shows a map of the approximate area of the perched water bodies at INTEC.

Both perched water bodies have an upper (100 and 140 feet below ground surface) and a lower zone (320 and 420 feet below ground surface). The lower perched water body was also partially formed by the failure of the injection well in the late 1960s and late 1970s.[73]

The ponds are estimated to contribute 70% of the water recharge to the southern perched water body at INTEC. The DOE has decided to control surface water recharge to the perched water at INTEC by taking the current ponds out of service and building new ponds about 3,048 meters (10,000 feet) southwest of INTEC by December 2003.[74] However, the problem will not be solved by moving the ponds a few thousand meters away, because water leaching through the vadose zone from the new percolation ponds will continue to mobilize contaminants and drive them to the aquifer.

Table 3 lists the maximum concentration of contaminants in the perched water bodies and the aquifer at INTEC in 1995. Tritium, strontium-90, and technetium-99 are found in all of the perched water bodies at INTEC.[75] The highest strontium-90 levels in the perched water occur in the northern upper perched water body, particularly associated with wells MW-2, MW-5, and CPP-55-06 (see Figure 9), though it is also present in significant concentrations in the Snake River Plain aquifer. Tritium and technetium-99 are also present in the aquifer.

Table 3: Maximum concentration of contaminants in aquifer at INTEC, 1995

Contaminants in groundwater at INTEC	Maximum Concentration, picocuries per liter	Location	Maximum Contaminant Level, picocuries per liter
Tritium	73,000 31,000	Northern lower perched water body Aquifer	 20,000
Strontium-90	320,000 84	Northern upper perched water body Aquifer	 8
Americium-241	0.54	Aquifer	<15
Neptunium-237	3.1	Aquifer	<15
Iodine-129*	3.8	Aquifer	1
Technetium-99	740 450	Northern lower perched water body Aquifer	 900
Uranium-234**	12 2.6	Perched aquifer Aquifer	
Uranium-238**	2.7 1.1	Northern upper perched water body Aquifer	

Source: DOE, December 1999, page 4-64 and 4-65

* Measured in 1990-91

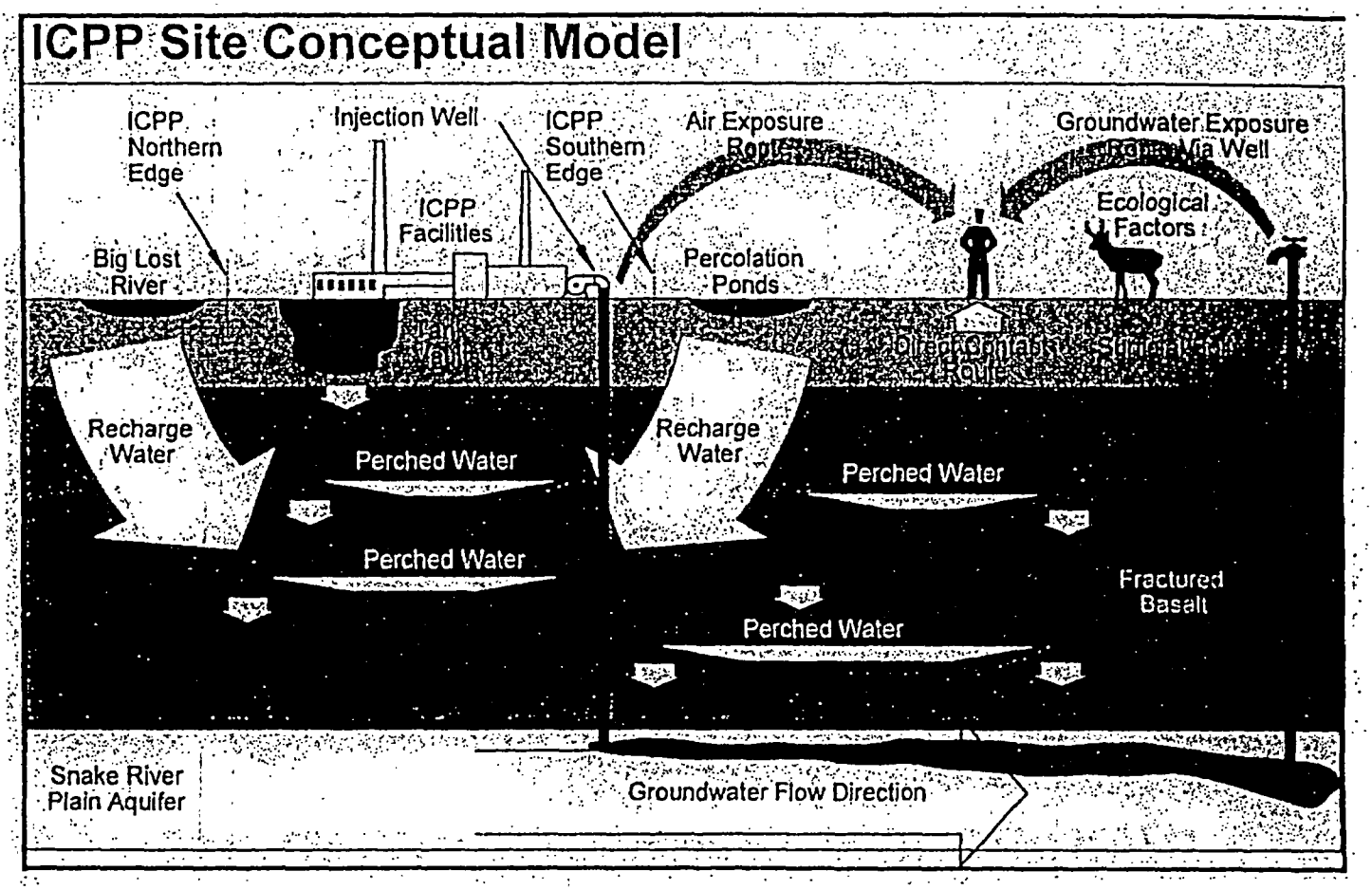
** The MCL for total uranium, as of December 2003, is 30 micrograms per liter.

[73] DOE, December 1999a, page 4-60 and 4-61

[74] DOE, October 1999a, page viii

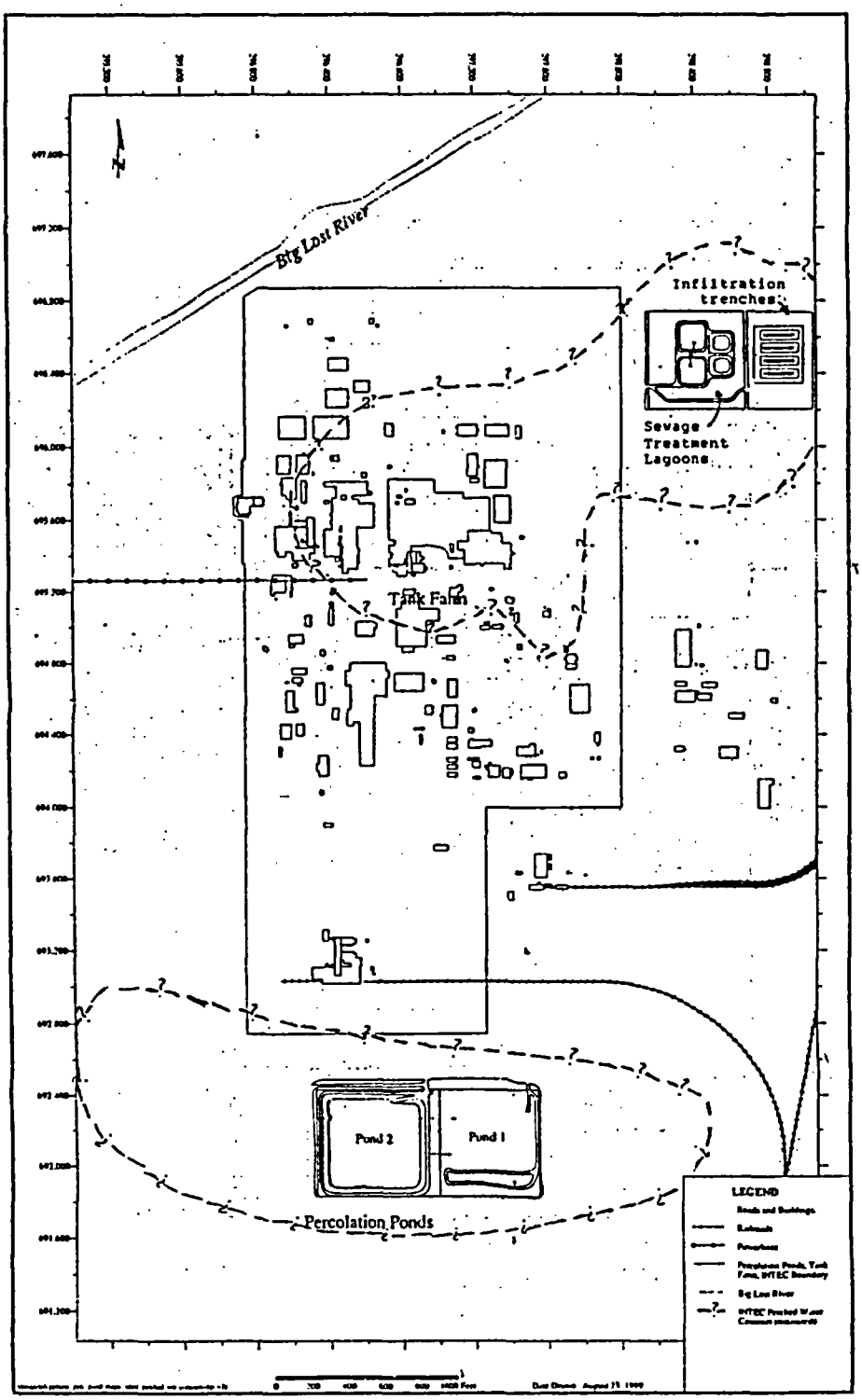
[75] DOE, December 1999a, page 4-63

Figure 7: Conceptual model of groundwater and perched water body recharge, contaminant sources, and exposure pathways at INTEC



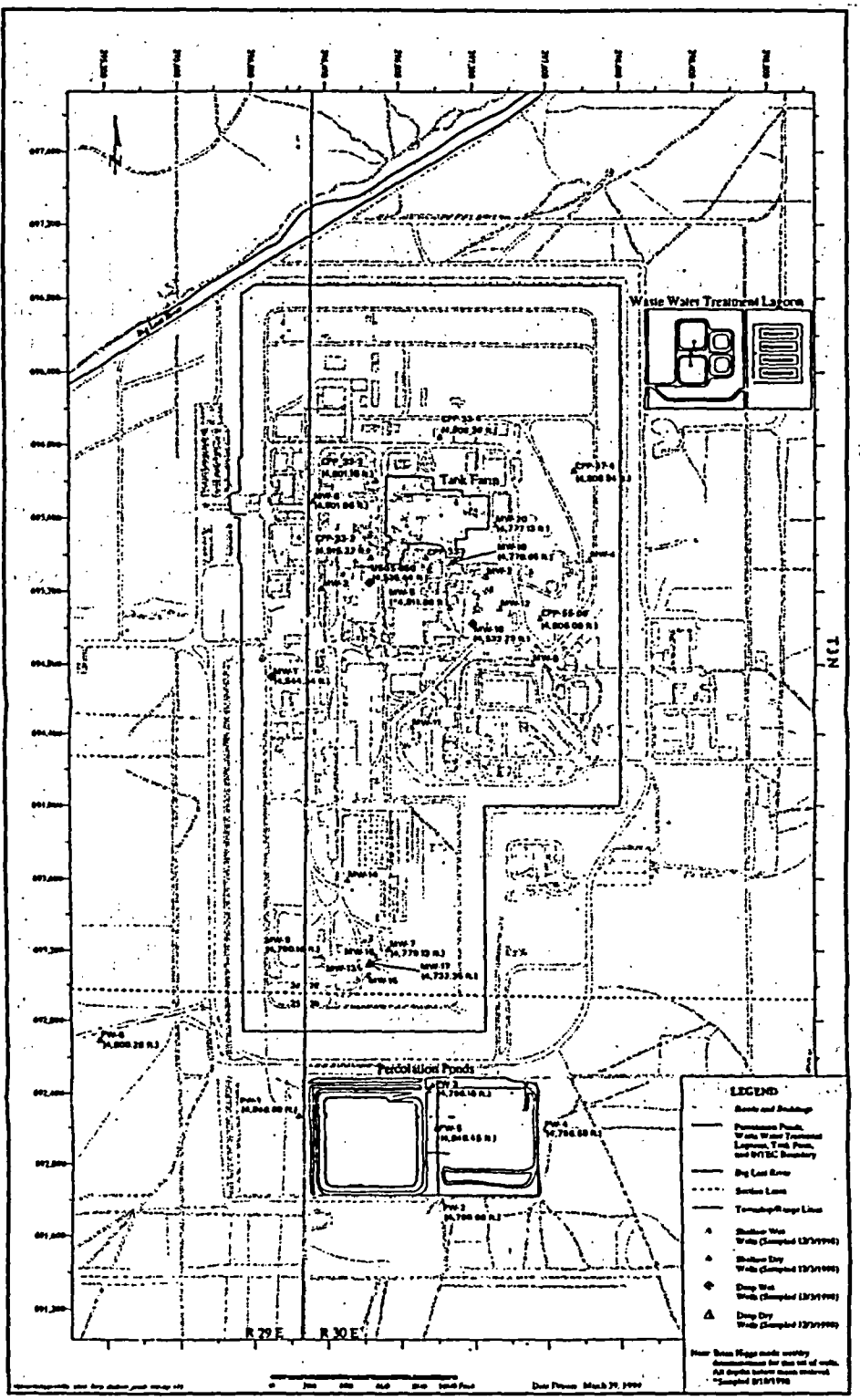
Source: DOE, July 1999

Figure 8: Approximate extent of the perched water at INTEC



Source: DOE, October 1999a, page 1-8

Figure 9: INTEC well map showing where perched water has been observed



Source: DOE, October 1999a, page 5-66

b. Test Area North (TAN) pond

In September 1972, the disposal well for waste water at Test Area North was replaced with a 35-acre, unlined pond.[76] The pond received sanitary waste discharges, low-level radioactive waste, industrial waste water, and treated sewage effluent. Between September 1972 and July 1985, a total of 11.124 curies were released to the disposal pond.[77]

Most of the pond is no longer used, but sanitary and industrial wastes are still discharged to a 2.5-acre portion of the pond. Five acres in the northeast corner and on the eastern edge is contaminated with radionuclides and metals, including beryllium, chromium, mercury, and thallium.[78] Cesium-137 has been found 3.4 meters (11 feet) below the bottom of the pond.[79]

A small perched water body has formed beneath the disposal pond from the infiltrating pond water. The lateral extent of the perched water zone is not known, but the thickness ranges from 2.7 to 12.2 meters (9 to 40 feet).[80] Gross alpha, gross beta, and strontium-90 exceed their respective maximum contaminant levels (MCLs).[81] Strontium-90 was detected in the perched water with concentrations ranging from 1.0 to 136 picocuries per liter.[82]

c. Test Reactor Area (TRA) ponds

From 1952, low-level radioactive, chemical, and sanitary waste water at the Test Reactor Area was discharged to infiltration and evaporation ponds, including warm waste ponds, sanitary waste ponds, a chemical waste pond, and cold waste ponds. The cold waste ponds are still in use.[83]

Both an upper and a lower perched water body have formed beneath the infiltration ponds. The lower perched water body sits on a relatively impermeable layer of clay about 140 to 200 feet below ground surface and 300 feet above the aquifer.[84] In March 1991, it was about 6,000 feet by 3,000 feet with a volume of 140 million cubic feet. The upper perched water is located about 50 feet below ground surface. The area and volume of this water body is unknown.[85]

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[76] USGS, April 1997, page 17
[77] DOE, December 1993, page 3-9, Table 3-3
[78] DOE, October 1999b, page Part II 8-12
[79] DOE, November 1997b, page 4-105
[80] DOE, November 1997b, page 4-105
[81] DOE, June 1993, page 9-80
[82] DOE, November 1997b, page 4-105
[83] USGS, April 1997, page 14; Warm waste is contaminated with radionuclides and cold waste is not contaminated with radionuclides.
[84] DOE, June 1992, pages 3-73 and 3-74
[85] DOE, June 1992, pages ix, 3-85, and 3-124

Contaminants from the ponds have migrated from the upper perched water system, through the lower perched water, to the aquifer. From 1962 to 1990, a total of 6,700 million gallons of water were discharged to the vadose zone at the Test Reactor Area.[86] The primary source of radionuclide contamination and recharge to the perched groundwater zones was from the warm waste disposal ponds. In August 1993, they were replaced by two lined evaporation ponds, but the percolation pond sediments continue to be a source of tritium, strontium-90, and technetium-99 contamination to the perched water.[87] The other waste ponds are primarily sources of recharge to the perched water.

[86] DOE, June 1992, pages ix and 3-124
[87] USGS, April 1997, page 14

Table 4: Main infiltration ponds at INEEL

Area	Structures	Wastes	Contaminants of concern
INTEC (Chem Plant): Two percolation ponds	Since 1984; to be closed by 2003 and moved 10,000 feet southwest of INTEC	Radioactive service waste water	Aquifer: strontium-90, tritium, fluoride; Perched water body: strontium-90, chloride, aluminum, iron
Test Area North (TAN): Disposal pond	Since 1972: 35-acre, unlined disposal pond replaced injection well; 2.5 acres still in use	Low-level waste, industrial waste, sanitary	Five acres contaminated: Cesium-137 (migrated to about 3 meters below bottom of pond), arsenic, mercury, tetrahydrofuran, thallium
Test Reactor Area (TRA): Two cold-waste infiltration ponds	Since March 1982: replaced injection well	Commercial corrosion inhibitors, commercial slimicides, and phosphates, bromine, chlorine, sodium sulfate, sodium sulfite, and chromium	Arsenic in effluent greater than MCL
Test Reactor Area (TRA): Warm-waste ponds	3 cells constructed between 1952 and 1964 (closed in August 1993)	1952-64: Waste water (except sanitary); after 1964: low-level waste water ; 1952-93 received 708 million cubic feet of waste water	Cesium-137, cobalt-60, and chromium
Test Reactor Area (TRA): Chemical waste pond	Since 1962	Chemical waste water from ion-exchange system and water softeners	Sodium and sulfate predominant constituents
Auxiliary Reactor Area: ARA-I Chemical evaporation pond	1970-88: Shallow, unlined, surface impoundment (30x90meters); dry since 1988, except during spring runoff and heavy precipitation	1970-88: Lab waste water with small quantities of radionuclides, acids, bases, volatile organic compounds	Soil (1,821 cubic meters): arsenic, selenium, thallium
Auxiliary Reactor Area: ARA-III Radioactive waste leach pond	Unlined, surface impoundment (115x50 meters); dry since 1987, except during spring runoff and heavy precipitation	Disposal of low-level waste liquids from reactor research operations	Soil (1,503 cubic meters): silver, copper, mercury, selenium
Power Burst Facility (PBF): SPERT-II Leach pond	Unlined, surface impoundment (70x51meters)	1959-64: disposal of demineralizer effluent, discharges from floor drains of reactor building	Soil (382 cubic meters): mercury

Ponds designated mainly for sewage have been omitted.

Sources: USGS, April 1997; DOE, October 1999b; USGS, November 1999; DOE, June 1992; DOE, December 1997; USGS, November 1999; USGS, April 1997; DOE, December 1999; and DOE, January 2000

B. Contamination levels in INEEL groundwater

Groundwater contamination may occur in plumes or in a more scattered and unpredictable fashion, depending on the pollutants in question, the methods of their discharge, and their interaction with the environment. Some areas of contamination in the aquifer under INEEL are greater than the allowable maximum contaminant levels (MCL) set by the U.S. Environmental Protection Agency under the Safe Drinking Water Act. See Appendix B for a list of the drinking water maximum contaminant levels of radioactive, inorganic, and organic chemicals.

1. Radionuclides

There are currently several contaminant plumes in the Snake River Plain aquifer with large areas greater than the maximum contaminant level: tritium, strontium-90, iodine-129, and several volatile organic compounds (primarily trichloroethylene, TCE). Other contaminant plumes include technetium-99 and chromium. The plume concentrations are shown in Figure 10 through Figure 15. The primary point sources for these plumes are injection wells, through which waste was disposed directly into the aquifer, and percolation ponds, through which contaminants migrate into the vadose zone and ultimately to the aquifer. In the case of pollutants that were dumped into pits or discharged into surface ponds, their concentrations in groundwater also depend on the manner and duration of transport through the vadose zone. (See Chapter III.)

The plume data show that direct injection has damaged the Snake River Plain aquifer in considerable areas above allowable drinking water levels for some radionuclides and for TCE. Drinking water maximum contaminant levels (MCLs) are set for individual radionuclides, but the allowable amounts are reduced when more than one radionuclide is present. Hence, areas of the Snake River Plain aquifer are contaminated beyond drinking water limits when the radionuclides are combined in the manner prescribed in the regulations.[90] While this water is not currently being used for drinking, comparing the contamination to drinking water standards provides an indication of future usability of the water once site control is lost or if all or part of the site is used for civilian purposes, as is being done at several other DOE sites now. For instance, in the early 1990s, the federal government sold land near the DOE Oak Ridge Reservation in Tennessee to be used as a golf course. Although the deed prohibited the use of groundwater, which was contaminated with TCE from the Y-12 plant, a well was drilled within only a few years to irrigate the course.[91]

Despite the fact that there is a known plume of iodine-129, DOE rates its own monitoring of iodine-129 as 'poor.'[92] The most contaminated well with iodine-129 had a

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[90] The contamination is estimated by adding the sum of the ratios of the actual level of each radionuclide to the MCL for that radionuclide. If the sum of the ratios for all radionuclides is less than one, the sample complies with the standard. In this report, we have calculated the combined burden, expressed as a percentage of MCL, in Table 11. If the percentage exceeds 100 (on an annual average basis), the standard has been violated.; 40 CFR 141.15 and 141.16

[91] NAS-NRC, 2000a, page 52

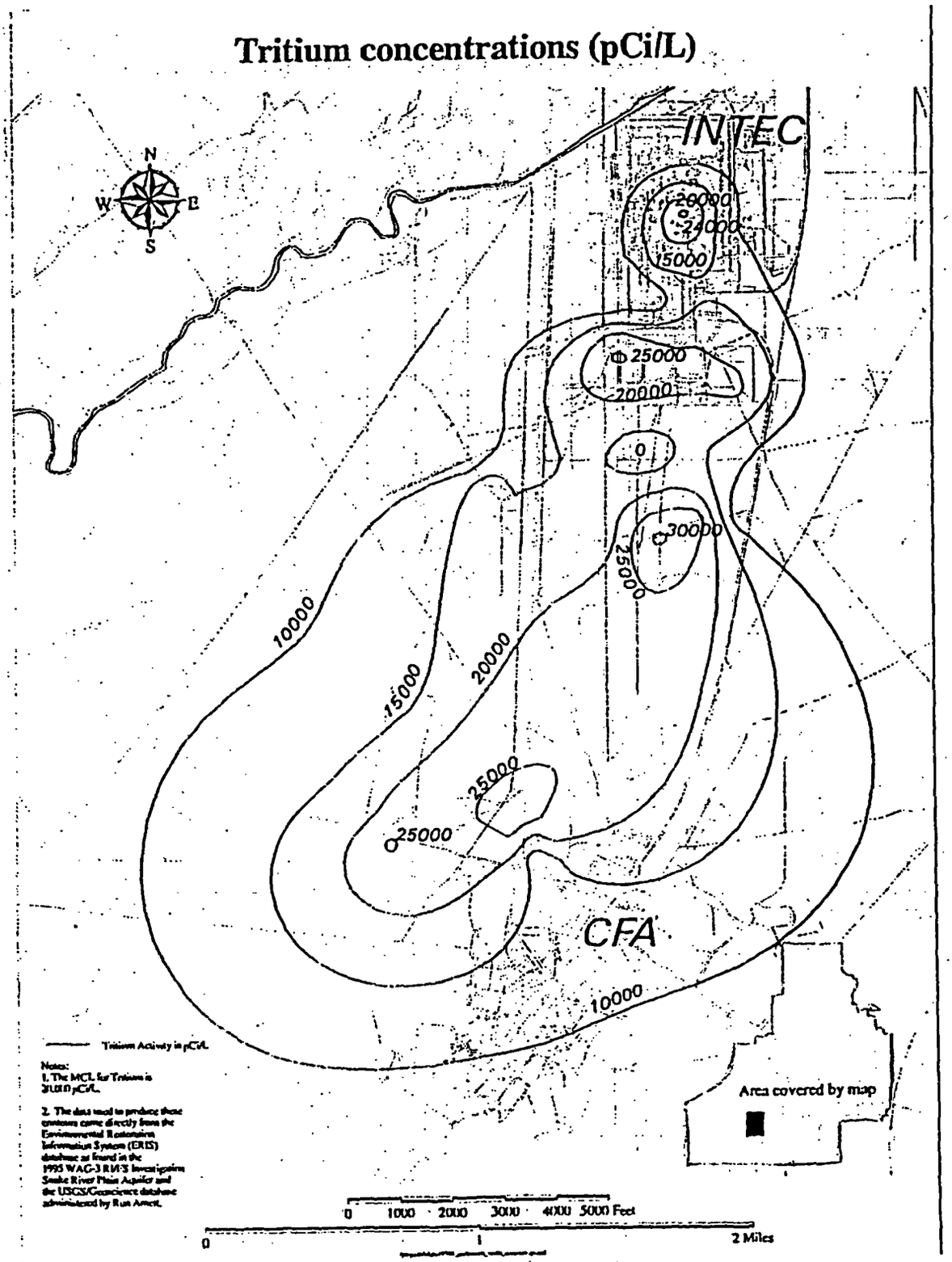
[92] DOE, July 2000. Book 1, page 4-77.

concentration of 3.82 picocuries per liter in 1991 (its maximum contaminant level is 1 picocurie per liter). In the same year, iodine-129 from waste disposal at INEEL was detected in a well off site (Well 14, 26 kilometers south of INTEC) with a concentration of 30×10^{-6} picocuries per liter, which is far less than the allowable maximum contaminant level.[93] However, even though discharges of iodine-129 to the environment have stopped, the current source of iodine-129 in buried waste presents a serious problem due to its rapid migration through the vadose zone and its very long half-life (17 million years).[94] Radioactive iodine affects the thyroid, especially in children.

Table 5 shows the highest plume concentrations in the aquifer, both as picocuries per liter and as a percent of the drinking water standard, and the area with concentrations greater than the drinking water standard. The highest concentrations in the tritium, strontium-90, and iodine-129 plumes are all much higher than the drinking water standards. The largest technetium-99 concentration is 50% of the drinking water standard. The highest concentration of the TCE plume is 640,000% greater than the drinking water standard. The reasons for showing the highest concentrations are (i) to indicate the extent to which contaminants have migrated and (ii) illustrate a possible upper limit of dangers, should site control and institutional memory be lost.

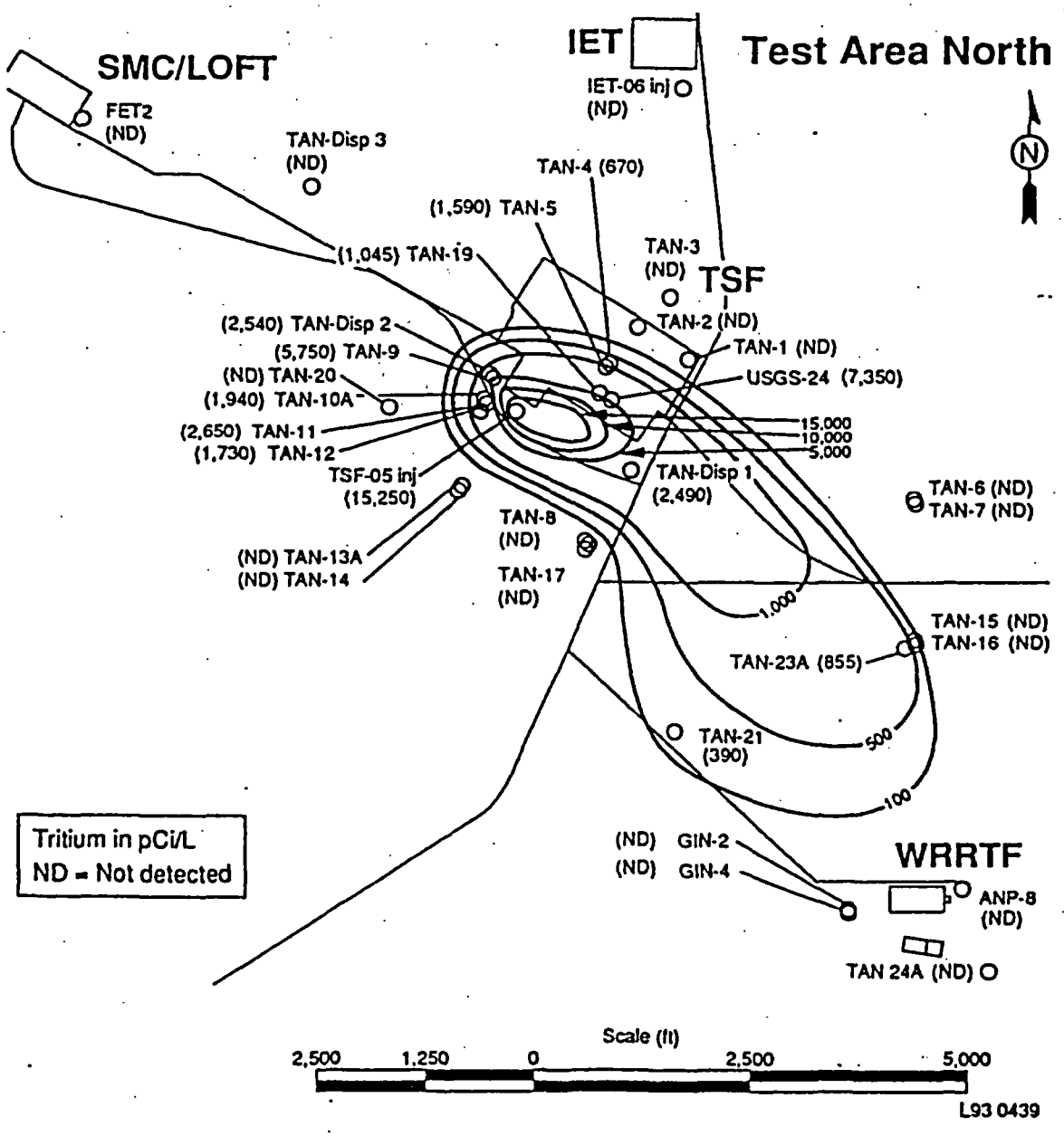
[93] Mann and Beasley, December 1994, page 85
[94] Langmiur, 1997, pages 519-520 and 536

Figure 10: Tritium plume in the Snake River Plain aquifer at INTEC, 1995



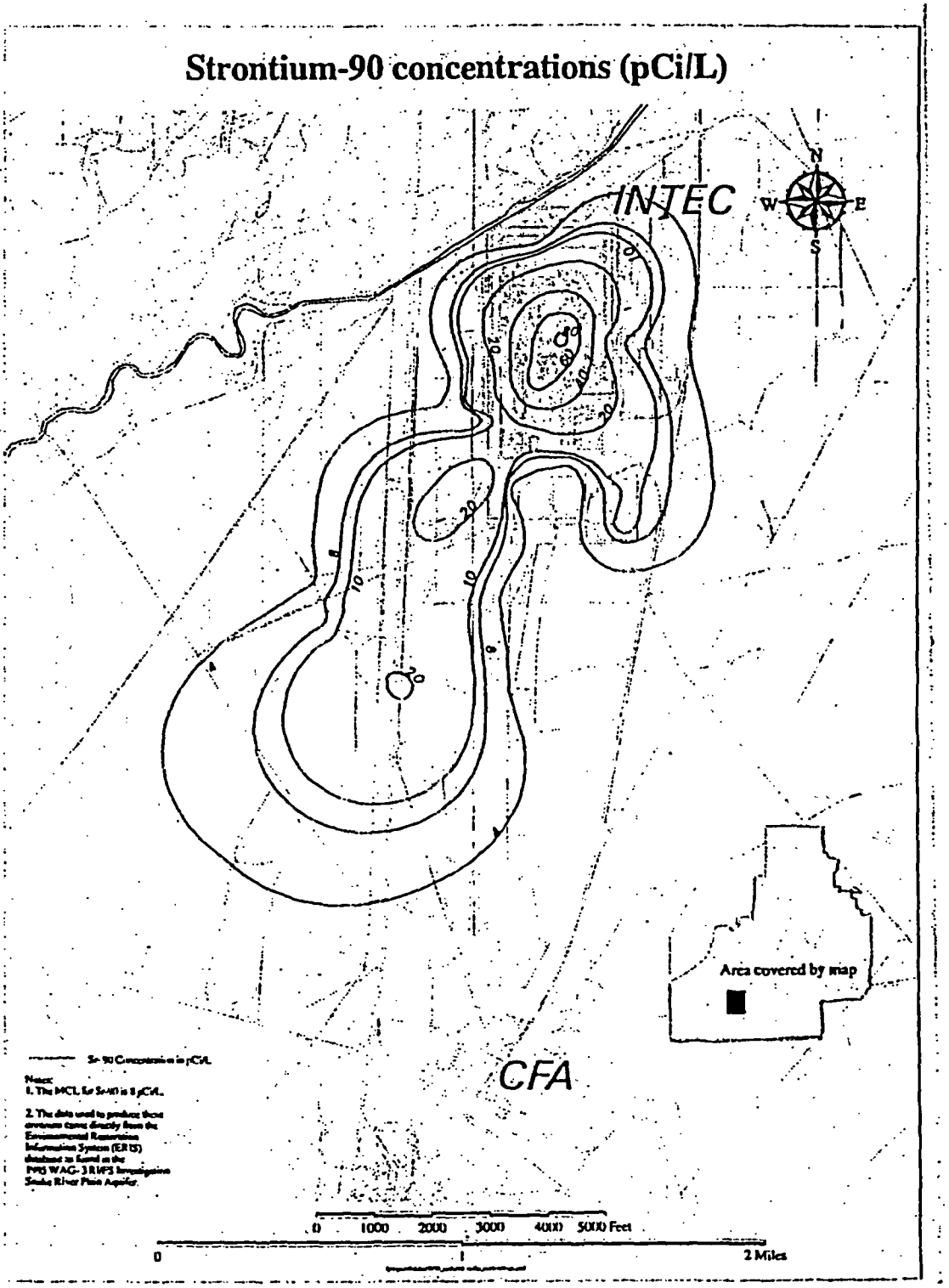
Source: DOE, October 1999a, page 5-7

Figure 11: Tritium plume in the Snake River Plain aquifer at Test Area North, 1992



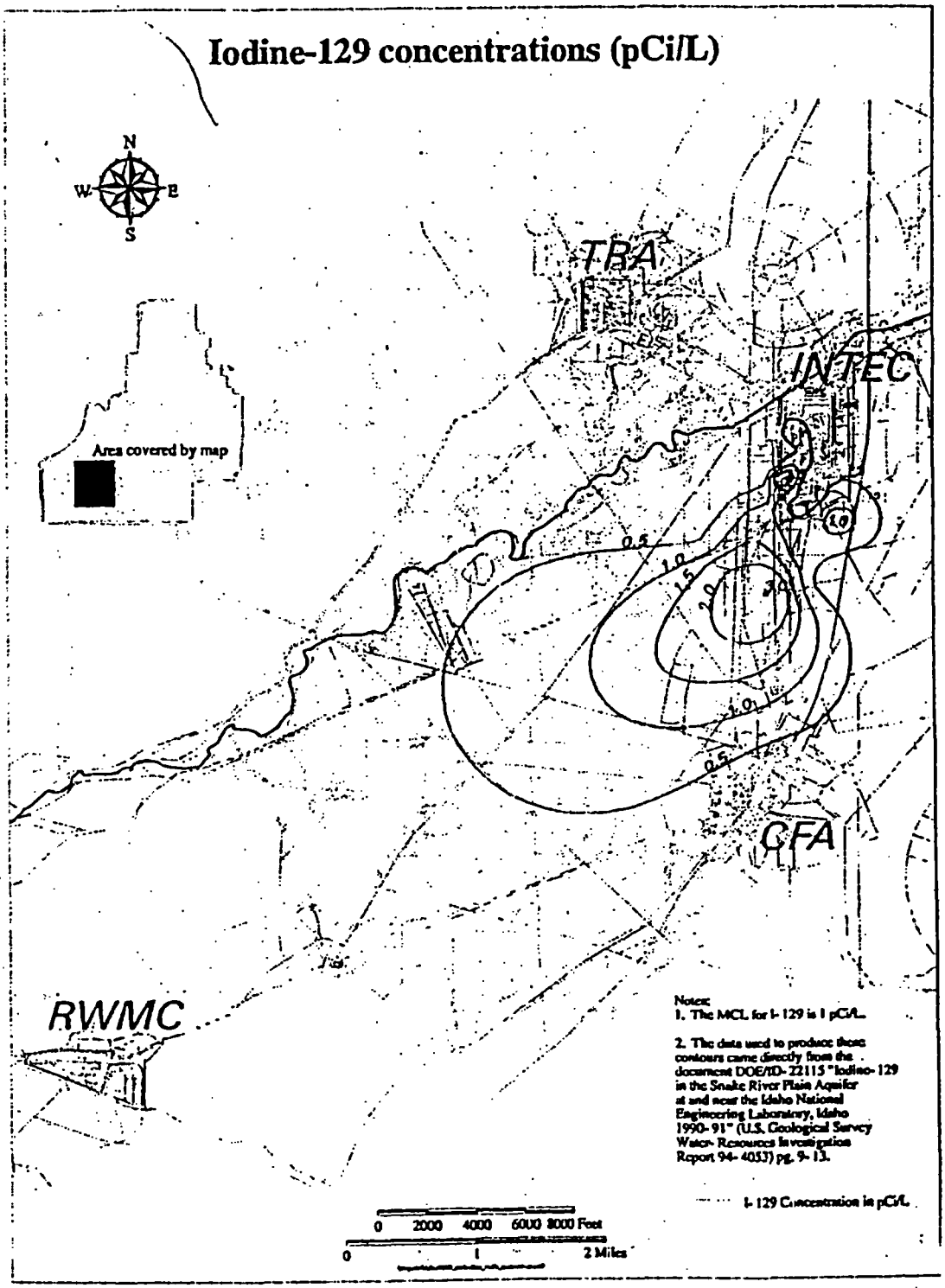
Source: DOE, December 1993, page 5-17

Figure 12: Strontium-90 plume in the Snake River Plain aquifer at INTEC, 1995



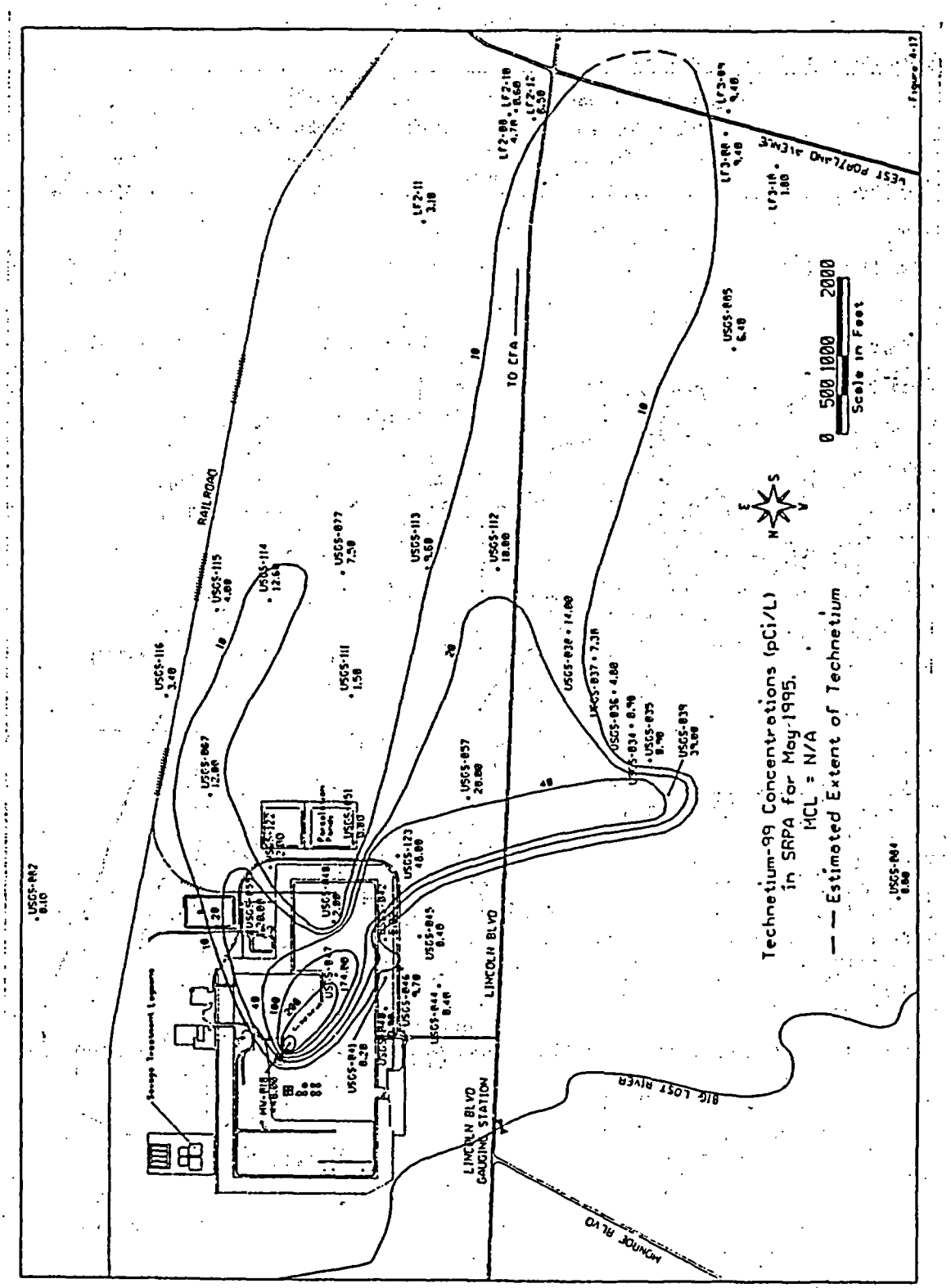
Source: DOE, October 1999a, page 5-8

Figure 13: Iodine-129 plume in the Snake River Plain aquifer at INTEC, 1991



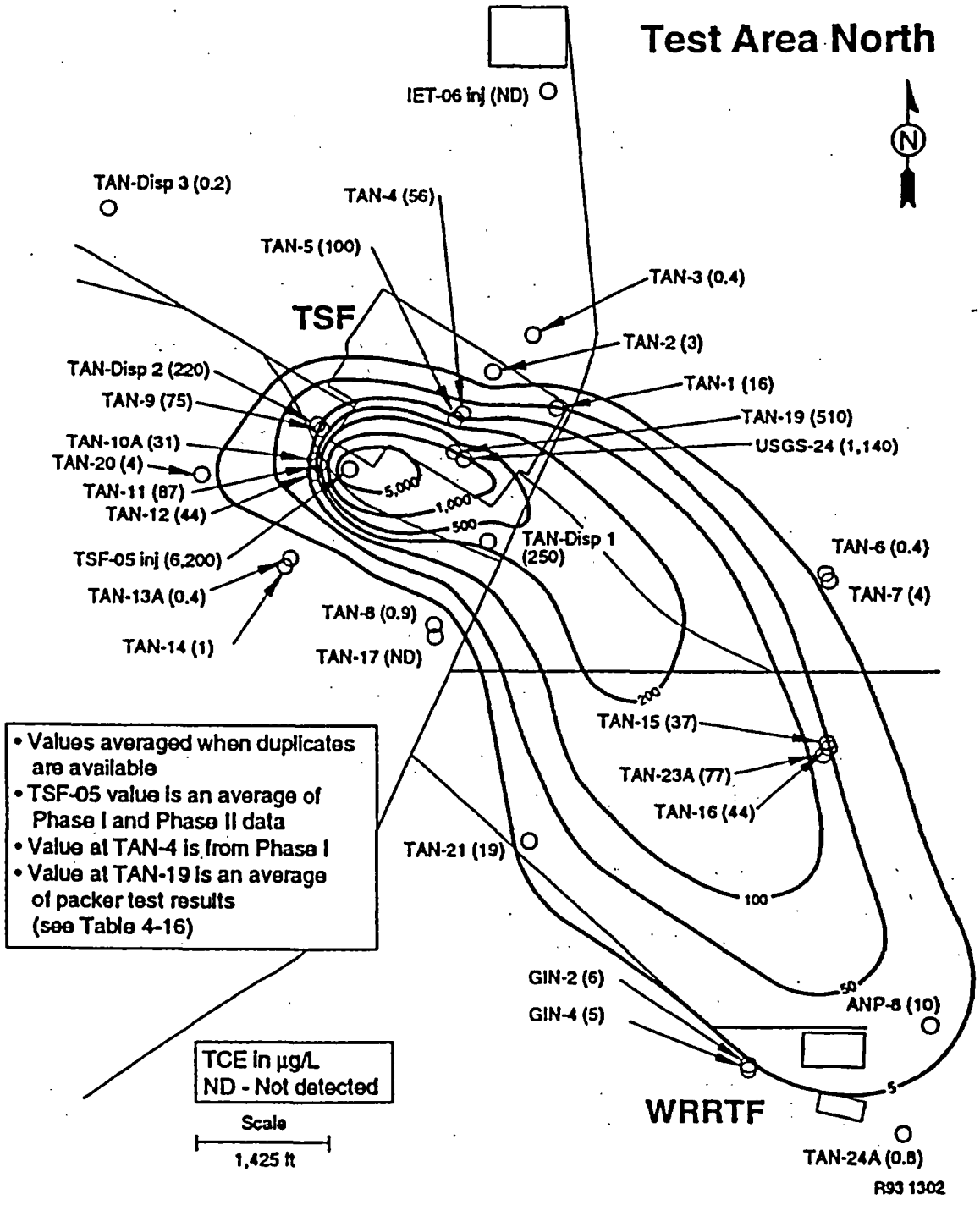
Source: DOE, October 1999a, page 1-9

Figure 14: Technetium-99 plume in the Snake River Plain aquifer at INTEC, 1995



Source: DOE, November 1997a, page 4-55

Figure 15: Trichloroethylene (TCE) plume in the Snake River Plain aquifer at Test Area North, 1992



Source: DOE, December 1993, page 5-8

Table 5: Highest plume concentrations in the Snake River Plain aquifer						
Contaminant	Highest concentration in plume (picocuries per liter; TCE in micrograms per liter)	Drinking Water Standard (picocuries per liter; TCE in micrograms per liter)	As % of Drinking Water Standard	Area with concentration greater than Drinking Water Standard (square miles)	Date (year)	Source
Iodine-129	3.82	1	382 %	1.5	1991	USGS, April 1994, page 14
Strontium-90	84	8	1,050 %	0.6	1995	DOE, November 1997, page 4-49
Technetium-99	448	900	49.8 %	0	1995	DOE, November 1997, page 4-54
Trichloroethylene (TCE)	32,000	5	640,000 %	2,700 meters long; maximum width of 900 meters	1995	DOE, November 2000, page 7
Tritium	30,700	20,000	153.5 %	1.3	1995	DOE, November 1997, page 4-49

Note: Data are based on a review of available documents. Typical concentrations and variations of concentrations in plumes are shown in Figure 10 through Figure 15.

Tables 6 and 7 show some of the highest concentrations of radionuclide contamination in the aquifer and perched water as measured at various monitoring wells on the INEEL site that we have found in DOE and USGS reports. Most of the measurements were taken in the 1990s. We have not been able to identify the dates for all of the data. The highest concentration of tritium is from the mid-1960s. Tritium concentrations in the plume, while still substantial, have declined considerably, in large part due to dilution and radioactive decay, since tritium has a half-life of 12.3 years.[92] The values in the tables may not be the highest concentrations that actually occurred or the most recently reported high concentrations. The sampling program and reporting of the data at INEEL are rather difficult to penetrate and are sometimes inconsistent. We present these data here to give some idea of the extent to which some areas have become severely contaminated, not only in the perched water from which water will not directly migrate off site, but also in the Snake River Plain aquifer itself.

It should be noted that these measurements are *not* representative of the current contamination throughout the entire Snake River Plain aquifer. More representative contaminant levels for some radionuclides are indicated by looking at the entire contaminant plume (Figure 10 to Figure 15).

Table 6 and Table 7 also list the safe drinking water standards. In interpreting the safe drinking water limits, it should be remembered that they are based on doses resulting from exposure to single contaminants. The allowed concentration for a radionuclide is reduced if other contaminants are present.

Plutonium-239/240, plutonium-238, and americium-241 have also been found in the Snake River Plain aquifer, but no pattern or plume has been detected or established. See Table 8 for the plutonium detections in the aquifer since 1972 near the Radioactive Waste Management Complex. Measurements of plutonium-239/240 as high as 24 picocuries per liter have been reported. The highest concentration of americium-241 found in the groundwater was 1.97 picocuries per liter, which is still well below allowable drinking water limits (its maximum contaminant level is 15 picocuries per liter).[93] The table also shows that the results of the measurements have been highly variable. They are also subject to considerable uncertainty.

On March 14, 2001, the State of Idaho, joined by the U.S. Geological Survey and the Department of Energy, held a press conference to announce that state and federal scientists found plutonium-238 and other transuranic radionuclides in the Snake River Plain aquifer at INEEL. The concentrations ranged from 0.08 picocuries per liter to 0.02 picocuries per liter.[94] The highest concentration is 225 times less than the allowable drinking water standard.[95] There has been and continues to be some controversy and

[92] Tritium discharged during the 1950s and 1960s (assuming an even discharge rate) would have declined by the year 2000 to about a tenth of its original value.
[93] INEEL OP, March 2001
[94] DOE, March 2001
[95] It should be noted, however, the Safe Drinking Water standard of 15 picocuries per liter for alpha emitting transuranics like plutonium-238, plutonium-239, or americium-241 allows doses on the order of a hundred times higher than the 4 millirem annual limit specified for most beta emitters. A concentration of

uncertainty about the validity of the positive results and their interpretation. The possibility was raised at the press conference that the results might not be attributable to migration of transuranics through the vadose zone, but rather to contamination of the samples or other factors.

> "Officials from DOE, the state, and USGS believe there could be several potential causes of the positive detections - contaminated dust that may have blown into the sampling wells or taken down by sampling equipment; radionuclides that were released into the aquifer in years past by now-closed injection wells at INEEL facilities; or from waste buried in the past at the Subsurface Disposal Area. The results also will be reviewed to determine the possibility of laboratory or sampling error."[96]

This idea has been reinforced by a study of nine samples of water from the Snake River Plain aquifer and 13 from perched zones published by Los Alamos National Laboratory. This analysis found no significant measurements of plutonium in the samples.[97] However, it must be noted that there were only a few samples taken at one time, and they are not necessarily representative of a longer pattern of plutonium detections and plutonium migration throughout the vadose zone.

Further, it seems unlikely that all of the positive detections, including the highest readings, which were taken at intervals decades apart and in which no systematic measurement errors have been identified, would be attributable to measurement or sampling protocol errors. The highly variable results may be a result of the fact that plutonium transport in the vadose zone is highly complex and can be greatly affected by very localized factors. One of these factors relates to colloidal transport – that is, transport of plutonium that is not dissolved but moves as tiny colloidal particles in

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plutonium of only about 0.08 picocuries per liter in drinking water is required to produce a dose of 4 millirem per year to the bone surface (the critical organ for plutonium). The Safe Drinking Water standard specifies dose limits, concentration limits, and calculation procedures for doses that are not consistent and are more stringent in some cases (such as nickel-63, cesium-137, and tritium) and less stringent in others, notably transuranic radionuclides and strontium-90. Since the latter are among those presenting the most serious threats in Idaho, a more conservative approach that would limit groundwater contamination from transuranics is warranted. None of these limits take into account the potentially more serious problems arising from fetal exposure.

[96] DOE, March 2001

[97] Roback *et al.*, November 2000, page 3

Table 6: Maximum radionuclide concentrations in the Snake River Plain aquifer

Radionuclide	Highest concentrations (picocuries per liter)	Drinking Water Standard[98] (picocuries per liter)	Highest concentration as % of Drinking Water Standard	Facility and well name	Date	Source and Comments
Tritium	401,000	20,000	2,005%	USGS 20	April, 1965	DOE, July 2000, page G-37
Strontium-90	84	8	1,050%	INTEC, MW-18	June, 1995	DOE, Nov 1997, page 4-33
Technetium-99	448	900	50%	INTEC, MW-18	June, 1995	DOE, Nov 1997, page 4-33
Iodine-129	137	1	13,700%	INTEC	?	DOE, June 1993a, page 6-76
Cesium-137	6,300	160	3,938%	INTEC	?	DOE, June 1993a, page 6-76
Uranium-total	7.3	30 micrograms per liter		INTEC	?	DOE, June 1993a, page 6-76; EPA limit is in micrograms per liter to limit heavy metal toxicity
Neptunium-237	3.1	15	21%	INTEC, MW-18	?	DOE, Nov 1997, page 4-33
Plutonium-238	3	15	20%	INTEC	?	DOE, June 1993a, page 6-76
Plutonium-239/240	24	15	160%	RWMC, M1SA	October, 2000	INEEL OP, March 2001
Americium-241	1.97	15	13%	RWMC, M1SA	May, 1998	INEEL OP, 2001

? = Unknown

[98] The Safe Drinking Water standards of the US EPA use several different approaches to setting maximum contaminant limits for different radionuclides. The limits of 15 picocuries per liter for most alpha emitters is not set according to the current dose conversion factors. The 15 picocuries per liter limit for alpha emitters implies a considerably larger dose to the critical organ than the 4 millirem committed dose per year allowed under the Safe Drinking Water standards, which are based on radiological exposure given certain assumptions (e.g., a 70 kilogram (154 pound) male drinking 2 liters of water per day). The uranium limit is set for its toxicity of uranium as a heavy metal and not for uranium as a radioactive material. If radium contamination is present, then this must be subtracted from the other alpha-emitter pollution. The maximum allowable radium contaminant level is 5 picocuries per liter.

Table 7: Maximum radionuclide concentrations in the perched water bodies

Radionuclide	Highest Concentrations (picocuries per liter)	Drinking Water Standard[99] (picocuries per liter)	Highest concentration as % of Drinking Water Standard	Facility and well name	Date	Source and Comments
Tritium	73,000	20000	365%	INTEC, MW-18	June, 1995	DOE, Nov 1997, page 4-11
Strontium-90	320,000	8	4,000,000%	INTEC, MW-2	June, 1995	DOE, Nov 1997, page 4-13
Technetium-99	736	900	82%	INTEC, MW-18	June, 1995	DOE, Nov 1997, page 4-11
Iodine-129	ND?	1				
Cesium-137	1048	160	655%	INTEC, CPP 33-3	April, 1991	DOE, June 1993a, p. 6-52
Uranium- total	16.2	30 micrograms per liter		INTEC, CPP 33-2	April, 1991	DOE, June 1993a, p. 6-52
Neptunium-237	215	15	1433%	INTEC, CPP 33-3	April, 1991	DOE, June 1993a, p. 6-52
Plutonium-238	0.39	15	2.6%	RWMC, USGS 92	1994	INEEL OP, March 2001
Plutonium-239/240	?	15				
Plutonium-241	?	15				
Americium-241	25.3	15	169%	INTEC, CPP 33-2	April, 1991	DOE, June 1993a, p. 6-52

ND = Not detected ? = Unknown

[99] The Safe Drinking Water standards of the US EPA use several different approaches to setting maximum contaminant limits for different radionuclides. The limits of 15 picocuries per liter for most alpha emitters is not set according to the current dose conversion factors. The 15 picocuries per liter limit for alpha emitters implies a considerably larger dose to the critical organ than the 4 millirem allowed under the Safe Drinking Water standards, which are based on radiological exposure given certain assumptions (e.g., 70 kilogram (154 pound) male drinking 2 liters of water per day). The uranium limit is set for its toxicity of uranium as a heavy metal and not for uranium as a radioactive material. If radium contamination is present, then this must be subtracted from the other alpha-emitter pollution. The maximum allowable radium contaminant level is 5 picocuries per liter.

Table 8: Americium-241 and plutonium detections in the Snake River Plain aquifer

Date	USGS detections[ac]						Contractor detections[bd]						INEEL OP detections[ae]					
(year)	Americium-241 (picocuries per liter)		Plutonium-238 (picocuries per liter)		Plutonium-239/240 (picocuries per liter)		Americium-241 (picocuries per liter)		Plutonium-238 (picocuries per liter)		Plutonium-239/240 (picocuries per liter)		Americium-241 (picocuries per liter)		Plutonium-238 (picocuries per liter)		Plutonium-239/240 (picocuries per liter)	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
1972-1976	0.01	0.3; 5[f]; 1.5[g]	0.02	0.96; 9[g]	0.02	0.29												
1981		0.14																
1993-2000		0.14[h]		0.39[i]			0.008	1.97	0.012	0.3	0.006	4.3		0.039[i]	0.36	0.9	0.42	24

USGS = U.S. Geological Survey
INEEL OP = INEEL Oversight Program

[a] The reported concentrations exceed 3 times the sample uncertainty (>3s)
[b] The reported concentrations exceed 2 times the sample uncertainty (>2s)
[c] Samples from wells USGS 87, USGS 88, USGS 89, USGS 90, and USGS 92 (perched water)
[d] Samples from wells M1SA, M3S, M4D, M6S, M7S, M10S, M11S, M12S, M13S, M14 S, and M17S
[e] Samples from wells M3S and M1SA
[f] One sample in 1972 from well USGS 89
[g] One sample in 1972 from well USGS 90
[h] Perched water well UGGS 92 in 1992
[i] Perched water well UGGS 92 in 1994

suspension. Even single sub-micron size colloidal particles of plutonium-238 and micron size particles of plutonium-239 carry significant amounts of radioactivity, so that high variability between different aliquots (portions) of the same sample may be expected.[100] As a result, plutonium migration is quite unpredictable. The findings of plutonium in the water also support findings of plutonium in the vadose zone. (See Chapter III for further discussion of plutonium migration.)

2. Hazardous chemicals

Both the perched water bodies and the Snake River Plain aquifer on the INEEL site are already severely contaminated in some places with organic chemicals as well as with beryllium, cadmium, and chromium. Contamination levels that exceed drinking water standards have been measured at various places, including in drinking water wells on site. Table 9 and Table 10 show some of the highest concentrations of hazardous chemicals in the aquifer and perched water bodies as measured at various monitoring wells on the INEEL site. See Appendix C for the properties and health effects of the main inorganic and organic contaminants.

Several organic chemicals that are migrating through the vadose zone are called dense, non-aqueous phase liquids (DNAPLs), because they are more dense than water and relatively insoluble in it. As a result of these two properties, their distribution in the subsurface environment tends to be very complex. DNAPLs tend to migrate along vertical fractures, and then form more lateral structures of pollution when they encounter less permeable layers. Because they are more dense than water, they move through water-bearing layers. Between 5 to 50 percent of the total pore volume might become filled with these dense liquids. The pollutants trapped in the pore space slowly dissolve in the water and can remain a continuing source of groundwater contamination over a long period of time.[101] These complex mechanisms can create pollution of the subsurface environment that is very difficult to characterize.[102] A typical distribution pattern of these DNAPLs underground is shown in Figure 16.

Dissolution of even small amounts of DNAPLs in groundwater can result in serious pollution, since only trace amounts of many hazardous organic chemicals (a few parts per billion) can make water unusable for drinking. Drilling into areas of DNAPL in order to sample and determine the extent of the contamination can sometimes exacerbate the problem by mobilizing the contaminants and increasing their migration.[103] Clean-up of contaminated vadose zones is therefore a crucial component of remediation, along with clean-up of contamination in the aquifers.

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[100] We are grateful to Gary Richardson of the Snake River Alliance for pointing this out.
[101] DOE, December 1993, page 5-30
[102] NAS-NRC, 1999b, pages 131-133
[103] NAS-NRC, 1999b, page 133

Table 9: Maximum concentrations of hazardous chemicals in the Snake River Plain aquifer

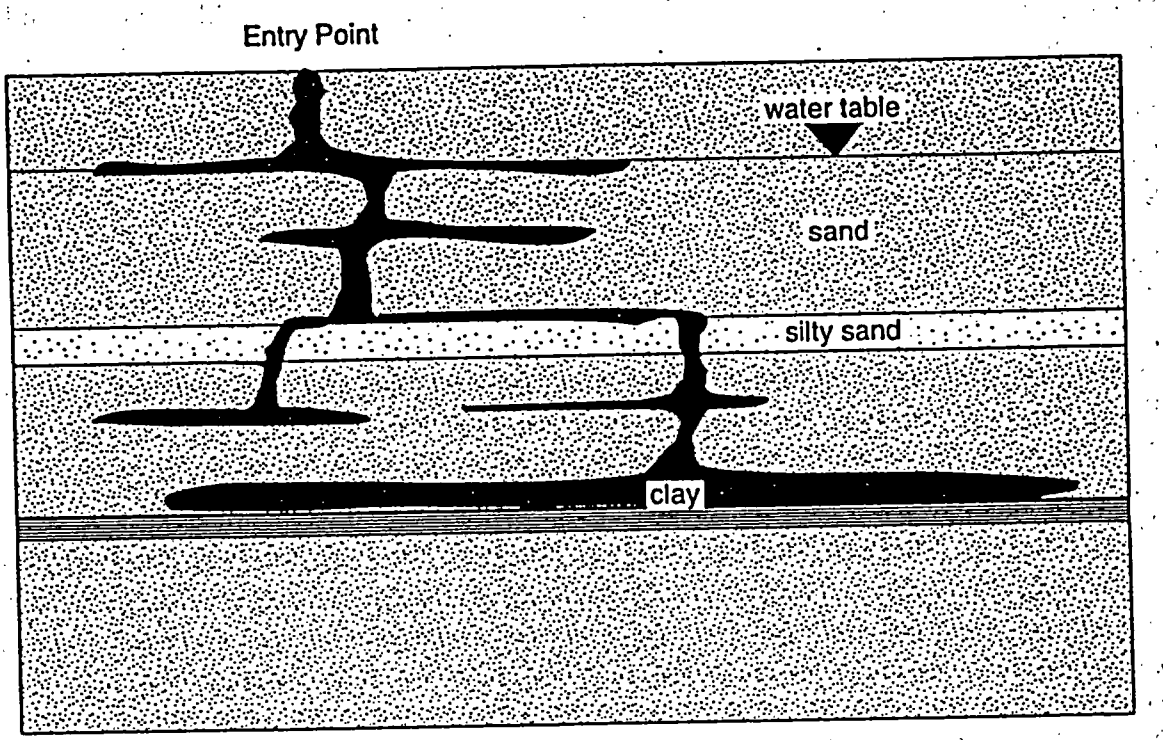
Hazardous chemical	Highest Concentrations (micrograms/liter)	Drinking Water Standard (micrograms/liter)	Highest concentration as % of std	Facility and well name	Date	Comments
Carbon tetrachloride	51,000	5	1,020,000%	TAN		DOE, June 1993a, page 9-83
Trichloroethylene (TCE)	32,000	5	640,000%	TAN, Near inj well	1995?	DOE, Nov 2000, page 7
Tetrachloroethylene	120	5	2,400%	TAN	?	DOE, June 1993a, page 9-84
Cis-1,2-dichloroethylene	5800	70	8,286%	TAN	?	DOE, June 1993a, page 9-84
Trans-1,2-dichloroethene	3,900	100	3,900%	TAN, Near inj well	1995?	DOE, Nov 2000, page 7
Beryllium	8.9	4	223%	CFA, CFA-1	June 1993	DOE, July 2000, page G-37
Cadmium	120	5	2,400%	CFA, LF2-11	August, 1993	DOE, July 2000, page G-37
Chromium	90	100	90%	RWMC	1989?	DOE, June 1993a, page 8-71
Vinyl chloride	25	2	1,250%	TAN		DOE, June 1993a, page 9-85
Ethylbenzene	1	0.7	143%	TAN	?	DOE, June 1993a, page 9-84

Table 10: Maximum concentrations of hazardous chemicals in perched water bodies

Hazardous chemical	Highest Concentrations (micrograms/liter)	Drinking Water Standard (micrograms/liter)	Highest concentration as % of std	Facility	Date	Comments
Carbon tetrachloride	1400	5	28,000%	RWMC	?	DOE, June 1993a, page 8-85
Trichloroethylene (TCE)	1100	5	22,000%	RWMC	?	DOE, June 1993a, page 8-86
Tetrachloroethylene	120	5	2,400%	RWMC	?	DOE, June 1993a, page 8-86
Beryllium	44	4	1,100%	RWMC	July 1990	DOE, June 1993a, page 8-80
Cadmium	4	5	80%	RWMC	July 1990	DOE, June 1993a, page 8-80
Chromium	857	100	857%	RWMC	July 1990	DOE, June 1993a, page 8-80

? = Unknown

Figure 16: Typical distribution of a DNAPL in the subsurface



Source: NAS-NRC, 1999b, page 132

A DNAPL contaminant plume containing the volatile organic compounds trichloroethylene (TCE), tetrachloroethene (PCE), and dichloroethene (DCE) has been identified in the Snake River Plain aquifer. The plume is primarily due to direct injection into the aquifer at Test Area North.[104] TCE is used to define the extent of the current contaminant plume, because it has the largest distribution of concentrations greater than its maximum contaminant level (5 microgram per liter). The TCE plume extends about 2.7 kilometers (1.7 miles), with a maximum width of about 0.9 kilometers (0.6 miles).[105] Up to 35,000 gallons of TCE were disposed into the TAN injection well.[106] Figure 15 shows the area concentrations of the TCE contaminant plume at Test Area North. Other DNAPLs in the water or soil at INEEL include carbon tetrachloride, trichloroethane, and vinyl chloride.

Many DNAPLs like TCE are also volatile – that is, they evaporate at relatively low temperatures. This physical property is used in pump-and-treat programs to remediate groundwater that is polluted with volatile organic compounds (VOCs). In August 1995, the DOE decided to use pump-and-treat technology to remediate both the area with the highest volatile organic compound contamination ("hot spot") under Test Area North and the zone with TCE concentrations from 25 to 1,000 micrograms per liter. Contamination levels at the "hot spot" near the injection well for TCE alone exceeded 20,000 micrograms per liter (compared to the drinking water standard of 5 micrograms per liter). DOE also decided to rely on natural attenuation for areas with TCE concentrations between 5 and 25 micrograms per liter.[107]

The pump-and-treat plant, which began operation in November 1996, does not treat the groundwater for radionuclides. Moreover, pump-and-treat has not been shown to be very effective as a clean-up technology under many circumstances. According to the National Research Council, "Studies indicate...that pump-and-treat systems may be unable in most cases to remove enough contamination to restore groundwater to drinking water standards, that removal may require a very long time - in some cases centuries."[108] A National Research Council survey of 77 contaminated sites found that "pump-and-treat systems had achieved cleanup goals at just 8 of the sites."[109]

In November 2000, DOE proposed to change the 1995 decision and use in-situ bioremediation to clean up the most contaminated area near the injection well. Bioremediation is the use of bacteria to breakdown organic contaminants.[110] Like pump-and-treat, bioremediation will not treat radionuclides in the groundwater, but it can potentially remove the DNAPLs in the vadose zone. A separate pump-and-treat facility

[104] DOE, November 2000, page 7
[105] DOE, November 2000, page 7
[106] DOE, November 2000, page 2-3
[107] DOE, November 2000, page 12; Natural attenuation is the naturally occurring reduction of contaminant concentrations in the aquifer through radioactive decay, dilution, and dispersion, and biological decay in the case of organics.
[108] NAS-NRC, 2000a, page 31
[109] NAS-NRC, 1999b, page 3
[110] For a description of bio-remediation and other clean-up technologies, see NAS-NRC, 1999b, pages 173-182

is currently being built to remediate the portion of the plume in which concentrations of TCE are between 1,000 and 20,000 micrograms per liter.

DOE has proposed "monitored natural attenuation" as the remediation method for the portion of the plume in which concentrations of TCE are between 5 and 1,000 micrograms per liter.[111] Allowing natural attenuation to mitigate concentrations up to 1,000 micrograms per liter is a considerable relaxation of the August 1995 plan to treat contaminated water to 25 micrograms per liter, which is still 5 times the drinking water standard. The goal of the TCE cleanup plan at TAN is to reduce contamination levels to less than the MCL within 100 years.[112] This may be an optimistic assumption about the speed of natural attenuation. If so, it means that contamination that exceeds the drinking water standard would persist for over a century. This is a rather long planning horizon, especially when more vigorous and innovative technology and clean-up might achieve the goal in a shorter time.[113] The Record of Decision Amendment is scheduled to be completed on or before October 2001.[114]

In the Subsurface Disposal Area at the Radioactive Waste Management Complex, INEEL has been using vapor vacuum extraction to remove organic chemical contaminants from the vadose zone. According to information provided by INEEL, 85,455 pounds of volatile organic compounds have been removed since January 1996, including 55,400 pounds of carbon tetrachloride.[115]

C. Contaminant levels in INEEL drinking water

Several sets of wells drawn from the Snake River Plain aquifer provide drinking water to workers on the INEEL site. Table 11 shows data on three water supply systems at INEEL: the Central Facilities Area, the Technical Support Facility, and the Radioactive Waste Management Complex. Much of the drinking water on the site is significantly contaminated with both radioactive and hazardous chemicals, notably TCE and carbon tetrachloride. Compliance with drinking water standards can be expressed by calculating the ratio of actual contamination to allowable contamination for each pollutant. Table 11 shows the percentages for individual pollutants and also the total percentage of maximum allowable concentrations for each system. While each single pollutant as well as the sum of the radionuclide pollution percentages are currently less than allowable drinking water limits, the cumulative burden is greater than the allowable drinking water limits in the RWMC well, if TCE and carbon tetrachloride are added.

This is a standard procedure for radionuclides. However, it is not mandated for hazardous chemicals, even though it provides a reasonable estimate of the quality of the water. It is not the most conservative way to estimate the impact of the pollutants in the water, since simple addition ignores synergistic effects between various hazardous

[111] DOE, November 2000, pages 12 and 18
[112] ESRF, 1998, pages 3-4 and 3-5
[113] For an analysis regarding the DOE's failure to use innovative approaches to clean-up or even to consider them, see NAS-NRC, 1999b, Chapter 5. See especially the analysis in relation to Table 5-2, page 205
[114] DOE, November 2000, page 2
[115] Erik Simpson (DOE), personal email communication to Snake River Alliance, April 24, 2001

chemicals and between hazardous chemicals and radionuclides. Table 11 does not indicate the regulatory compliance, but rather the suitability of the water for drinking as a public health measure. It should also be noted that some radionuclides, such as iodine-129, are not being monitored, so that this set of data does not yield a definitive picture of compliance.

In all cases, the well water goes through a distribution system before it is consumed. In the case of the RWMC well, a purging system, known as a sparger, is used to reduce the level of carbon tetrachloride before the water enters the distribution system. Carbon tetrachloride contamination levels have been rising and the use of the sparger is essential to meet drinking water limits.[116] See Figure 17 for the carbon tetrachloride concentrations in RWMC drinking water from October 1989 to October 1998.

Historically, the Technical Support Facility (TSF) system at Test Area North got its water from TSF well #1, which was found to be contaminated with TCE. TCE levels in this well have exceeded or been very near the allowable drinking water limit. The first official reports that we are aware of showing TCE contamination in the TSF system date from 1987. The area was supplied with bottled water between 1987 and 1988. From 1988 to 1997, the water was purged before entering the distribution system and the content of TCE in the drinking water was reportedly less than the drinking water standard.[117]

We are not in a position to analyze whether personnel at this facility drank contaminated water that exceeded drinking water standards prior to 1987, but this would seem to be the logical conclusion of a simple extrapolation of the TCE data backwards in time. It is highly unlikely that TCE contamination would suddenly appear in 1987, but we do not have the data to determine how many years prior to 1987 the water may have been contaminated. In 1980, the USGS had an organic solute sampling program in place, but Test Area North was not identified as a probable source for contamination of this nature, because none of the samples exceeded the screening limit for dissolved organic compounds (20 milligrams per liter).[118] However, the amount of dissolved organic compounds does not necessarily provide a good indication of volatile organic contamination, since many chlorinated organic compounds, such as TCE, have low solubilities in water.[119]

The TCE contamination in the drinking water from TSF well #2 , while less than the drinking water standard, is still significant. It is unclear why the TSF distribution system contamination is substantially lower than the TSF well #2 concentration of TCE, since the latter is the only source of supply and the sparger is not in use. The small number of measures and the variability in TCE concentrations from one sample to the next may provide a possible explanation. About 100 people use this water daily.[120] Figure 18

[116] LMITCO, September 1999, pages 4-5 to 4-7
[117] LMITCO, September 1999, page 4-7
[118] DOE, December 1993, page 4-1 and 4-3
[119] NAS-NRC, 1999b, pages 129-130
[120] LMITCO, September 1999, page 4-7

shows the TCE levels in the two supply wells and in the TSF drinking water distribution system from October 1989 to October 1998.

At the Central Facilities Area (CFA), tritium levels in the CFA wells are significant, though less than the current drinking water standard. Over 1,000 people use the CFA system daily.[124]

Overall, the drinking water systems on the INEEL site have been significantly compromised as measured by the total percentage of contaminants relative to the individual maximum contamination levels. While no distribution system exceeds 100 percent of the cumulative contaminant limits, the RWMC system is close and carbon tetrachloride levels in the RWMC drinking water have been gradually increasing.[125]

Moreover, not all contaminants are being monitored. According to the DOE:

> "Analysis of groundwater data from CFA wells indicated that five of the 26 COCs [contaminants of concern] identified for CFA have never been sampled for in the groundwater and less than half of the remaining 21 have had adequate monitoring in order to determine a source(s) location. Several COCs were sampled once or several times in the past with all samples indicating a positive detection and have not been sampled since."[126]

Table 12 summarizes the groundwater contaminants of concern at the Central Facilities Area (CFA), the monitoring practice and results, and the possible sources at CFA and at INTEC and Test Reactor Area (TRA), which are both upgradient. The table shows that many of the contaminants of concern are not regularly monitored.

The failure to monitor crucial hazardous materials and to sufficiently and accurately monitor iodine-129 in the aquifer is especially troubling, particularly because extensive contamination of the perched water bodies as well as the Snake River Plain aquifer is already recognized. These problems take on even greater significance when the long half-life of iodine-129 and the fact that the concentration of this radionuclide already exceeds the safe drinking water standard in parts of the Snake River Plain aquifer under the site are taken into account. Unlike many characterization problems of the vadose zone or of buried transuranic wastes, which are very complex, difficult, and sometimes even risky, monitoring of the groundwater for known contaminants is a straightforward matter, especially when there is already an extensive infrastructure for sampling and analyzing water samples. It is certainly not indicative of a high priority given by INEEL management to environmental management or to transparency that such extensive failures of monitoring have become routine.

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[124] LMITCO, September 1999, page 4-5
[125] LMITCO, September 1999
[126] DOE, July 2000, page 4-74

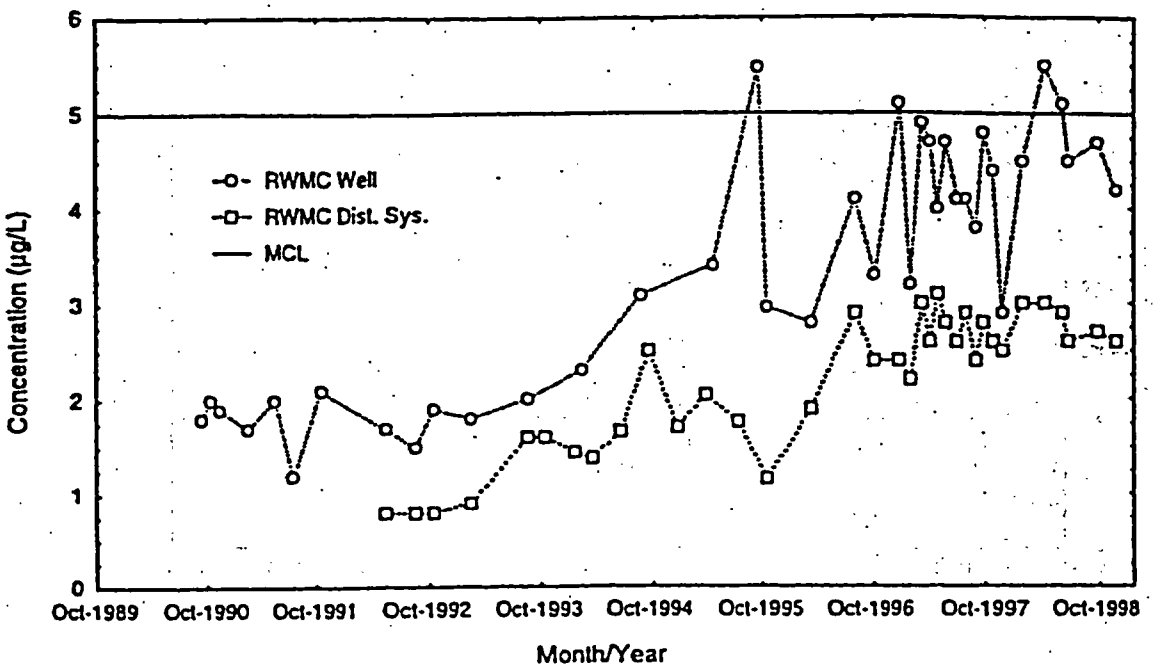
Table 11: Drinking water at INEEL, 1998

Percent of maximum contaminant levels (MCL) for drinking water standard for some contaminants at INEEL Reported mean values										
	CFA Well #1	**CFA Well #2**	**CFA Distribution**	**TSF Well #1**	**TSF Well #2**	**TSF Distribution**	**RWMC Well**	**RWMC Distribution**	**Drinking Water Standard**	**Units**
Tritium	65%	54%	59%	Low	Low	Low	7%	7%	20,000	picocuries per liter
Strontium-90	?	?	?	?	?	?	?	?	8	picocuries per liter
Technetium-99	?	?	?	?	?	?	?	?	900	picocuries per liter
Iodine-129	?	?	?	?	?	?	?	?	1	picocuries per liter
Carbon tetrachloride	?	?	2%	?	?	?	95%	56%	5	micrograms per liter
TCE	?	?	6%	92%	52%	28%	44%	29%	5	micrograms per liter
Total burden, %	**65%**	**54%**	**67%**	**92%**	**52%**	**28%**	**146%**	**92%**		

CFA = Central Facilities Area
TSF = Technical Support Facility
RWMC = Radioactive Waste Management Complex
? = not reported in the sources cited
Total burden = sum of percent MCLs
Alpha emitter measurements not reported

Sources: ESRF, July 2000 and LMITCO, September 1999

Figure 17: Carbon tetrachloride concentration in the Radioactive Waste Management Complex (RWMC) drinking water, October 1989 to October 1998

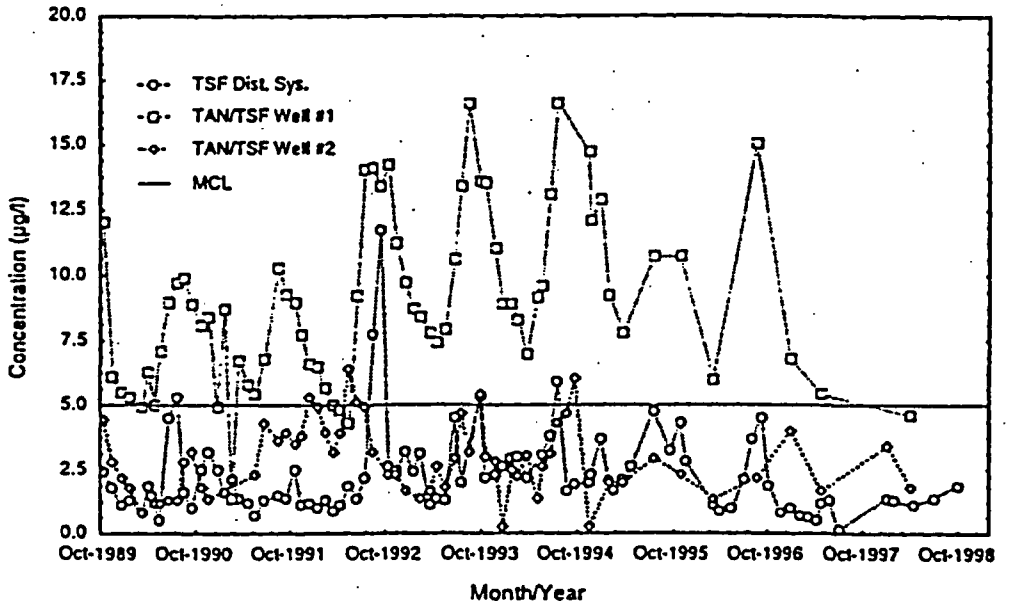


Carbon tetrachloride concentrations at Radioactive Waste Management Complex drinking water well and distribution system (1998).

Well/Dist.	Number of Samples	Carbon Tetrachloride Concentration (µg/L)			
		Minimum	Maximum	Mean	MCL
RWMC WMF-603 Well	6	4.20	5.50	4.75	5.0
RWMC WMF-604 Dist.	6	2.60	3.00	2.80	5.0

Source: LMITCO, September 1999, page 4-7

Figure 18: Trichloroethylene (TCE) concentrations in the Test Area North drinking water, October 1989 to October 1998



Trichloroethylene concentrations at Test Area North/Technical Support Facility wells and distribution system (1998).

Well/Dist.	Number of Samples	Trichloroethylene (µg/L) Minimum	Maximum	Mean	MCL
TSF #1 (612)	1	4.60	4.60	4.60	5.0
TSF #2 (613)	2	1.80	3.40	2.60	5.0
TSF Dist. (610)	5	1.10	1.90	1.42	5.0

Source: LMITCO, September 1999, page 4-8

Table 12: Summary of groundwater monitoring at the Central Facilities Area

Contaminants of Concern	Monitoring Practice	Result of Monitoring	Possible Sources CFA	Possible Sources INTEC/TRA	Comments
1-2, Dichloroethane	Inconsistent	Limited samples suggest the COC is not present at either facility	Unknown	Unknown	
Americium-241	No samples from CFA wells. Inconsistent monitoring in wells between INTEC and CFA.	Predominately non-detects, however, some positive detects in wells between INTEC and CFA.	Unknown	Yes	Model predictions indicate Am-241 originating at INTEC should not significantly effect groundwater concentrations at CFA.
Arsenic	Good	CFA wells indicate increasing concentrations since 1996. Widely distributed throughout the regional area.	Unknown – the latest concentrations are higher at CFA than in upgradient wells. However, this could be due to INTEC plume movement downgradient to CFA area.	Yes	Model predictions indicate arsenic from INTEC will significantly affect concentrations at CFA.
Beryllium	Inconsistent	Not consistently detected above background levels	Unknown	Unknown	
Cadmium	Good at CFA wells. Inconsistent in upgradient wells.	Widely distributed in both soil and groundwater throughout regional area.	Probable – Concentrations at CFA are higher than in upgradient wells	Unknown	It is unlikely that a cadmium source exists at CFA due to widespread distribution I the soil and groundwater regionally.
Chloromethane	Good at CFA wells. Moderate to poor in upgradient wells.	Does not appear to be present in the area near CFA.	No	Probably not, unless it is a recent release.	
Chromium	Good	Widely distributed in wells near INTEC and CFA.	Unknown – high concentrations from upgradient sources	Yes	

Source: DOE, July 2000, pages 4-76 to 4-79

Table 12: Continued

Contaminants of Concern	Monitoring Practice	Result of Monitoring	Possible Sources CFA	Possible Sources INTEC/TRA	Comments
			overshadow any contributions from a local source.		
Cesium-137	Inconsistent at CFA. Recent monitoring in upgradient wells is good.	Not present in any of the monitored wells near CFA or INTEC.	Unknown – limited data suggests it is not present.	No	Only one well sampled near CFA since 1995.
Iodine-129	Poor	Concentrations from 1986 to 1995 indicate high concentrations originating near INTEC and through time this plume has moved downgradient to CFA.	Unknown – upgradient concentrations are overshadowing any local contributions to the aquifer.	Yes	
Mercury	Good at CFA. Inconsistent in upgradient wells.	Inconsistent detections at levels slightly higher than background in most CFA and INTEC wells.	Possible – overall, concentrations in CFA wells are higher than in upgradient wells.	Unknown, the few positive concentrations are slightly above background levels.	No consistent positive concentrations from wells near CFA and INTEC.
Phenol	Not monitored in wells near CFA. One round of samples from upgradient wells.	One round (6 wells) of samples from upgradient wells did not have a positive detect.	Unknown	Unknown	
Plutonium-238	Poor at CFA wells. Inconsistent at upgradient wells.	Sparse data suggests it is not a significant problem in the aquifer at CFA or upgradient near INTEC.	Unknown	Unknown	
Plutonium-239	No wells are sampled at CFA nor at INTEC.		Unknown	Unknown	

Table 12: Continued

Contaminants of Concern	Monitoring Practice	Result of Monitoring	Possible Sources CFA	Possible Sources INTEC/TRA	Comments
Plutonium-239/240	No wells at CFA are monitored. Inconsistent monitoring in upgradient wells.	Sparse sampling data from upgradient wells suggests it not present.	Unknown	Unknown	Model predictions suggest INTEC sources will significantly affect CFA in the future.
Strontium-90	Inconsistent at CFA wells. Good in upgradient wells.	Few positive detections at CFA. Upgradient wells have higher concentrations.	Unknown – Due to inconsistent monitoring and/or overshadowing of upgradient concentrations.	Yes	Models suggest that concentrations at CFA will not be significantly affected from upgradient sources until approximately 2025.
Tritium	Good	Higher concentrations in upgradient wells.	Unknown – high concentrations from upgradient sources would most likely overshadow all local sources.	Yes	
Trichloroethene	Good in CFA wells. Inconsistent in upgradient wells.	Overall, higher concentrations from CFA wells.	Yes	Probable – Several positive detections at the detection level.	
Uranium-234 and 238	Poor	Five wells (1 samples each) had positive detection	Unknown	Probable – all samples have positive detections	
Uranium-235	Poor	Five wells (1 sample each, all nondetects)	Unknown	Unknown – limited samples did not detect U-235.	
Zinc	Good	Widely distributed in the CFA-INTEC area	Yes	Yes	Detections of zinc are due to galvanized components on the monitoring wells.
Aroclor-1254	No Data				

Table 12: Continued

Contaminants of Concern	Monitoring Practice	Result of Monitoring	Possible Sources CFA	Possible Sources INTEC/TRA	Comments
Aroclor-1260	No Data				
Benzaldehyde	No Data				
TPH-gasoline	No Data				
TPH-diesel	No Data				

Chapter III: Future threats: Radioactive, mixed, and hazardous buried waste at INEEL

A. Sources of contaminants

Like other major nuclear weapons plants, INEEL produced large quantities of radioactive and non-radioactive wastes, including spent nuclear fuel, high-level waste, transuranic waste, low-level waste, mixed waste, and hazardous wastes. INEEL has some particular features that caused the volumes and radioactivity amounts in waste to increase beyond its nuclear weapons production-related functions. The main special factors relevant to radioactive waste and to possible threats to water resources are:

- Naval and other spent fuel was sent to INEEL for reprocessing. The wastes from that reprocessing, high-level and other, are stored or have been disposed of at INEEL. The reprocessing plant is now shut down but spent fuel continues to be sent to INEEL for storage and examination, which results in Class 2 low-level waste disposal at the Radioactive Waste Management Complex.
- Large amounts of plutonium-contaminated waste were sent to INEEL from Rocky Flats, particularly after the fires in 1957 and 1969 at the latter site.
- INEEL has been the leading governmental center for reactor development in the United States, and has had a role in developing naval as well as commercial reactors and in the testing of these reactors and their operational and safety characteristics. Wastes from reactor operations and decommissioning are stored or have been discarded at INEEL.

Much of the waste was buried in pits and trenches at the Radioactive Waste Management Complex (RWMC). Besides a variety of long-lived radionuclides, these wastes contain very large amounts of non-radioactive hazardous chemical pollutants that would pose a major threat to the environment even in the absence of radioactive contamination.

This chapter examines buried wastes and, to a lesser extent, some stored wastes that pose potential threats to the aquifer. It will also evaluate ways in which these contaminants have been mobilized to the aquifer and the potential for such mobilization in the future.

1. Buried Waste at the Radioactive Waste Management Complex (RWMC)

Mixed hazardous and radioactive wastes, transuranic wastes, and low-level radioactive wastes were dumped for about two decades in unlined pits and trenches in the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex (RWMC). During this period, the wastes were disposed of in wooden and cardboard boxes and 55-gallon drums.[124] Many, possibly most, of these containers have lost their integrity partly or fully

[124] EG&G, August 1991, page 3

and the rest may be expected to do so long before the pollutants in them cease to be a threat to the Snake River Plain aquifer.[125]

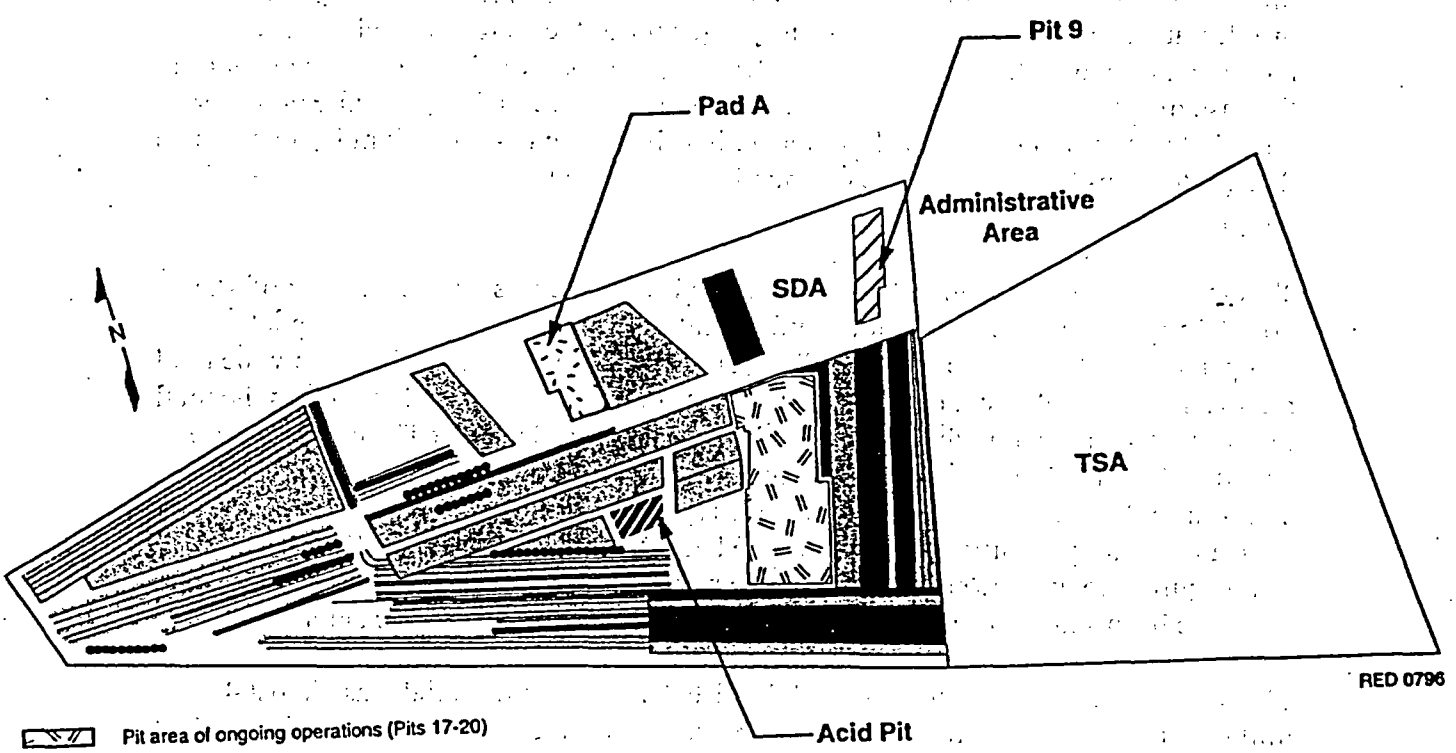
The DOE is continuing to dump low-level radioactive waste, which can contain long-lived radionuclides, at the Subsurface Disposal Area. Through 1996, 150,200 cubic meters of low-level waste were disposed of at INEEL.[126] Approximately 19,828 cubic meters of low-level radioactive waste are being buried annually in unlined pits and trenches at the SDA.[127] Figure 19 shows an overview of the layout of the RWMC.

INEEL has expended considerable effort to assess the amounts of radioactive and non-radioactive materials that were put into shallow land burial at the RWMC. The results of this assessment were published in 1995 in a report entitled *A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952-1983.*[128] Unfortunately, the assessment omitted some critical information: buried transuranic waste data – that is, wastes heavily contaminated with transuranic radionuclides like plutonium-239 and americium-241 – were not well documented in the *Comprehensive Inventory.* As a result of a critique by IEER,[129] the buried TRU data were re-assessed by the DOE and published in June 2000.[130]

The *Comprehensive Inventory* is organized according to the area or the set of facilities in which the wastes were generated. These data include wastes sent from offsite to INEEL for disposal. However, despite the title of the report, there are many important gaps in the data that create significant uncertainties in the nature and magnitude of future risks to the Snake River Plain aquifer.

[125] Fioravanti and Makhijani, 1997, page 61
[126] ORNL, December 1997, page 4-12
[127] DOE, June 2000b
[128] Lockheed, August 1995
[129] See *Containing the Cold War Mess* (Fioravanti and Makhijani, 1997).
[130] DOE, June 2000a

Figure 19: Overview layout of the Radioactive Waste Management Complex (RWMC)



Source: Lockheed, August 1995, page 1-5

a. Radionuclides

Table 13 shows the main long-lived radionuclides, defined here as radionuclides with half-lives of more than ten years, that were buried in the Subsurface Disposal Area (SDA) of the RWMC. The radioactivity content of the wastes was estimated as of the time of disposal and are not corrected for decay. The decay products may be as problematic (long-lived and toxic) as the progenitor of the daughter product. Some radionuclides would have decayed considerably (perhaps by a factor of three or four in the case of tritium, which has a half-life of just over 12 years) from the time they were buried. Other radionuclides with far longer half-lives, such as plutonium isotopes (other than plutonium-241), would have essentially the same radioactivity as at the time of burial.

Tritium, despite its large inventory in the buried wastes, poses a lower risk for offsite pollution of the Snake River Plain aquifer because tritium decays relatively quickly compared to its travel time to the INEEL boundary. Therefore, the tables show the total radioactivity for radionuclides with half-lives of more than ten years, as well as the total radioactivity for what might conventionally be put in the "long-lived" category (>100 years) and the total radioactivity for strontium-90 and cesium-137. In particular, strontium-90 and cesium-137 have half-lives (roughly 30 years) that are long enough to have a potentially significant impact offsite because groundwater in the Snake River Plain aquifer flows an average of about one kilometer per year.[131] A separate total has therefore been shown for these two radionuclides in the tables in this chapter.

The total radioactivity of the radionuclides listed at the time of burial was almost 4 million curies. The total radioactivity of the very long-lived radionuclides, with half-lives greater than 100 years, is about 1 million curies. Of these very long-lived radionuclides, the amount of americium-241 will increase somewhat for several decades after disposal, due to the decay of beta-emitting plutonium-241, which has a half-life of 14.4 years, into americium-241. See Figure 20 for a schematic representation of the decay of another radionuclide buried at RWMC, plutonium-238.

The *Comprehensive Inventory* does not distinguish between wastes disposed of before 1970 and those after that period, because in 1970 DOE created a new category of transuranic waste that was not to be disposed of by burial. While implementation of this rule within the DOE was not uniform, the main problem of buried transuranic waste arises from those wastes that were dumped before 1970. In any case, most of the long-lived radionuclides as well as the non-volatile non-radioactive contaminants can be expected to far outlast the containers in which the wastes were buried. Since protecting the aquifer will require recovery of these wastes (see Chapter IV), this uncertainty will cause a problem for waste characterization and recovery.

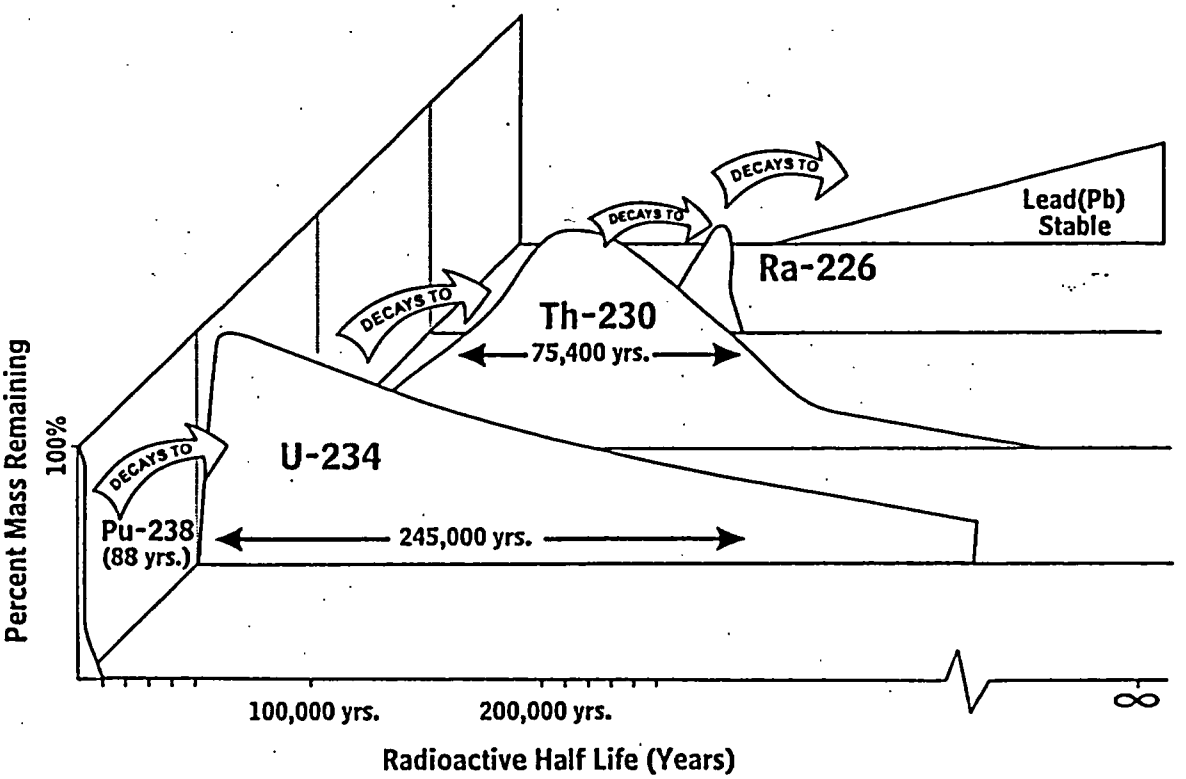
[131] DOE, November 2000, page 7

Table 13: Main buried radionuclides with half-lives greater than 10 years, 1952-1983

Radionuclide	Half-life (years)	Main decay mode	Total Radioactivity (curies)	Test Reactor Area (curies)	INTEC (Chem Plant) (curies)	Naval Reactors Facility (curies)	Argonne West (curies)	RWMC SDA (curies)
Tritium	12.3	beta	1,200,000	1,200,000				0.36
Carbon-14	5,730	beta	16,000	16,000	43			
Nickel-59	76,000	EC	5,100	1,400	160			
Nickel-63	100	beta	750,000	500,000	25,000	220,000		
Strontium-90	29.1	beta	450,000	65,000	20,000	140,000	220,000	
Technetium-99	213,000	beta	260	260	0.03			
Iodine-129	17,000,000	beta	0.099	0.099				
Cesium-137	30.2	beta	700,000	350,000	42,000	140,000	140,000	210
Plutonium-238	87	alpha	2,500	620	1.0		0.022	1,900
Plutonium-239	24,110	alpha	66,000	86	0.48		11	65,000
Plutonium-240	6,537	alpha	15,000	24	0.01		0.008	14,000
Plutonium-241	14.4	beta	400,000	12,000	1.5			390,000
Americium-241	432	alpha	150,000	680			1.8×10^{-07}	150,000
Neptunium-237	2,140,000	alpha	2.4	2.4				
Total			**3,800,000**	**2,100,000**	**87,000**	**500,000**	**360,000**	**620,000**
Percent of total radioactivity				**55 %**	**2.3 %**	**13 %**	**9.5 %**	**16 %**
Radionuclides with >100 year half life			**1,000,000**	**520,000**	**25,000**	**220,000**	**11**	**229,000**
Percent of radionuclides >100 year half life			**26 %**	**25 %**	**29 %**	**44 %**	**0 %**	**37 %**
Strontium-90 and cesium-137			**1,100,000**	**420,000**	**62,000**	**280,000**	**360,000**	**210**
Percent strontium-90 and cesium-137			**29 %**	**20 %**	**71 %**	**56 %**	**100 %**	**0 %**

Totals are rounded to two significant figures.
EC = electron capture.
Source: Lockheed, August 1995. This source document contains data for all radionuclides as well as hazardous materials. The data for transuranic radionuclide content of waste listed above are consistent with a later DOE publication on TRU waste alone (DOE, June 2000).

Figure 20: Radioactive decay



Radiological constituents, or radionuclides, decay over time. As a radionuclide decays, it changes into a different radionuclide, or "decay product," by the spontaneous emission of an alpha particle, beta particle, or gamma rays, or by electron capture. Radionuclides decay at a fixed rate, unaffected by factors such as temperature or pressure. The fixed rate of decay is described by the "half life," which is the time required for half of the atoms of a given radionuclide to decay into a decay product. The decay product may have a shorter or longer half life than the radioactive isotope itself.

This Exhibit illustrates the radioactive decay chain of Plutonium-238. Plutonium-238, which has a radioactive half life of 88 years, decays to Uranium-234, which has a half life of 245,000 years. Uranium-234 decays to Thorium-230, which has a half life of 75,400 years. Thorium-230 decays to Radium-226, which has a half life of 1,600 years, and then to Radon-222 and shorter half life radionuclides (not shown in Exhibit) to Lead-206, a stable element. The Plutonium-238 decay chain illustrates that, although the Plutonium-238 itself would persist in the environment for approximately 880 years (10 half lives), the radioactive decay products would persist in the environment for hundreds of thousands of years before decaying into a stable, nonradioactive element (which itself is a hazardous substance).

Source: DOE, October 1999c, page 12

More serious biases may exist in the amounts of radioactivity estimated to be in the buried waste. One of the most important deficiencies that underestimates the amount of buried wastes is that waste shipments contained entries that identified only a single radionuclide, such as cobalt-60 or plutonium-239, as present in the container, "whereas knowledge of the waste generating process indicates that other radionuclides must also be present."[132] In cases where only a relatively short-lived radionuclide was listed, such as cobalt-60 (half-life of five years), the long-lived inventory would not show up at all in the data we have compiled here.

The data on neptunium in the waste are also suspect. Only 2.4 curies of this radionuclide are shown to be in the waste, though more might be expected given the high concentrations that are in the groundwater on site. Also, wastes from Rocky Flats and INEEL reprocessing would be expected to have some neptunium-237 in them, though none is indicated.[133] An underestimate of this radionuclide would be particularly serious, since neptunium-237 is a very long-lived alpha-emitter (with a half-life of more than two million years) and, under many circumstances, is more soluble than plutonium.[134] Neptunium-237 in buried waste is only reported from the Test Reactor Area.[135]

Moreover, it is not well established whether any of the containers buried at the Subsurface Disposal Area have enough plutonium to go critical (a spontaneous uncontrolled nuclear reaction) if they fill up with water. For example, there is currently a controversy between the EPA and the DOE as to whether a fire in a waste barrel in 1970 was the result of an accidental nuclear criticality.[136] Also, plutonium that has leaked from the buried wastes could accumulate in a small volume of soil, which could lead to an accidental criticality in times of heavy rainfall or flooding. With concentrated plutonium, water can act as a moderator during a flood to allow a nuclear reaction (criticality) to occur. There were floods at the Subsurface Disposal Area of the RWMC in 1962, 1969, and 1982. Water also increases the potential that a container will lose its integrity and thus increases the risks to workers.

b. Hazardous materials

A variety of hazardous wastes have also been buried at INEEL along with the radionuclides. These include highly toxic organic compounds, such as carbon tetrachloride and trichloroethylene (TCE), and toxic metals, such as lead and chromium. Table 15 shows some of these hazardous materials in the Subsurface Disposal Area, according to where the waste was generated. It is clear from this table that most of the toxic organic chemicals were sent to INEEL from the Rocky Flats Plant in Colorado as part of that site's transuranic waste shipments. Rocky Flats used large amounts of these solvents in the processing and production of the plutonium pits for nuclear weapons. The large amount of lead in the waste is due to its use as a shielding material in reactor and

[132] Lockheed, August 1995, page 2-10

[133] Neptunium-237 is created in nuclear reactors. Neptunium-237 is also the raw material from which plutonium-238 is made in reactors.

[134] LANL, August 1996, pages 1-2

[135] Lockheed, August 1995, Table 3-6b, 3-2b

[136] Nokkentved, April 2001. The report on that fire is still classified.

other operations involving gamma radiation, as for instance in processes involving americium-241.

The principal difficulty with evaluating the potential effect of dumped hazardous materials is that the records are so inadequate that the total waste inventory is essentially unknown. Besides the major uncertainties with respect to those chemicals for which some data are available, there are chemicals for which essentially no data exists. An attempt has been made to assess the upper limit for these in the *Comprehensive Inventory*,[137] but the quality of such estimates is even more questionable than the ones based on process knowledge and other data. These include the materials shown in Table 14 below. Several of them, such as beryllium, cyanides, mercury, and polychlorinated biphenyls (PCBs), are highly toxic. These materials originated in various reprocessing, reactor, and other operations at INEEL, as well as the support facilities (such as transformers) needed for them.

Table 14: Some unquantified materials

1,4-bis(5-phenyloxazol-2-yl)benzene	Unknown
Methyl-cholanthrene	Unknown
Beryllium oxide	Unknown
Benzene	Unknown
Cyanide	Unknown
Dibutylethylcarbitol	Unknown
di-isoproplylfluorophosphate	Unknown
Ether	Unknown
Lithium hydride and oxide	Unknown
Mercury	Unknown
Nitrobenzene	Unknown
Nitrocellulose	Unknown
Organic acids	Unknown
Organophosphates	Unknown
Polychlorinated biphenyls (PCBs)	Unknown
Versenes	Unknown

Source: Lockheed, August 1995

[137] Lockheed, August 1995, page xxiii

Table 15: Main buried non-radioactive materials, 1952-1983

Chemical	Total Amount (grams)	Test Area North (grams)	Test Reactor Area (grams)	Chem Plant (INTEC) (grams)	Naval Reactors Facility (grams)	Argonne West (grams)	Central Facilities Area (grams)	Rocky Flats Waste (grams)	Other Offsite Generators (grams)	Power Excursion Reactor (grams)
Organic chemicals										
1,1,1-trichloroethane	110,000,000			1,700,000				110,000,000		220,000
Carbon tetrachloride	120,000,000			26,000		16		120,000,000	Unknown	
Tetrachloroethylene	27,000,000							27,000,000		
Trichloroethylene	100,000,000							100,000,000		410,000
Inorganic chemicals										
Asbestos	1,200,000		1,100,000	110,000	Unknown	Unknown			Unknown	11,000
Sodium cyanide	940						940			
Metals (various chemical forms)										
Chromium	1,000	550		20		Unknown				450
Lead	580,000,000	Unknown	140,000,000	26,000,000	Unknown	14,000,000	180,000,000	190,000,000	19,000,000	2,100,000
Uranyl nitrate (also radioactive)	220,000			220,000						
Uranium-238	320,000,000	17,000	3,500,000	1,900,000		3,500,000		240,000,000		

Totals are rounded to two significant figures.
Source: Lockheed, August 1995

The large gaps in the data and the major uncertainties present severe obstacles to any attempt to assess the nature and magnitude of the threat posed by buried wastes to the people of the region and to those who consume the agricultural products grown there. According to our assessment, the DOE has been more successful in estimating the amount of radioactive materials buried at the RWMC than in determining the inventories of hazardous materials there. One reason for this conclusion is that the water sampling data presented in Chapter II show that contamination of the Snake River Plain aquifer, as well as the perched water bodies, with hazardous materials is at least as serious as that due to radionuclides. Hence, the potential for significant localized contamination of the Snake River Plain aquifer is significant.[138]

Another major concern is that hazardous chemicals in the subsurface can alter the ion exchange capacity of the soil, thereby increasing or decreasing contaminant mobility. Contaminants that are sorbed to immobile soil surfaces can be mobilized when the subsurface environment becomes acidic, for example in the form of discharges of pollutants such as nitric acid. Acidification mobilizes contaminants in colloid particles, such as plutonium (see "Transport of Contaminants" in this chapter), as well as sorbed metals, such as cadmium and lead.[139]

A further complication in assessing the effect of hazardous materials is that there are no maximum contaminant levels for many of them specified in the drinking water regulations. Finally, a long-term prognosis under such circumstances is very difficult since the rates of degradation of organic compounds and of migration of all hazardous non-radioactive materials depend on local hydrogeologic conditions, such as vapor pressure, contact angle and capillary effects.

c. Potential Impacts

The time and financial resources available for the present work do not allow us to undertake even a modest effort to model the future impacts to the Snake River Plain aquifer from migrating contaminants.[140] Moreover, the current state of the data, as well as the knowledge of the mechanisms of migration of plutonium and other transuranic radionuclides, is inadequate for even a sophisticated modeling effort to yield reliable results. As we will discuss later, fundamental uncertainties remain regarding the methods and speed of migration of actinides (all transuranic elements of concern in the present context belong to this chemical group, as well as uranium and radium). Long neglect and lack of coordination of the fundamental scientific work in this area has led to a situation where the potential for long-term impact must be assessed by indirect means.

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[138] INEEL presents an estimate of the unknown quantities of some of the hazardous chemicals in Table 6-1 of the *Comprehensive Inventory* (Lockheed, August 1995). These range from a few metric tons to almost a hundred metric tons. Despite these efforts, there are no estimates at all for some chemicals, cyanides for instance.

[139] Runde, 2000, page 399

[140] DOE is to release a report, of which the 1995 *Comprehensive Inventory* is a part, assessing the risks arising from the waste at RWMC, but this effort has not yet been completed.

One criterion by which the amounts of radionuclides present in buried INEEL wastes might be evaluated is to ask the following question: were all the long-lived or very long-lived radionuclides (defined as those with half lives of more than ten years and 100 years, respectively) in the buried waste to end up uniformly distributed in the Snake River Plain aquifer, would the contamination in the aquifer exceed allowable limits, and if so, by how much?

This is calculated by dividing the total concentration (radioactivity) of a contaminant in the buried waste by the drinking water standard for that contaminant. The result, called the dilution volume, is the volume of water that would be required to keep the concentration of the contaminant within allowable drinking water limits. The dilution volume can then be compared to the total amount of water in the aquifer.

One must recognize the limitation of such an approach at the outset. Radionuclides will never be mixed uniformly throughout an aquifer. A contaminant becomes diluted as it moves further from the source. Thus, concentrations nearer the source will be higher. In this way, dilution volumes overestimate the potential average concentration of a contaminant in an aquifer, and at the same time, underestimate the concentration of a contaminant near the source. The dilution volume approach also ignores any synergistic effects of pollutants. Despite these limitations, estimating water dilution volumes is a standard way of assessing the overall environmental significance of waste containing a variety of radionuclides because it provides a straightforward way to assess the order of magnitude of the potential problem.[141]

The dilution volumes for buried long-lived radionuclides at INEEL are shown in Table 16. According to the dilution volumes, the most important long-lived radionuclides in the buried wastes are strontium-90, cesium-137, plutonium-239/240, and americium-241. However, it is necessary to consider current contamination in the groundwater along with these results. For example, americium has been far more mobile than plutonium and hence may pose a larger threat than plutonium in the next hundred or two hundred years. Also, iodine-129 is far more important than indicated by its relative dilution ratio because it migrates much faster than most other radionuclides, it has an exceptionally long half-life (about 17 million years), and it bioaccumulates in the thyroid. Although neptunium is missing from the table (because its total radioactivity in buried waste is not available), this radionuclide is very important because it tends to migrate much faster than plutonium under many circumstances.

The total radioactivity of radionuclides with half-lives greater than 100 years would require 10 times the volume of the Snake River Plain aquifer to achieve allowable drinking water levels. How significant this figure is for indicating the actual future health of the aquifer will depend on a variety of factors, such as the rapidity of migration of the radionuclides.

[141] See for instance NAS-NRC, 1983, Chapter 9

Table 16: Dilution volumes of buried radionuclides with half-lives greater than 10 years, 1952-1983

Radionuclide	Half-life (years)	Main decay mode	Total radioactivity of buried waste (curies)	Drinking Water Standards (picocuries per liter)	Dilution volume (liters)	Ratio of dilution volume to volume of Snake River Plain aquifer
Tritium	12.3	beta	1,200,000	20,000	6.0×10^{13}	0.02
Carbon-14	5730	beta	16,000	2,130	7.5×10^{12}	0.00
Nickel-59	76000	EC	5,100	533	9.6×10^{12}	0.00
Nickel-63	100	beta	750,000	80	9.4×10^{13}	3.8
Strontium-90	29.1	beta	450,000	8	5.6×10^{16}	23
Technetium-99	213,000	beta	260	800	3.3×10^{11}	0.00
Iodine-129	17,000,000	beta	0.099	0.533	9.9×10^{10}	0.00
Cesium-137	30.2	beta	700,000	160	4.4×10^{15}	1.8
Plutonium-238	87	alpha	2,500	15	1.7×10^{14}	0.07
Plutonium-239	24,110	alpha	66,000	15	4.4×10^{15}	1.8
Plutonium-240	6537	alpha	15,000	15	1.0×10^{15}	0.41
Plutonium-241	14.4	beta	400,000	533	7.5×10^{14}	0.31
Americium-241	432	alpha	150,000	15	1.0×10^{16}	4.1
Total			**3,800,000**		**8.6×10^{16}**	**35**
Radionuclides >100 year half-life			**1,000,000**		**2.5×10^{16}**	**10**
Strontium-90 and cesium-137			**1,150,000**		**6.0×10^{16}**	**25**

Note:

1. EC = electron capture
2. Snake River Plain aquifer volume = 2.44×10^{15} liters
3. Numbers are rounded to two significant digits.
4. Decay is not calculated.
5. The transuranic isotopes all have radioactive decay products that build-up over time. In particular, plutonium-241 decays into americium-241.

Source for total radioactivity of buried waste: Lockheed, August 1995

Soluble radionuclides with relatively short half-lives, such as tritium, pose immediate threats to water quality on site. Since short-lived radionuclides decay substantially before they can migrate off site, the likelihood of off site contamination of these radionuclides greater than allowable drinking water limits is low. For off-site populations and agriculture, long-lived radionuclides (i.e., with half-lives more than 100 years) are more important, because they will not decay before migrating off site. This does not mean contamination from short-lived radionuclides will be negligible for off-site populations - some off-site tritium contamination has already occurred. However, the off-site tritium concentration is less than allowable drinking water limits and continuing to decrease due to the decay of tritium.[142]

[142] The groundwater velocity in the Snake River Plain aquifer averages about 1 kilometer per year (about 1.5 to 6 meters or 5 to 20 feet per day). ERSF, August 1998, page 1-4

Strontium-90 and cesium-137 are of greater concern because their half-lives are long enough that they can reach off site. Strontium-90 in particular moves rapidly through the vadose zone and is not highly sorbed in the soil. They mimic calcium and potassium, respectively, both of which the body needs. Hence their uptake by plants and animals and humans is a serious concern.

Radionuclides that are the longest lived, with half-lives of more than 100 years, present the most serious long-term risk in the agricultural regions, because they will not decay significantly relative to the speed of migration off the site. Indeed, these radionuclides, including americium-241, plutonium-239, neptunium-237 and iodine-129, have the potential to migrate well beyond the site boundaries before significant decay. Moreover, the total allowable contamination of transuranics under the drinking water standards involves a non-trivial radiation dose. Since the prevailing scientific opinion, on which radiation regulations are based, is that every increment of dose produces a proportional increment of cancer risk – i.e., there is no threshold of exposure below which radiation can be deemed harmless, – the contaminant levels should be kept as close to zero as possible (which is the EPA's maximum contaminant level goal[143]).

With a half-life of 432 years, americium-241 is one of the most important of the alpha-emitting radionuclides in terms of its threat to the environment. Water travels from under INEEL to the Magic Valley, the heart of southern Idaho's agricultural region, in roughly half that time.[144] There would be some attenuation of radionuclides, such as americium-241, as they travel downstream in the aquifer due to dilution as well as sorption in the geological medium.[145] Some americium-241 has already migrated through the vadose zone into the aquifer. The highest concentration of americium-241 found in the groundwater was 1.97 picocuries per liter in 1997. The levels of americium-241 are still below allowable drinking water limits (its maximum contaminant level is 15 picocuries per liter), and no plume has as been identified.[146] However, it is not possible to predict the fate of the americium-241 with confidence, because the amount of time that has elapsed since americium started migrating through the vadose zone at INEEL is far shorter than a single half-life of americium. Moreover, the amount of americium-241 will increase over the next several decades because the decay of plutonium-241 (half-life of 14.4 years) results in americium- 241. The prevention of pollution of the aquifer depends mainly on the possibility of limiting the amount of americium by recovering transuranic buried wastes from the pits and trenches into which they were dumped.

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[143] The maximum contaminant level goals provide an indication of a threshold below which no harm may be expected. Since the generally used regulatory model for radiation exposure is that there is no threshold below which harm will be zero, the maximum contaminant guides for radionuclides have been set at zero.

[144] The travel time of water is not uniform and varies from one region of the aquifer to the next and over time. Further, the transport of radionuclides is complex. Some radionuclides like tritium and iodine-129 travel at the rate of water flow, while others are retarded. See discussion in the text. The use of travel time in this context is meant to give an order of magnitude estimate of the threat a particular radionuclide might pose, given the amount present in buried wastes and its half life in relation to travel time.

[145] Penrose *et al.*, 1990, page 228

[146] INEEL OP, March 2001

Plutonium-239/240 presents yet another set of problems. First, the amount of plutonium-239 in the buried wastes at INEEL – more than a metric ton[147] – presents a security concern, should control of the site be lost. It is enough to make more than 200 nuclear bombs. The plutonium in the wastes was in relatively concentrated form when the dumping took place, which heightens the security problem. The pits and trenches therefore represent a potential plutonium mine in case of loss of site control. Second, if the plutonium has migrated, this represents a serious environmental problem. Buried plutonium is a serious concern at other DOE sites as well, but the security aspect appears to be most serious at INEEL. The only larger amount of buried plutonium in the United States is underground at the Nevada Test Site. While this is an environmental concern as well, its security implications are somewhat lower, because the plutonium is mixed with fission products and not in a single location. Moreover, it is deep underground, with much or most of it in glassy matrices that would be difficult to process for re-extraction of plutonium.

The evidence from groundwater sampling so far indicates that plutonium migrates far more slowly than americium.[148] Neither appear to have migrated off site. But the half-life of plutonium-239 – more than 24,000 years – is far longer than americium. How the migration of plutonium will evolve, and how the climatic conditions of the site will evolve over such long periods, is unknown. The long-term risks of leaving plutonium in the buried wastes are therefore substantial from the security as well as the environmental points of view.

Calculating the dilution volume for the known hazardous chemicals in the buried waste yields a total dilution volume of about 4 percent of the volume of the Snake River Plain aquifer. However, the limitations of the toxic waste data are even greater with hazardous chemicals than with radionuclides. No estimates of the amount of hazardous chemicals that were dumped exist for many areas. Further, unlike radionuclides, many hazardous materials have no set upper limit for contamination under the Safe Drinking Water Act. When these limitations are combined with the high concentrations of some hazardous chemicals in the groundwater, the relatively low total dilution volume for hazardous chemicals compared to that for radionuclides is somewhat misleading.

2. Tank Farm at INTEC (Chem Plant)

Since 1954, liquid wastes from reprocessing operations have been stored in underground tanks in an area called the Tank Farm at the INTEC facility. These are primarily high-level wastes from reprocessing of naval reactor spent fuel. In addition, some solidified ("calcined") high level waste is stored there. The Tank Farm consists of eighteen stainless steel tanks ranging in volume from 68,137 liters (18,000 gallons) to 1,135,624 liters (300,000 gallons). In 1997, there were approximately 6,740 cubic meters of liquid waste, containing 2.6 million curies of radioactivity, though a portion has since been

[147] There are also an estimated 65 kilograms of plutonium-240. The lower and upper limits for the plutonium-239/240 totals are estimated to be 0.8 metric tons and 1.5 metric tons respectively. Lockheed, August 1995, Table S-2.

[148] Penrose *et al.*, 1990, page 231

calcined.[149] The 300,000-gallon tanks are housed in underground concrete vaults with the top of the vaults about 3.0 meters (10 feet) below grade. The 30,000-gallon tanks, which do not have secondary containment, have been emptied of all hazardous waste.[150] According to the State of Idaho's Consent Order, use of the Tank Farm must be phased-out by 2015. The stipulated deadline for the first five tanks to cease use is 2009 and the tanks are to be emptied to the heel at that time, which was DOE's original schedule before the Settlement Agreement.[151]

Most of the high level waste was calcined – that is, heated until it formed an oxide powder – to put it into a stable form suitable for storage for a considerable period. Calcine is stored at INTEC in the "bin sets." As of February 1998, all of the liquid high level waste derived from first cycle uranium extraction had been converted to calcine.[152] The calciner was operated with only an interim Part A Resource Conservation and Recovery Act (RCRA) permit for 15 years.[153] Under a consent order between the DOE, EPA and Idaho Department of Environmental Quality, it was agreed that the DOE would apply for a permanent Part B permit or close the facility by June 1, 2000. DOE chose to begin closure.[154] There were also technical problems because the calciner could not handle the high levels of sodium without substantial modification. There are currently about 4,200 cubic meters of mixed high level waste calcine in the bin sets.[155]

Contamination from the Tank Farm soils represents a serious threat to the aquifer due to potential for leaching and transport of contaminants that were discharged into the environment deliberately or accidentally.[156] For example, an underground waste transfer line was accidentally ruptured by drilling, releasing as much as 3,600 gallons of high-level waste with a total activity of over 32,000 curies between 1956 and 1972. Another leak in the tank farm resulted in the release of approximately 14,000 gallons containing approximately 28,000 curies in 1972.[157] According to the EPA, the primary source of underground storage tank leaks, more than 80 percent, are not from the tank vessels, but from the appurtenances (e.g., pipelines, valves, etc.).[158] DOE has not made an adequate search of these sources of leaks and improperly claims that the tanks do not leak, even

[149] ORNL, December 1997, page 2-23. The DOE has created a Central Internet Database (http://cid.em.doe.gov/) on radioactive waste as a result of the settlement of a lawsuit brought by a number of environmental organizations. This database is supposed to be maintained with up-to-date and accurate data on stored waste, such as those in the INEEL tank farm. However, we have found the database to be woefully incomplete and have therefore had to use other, older publications as our sources for the data.
[150] DOE, November 1997a, page 1-11
[151] DOE, November 1997a, page 1-20
[152] Calcination is a process by which liquid HLW and mixed TRU are converted into the granular solid, known as calcine, which is more stable for storage.; DOE, December 1999a, pages 1-11 and 1-16
[153] DOE, December 1999a, page 3-10
[154] Kathleen Trever (Idaho Department of Environmental Quality), email communication to the Snake River Alliance, August 30, 2001
[155] DOE, December 1999a, page 1-11
[156] DOE, October 1999a, page iv
[157] NAS-NRC, 2000b, page 37
[158] EPA, September 1987

though the legal and technical definition of a tank system includes the underground pipes.[159]

No decision has been made yet on a remediation plan for the Tank Farm soils because current information regarding the nature and extent of Tank Farm contamination is considered inadequate. It is known that the major radionuclide contaminants in the Tank Farm soils are americium-241, strontium-90, cesium-137, europium-154, plutonium-238, plutonium-239/240, plutonium-241, and uranium-235, and the primary non-radioactive contaminants include mercury and nitrate.[160] See Table 17 for a summary of sampling results for Tank Farm soil contaminants. Appendix D lists the soil absorption properties of some of the main radioactive, inorganic, and organic chemicals.

Contaminants are moving through the soil to the perched water body. For example, sampling from the perched water (well MW-2) in 1993 and 1994 found a large amount of gross beta activity (as much as 76,000 picocuries per gram), most of which is due to strontium-90. According to DOE, "This confirms that Sr-90 [strontium-90] has migrated to the 110 ft interbed from a number of possible sources that include the release areas within the tank farm or possibly from the old calcine bin storage located next to the MW-2 [well]."[161]

In addition, the continued storage of liquid high-level radioactive wastes creates some risk of leaks and fires. This makes it important to convert the liquid into solid form as soon as it is possible to do so.

[159] INEEL, October 1998, page 12; 40 CFR 280.12
[160] DOE, October 1999a, page 5-9
[161] DOE, November 1997a, page 4-28

Table 17: Summary soil sampling for the Tank Farm at INTEC

Contaminants	Soil Concentration (mg/kg [nonradionuclide] or pCi/g [radionuclide]) Minimum	Maximum	Arithmetic Mean	Standard Deviation	RME[b]	Number of Samples	Number of Detects	Frequency of Detection	INEEL Background[c] (mg/kg or pCi/g)	Number of Samples Greater than Background
Ag	2.80E-01 B	1.15E+00 J	6.54E-01	1.78E-01	1.01E+00	50	35	70%	0.00E+00	35
As	2.80E+00 J	6.80E+00 J	4.25E+00	9.25E-01	6.10E+00	50	47	94%	5.80E+00	3
Ba	4.45E+01	1.93E+02 J	9.06E+01	4.39E+01	1.78E+02	50	50	100%	3.00E+02	0
Be	2.43E-02	4.50E-01	2.84E-01	1.49E-01	5.82E-01	16	15	94%	1.80E+00	0
Cd	2.20E-01 B	1.12E+01 J	3.84E+00	3.39E+00	1.06E+01	83	53	64%	2.20E+00	34
Co	1.86E+00	4.40E+00 B	3.33E+00	6.47E-01	4.62E+00	16	16	100%	1.10E+01	0
Cr	1.00E+00 J	1.13E+02 J	2.05E+01	2.07E+01	6.19E+01	58	58	100%	3.30E+01	10
Cu	7.38E+00	1.28E+01	9.92E+00	1.81E+00	1.35E+01	16	16	100%	2.20E+01	0
Hg	2.00E-02 J	4.44E+00	3.03E-01	6.32E-01	1.57E+00	95	59	62%	5.00E-02	53
Pb	4.80E+00	3.17E+01 J	1.17E+01	6.82E+00	2.53E+01	50	50	100%	1.70E+01	10
Mn	9.15E+01	1.18E+05	5.08E+03	2.42E+04	5.35E+04	24	24	100%	4.90E+02	1
Ni	1.34E-01 J	1.94E+01 J	1.35E+01	4.03E+00	2.16E+01	24	24	100%	3.50E+01	0
Se	5.10E-01 J	8.00E-01 B	6.97E-01	1.62E-01	1.02E+00	34	3	9%	2.20E-01	3
Sr	3.61E+03	3.61E+03	3.61E+03	NA	NA	1	1	100%	NA	NA
Th	4.85E+00	4.85E+00	4.85E+00	NA	NA	16	1	6%	4.30E-01	1
V	9.10E+00 B	1.85E+01	1.47E+01	2.77E+00	2.02E+01	17	17	100%	4.50E+01	0
Zn	3.20E+01	5.55E+01	4.18E+01	6.98E+00	5.58E+01	16	16	100%	1.50E+02	0
Zr	5.13E+00	1.40E+01	8.61E+00	3.55E+00	1.57E+01	5	5	100%	NA	NA
Fluoride	5.30E-01	6.72E+00 J	1.70E+00	1.14E+00	3.98E+00	41	40	98%	NA	NA
Nitrate	3.50E-01	8.10E+00	1.68E+00	1.54E+00	4.76E+00	54	51	94%	NA	NA

Source: DOE, October 1999a, page 5-10 to 5-12

Table 17: Continued

Contaminants	Soil Concentration (mg/kg [nonradionuclide] or pCi/g [radionuclide]) Minimum	Maximum	Arithmetic Mean	Standard Deviation	RME[b]	Number of Samples	Number of Detects	Frequency of Detection	INEEL Background[c] (mg/kg or pCi/g)	Number of Samples Greater than Background
Methylene Chloride	5.90E-03 JB	9.10E-03 JB	8.08E-03	1.31E-03	1.07E-02	5	5	100%	NA	NA
Toluene	1.00E-03 J	2.00E-03 J	1.14E-03	3.78E-04	1.90E-03	22	7	32%	NA	NA
Trichloroethane	1.00E-03 J	4.60E-03 J	2.80E-03	2.55E-03	7.90E-03	6	2	33%	NA	NA
Am-241	6.00E-02	1.66E+04 J	6.25E+02	3.08E+03	6.79E+03	64	29	45%	1.1E-02	29
Ce-144	1.44E+01	1.44E+01	1.44E+01	NA	NA	12	1	8%	NA	NA
Co-60	9.00E-02	2.27E+04	1.81E+03	6.28E+03	1.44E+04	41	13	32%	NA	NA
Cs-134	1.30E-01	7.55E+04	5.40E+03	2.02E+04	4.58E+04	41	14	34%	NA	NA
Cs-137	4.78E-02	1.02E+08	1.31E+06	1.02E+07	2.17E+07	119	111	93%	8.2E-01	99
Eu-154	1.54E-01 J	5.65E+05	1.65E+04	9.54E+04	2.07E+05	45	35	78%	NA	NA
H-3	2.49E+04	2.49E+04	2.49E+04	NA	NA	1	1	100%	NA	NA
Np-237	1.00E-01 J	1.63E+00	5.12E-01	4.94E-01	1.50E+00	46	14	30%	NA	NA
Pu-238	2.99E-02	2.76E+05	8.25E+03	4.73E+04	1.03E+05	64	34	53%	4.90E-03	34
Pu-239/240	2.58E-02	1.26E+04	1.08E+03	3.35E+03	7.78E+03	70	26	37%	1.00E-01	17
Pu-241	1.05E+06	1.05E+06	1.05E+06	NA	NA	1	1	100%	NA	NA
Pu-242	3.20E+01	3.20E+01	3.20E+01	NA	NA	1	1	100%	NA	NA
Ru-106	6.66E-02	5.41E+01	2.71E+01	3.82E+01	1.04E+02	31	2	6%	NA	NA
Sr-90	1.60E-01	5.68E+07	7.02E+05	5.97E+06	1.26E+07	93	91	98%	4.90E-01	85
Tc-99	9.00E-01	3.67E+01	4.40E+00	1.02E+01	2.48E+01	12	12	100%	NA	NA
U-234	7.00E-02	2.12E+01	9.85E-01	2.75E+00	6.49E+00	63	61	97%	1.44E+00	3
U-235	2.03E-02	9.00E+03	7.70E+02	2.17E+03	5.11E+03	53	19	36%	NA	NA
U-236	7.55E-01	7.55E-01	7.55E-01	NA	NA	1	1	100%	NA	NA

Table 17: Continued

Contaminants	Soil Concentration (mg/kg [nonradionuclide] or pCi/g [radionuclide]) Minimum	Maximum	Arithmetic Mean	Standard Deviation	RME[b]	Number of Samples	Number of Detects	Frequency of Detection	INEEL Background[c] (mg/kg or pCi/g)	Number of Samples Greater than Background
U-238	4.51E-02	1.39E+00	5.42E-01	4.31E-01	1.40E+00	63	58	92%	1.4E+00	0
Gross Alpha	5.20E+00	1.20E+01	7.35E+00	2.19E+00	1.17E+01	11	11	100%	NA	NA
Gross Beta	3.60E+01	6.89E+02	1.62E+02	1.86E+02	5.34E+02	11	11	100%	NA	NA

a. NOTE:

- Duplicate sample results were not included in the statistical analysis.
- Analytical results used in the table are taken from Appendix G of the OU3-13 RI/FS Part A (DOE-ID, 1997b) for Group 1 Sites: CPP-15, -20, -25, -26, -27, -28, -31, -32A, -32B, -33, -58A, -58B and 79.
- Only those constituents that were identified above detection limits are shown in the table except for the following constituents which were detected but are not considered to be present at hazardous concentrations: Al, Ca, Fe, Mg, K, Na and K-40.
- Samples rejected because of an unacceptable quality control parameter are not included in the table.

b. The RME concentration is the 95% upper value based on the empirical rule (95%of the measurements lie within two standard deviations of their mean).

c. The INEEL background concentrations represent the 95% upper confidence limit (Rood et al. 1995)

B = The analyte reported value is <RDL, but >IDL.

J = The analyte was identified in the sample but the numerical result may not be accurate.

NA = Not Applicable.

RME = Reasonable Maximum Exposure.

B. Transport of contaminants

At many sites in the U.S. nuclear weapons complex, large amounts of transuranic radionuclides were dumped into shallow pits and trenches, based on the premise that it would take a very long time for these radionuclides to travel through the vadose zone.

At INEEL, a few hundred feet of variably fractured, porous soil and rock are the principal barriers between the Snake River Plain aquifer and the 1,163 kilograms of transuranic radionuclides that were dumped into shallow trenches and pits at the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex.[162] The wastes were packaged in cardboard and wooden boxes that must be presumed to have already lost their integrity, and in 55-gallon steel drums that will not be able to contain the wastes for much longer, if they are still intact.[163]

Therefore, the health of the aquifer depends largely on the barrier created by the vadose zone. But as early as 1952, a USGS report noted:

> "The Snake River basalt is more permeable than the sediments, but the permeability differs from layer to layer and laterally within layers so the rate and direction of percolation of fluids in individual layers cannot be predicted."[164]

Other than direct injection of wastes into the Snake River Plain aquifer, no single waste management method has created more problems than dumping waste into shallow trenches. Based on decades of research and actual results in the field, there is broad scientific consensus that rapid migration of transuranics in both colloidal and soluble forms can occur. Such radionuclides have migrated rapidly through vadose zones at several DOE sites, including INEEL.

1. Ion exchange capacity

It was assumed that ion-exchange in the soil would retard the movement of plutonium, preventing it from reaching aquifers for tens of thousands or even hundreds of thousands of years.[165] Ion-exchange is a reversible chemical reaction in which an ion (an atom or molecule with an electrical charge) from solution is exchanged for a similarly charged ion attached to an immobile solid particle. That is, insoluble forms of plutonium (such as plutonium dioxide) would not migrate significantly in the underground environment because the plutonium would sorb onto rocks. It was further assumed that plutonium and other radionuclides had to actually dissolve in water to be transported.

Measurements of plutonium in the groundwater have long shown that its migration rates in the vadose zones at various U.S. nuclear weapons sites in a variety of climatic and

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[162] Fioravanti and Makhijani, 1997, page 76
[163] Fioravanti and Makhijani, 1997, page 61
[164] Deutsch *et al.*, August 1952, page 41
[165] NAS-NRC, 2000b, page 30; Makhijani *et al.*, July 1986, page 74

geologic settings have been orders of magnitude faster than those presumed by a policy of shallow-land dumping. Figure 21 shows the evolution of the estimates of travel time for plutonium to migrate to the aquifer at INEEL from the mid-1960s to the late 1990s. The early estimates were tens of thousands of years; the most recent ones are tens of years.

By the 1970s, plutonium had been discovered in the groundwater across the country: at the Savannah River Site in South Carolina, at the Maxey Flats low-level waste disposal site in Kentucky, and at INEEL itself.[166] Yet, throughout the nuclear weapons complex, nothing seems to have been done to bring the predicted migration rates into line with the actual measurements. This failure is even more remarkable given that the National Academy of Sciences has pointed out since the 1960s that the assumption that the environment could contain the buried wastes was not warranted. For instance, in May 1965, a committee of the National Academy of Sciences visited INEEL. It appeared to the committee

> "(1) that considerations of long-range safety are in some instances subordinate to regard for economy of operation, and (2) that some disposal practices are conditioned on over-confidence in the capacity of the local environment to contain vast quantities of radionuclides for indefinite periods without danger to the biosphere."[167]

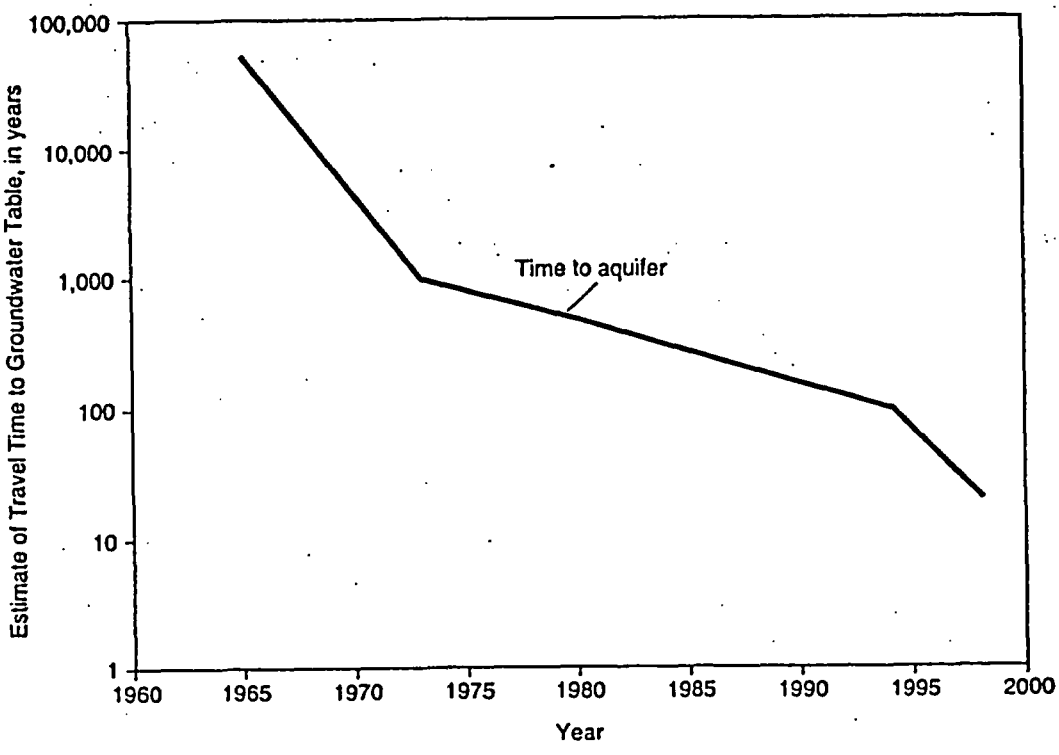
The relatively dry climate in Idaho seems to have reinforced the belief that shallow-land dumping would not cause problems. However, a 1966 National Research Council report to the Atomic Energy Commission warned against reliance on a dry climate to contain the wastes:

> "The protection afforded by aridity can lead to overconfidence: at both sites [INEEL and Hanford, Washington] it seemed to be assumed that no water from surface precipitation percolates downward to the water table, whereas there appears to be as yet no conclusive evidence that this is the case, especially during periods of low evapotranspiration and heavier than average precipitation, as when winter snows are melted."[168]

The lack of sufficient evaporation was evident at INEEL, though it had not been factored into waste management policy. Flooding has occurred at several INEEL facilities, including Idaho Nuclear Technology and Engineering Center (INTEC), Radioactive Waste Management Complex (RWMC), and Test Area North (TAN). During periods of high flow or low irrigation demand, the Big Lost River passes within 200 feet of INTEC and within 3 kilometers of the RWMC. In response to flooding at INTEC in 1952, a stormwater drainage ditch system designed to handle a 25-year, 24-hour storm was built

[166] Lipschutz, 1980, page 132; Nokkentved, March 2001
[167] As quoted in USGS, August 1976 page 4
[168] As quoted in USGS, August 1976, pages 3 and 4

Figure 21: Estimates of plutonium travel time through the vadose zone to the aquifer at the Radioactive Waste Management Complex (RWMC)



Source: NAS-NRC, 2000b, page 30

around the facility.[169] A 1986 study evaluated the potential impact on INEEL facilities of flooding due to a failure of the Mackay Dam, which is located 40 miles upstream of INEEL. If the flood resulted from a "probable maximum flood" and rapid failure of the Mackay Dam, portions of INTEC would be flooded, which could result in the floating of one or more buried waste tanks.[170]

The Subsurface Disposal Area (SDA), which is located in a topographic depression, was flooded in 1962, 1969, and 1982. At the time of the 1962 flood, Pits 2 and 3 and Trenches 24 and 25 were open and filled with water. Boxes and barrels containing low-level radioactive waste floated freely. A diversion drainage system was then constructed around the perimeter of the SDA.[171] In 1969, water ponded in Pit 9, causing some barrels of waste to float freely (see Figure 22). Security guards shot holes into some of the barrels to make them sink to the bottom of the pit; leakage of waste from these barrels is likely.[172] Measurements of plutonium in samples of floodwater taken during the 1969 flood indicated that plutonium from the waste was dissolving in the water.[173] In response to this flood, the dikes surrounding the SDA were raised and the exterior drainage ditches were enlarged. Additional work was conducted on the perimeter dike and drainage channel surrounding SDA when water accumulated in the southeast corner in 1982. Despite this, ponding still occasionally occurs in small depressions on the SDA.[174]

Soil samples taken at various depths in 1971 and 1972 indicated a rapid migration of transuranics originating in the waste burial area (see Table 18). Soil concentrations were greater at 110 feet than at 240 feet, indicating such migration. Some sedimentary samples from wells contained plutonium-239/240 over 100 picocuries per gram, with the highest sample being 540 picocuries per gram (sediment from well 93). The highest amercium-241 concentration in that set of measurements was 230 picocuries per gram (sediment from well 96).[175]

For three decades, the theory of soil sorption has been contradicted by direct measurements in the field. Figure 23 shows the americium-241 and plutonium isotope detections in groundwater beneath the Radioactive Waste Management Complex between the years 1972 and 2000. Water samples were already showing highly variable amounts of plutonium and americium between September 1971 and February 1973. Some of them were high. They ranged from tiny fractions of a picocurie per liter to 9 picocuries per liter for plutonium-238 in one sample (well 90, in 1972) and 5 picocuries per liter for americium-241 (well 89, in 1972).[176]

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[169] DOE, December 1999a, pages 4-49 and 4-51
[170] Koslow and Van Haaften, June 1986, page 24; DOE, December 1999, pages 4-51 and 4-55
[171] DOE, June 1993, page 8-49
[172] DOE, June 1993, page 8-18
[173] USGS, August 1976, page 70
[174] DOE, June 1993, page 8-49
[175] USGS, August 1976, Table II, page 63
[176] USGS, August 1976, Table IV, page 66

Figure 22: Picture of flooding in Pit 9 at the Radioactive Waste Management Complex in 1969

Source: DOE

Table 18: Concentration of some radionuclides found in selected water samples in the Subsurface Disposal Area at the Radioactive Waste Management Complex (RWMC)

(All concentrations in terms of 10^{-9} μCi/ml = pCi/l)

Well	Sampling depth (feet)	Date	Tritium pCi/l	^{57}Co pCi/l	^{60}Co pCi/l	^{90}Sr pCi/l	^{137}Cs pCi/l	^{238}Pu pCi/l	$^{239/240}Pu$ pCi/l	^{241}Am pCi/l
87	597	9-06-71	10,000±2,000[a,b]	—	—	—	—	[c]	[c]	[c]
	600	9-20-72	<2,000	—	< 20	<2	< 20	<0.05	0.09 ± .045	0.01 ± .03
	600	9-20-72	7,000±2,000[a]	—	< 20	<5	< 20	0.008±0.001[a]	0.01 ±0.01	0.005± .01
88	610	9-20-72	<2,000	—	< 20	<2	< 20	<0.09	<0.05	0.09 ±0.40
	610	2-02-73	<2,000	—	<100	10±4[a]	<400	0.02 ±0.05	0.006±0.02	0.01 ±0.03
	610	2-24-73	6,000[a]	—	< 10	9±3[a]	< 20	0.008±0.009	0.003±0.003	0.001±0.001
89	620	2-24-72	<2,000	—	< 20	<1	< 20	<0.05	<0.05	1.0 ±3.0
	620	10-12-72	[c]	—	< 20	<1	27± 6[a]	<0.05	<0.05	5.0 ±1.0[a]
	620	2-02-73	<2,000	—	< 80	<7	<300	0.007±0.02	0.04 ±0.02	0.04 ±0.03
	620	2-24-73	10,000±2,000[a]	—	< 20	<5	< 20	0.004±0.01	0.004±0.005	0.02 ±0.05
90	600	2-04-72	<2,000	—	< 20	<2	30± 6[a]	0.96 ±0.09[a]	0.04 ±0.016[a]	[c]
	600	9-20-72	<2,000	—	< 20	<2	< 20	9.00 ±0.03[a]	0.14 ±0.05[a]	15 ±0.04[a]
	600	10-12-72	[c]	48±7.0[a]	91±9.0[a]	<1	90±10[a]	<0.04	<0.02	0.06 ±0.03
	600	2-02-73	<2,000	—	< 20	<7	< 30	0.01 ±0.04	0.05 ±0.05	[c]
	600	2-24-73	7,000±2,000[a]	—	< 20	<5	< 20	0.01 ±0.01	0.02 ±0.01	0.002±0.002

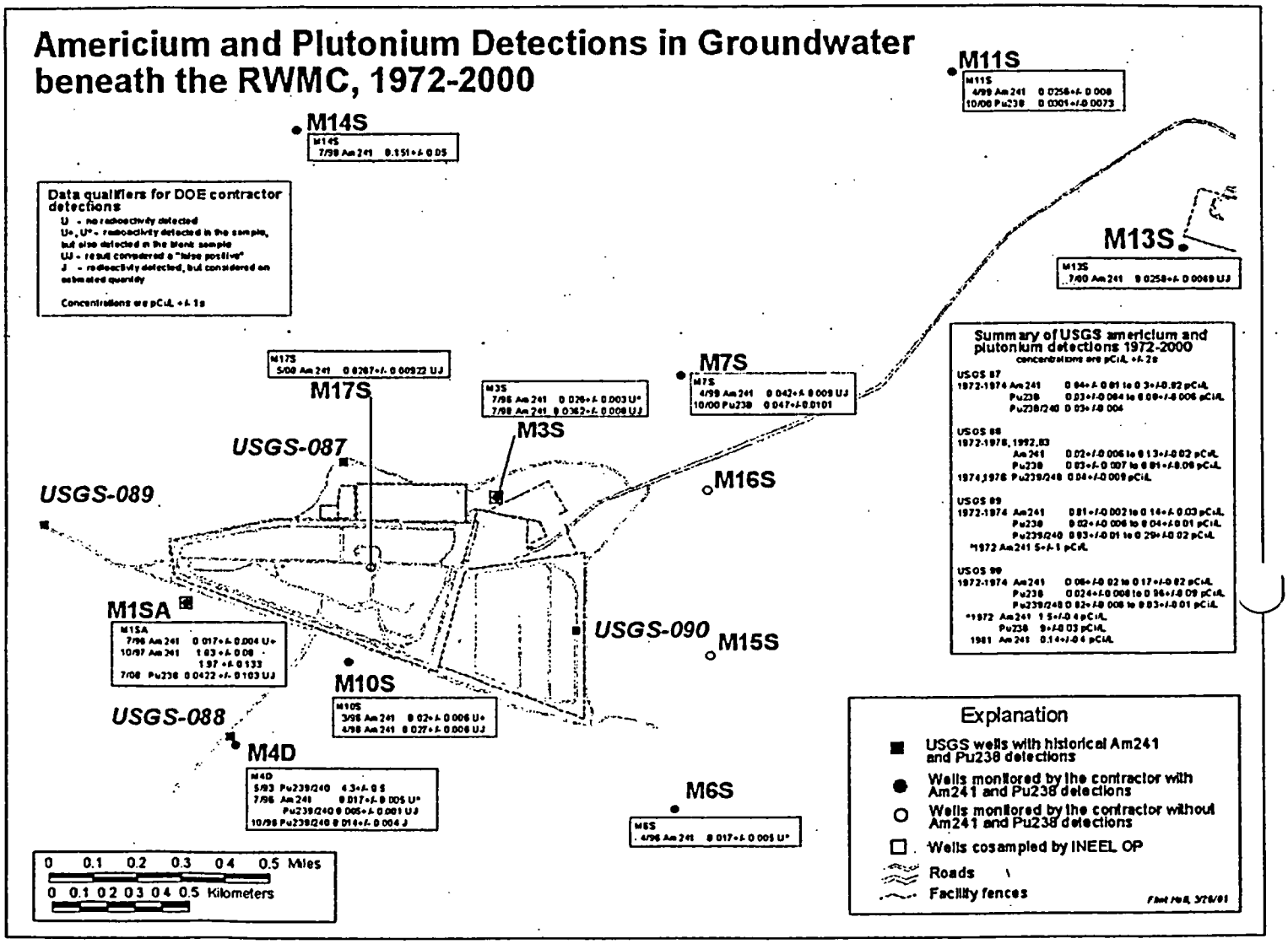
[a] Concentration greater than 2 σ.

[b] Drilling water obtained from supply well contaminated with tritium.

[c] NA = not analyzed.

Source: USGS, August 1976, page 66

Figure 23: Americium and plutonium detections in groundwater beneath the Radioactive Waste Management Complex (RWMC), 1972-2000



Source: INEEL OP, 2001

A 1976 USGS report on INEEL noted that the solubility characteristics of the several long-lived radionuclides, including transuranics, which were of the "most concern at the burial ground because of their long half-lives," were "complex and poorly understood." The urgent need for such understanding was clearly indicated by experimental evidence, cited in the report, that the chemical and physical properties of the waste alone could result in a variation in solubility of plutonium of one million times. A "theoretical appraisal of the solubility of plutonium in water," completed in 1971, appeared to be "consistent" with the experimental findings.[177]

The fragmentary evidence of rapid plutonium migration in water samples is corroborated strongly by the plutonium content of well sediments reported by the USGS in 1976. Plutonium-239/240 concentrations ranging from a fraction of a picocurie per kilogram in sediment to a hundred or more picocuries per kilogram have been detected in many wells at depths of a hundred feet or more. The highest concentration of plutonium-239/240 at 22 picocuries per kilogram was detected in the sediments at a depth of 522 feet (well 88).[178] High americium concentrations were also detected in some wells, along with significant plutonium-238 concentrations.[179]

The 1976 USGS report went on to examine at length the possible reasons for the detection of transuranics in the water, including the possibility of contamination from other sources, the migration of radionuclides from the surface due to well drilling and associated operations, etc. It also looked at those factors indicating that migration of plutonium through the vadose zone had indeed occurred. On balance, it concluded as follows:

> "...there is no direct evidence that any core samples from the interior wells were artificially contaminated by waste isotopes. However, it is impossible to eliminate all potential sources of contamination in any of the wells in a study of this type. There is, then, a possibility that artificial contamination, analytical error, and statistical error are responsible for some of the positive results. However, there are no apparent artificial contamination mechanisms that could reasonably account for all observed values."[180]

We do not know whether these explanations of artificial contamination sources for the high radionuclide readings were due to internal pressure to look for explanations other than the most evident one – that unpredictable, scattered migration of transuranic radionuclides was occurring at INEEL. We do know, however, that the fact that nothing but migration could reasonably explain the high readings did not lead to remediation action.

[177] USGS, August 1976, page 70
[178] USGS, August 1976, Table II, page 63
[179] USGS, August 1976, page 81
[180] USGS, August 1976, pages 80-81

2. Transport in colloidal and dissolved forms

Theory and laboratory understanding can now explain the observed rapid migration of plutonium. Research has produced evidence that sorption of plutonium onto tiny, sub-micron particles, which occur naturally in groundwater, is a potential powerful and rapid transport mechanism. Such particles, or colloids, move suspended in the water and can therefore be transported along quite rapidly. The findings on colloidal transport are very significant because they mean that plutonium does not have to dissolve in the water to be rapidly transported.

The possibility that transuranics in the form of very fine suspended particles can be transported rapidly in the water was recognized as long ago as 1976. In regard to these issues, the 1976 USGS report states as follows:

> "Although the chemistry of plutonium is poorly understood, most studies have indicated that it can be subjected to strong adsorption (W. L. Polzer, oral commun., 1974). However, if plutonium or americium is in a microcolloidal suspension, as Adams and Fowler (1974) suggest, it may be much more mobile than ionic forms, and thus subject to less sorption. The suspended particles might be so small that they resemble a true solute in aqueous mobility and thus are not subject to significant filtering effects and therefore not uniformly distributed in the environment."[181]

This was a prescient observation in regard to the possible rapid transport of colloidal forms of transuranics; yet it still has not been factored into waste management policy. Present policy for buried waste still assumes that the waste will migrate only very slowly and that it does not pose a threat to groundwater resources.

Another possibility is the transport of tiny colloidal plutonium particles themselves. Researchers from Lawrence Livermore and Los Alamos national laboratories found plutonium in a water sample taken 1.3 kilometers (about 0.8 miles) away from the Nevada Test Site's underground test location for nuclear weapons. Their main conclusions were as follows:

> "The data obtained in this study suggest that Pu [plutonium] and other radionuclides are transported as colloidal material. Although Pu has been shown experimentally to strongly sorb onto clays and zeolites, Pu can also exist as an intrinsic colloid, composed of Pu oxide. Both types of colloids have the capacity to be transported by groundwater.
>
> "The present work thus demonstrates that Pu is not immobile in the subsurface, but can be transported over significant distances. Pu transport models that only take into account sorption and solubility may therefore underestimate the extent to which this species is able to migrate in ground water."[182]

[181] USGS, August 1976, page 72
[182] Kersting *et al.*, January 1999, pages 58-59

In 2000, Los Alamos researchers published an extensive paper on their investigations of actinide migration in soluble, as well as colloidal, forms. The complexity and immense variability of the behavior of plutonium and other transuranics depending on their chemical forms and on environmental conditions (such as the chemistry of the water) is amply demonstrated by this research. Moreover, despite the general chemical similarities in the group of elements known as actinides, there are large variations among them under the same conditions. Many actinides, including plutonium, americium, and neptunium, exhibit multiple oxidation states that behave as distinct molecular species. Plutonium, uranium, and neptunium can change their oxidation states even under mild conditions and can display two or more states simultaneously in the same solution. Local conditions that can affect how these radionuclides interact in the environment include, among other factors, the site-specific minerals, temperature, and pH.[183] For example, neptunium solubility can be as much as 100 times as great as plutonium solubility under certain circumstances.[184]

Even forms of plutonium that are relatively insoluble will be affected by the presence of solvents, organic materials in the soil, and other factors. The presence of acidic materials in the soil, for instance in the form of discharges of pollutants such as nitric acid, as well as solvents such as tri-butyl phosphate, could aid in the rapid transport of transuranic radionuclides.[185] Such pollutants help mobilize the transuranics and other contaminants, especially heavy metals. If present beyond the buffering capacity of the soil, they also reduce the capacity of the soil to adsorb positively charged metal ions like plutonium and americium.

Laboratory experiments published in 1993 on plutonium solubility in waters from various wells at INEEL indicated that "[b]y far the highest plutonium solubility is in water from well 92."[186] The researchers concluded that the probable reasons for the high solubility of plutonium in that case was "the result of the reducing action of the dissolved organic compounds along with the complexing by carbonate ions, and possibly, to a much smaller extent, by dissolved trace organic compounds."[187] They stated that "to conclude that the plutonium in the waste would not leach into the ground water over a period of time is not warranted."[188]

As we discussed in Chapter II, the State of Idaho announced at a press conference in March 2001 that plutonium and other transuranic radionuclides had been detected in the Snake River Plain aquifer at INEEL. Analysis of a second subsample drawn from the same sample container in August 2001 did not detect plutonium. One possible explanation for the large variations in plutonium quantities between the samples is the possibility that plutonium is being transported in microcolloidal form. The radioactivity content of a single particle of plutonium-238 with a diameter of one micron would be about 90 picocuries. A plutonium-239 particle of the same size would have about 0.3

[183] Runde, 2000, page 392
[184] Runde, 2000, page 402
[185] Runde, 2000, page 399
[186] USGS, 1993b, page 4
[187] USGS, 1993b, page 4
[188] USGS, 1993b, page 4

picocuries of radioactivity.[189] For a particle with a diameter of 0.2 microns (radius of 0.1 microns), there is about 0.7 picocuries of plutonium-238 and about 1/300 of that for plutonium-239. This would only apply to plutonium in particulate form.

Generally, we expect plutonium-238 concentrations to be lower on average than plutonium-239/240 concentrations due to the much high source term for the latter. But local variation due to non-uniform dumping patterns and the highly variable nature of plutonium migration may obscure this overall difference in source term for some time.

Overall, the theoretical, experimental, and field evidence for rapid plutonium and americium migration though the vadose zone is very strong and more than sufficient basis for urgent action to clean up the buried wastes. While there is need for further research on the mechanisms and speed of transport, there is sufficient evidence to conclude that the buried wastes at INEEL present an urgent threat to the Snake River Plain aquifer and all the people who depend on it.

[189] This assumes a density of 10 grams per milliliter for plutonium particles.

Chapter IV: Policy Considerations for Clean-up

This report has focused primarily on technical issues and facts: buried plutonium seriously threatens the Snake River Plain aquifer and DOE is not addressing the problem adequately. Any analysis of this problem would be incomplete, however, if we did not address the more fundamental policy and institutional issues that are critical to solving the problem.

The threat to the Snake River Plain aquifer has been indicated by data for a quarter of a century. Even though these data may not have been definitive, action to prevent serious contamination has long been imperative, because once the aquifer is seriously contaminated with plutonium, americium or other long-lived radionuclides, the situation will likely be irremediable. The problem is therefore more than just a technical one. It is also institutional. Despite the data, the DOE as an institution has managed to ignore the potential problem. As we discuss below, institutional change is essential to accomplishing clean-up and protecting the Snake River Plain aquifer.

The buried wastes that were dumped into pits and trenches at the Subsurface Disposal Area (SDA) at the Radioactive Waste Management Complex present the greatest long-term threat to the Snake River Plain aquifer, because they not only contain dangerous radionuclides but also hazardous, flammable and explosive chemicals. The wastes are very heterogeneous. It will not be possible to get thorough knowledge of the waste characteristics through a sampling program prior to removal of the wastes. According to the INEEL *Comprehensive Inventory* report:

> "Drilling, sampling, and analysis to determine an appropriate SDA inventory is not considered feasible or practical for several reasons: (a) the area is quite large; (b) drilling into disposal units containing radioactive waste is hazardous, and (c) the contaminants are distributed unevenly over the area, in concentrated and dilute form. Even a massive drilling and sampling campaign would not result in an inventory in which high confidence could be placed because of the heterogeneity of the waste."[190]

In view of these difficulties, a large-scale pilot project to recover and remediate the wastes at Pit 9 in the SDA was initiated. This project resulted in abject failure for a variety of reasons, many of which are still in dispute between the DOE and its contractors. Not a single barrel of waste was retrieved. The main result has been vast expenditure and litigation between the government and its contractors as to who is responsible for the problems and the non-performance of the contract. In February 2001, the DOE asked regulators to delay the project for another 13 years. The State of Idaho denied the request and gave DOE until October 2001 to indicate how it intends to meet deadlines agreed to three years ago.[191]

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[190] Lockheed, August 1995, page 2-1

[191] Langston, August 2001

The DOE even failed to learn the lessons from this failure and proceeded to set up a similar contract for the even more difficult problem of dealing with the Hanford high-level waste tanks, which contain the largest volume of highly radioactive wastes in the world. IEER analyzed both the INEEL Pit 9 and the Hanford tank projects in 1997 and predicted that the Hanford project, then still in the contract-bidding stage, appeared likely to fail, which it has since done.[192]

DOE tends to rely on large projects without proper preparatory scientific and technical work. It does not make plans for back up technologies or approaches in case highly complex, one-of-a-kind projects fail. There is little careful review of projects before they are put into place because political short-term considerations too often drive the process. DOE also tends to make legal commitments that are very difficult or impossible to meet, making it necessary to go back and revise agreements when milestones are missed.

The buried transuranic wastes at INEEL present specific, difficult challenges that must be addressed at the outset and incorporated into the design of the retrieval and treatment plans if the effort is to be successful. One of the most important considerations is that the exact nature of the wastes will only become clear as the recovery and processing proceed. One of the main reasons for the failure of the Pit 9 project was that both the DOE and its contractor approached the problem without adequately factoring in its complexity.

While the threat to the Snake River Plain aquifer from the buried wastes increases with time, the DOE's main priority has been to lavish funds on the stored transuranic wastes at the Radioactive Waste Management Complex, even though they are kept in relatively secure conditions indoors. Agreements with the State of Idaho dating back three decades (with many missed milestones in the interim) mean that the DOE is focused on moving stored transuranic wastes from various sites to the Waste Isolation Pilot Project (WIPP) in New Mexico. This in turn permits the nuclear Navy to move its reactor spent fuel from other locations to INEEL. In other words, grossly insufficient resources are being devoted to clean-up of the dumped transuranic wastes, while far greater funding is given to WIPP, which is essentially a waste shell game. This consists of moving wastes that are relatively safely stored at INEEL to WIPP so that more waste can be shipped to INEEL from the outside. The low funding priority and consequent delays in the buried wastes program continues, even though INEEL has been on the Superfund list since November 1989[193] and the DOE, EPA, and the State of Idaho negotiated a Federal Facilities Agreement/Consent Order in 1991. This agreement describes how the DOE, EPA, and State of Idaho will implement CERCLA activities.[194]

The huge cost of WIPP – $19 billion across the nuclear weapons complex, even though it does little to reduce risk at INEEL – is a major roadblock to sensible waste management and clean-up priorities. WIPP increases transportation risks and the risks associated with a geologic repository sited in an area rich in natural resources. Yet, the DOE has done

[192] Fioravanti and Makhijani, 1997
[193] Superfund is formally known as the Comprehensive Environmental Response, Compensation, and Liabilities Act (CERCLA). 54 FR 29820
[194] Settlement Agreement, 1995

nothing to alert national or state policy-makers to the serious environmental risks of the current course. On the contrary, since moving existing transuranic wastes to WIPP makes room at its various sites for generation of new wastes, it is a program that is well suited to new production missions. Despite the post-Cold War rhetoric of attention to environmental issues as a top priority, the focus seems to be back on nuclear weapons.

A refocusing of the expenditures on waste management and clean-up so that environmental protection at INEEL is the driving concern would mean that the priority should be given to efforts that would result in:

- Prevention of further contamination of groundwater offsite;
- Recovery and remediation of buried wastes in order to limit groundwater contamination;
- Solidification and storage of liquid high-level waste.

The last two of these three are needed to ensure that the Snake River Plain aquifer offsite will remain usable and not be threatened by large amounts of wastes that were dumped at INEEL or that may be released in case of a severe accident involving high-level liquid wastes.

A modular approach to recovery and processing of the waste into stable form would be far less risky than what was attempted at Pit 9. This would involve many parallel recovery processes, all remote, as well as many parallel processing lines. Each recovery and processing line would handle relatively small amounts of materials at a time. They would be constructed so as to contain explosions or fires should they occur, though sufficient characterization prior to treatment should be conducted to minimize the possibility of such accidents. Remote processing of small amounts of material at a time in explosion-proof structures would minimize both routine operating doses and reduce the risk of contamination of workers or the environment in case of an accident. This approach is quite different from the business-as-usual DOE method of creating a single large plant to do the whole job, whether or not the technology is available and the wastes are properly characterized. The risk of off-site releases could be made very small by properly designing the project, although there is no approach that will reduce risk to zero when recovery of such wastes is concerned. But doing nothing puts the health of one of the most precious groundwater resources in the United States at stake.

Consideration of institutional issues

The Department of Energy's Environmental Management program was initiated in 1989, as the Cold War was ending. It was an explicit institutional recognition that the damage from nuclear weapons production and testing to the environment in the United States was substantial and that concerted efforts needed to be made to remediate a variety of problems, if the environment was to be protected from past mismanagement. In the dozen years that have elapsed since that time, the DOE has commissioned a number of studies and assessments that have provided the country with a much clearer and more detailed picture of the nature and extent of the problem of environmental management.

DOE has acknowledged that long-term stewardship will be needed at DOE's principal sites and a large number of others where nuclear weapons related work was conducted.[195]

Some development of new technology has occurred, as for instance with development of non-incinerator methods of thermal treatment of mixed radioactive and hazardous chemical waste. Some useful projects have been or are being implemented. But overall, DOE has wasted a large amount of money. Its internal culture does not seem suited to oversee the complex and difficult job of environmental restoration and management in the nuclear weapons complex.[196]

A part of the problem stems from the continued focus on nuclear weapons and the lack of attention to missions related to environmental management and clean-up. INEEL has been designated as the lead site for nuclear power technology development. New non-environmental missions seem to sap the potential for a sound approach to clean-up.[197]

It is easier to conclude that the present structure is not working than to come up with an alternative. Congress has given some clean-up projects to the Army Corps of Engineers, the agency that was in charge of the Manhattan Project. But putting clean-up into a branch of the Pentagon, the agency that puts the nuclear weapons into the U.S. arsenal, only shifts the conflict of interest problem.

Alternatives to business-as-usual, which has made clean-up a large cash cow for contractors without commensurate results, could be:

1. The DOE could assume more direct responsibility for clean-up. It should examine the clean-up contracting policies of the Environmental Protection Agency (EPA), Department of Defense, and National Aeronautics and Space Administration to see what positive lessons they may hold. Their approach is to contract with companies for specific, smaller jobs and to foster more competition. Consistent and reliable external regulation is also crucial. Self-regulation of the clean-up process has not provided good results overall. The EPA and Nuclear Regulatory Commission should be given legal authority and adequate resources to enforce all environmental laws and promulgate a strict set of national clean-up standards.[198]

2. Congress should create an escrow fund for clean-up and give the job of clean-up to the states at sites where no production is occurring. The latter would contract with private companies as necessary and desirable for specific pieces of work. The work would be done under national clean-up standards enforced by the EPA, as under

[195] NAS-NRC, 2000a

[196] We have researched this issue in some depth, in part by doing case studies. See Fioravanti and Makhijani, 1997. That report also discussed institutional issues.

[197] Fioravanti and Makhijani, 1997

[198] IEER has advocated clean-up to background levels where possible. When it is not, the maximum allowable dose to the maximally exposed individual should not exceed 10 millirem under a subsistence farmer scenario. The guideline for clean-up to levels as low-as-reasonably achievable should not exceed 2 millirem.

Option 1 above. This would still leave open the question of sites where there is still a non-environmental management production mission.

3. A new federal agency dedicated to long-term stewardship and long-term waste management could be created. This agency would be responsible for stewardship at sites where there is no production mission and portions of sites where clean-up is complete. As in Option 2 above, this would also leave open the question of clean-up at sites with ongoing production.

A large part of the problem with Options 2 and 3 is the issue of ensuring adequate funding, should clean-up be separated from the DOE. The question of clean-up expertise and general experience with nuclear technology may also be an issue if clean-up becomes a state responsibility.

While there is no simple answer to the institutional question, serious re-vamping in the process for selecting contractors for specific projects is clearly needed. There have been far too many failures of many projects. It is inappropriate to use contractors for complex clean-up projects that have too little experience and expertise. It is also inappropriate to "privatize" complicated clean-up projects by pretending that there is a marketplace in which contractors with the needed expertise are lining up to compete and take the immense financial risks that are involved in the large projects.

The need for such a re-focusing of priorities is clearly indicated by the evidence we have discussed in this report. The aquifer beneath INEEL is already contaminated and there is a large amount of evidence that long-lived radionuclides, including plutonium and americium, have migrated through the vadose zone into the Snake River Plain aquifer.

The clean-up problems in the DOE weapons complex are difficult and often unique. They require research and development and proper technology selection. Independent review of new projects, contractor selection, and possibly an entirely new institutional arrangement at least for sites where there is no production mission should be considered with some urgency. A great deal of money has already been spent, and a considerable amount of it has been wasted. Both environmental and fiscal considerations demand action for institutional change.

Appendix A: The Snake River Plain aquifer

The Snake River Plain aquifer is one of the most important water sources in North America. It is approximately 325 kilometers (200 miles) long, 65 to 95 kilometers (40 to 60 miles) wide, and covers an area of about 25,000 square kilometers (9,600 square miles).[199] With approximately 2 billion acre-feet of water, it is the largest unified aquifer in Idaho and the second largest in North America.[200]

The aquifer consists of a thick sequence of basalts and sedimentary rock that fill a large, bow-shaped basin. Basalt is formed from molten lava expelled from a vent or fissures in the crust of the planet.[201] These layers of basalt, or lava rock, are interspersed with sedimentary interbeds, which were accumulated during periods of volcanic inactivity (thousands to hundreds of thousands of years). The sedimentary interbeds consist of clay, silt, sand, and gravel that were deposited by rivers, lakes and wind.[202]

Snake River Plain aquifer discharges from springs that flow into the Snake River and from irrigation pumping. Numerous springs break out of the basaltic cliffs on the north and east banks of the Snake River at Thousand Springs in south central Idaho (near Twin Falls, 100 miles southwest of INEEL). Another major area of springs and seepage from the aquifer occurs in the vicinity of the American Falls Reservoir (west of Pocatello).[203] About 7.1 million acre-feet of water is discharged by the aquifer annually to springs and rivers (estimate in 1986).[204]

Recharge to the Snake River Plain aquifer is primarily from infiltration of applied irrigation water (5.1 million acre-feet), which accounts for as much as 60% of the water returning to the aquifer, and from valley underflow (1.5 million acre-feet). Recharge from river seepage is approximately 1.3 million acre-feet. Significant recharge of the aquifer beneath INEEL comes from the infiltration of streamflow and groundwater inflow from adjoining mountain drainage to the north and northeast, including the Henry's Fork of the Snake River, Big Lost River, Little Lost River, and Birch Creek drainage areas.[205] This drainage area is approximately 35,000 square miles.[206] Some recharge also occurs from direct infiltration of precipitation, estimated at 0.8 million acre-feet.[207] However, the low annual precipitation, evapotranspiration, and the great depth to the aquifer probably minimize this source of recharge.[208]

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[199] DOE, December 1993, page 2-58
[200] DOE, December 1999, page 4-58; USGS, 1995a, page 2
[201] USGS, February 1999, page 4
[202] USGS, May 1989, page 1
[203] DOE, December 1999, page 4-58
[204] DOE, December 1993, page 2-58
[205] DOE, December 1993, pages 2-58 and 2-60
[206] DOE, December 1999, page 4-58
[207] DOE, December 1993, page 2-58
[208] USGS, April 1997, page 18

Localized zones of perched groundwater at INEEL are attributed mainly to infiltration of water from unlined percolation ponds and to recharge from the Big Lost River.[209]

Water in the Snake River Plain aquifer moves principally through fractures and interflow zones in the basalt.[210] A significant portion of the groundwater moves through the upper 200 to 900 feet of the basaltic rocks. The thickness of the aquifer ranges from 250 to more than 3,000 feet.[211] The regional direction of groundwater flow is generally southwestward, at a rate of 1.5 to 6 meters per day (5 to 20 feet per day), from areas of recharge to areas of discharge.[212] However, the local groundwater flow is quite complex and only partially understood. Water flows along the path of least resistance and is affected by recharge from rivers, surface water spreading areas, pumpage, and inhomogeneities in the aquifer.

INEEL is located in a closed drainage basin, the Pioneer Basin, which includes three main surface-water bodies: the Big Lost River, Little Lost River, and Birch Creek. The Big Lost River is the major surface water at INEEL, but the river does not always reach the site boundary. Forty miles upstream of INEEL, the waters of the Big Lost River are impounded and regulated by the Mackay Dam. Water that is released from the dam is drawn out of the river at several irrigation diversions between the Mackay Dam and the Eastern Snake River Plain. When flow in the Big Lost River reaches INEEL, it is first diverted by a dam, located near the southwestern boundary of the site, to a series of natural depressions or spreading areas. The diversion dam was built in 1958 (and enlarged in 1984) to prevent the flooding of downstream areas during periods of heavy runoff. The water in the spreading areas quickly infiltrates to the Snake River Plain aquifer. The artificially constructed spreading area has resulted in surface water flow off of the INEEL southern boundary.[213]

Birch Creek flows in a southeasterly direction onto the Snake River Plain. The water in the creek is diverted from its natural channel 6.4 kilometers (4 miles) upstream of the INEEL northern boundary by a canal for irrigation and hydropower. Water not used for irrigation during the off-season, usually November through mid-April, is returned to the main Birch Creek channel within the site boundary. The channel leads to a gravel pit near Playa 4, which is 6.4 kilometers (4 miles) north of the main facilities at Test Area North, where it infiltrates the ground. If the flow is interrupted in the winter, the channel and pit bottom may freeze, reducing infiltration rates. A second channel is then used to deliver the water to a second gravel pit east of Test Area North.[214]

The Little Lost River streamflow is diverted for irrigation before it reaches the INEEL boundary. Surface water from the river rarely reaches the site.[215]

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[209] USGS, February 1999, page 7
[210] USGS, April 1997, page 1
[211] DOE, December 1999, page 4-58
[212] ESRF, August 1998, page 1-4; USGS, November 1995, page 6
[213] USGS, April 1997, page 18; DOE, December 1999a, pages 4-49 to 4-54
[214] DOE, December 1993, page 2-7
[215] DOE, December 1999, pages 4-49 to 4-54

Appendix B: Maximum Contaminant Levels in Drinking Water

Radioactive contaminant	MCL[216] (picocuries per liter, unless stated)
Tritium	20,000
Strontium-90	8
Iodine-129	1
Technetium-99	900
Total uranium (As of Dec 2003)	30 micrograms per liter
Plutonium-238	15
Plutonium-239/240 (undivided)	15
Americium-241	15
Neptunium-237	15
Gross alpha[217]	15[218] (The sub-limit for radium is 5 picocuries per liter)
Gross beta/photon emitters	4 millirem/year[219]
Cesium-137	200
Cobalt-60	100

Inorganic contaminant	MCL[220] (milligrams per liter)
Chromium (total)	0.1
Mercury	0.02
Total nitrate & nitrogen (as nitrogen)	10
Chloride	250
Sulfate	250
Lead	50 micrograms per liter
Sodium	None - 250 advisory based on aesthetic concerns

Purgeable organic compounds	MCL[221] (micrograms per liter)
Carbon tetrachloride	5
Trichloroethylene (TCE)	5
1,1,1-trichloroethane	200
Tetrachloroethylene (PCE)	5
Total trihalomethane	100
Ethylbenzene	700
Total xylenes	10,000
p-dichlorobenzene	75
Toluene	1000
Chloroform	100

[216] 10 CFR 20, Appendix B and DOE Order 5400.5
[217] Includes radium-226, but not radon and uranium.
[218] 40 CFR 141 Subpt. O, Appendix B
[219] 40 CFR 141 Subpt. O, Appendix B
[220] 40 CFR 141.62
[221] 40 CFR 141.61

Appendix C: Properties of Relevant Chemicals

Chemical	Uses	Properties	Health Effects
Trichloroethylene (TCE) (CAS 79-01-6)	• Solvent, machine degreaser • Building block for other chemicals	• Decomposes when heated to form phosgene, HCl, and chlorine • Reacts violently with some metals • Slowly decomposed by light in the presence of moisture	• Swallowing can cause aspiration of lungs • Exposure to high doses can affect central nervous system • Repeated and prolonged exposure can cause kidney and liver damage
Carbon tetrachloride (CAS 56-23-5)	• Produced in large quantities to make refrigerator fluid and propellants for aerosol cans • Used as an organic solvent	• Colorless liquid with a sweet odor • Produces noxious fumes when heated • Reacts violently with some metals such as aluminum, barium, magnesium, potassium, sodium, fluorine, causing fire and explosion hazard • Attacks copper, lead and zinc • Evaporates easily	• Causes eye irritation • May affect the liver, kidneys and the central nervous system, resulting in unconsciousness • Repeated or prolonged contact with skin may cause dermatitis • Classified as a probable human carcinogen
Tetrachloroethylene (CAS 127-18-4)	• Used for dry cleaning and for metal-degreasing operations • Building block for many other chemicals	• Colorless with a distinctive odor • When heated, decomposes to form HCl, phosgene, and chlorine • Reacts with metals such as aluminum, lithium, barium, beryllium	• Causes irritation of eye, skin, and respiratory tract • Swallowing can lead to chemical pneumonitis • Repeated exposure can affect liver and kidney • Classified as a definite animal carcinogen with limited evidence that it is carcinogenic to humans
Trichloroethane (CAS 71-55-6)	• Used as a solvent • Found in household items such as glue, paint, and cleaners	• Colorless liquid with distinctive odor • Reacts violently with aluminum, manganese and their alloys, alkalis, strong oxidants, acetone and zinc	• Exposure can lead to irritation of eyes, skin, and respiratory tract • Exposure can cause effects on the heart and central nervous system, kidneys and liver, resulting in cardiac disorders and respiratory failure
Chromium (CAS 7440-47-3)	• Naturally occurring in three forms • Also used in steel, dyes, plating, tanning, and wood preservation	• Steel grey metal • Binds strongly to soil particles	• Chronic exposure can lead to lung and kidney damage • Shown to cause reproductive problems in lab animals • Some forms are carcinogenic
Cadmium (CAS 7440-43-9)	• Naturally occurring • Also found in: batteries, pigments, metal coatings, plastics	• Bluish solid • Slightly soluble in water • Binds tightly to soil particles	• Builds up in kidneys, possibly leading to kidney malfunction • Causes lung damage and fragile bones • Classified as a probable human carcinogen

Lead (CAS 7439-92-1)	• Naturally occurring • Also found in batteries, ammunition, metal products, x-ray shielding	• Bluish grey metal • Binds to soil • Does not move to water unless water is slightly acidic or "soft"	• Affects almost every organ in body, central nervous system most sensitive • Children are particularly sensitive • Classified as a probable human carcinogen
Mercury (CAS 7439-97-6)	• Used in a variety of chemical processes • Used to produce chlorine gas and caustic soda and in thermometers, dental fillings, and batteries • Used in pulp and paper manufacturing	• Reacts violently with alkali metals, acetylene, azides, ammonia gas, chlorine, chlorine dioxide, sodium carbide and ethylene oxide • Toxic fumes are formed upon heating	• Causes kidney damage • Prolonged low level exposure can cause clouding of the eyes • Can damage central nervous system

CAS = Chemical Abstract Service registry number

Sources: University of Vermont Material Safety Data Sheet Archive (http://siri.uvm.edu/msds/);
New Jersey Right to Know Program (http://www.state.nj.us/health/eoh/rtkweb/rtkhsfs.htm);
ATSDR ToxFaq Archive (http://www.atsdr.cdc.gov/toxfaq.html)

Appendix D: Fate of Pollutants in the Soil

Chemical	Soil absorption properties
1,1,1-Trichloroethane	• Not adsorbed strongly by soils, especially subsurface soils
Carbon Tetrachloride	• High mobility in soil
Tetrachloroethylene	• Showed high mobility in soils with little organic content
Trichloroethylene	• Readily transported through soil • Low potential adsorption to sediments
Cadmium	• Soil pH is the principal factor affecting the distribution of cadmium between soil and water. Sorption increases with increasing pH. Increasing the cation exchange capacity and the iron and magnesium hydroxy-oxide, organic, and calcium carbonate content of the soil decreases the adsorption of cadmium to soil
Chromium	• In study of treatment of soil with sewage sludge, chromium was seen to move to a depth of 10 cm with most of it (87%) being retained in the upper 5 cm
Lead (Pb)	• Limited mobility except when soluble organic complexes or when the soil lead exchange capacity approaches saturation • Three processes, adsorption at mineral surfaces (or on hydrous iron oxides), formation of stable organic complexes, and precipitation of sparingly soluble Pb compounds (sulfates, phosphates, carbonates), act to limit Pb availability to plants from the soil • Pb is most available from acidic sandy soils which contain little material capable of binding Pb
Mercury*	• Strongly sorbed in soils with high organic content and pH higher than 4
Strontium	• The main parameters governing strontium sorption were cation-ion exchange capacity of the sediment and ionic strength of the groundwater
Iodine	• Mobility is dependent upon the organic content of the soil
Plutonium**	• Has the potential for high mobility in soil • Major factors involved are pH, clay content, calcium carbonate and organic matter content
Americium	• Same as plutonium
Tritium	• Migrates at the same rate as surface and ground waters • May be fixated on soils containing clay and other Hydrated minerals

Source: National Library of Medicine, *ToxNet Hazardous Substance Database* (http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB);
*ATSDR Toxicological Profile for Mercury, 1999;
**Adams and Carboneau (1999), *National Low Level Waste Program Vol 17: Pu-239* (http://www.inel.gov/national/pdf/llw-251.pdf)

Glossary

Aliquot: A portion of a sample. It is common practice to subdivide a sample into aliquots that are used when needed rather than handling the total sample.[222]

Aquifer: Underground porous rock that is saturated with water and is sufficiently permeable to conduct groundwater so as to enable its extraction.

Acre-foot: The volume of water necessary to cover one acre to a depth of one foot. Equal to 43,560 cubic feet or 325,851 gallons or 1,233 cubic meters.

Alpha decay: The emission of a nucleus of a helium atom from the nucleus of an element, generally of a heavy element, in the process of its radioactive decay.

Beta decay: The emission of electrons or positrons (particles identical to electrons, but with a positive electrical charge) from the nucleus of an element in the process of radioactive decay of the element.

Calcination: The process by which liquid HLW and mixed TRU are converted into the granular solid, known as calcine, which is more stable for storage

Closed drainage basin: A basin draining to some depression or pond within its area, from which water is lost only by evaporation or percolation.[223]

Cold waste: Waste that is not contaminated with radionuclides

Colloid: A substance consisting of very tiny particles that are suspended in a continuous medium, such as a liquid.

Contaminant: Any substance that when added to water (or another substance) makes it impure and unfit for consumption or use.[224]

Contaminant plume: The zone of polluted groundwater down-gradient from a point source of pollution.

Criticality accident: An unintended amassing of fissile material (like plutonium-239) that results in the unintended creation of a chain reaction. The emission of neutrons and gamma radiation during an accidental criticality can cause severe radiation exposure to workers. The fission products resulting from such an accidental criticality would increase contamination of the location.

Curie: Unit of radioactivity equal to the radioactivity of 1 gram of radium-226. It is equal to 37 billion disintegrations per second.

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[222] CancerWEB, November 1997
[223] WGRFC, 2001
[224] Groundwater Foundation, 2001

Derived concentration guide (DCG): The concentration that would result in a radiation dose equal to the public dose limit of 100 millirems per year. The DCGs consider the inhalation of air, the ingestion of water, and submersion in air, but not the intake of contaminated food. This is 100 millirem each for air and water in DOE regulations.

DNAPL (dense, non-aqueous phase liquid): Layer or film of fluid insoluble in water with a specific gravity greater than that of water.[225]

Evaporation pond: An artificial pond into which aqueous wastes are discharged. The theory is that the water would evaporate leaving solid residues behind. In practice some seepage of water (and hence contaminants) generally occurs.

Groundwater: Water beneath the surface of the earth that can be collected with wells, tunnels, or drainage galleries, or that flows naturally to the earth's surface via seeps or springs.[226]

Half-life: The amount of time that it takes half a given quantity of a radioactive element to decay.

Hazardous chemicals: Chemicals that are toxic, corrosive, flammable, or reactive. Waste consisting of hazardous materials may be solid, semi-solid, or liquid.

Hydraulic containment: Pumping (extracting) groundwater at a rate that does not allow incoming groundwater to flow past the source material, to prevent the contamination from spreading away from the containment area.

Hydraulic conductivity: The constant of proportionality that allows equation of the proportional relationship between specific discharge through a porous medium and hydraulic gradient. Hydraulic conductivity is a function of both the porous medium and the fluid flowing through the porous medium.[227]

Ion-exchange: A reversible chemical reaction in which an ion (an atom or molecule with an electrical charge) from solution is exchanged for a similarly charged ion attached to an immobile solid particle. Soil exhibits ion-exchange activity.

Ion-exchange capacity: The measure of the ability of an immobile solid particle to undergo displacement of previously attached ions by oppositely charged ions present in the surrounding solution.

Infiltration pond: A pond (usually man-made) designed to allow wastewater to percolate slowly into the ground. The pond acts as a holding facility while gravity allows the water to percolate or seep through the soil or other unconsolidated medium into the local water table and lower aquifers.[228] (Also called percolation pond.)

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[225] GWRTAC, 2001
[226] University of Arizona, 2001
[227] GWRTAC, 2001
[228] USGS, 2001

Injection well: A well used for injecting water or other fluid into a groundwater aquifer.[229]

In-situ bioremediation: Amendments (such as sodium lactate or molasses) are added to the groundwater to stimulate the growth of bacteria that can breakdown the pollutant. Can also involve the use of plants or non-endemic bacteria.

Irrigation: The controlled application of water to agricultural land to supplement natural precipitation.

Isotope: A variant of an element that has the same number of protons (and hence the same chemical properties), but a different number of neutrons, and therefore, a different atomic weight.

Low-level wastes: In the United States, any radioactive waste that is not classified as high-level waste, transuranic waste, or uranium mill tailings. Low-level wastes can contain short- and long-lived radionuclides.

Maximum contaminant level goal (MCLG): The level of a contaminant in drinking water below which there is not known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals. In cases where there is no threshold, according to current best available scientific analysis, the maximum contamination goal is zero.[230]

Maximum contaminant level (MCL): The maximum permissible level of a chemical or radionuclide contaminant in water that is delivered to any user of a public water system. MCLs are set as close to MCLGs as feasible using the best available technology and taking cost into consideration. MCLs are enforceable standards set by the EPA or the NRC.[231]

Monitoring well: A non-pumping well used for drawing water quality samples.

Natural attenuation: Naturally occurring reduction of contaminant concentrations in the aquifer through radioactive decay, dilution, and dispersion.

NRC: Nuclear Regulatory Commission.

Perched water table: The water table of a relatively small groundwater body lying above the general groundwater body.[232]

Percolation pond: A pond (usually man-made) designed to allow wastewater to percolate slowly into the ground. The pond acts as a holding facility while gravity allows the water to percolate or seep through the soil or other unconsolidated medium into the local water table and lower aquifers.[233] (Also called infiltration pond.)

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[229] University of Arizona, 2001
[230] EPA, 2001
[231] EPA, 2001
[232] University of Arizona, 2001
[233] USGS, 2001

Playa: A dry, vegetation-free, flat area at the lowest part of an undrained desert basin, underlain by stratified clay, silt, or sand, and commonly by soluble salts. They are occasionally covered by shallow lakes in the wettest part of the year.[234]

Plutonium: A highly toxic, heavy radioactive metallic element. There are 15 isotopes of plutonium, of which only five have been produced in significant quantities: plutonium-238, -239, -240, -241, and -242. The fissile isotope used to make nuclear weapons is plutonium-239.

Pump-and-treat technology: A process for removing contaminants from groundwater by bringing groundwater to the surface, treating it to remove contamination and returning it to the ground

Radioactivity: The spontaneous discharge of radiation from atomic nuclei, usually in the form of beta or alpha radiation. Beta or alpha emission results in the transformation of the atom into a different element, changing the atomic number by +1 or –2 respectively. In many cases, the radioactive decay is accompanied by the emission of gamma radiation (high frequency electromagnetic radiation).

Radionuclide: Any radioactive nucleus of an element.

Recharge: replenishment of groundwater when water enters the aquifer.

Reprocessing: The chemical separation of irradiated nuclear fuel into uranium, plutonium, and fission products.

Sole-source aquifer: Aquifer that provides a minimum of 50% of the water for its users. Under the Safe Drinking Water Act, the U.S. EPA can determine that an area has an aquifer that is the sole or principal drinking water source for the area and, if contaminated, would create a significant hazard to public health. Thereafter, no Federal financial assistance can be used for any project that would contaminate the aquifer through a recharge zone so as to create a significant hazard to public health.

Sorption: The process in which chemicals become associated with solid phases.[235]

Source term: The amount of a specific pollutant emitted or discharged to a particular medium, such as the air or water, from a particular source.

Transuranic element: An element with an atomic number greater than 92, which is the atomic number of uranium.

Trichloroethylene (TCE): An industrial solvent and suspected human carcinogen commonly found as a pollutant in urban groundwater.[236]

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[234] S.CA Earthquake Data Center, 2001
[235] MSU, 2001
[236] University of Arizona, 2001

Tritium: A radioactive isotope of hydrogen with a half-life of 12.3 years and having one proton and two neutrons in its nucleus.

Vadose zone: The unsaturated zone lying between the earth's surface and the water table.[237]

Volatile organic compounds (VOCs): Organic compounds that evaporate readily at normal air temperatures and pressures. Examples of organic compounds are petroleum and petroleum-based solvents.

Warm waste: Waste that is contaminated with radionuclides.

Water table: The upper boundary of a free groundwater body, at atmospheric pressure.[238]

[237] University of Arizona, 2001
[238] University of Arizona, 2001

References

AEC, 1960 US Atomic Energy Commission, Health and Safety Division, Idaho Operations Office. *Environmental Monitoring Data Annual Summary for the National*

DOE, June 1993 — US Department of Energy, Idaho Operations Office. *Idaho National Engineering Laboratory Groundwater Monitoring Plan.* DOE/ID-10441. [Idaho Falls]. June 1993.

DOE, December 1993 — Kaminsky, J.F., K.N. Keck, A.L. Schafer-Perini, C.F. Hersley, R.P. Smith, G.J. Stormberg, and A.H. Wylie. *Remedial Investigation Final Report with Addenda for the Test Area North Groundwater Operable Unit 1-07B at the Idaho National Engineering Laboratory, Volume I.* EGG-ER-10643. Revision 0. Idaho Falls. December 1993.

DOE, May 1995 — US Department of Energy, Nevada Operations Office. *Cost/Risk/Benefit Analysis of Alternative Cleanup Requirements for Plutonium-Contaminated Soils On and Near the Nevada Test Site.* DOE/NV-399. [Las Vegas]. May 1995.

DOE, June 1996 — US Department of Energy, Office of Environmental Management. Office of Strategic Planning and Analysis. *The 1996Baseline Environmental Management Report.* Volume II, Alaska - New Jersey.DOE/EM-0290. [Washington, DC]. June 1996.

DOE, January 1997 — US Department of Energy, Office of Environmental Management. *Linking Legacies: Connecting the Cold War Nuclear Weapons Production Processes to Their Environmental Consequences.* DOE/EM-0319. January 1997.

DOE, November 1997a — Rodriguez, R.R., A.L. Schafer, J. McCarthy, P. Martian, D.E. Burns, D.E. Raunig, N.A. Burch, and R.L. VanHorn. *Comprehensive RI/FS for the Idaho Chemical Processing Plant OU 3-13 at the INEEL – Part A, RI/BRA Report (Final).* DOE/ID-10534. [Idaho Falls]. November 1997.

DOE, November 1997b — Blackmore, C.S., D.E. Burns, T.S. Green, S.M. Lewis, D.L. Michael, and I.E. Stepan. *Comprehensive Remedial Investigation/Feasibility Study for the Test Area North Operable Unit 1-10 at the Idaho National Engineering and Environmental Laboratory.* DOE/ID-10557. Idaho Falls: Idaho National Engineering and Environmental Laboratory; Lockheed Martin Idaho Technologies Company. November 1997.

DOE, December 1997 — US Department of Energy. *Final Record of Decision Test Reactor Area.* Idaho National Engineering and Environmental Laboratory. DOE/ID-10586. Idaho Falls: Operable Unit 2-13, Idaho National Engineering and Environmental Laboratory. December 22, 1997.

DOE, June 1998 — US Department of Energy, Office of Environmental Management. *Accelerating Cleanup: Paths to Closure.* DOE/EM-0362. Washington, DC. June 1998.

DOE, October 1998 — US Department of Energy, Idaho Operations Office. *Comprehensive RI/FS for the Idaho Chemical Processing Plant OU 3-13 at the INEEL – Part B, FS Supplement Report.* DOE/ID-10619. Revision 2. [Idaho Falls]. October 1998.

DOE, July 1999 — Jenkins, Talley. *INEEL Citizens Advisory Board Briefing.* Idaho National Engineering and Environmental Laboratory. Operable Unit 3-14 Work Plan (Idaho Nuclear Technology and Engineering Center. July 21, 1999.

DOE, September 1999 — US Department of Energy. *INEEL Reporter*. Idaho Falls: INEEL Environmental Management Program. September 1999.

DOE, October 1999a — US Department of Energy. *Final Record of Decision Idaho Nuclear Technology and Engineering Center*. DOE/ID-10660. Rev.0. Idaho Falls: Operable Unit 3-13, Idaho National Engineering and Environmental Laboratory. October 1999.

DOE, October 1999b — US Department of Energy. *Final Record of Decision for Test Area North*. DOE/ID-10682. Rev. 0. Idaho Falls: Operable Unit 1-10, Idaho National Engineering and Environmental Laboratory. October 1999.

DOE, October 1999c — US Department of Energy, Office of Environmental Management. *From Cleanup to Stewardship, a companion report to "Accelerating Cleanup: Paths to Closure" and background information to support the scoping process required for the 1998 PEIS Settlement Study*. DOE/EM-0466. [Washington, DC]. October 1999.

DOE, December 1999a — US Department of Energy, Idaho Operations Office. *Idaho High-Level Waste & Facilities Disposition Draft Environmental Impact Statement*. DOE/EIS-0287D. Idaho Falls. December 1999.

DOE, December 1999b — US Department of Energy, Environment, Safety and Health Office of Oversight. *Idaho National Engineering and Environmental Laboratory Site Profile*. [Washington, DC?]. December 1999.

DOE, January 2000 — US Department of Energy. *Record of Decision for the Power Burst Facility and Auxiliary Reactor Area*. DOE/ID-10700. Idaho Falls: Operable Unit 5-12, Idaho National Engineering and Environmental Laboratory. January 2000.

DOE, February/ March 2000 — US Department of Energy. *INEEL Reporter*. Idaho Falls: INEEL Environmental Management Program. Feb/March 2000.

DOE, June 2000a — US Department of Energy, Office of Environmental Management. *Buried Transuranic-Contamination Waste Information for U.S. Department of Energy Facilities*. [Washington, DC]. June 2000.

DOE, June 2000b — U.S. Department of Energy. *INEEL LLW Disposition Map. Dataset: IPAB-IS (6/26/00). Predecisional Draft.*

DOE, June/ July 2000 — US Department of Energy. *INEEL Reporter*. Idaho Falls: INEEL Environmental Management Program. June/July 2000.

DOE, July 2000 — Burgess, J., S. Flynn, P. Jessmore, J. Keck, S. McCormick, M. Rohe, I. Stepan, R. VanHorn, S. Fu, and L. Trozollo. *Comprehensive Remedial Investigation/ Feasibility Study for the Central Facilities Area Operable Unit 4-13 at the Idaho National Engineering and Environmental Laboratory*. DOE/ID-10680. Rev. 1. Idaho Falls: US Department of Energy, Idaho Operations Office; Idaho National Engineering and Environmental Laboratory. July 2000.

DOE, October/ November 2000 — US Department of Energy. *INEEL Reporter.* Idaho Falls: INEEL Environmental Management Program. October/November 2000.

DOE, November 2000 — US Department of Energy. *Draft Proposed Plan for Operable Unit 1-07B, Final Remedial Action at the TSF Injection Well (TSF-05) and Surrounding Groundwater Contamination (TSF-23).* Idaho Falls: Idaho National Engineering and Environmental Laboratory. November 2000.

DOE, March 2001 — US Department of Energy, Idaho Operations Office. "State and INEEL scientists focus on understanding results of radionuclide detection." *DOE News.* Idaho Falls. March 14, 2001.

DOE, August 2001 — US Department of Energy. *A National Roadmap for Vadose Zone Science & Technology: Understanding, Monitoring, and Predicting Contaminant Fate and Transport in the Unsaturated Zone.* DOE/ID-10871. August 2001.

EG&G, August 1991 — Arrenholz, D.A. and J.L. Knight. *A Brief Analysis and Description of Transuranic Wastes in the Subsurface Disposal Area of the Radioactive Waste Management Complex at INEL.* EGG-WTD-9438. DE92003329. Rev. 1. Idaho Falls: EG&G Idaho. August 1991.

EPA, September 1987 — U.S. Environmental Protection Agency. *Causes of Release From UST Systems.* EPA 510-R-92-702. Washington, DC. September 30, 1987.

EPA, 2001 — U.S. Environmental Protection Agency, Office of Water. *Current Drinking Water Standards.* http:// www.epa.gov/safewater/mcl/html (Viewed September 18, 2001).

ERDA, September 1977 — U.S. Energy Research & Development Administration. *Final Environmental Impact Statement, Waste Management Operations, Idaho National Engineering Laboratory, Idaho.* ERDA-1536. [Idaho Falls]. September 1977.

ESRF, July 1994 — Mitchell, Russell G. *Idaho National Engineering Laboratory Site Environmental Report for Calendar Year 1993.* DOE/ID-12082(93). Foundation-002. Idaho Falls: Environmental Science and Research Foundation. July 1994.

ESRF, July 1995 — Mitchell, Russell G., Don Peterson and Diana Hoff. *Idaho National Engineering Laboratory Site Environmental Report for Calendar Year 1994.* DOE/ID-12082(94). Idaho Falls. July 1995.

ESRF, August 1996 — Mitchell, Russell G., Don Peterson and Diana Hoff. *Idaho National Engineering Laboratory Site Environmental Report for Calendar Year 1995.* DOE/ID-12082(95). Environmental Science and Research Foundation report series, no. 014. Idaho Falls: Environmental Science and Research Foundation. August 1996.

ESRF, August 1998 — Evans, Roy B. Donny Roush, Ron W. Brooks, and Don B. Martin. *Idaho National Engineering and Environmental Laboratory Environmental Report for Calendar Year 1997.* ESRF-030. DOE/ID-12082(97).Idaho Falls: Environmental Science and Research Foundation. August 1998.

ESRF, August 1999 — Saffle, Troy and Roy Evans. *Idaho National Engineering and Environmental Laboratory Offsite Environmental Surveillance Program Report: Fourth Quarter 1998.* ESRF-029(4QT98). Idaho Falls: Environmental Science and Research Foundation. August 1999.

ESRF, December 1999 — Evans, Roy. *Idaho National Engineering and Environmental Laboratory Offsite Environmental Surveillance Program Report: Second Quarter 1999.* ESRF-035 (2QT99). Idaho Falls: Environmental Science and Research Foundation. December 1999.

ESRF, June 2000 — Luft, Amy Adams, Roy B. Evans, Troy Saffle, Russell G. Mitchell, and Don B. Martin.. *In Summary: Idaho National Engineering and Environmental Laboratory Site Environmental Report for Calendar Year 1998.* ESRF-036. Idaho Falls: Environmental Science and Research Foundation. June 2000.

ESRF, July 2000 — Environmental Science and Research Foundation. *Idaho National Engineering & Environmental Laboratory Site Environmental Report for Calendar Year 1998.* ESRF-034. DOE/ID-12082(98). Idaho Falls: Environmental Science and Research Foundation. July 2000.

Fioravanti and Makhijani, 1997 — Fioravanti, Marc and Arjun Makhijani. *Containing the Cold War Mess: Restructuring the Environmental Management of the U.S. Nuclear Weapons Complex.* Takoma Park, MD: Institute for Energy and Environmental Research. October 1997.

Freeze and Cherry, 1979 — Freeze, R. Allan. and John A. Cherry. *Groundwater.* Englewood Cliffs, NJ: Prentice-Hall. 1979.

Goodell, 1988 — Goodell, S.A. *Water Use on the Snake River Plain, Idaho and Eastern Oregon.* US Geological Survey Professional Paper 1408-E. Regional Aquifer-System Analysis. Washington, DC: US Geological Survey. 1988

Groundwater Foundation, 2001 — Groundwater Foundation. *Groundwater Basics: Groundwater ABCs,* http://www.groundwater.org/GWBasics/ABCs.htm. 2000. (Viewed August 29, 2001)

Guerrero, March 2000 — Guerrero, Peter F. *Water Quality: Identification and Remediation of Polluted Waters Impeded by Data Gaps.* Testimony before the Subcommittee on Fisheries, Wildlife, and Water, Committee on Environment and Public Works, United States Senate. GAO/T-RCED-00-131. [Washington, DC]: US General Accounting Office. March 23, 2000.

GWRTAC, 2001 — Ground-water Remediation Technologies Analysis Center. *Glossary of Hydrogeologic Terms,* http://www.gwrtac.org/html/glossary.html. 2001. (Viewed August 29, 2001).

Hursthouse and Livens, 1993 — Hursthouse, Andrew S. and Francis R. Livens. "Evidence for the remobilization of transuranic elements in the terrestrial environment." *Environmental Geochemistry and Health.* 15(2/3):163-171.

Idaho State Department of Agriculture, 2001	Idaho State Department of Agriculture, *Production Export Information*, Production Export Information.pdf, http://www.agri.state.id.us/facts.htm. 2001. (Viewed April 5, 2001).
INEEL, October 1998	INEEL Environmental Restoration Program. *Proposed Plan for Waste Area Group 3 at the Idaho Chemical Processing Plant.* [Idaho Falls]. October 1998.
INEEL, 2000	Idaho National Engineering and Environmental Laboratory. *Environmental Management at the INEEL: 2000 Progress.* http://environment.inel.gov. 2000. (Viewed January 25, 2001).
INEEL OP, March 2001	Flint Hall. *Summary of americium-241 and plutonium isotope detections for USGS and DOE contractor sampling the RWMC (through 4th calendar quarter 2000), including detections for State of Idaho OP co-sampling.* Idaho Falls: State of Idaho INEEL Oversight Program. March 23, 2001.
INEEL OP, 2001	Flint Hall. *Americium and Plutonium Detections in Groundwater Beneath the RWMC, 1972-2000.* [Idaho Falls: State of Idaho INEEL Oversight Program]. Map. http://204.134.138.241/ADS-CGI/viewer.pl/op/PDF/fm.PDF. 2001.
Jensen, 1983	Jensen, R.T. "Inventories and Characteristics of Transuranic Waste." *Nuclear and Chemical Waste Management.* 4:19-24. 1983.
Kaae, Holter and Garrett, January 1993	Kaae, P.S., G. M. Holter, and S.M.K. Garrett. *DOE Complex Buried Waste Characterization Assessment.* Buried Waste Integration Demonstration Program. PNL-8390. Richland, WA: Pacific Northwest Laboratory. January 1993.
Keneshea and Smith, 1983	Keneshea, F.J. and T.H. Smith. "Risk Analysis for Transuranic Waste at the Idaho National Engineering Laboratory." *Nuclear and Chemical Waste Management.* 4:63-79. 1983.
Kersting *et al.*, January 1999	Kersting, A.B., D.W. Efurd, D.L. Finnegan, D.J. Rokop, D.K. Smith and J.L. Thompson. "Migration of plutonium in ground water at the Nevada Test Site." *Nature* 397:56-59. January 7, 1999.
Koslow and Van Haaften, June 1986	Koslow, K.N. and D. H. Van Haaften. *Flood Routing Analysis for a Failure of Mackay Dam.* EGG-EP-7184. DE86013458. Idaho Falls: EG&G Idaho. June 1986.
Lakey *et al.*, 1983	Lakey, L.T., H. Christensen, P. DeJonghe, G. Frejaville, J.M. Lavie, and D.G. Thackrah. "Management of transuranic wastes throughout the world." *Nuclear and Chemical Waste Management.* 4: 35-46. 1983.
Langmuir, 1997	Langmuir, Donald. *Aqueous Environmental Geochemistry.* Upper Saddle River, NJ: Prentice Hall. 1997.
Langston, August 2001	Langston, Jennifer, "State Gets Tough with DOE on Pit 9," *Post-Register* (Idaho Falls). August 1, 2001.

LANL, August 1996 — Triay, Inés R., Charles R. Cotter, Suzanne M. Kraus, Matthew H. Huddleston, Steve J. Chipera, and David L. Bish. *Radionuclide Sorption in Yucca Mountain Tuffs with J-13 Well Water: Neptunium, Uranium, and Plutonium.* Yucca Mountain Site Characterization Program Milestone 3338. LA-12956-MS. [Los Alamos, NM]: Los Alamos National Laboratory. August 1996.

LANL, 2000 — Los Alamos National Laboratory, Nuclear Materials Technology Division. *The Actinide Research Quarterly.* Los Alamos, NM. 2nd/3rd quarter 2000.

LANL, December 2000 — Los Alamos National Laboratory. *Environmental Surveillance at Los Alamos during 1999, 30th Anniversary Edition.* LA-13775-ENV. Los Alamos, NM. December 2000.

LASL, June 1978 — Fowler, Eric B., Wilfred L. Polzer, and Edward H. Essington. *Characteristics of Wastes and Soils Which Affect Transport of Radionuclides Through the Soil and Their Relationship to Waste Management. July 1, 1976 – September 30, 1977.* NUREG/CR-0125. LA-7311-PR progress report. Los Alamos, NM: Los Alamos Scientific Laboratory. June 1978.

Lipschutz, 1980 — Lipschutz, Ronnie D. *Radioactive Waste: Politics, Technology, and Risk.* Union of Concerned Scientists. Cambridge, Mass: Ballinger Publishing Company. 1980.

LLNL, May 1998 — Smith, David K., Annie B. Kersting, Timothy P. Rose, Jacqueline M. Kenneally, G. Bryant Hudson, Gail F. Eaton, and M. Lee Davisson. *Hydrologic Resources Management Program and Underground Test Area Operable Unit, FY 1997 Progress Report.* UCRL-ID-130792. [Livermore, CA]: Lawrence Livermore National Laboratory. May 1998.

LMITCO, November 1997 — Lockheed Martin Idaho Technologies Company. *Comprehensive RI/FS for the Idaho Chemical Processing Plant OU 3-13 at the INEEL – Part B, FS report.* Idaho Falls: Idaho National Engineering and Environmental Laboratory. DOE/ID-10572. Idaho Falls. November 1997.

LMITCO, 1998 — Becker, Bruce, Swen Magnuson, and Jeff Sondrup. *Development of a Comprehensive Source Term Model for the Subsurface Disposal Area at the Idaho National Engineering and Environmental Laboratory.* Presented at Waste Management 1998. DE98054117. Tuscon, AZ: Lockheed Martin Idaho Technologies Company. 1998.

LMITCO, September 1998 — Lockheed Martin Idaho Technologies Company. *1997 LMITCO Environmental Monitoring Program Report for the Idaho National Engineering and Environmental Laboratory.* INEEL/EXT-98-00305. Idaho Falls: Idaho National Engineering and Environmental Laboratory, Lockheed Martin Idaho Technologies Company. September 1998.

LMITCO, September 1999 — Lockheed Martin Idaho Technologies Company. *1998 LMITCO Environmental Monitoring Program Report for the Idaho National Engineering and Environmental Laboratory.* INEEL/EXT-99-00002. Idaho Falls: Idaho National Engineering and Environmental Laboratory, Environmental Monitoring Group, Lockheed Martin Idaho Technologies Company. September 1999.

LMITCO, March 1999 — Ritter, P.D. and D.L. McElroy. *Progress Report: Tritium and Carbon-14 Sampling at the Radioactive Waste Management Complex.* INEEL/EXT-98-00669. Idaho Falls: Lockheed Martin Idaho Technologies Company. March 1999.

Lockheed, August 1995 — Lockheed Idaho Technologies Company. *A Comprehensive Inventory of Radiological and Nonradiological Contaminants in Waste Buried in the Subsurface Disposal Area of the INEL RWMC During the Years 1952-1983.* INEL-95/0310. Idaho Falls: Idaho National Engineering Laboratory. August 1995.

Lockheed, February 1997 — Lockheed Idaho Technologies Company. *Comprehensive Remedial Investigation/Feasibility Study for the Test Reactor Area Operable Unit 2-13 at the Idaho National Engineering and Environmental Laboratory.* DOE/ID-10531. Idaho Falls. February 1997.

Makhijani *et al.*, July 1986 — Makhijani, Arjun, Robert Alvarez, and Brent Blackwelder. *Deadly Crop in the Tank Farm: An Assessment of the Management of High-Level Radioactive Wastes in the Savannah River Plant Tank Farm, Based on Official Documents.* Washington, DC: Environmental Policy Institute. July 1986.

Mann and Beasley, December 1994 — Mann, Larry J. and T.M. Beasley. "Background Concentration of ^{129}I in Ground and Surface Water, Eastern Snake River Plain, Idaho - 1992." *Journal of the Idaho Academy of Science.* 30(2):75-87. December 1994.

Marty, Bennett and Thullen, 1997 — Marty, Richard C., Deborah Bennett, and Philip Thullen. "Mechanism of Plutonium Transport in a Shallow Aquifer in Mortandad Canyon, Los Alamos National Laboratory, New Mexico." *Environmental Science & Technology.* 31(7): 2020-2027. 1997.

McCarthy *et al.*, 1998 — McCarthy, John F., William E. Sanford, and Paige L. Stafford. "Lanthanide Field Tracers Demonstrate Enhanced Transport of Transuranic Radionuclides by Natural Organic Matter," *Environmental Science & Technology.* 32 (24). December 15, 1998.

MSU, 2001 — Michigian State University, College of Engineering. Glossary. http://www.egr.msu.edu/schoolcraft/glossary.htm. 2001. (Viewed September 27, 2001)

NAS-NRC, 1983 — National Research Council, Board on Radiation Effects Research, Waste Isolation Systems Panel. *A Study of the Isolation System for Geologic Disposal of Radioactive Wastes.* Washington, DC: National Academy Press. 1983.

NAS-NRC, 1999a — National Research Council, Board on Radiation Effects Research. Committee on Evaluation of EPA Guidelines for Exposure to Naturally Occurring Radioactive Material. *Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials.* Washington, DC: National Academy Press. 1999.

NAS-NRC, 1999b — National Research Council, Board on Radioactive Waste Management. Committee on Technologies for Cleanup of Subsurface Contaminants in the DOE Weapons Complex. *Groundwater & Soil Cleanup: Improving Management of Persistent Contaminants*. Washington, DC: National Academy Press. 1999.

NAS-NRC, 2000a — National Research Council, Board on Radioactive Waste Management, Committee on the Remediation of Buried and Tank Wastes. *Long-Term Institutional Management of U.S. Department of Energy Legacy Waste Sites*. Washington, DC: National Academy Press. 2000.

NAS-NRC, 2000b — National Research Council, Board on Radioactive Waste Management, Water Science and Technology Board. *Research Needs in Subsurface Science: U.S. Department of Energy's Environmental Management Science Program.* Washington, DC: National Academy Press. 2000.

Nimmo *et al.*, 2001 — Nimmo, J.R., K.S. Perkins, P.E. Rose, J.P. Rousseau, B.R. Orr, B.V. Twining, and S.R. Anderson. "Kilometer-Scale Rapid Flow in a Fractured-Basalt Unsaturated Zone at the Idaho National Engineering and Environmental Laboratory." Overhead presentation. Eighth Biannual Unsaturated Zone Interest Group Meeting. Idaho Falls. July 30-August 2, 2001.

Nokkentved, March 2001 — Nokkentved, N.S. "Plutonium detected in Snake River Plain Aquifer." *Times-News*, Twin Falls, Idaho. March 16, 2001.

ORNL, March 1980 — Jacobs, D.G., J.S. Epler, and R.R. Rose. *Identification of Technical Problems Encountered in the Shallow Land Burial of Low-Level Radioactive Wastes.* ORNL/SUB-80/13619/1. Oak Ridge, TN: Oak Ridge National Laboratory. March 1980.

ORNL, December 1997 — Oak Ridge National Laboratory. *Integrated Data Base Report – 1996: U.S. Spent Nuclear Fuel and Radioactive Waste Inventories, Projections, and Characteristics*. DOE/RW-0006, Rev. 13. Washington, DC: US Department of Energy, Office of Environment Management. December 1997.

OTA, February 1991 — US Congress, Office of Technology Assessment. *Complex Cleanup: The Environmental Legacy of Nuclear Weapons Production.* OTA-O-484. Washington, DC: US Government Printing Office. February 1991.

Penrose *et al.*, 1990 — Penrose, William R., Wilfred L. Polzer, Edward H. Essington, Donald M. Nelson, and Kent A. Olandini. "Mobility of Plutonium and Americium through a Shallow Aquifer in a Semiarid Region." *Environmental Science and Technology*. 24(2): 228-234. 1990.

Roback *et al.*, November 2000 — Roback, Robert C., Deward W. Efurd, Michael T. Murrell, Robert E. Steiner, and Clarence J. Duffy. *Assessment of Uranium and Plutonium in the Saturated and Unsaturated Zones Beneath the Subsurface Disposal Area, INEEL.* LA-UR-00-5471. [Los Alamos, NM]. Los Alamos National Laboratory. http:/lib-ww.lanl.gov/la-pubs/00818330.pdf. November, 13 2000.

Rodgers, 1983	Rodgers, John C. "Radiological Hazards of Waste Containing Alpha-Emitting Radionuclides." *Nuclear and Chemical Waste Management.* 4:95-101. 1983.
Rogers, 1983	Rogers, V.C. "Overview of risks from disposed waste containing transuranic elements." *Nuclear and Chemical Waste Management.* 4:53-62. 1983.
Runde, 2000	Runde, Wolfgang. "The Chemical Interactions of Actinides in the Environment," *Challenges in Plutonium Science, Volume II, Los Alamos Science, Number 26.* Los Alamos, NM : Los Alamos National Laboratory. 2000. pp. 392-411.
Ryan and Elimelech, 1996	Ryan, Joseph N. and Menachem Elimelech. "Colloid mobilization and transport in groundwater." *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 107:1-56. 1996.
Schwartz (ed), 1998	Stephen I. Schwartz (ed). *Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons since 1940.* Washington, DC: Brookings Institution Press. 1998.
S.CA Earthquake Data Center, 2001	Southern California Earthquake Data Center. *Glossary.* http://www/scecdc.scec.org/glossary.html. 2001. (Viewed August 29, 2001).
Settlement Agreement, 1995	*Settlement Agreement* [US Department of Energy, Department of the Navy Propulsion Program, and the State of Idaho]. October 16, 1995. http://environment.inel.gov/agree.html. 1995. (Viewed September 30, 2000).
Smith, 1983	Smith, C.F. "A Review of Risk Assessments for Radioactive Waste Containing Alpha-Emitting Radionuclides." *Nuclear and Chemical Waste Management.* 4:47-52. 1983.
Stacy, 2000	Stacy, Susan M. *Proving the Principle: A History of the Idaho National Engineering and Environmental Laboratory 1949-1999.* DOE/ID-10799. Idaho Falls: Idaho Operations Office of the Department of Energy. 2000.
Torstenfelt, Rundberg and Mitchell, 1988	Torstenfelt, Börje, Robert S. Rundberg, and Alan J. Mitchell. "Actinide Sorption on Granites and Minerals as a Function of pH and Colloids/Pseudocolloids." *Radiochimica Acta.* 44/45:111-117. 1988.
University of Arizona, 2001	University of Arizona, College of Agriculture, Water Resources Research Center. *Glossary of Water-Related Terms.* http://ag.arizona.edu/azwater/reference/gloss.html. (Viewed September 21, 2001).
USDA, March 2001	US Department of Agriculture, Economic Research Service. *Aquaculture Outlook.* LDP-AQS-13. [Washington, DC?]. March 14, 2001.
USGS, February 1974	Robertson, J.B., Robert Shoen, and J.T. Barraclough. *The Influence of Liquid Waste Disposal on the Geochemistry of Water at the National Reactor Testing Station, Idaho: 1952-70.* USGS Open-File Report IDO-22053. Idaho Falls: US Geological Survey. February 1974.

USGS, August 1976 — Barraclough, J.T., J.B. Robertson and V.J. Janzer, with a section on drilling and sample analysis by L.G. Saindon. *Hydrology of the Solid Waste Burial Ground, as Related to the Potential Migration of Radionuclides, Idaho National Engineering Laboratory.* Open-File Report 76-471. IDO-22056. Idaho Falls: US Geological Survey, Water-Resources Division. August 1976.

USGS, December 1988 — Knobel, LeRoy L. and Larry J. Mann. *Radionuclides in Ground Water at the Idaho National Engineering Laboratory, Idaho.* Open-File Report 88-731. DOE/ID-22077. DE89009736. Idaho Falls: US Geological Survey. December 1988.

USGS, May 1989 — Anderson, S.R. and B.D. Lewis. *Stratigraphy of the Unsaturated Zone at the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho.* Water-Resources Investigations Report 89-4065. DOE/ID-22080. Idaho Falls: US Geological Survey. May 1989.

USGS, 1992 — R.L. Whitehead. *Geohydrologic Framework of the Snake River Plain Regional Aquifer System, Idaho and Eastern Oregon.* US Geological Survey Professional Paper 1408-B. Regional Aquifer-System Analysis -- Snake River Plain, Idaho. Washington, DC: United States Government Printing Office. 1992.

USGS, 1993a — Bartholomay, Roy C., *Concentrations of Tritium and Strontium-90 in Water from Selected Wells at the Idaho National Engineering Laboratory After Purging One, Two, and Three Borehole Volumes.* Water-Resources Investigations Report 93-4201. DOE/ID-22111. Idaho Falls: US Geological Survey. 1993.

USGS, 1993b — Cleveland, Jesse M. and Ann H. Mullin. *Speciation of Plutonium and Americium in Ground Waters from the Radioactive Waste Management Complex, Idaho National Engineering Laboratory, Idaho.* Water-Resources Investigations Report 93-4035. Denver: US Geological Survey. 1993.

USGS, April 1994 — Mann, Larry J. and T.M. Beasley. *Iodine-129 in the Snake River Plain Aquifer At and Near the Idaho National Engineering Laboratory, Idaho, 1990-91.* Water-Resources Investigations Report 94-4053. Idaho Falls: US Geological Survey. April 1994.

USGS, 1995a — Ackerman, Daniel J. *Analysis of Steady-State Flow and Advective Transport in the Eastern Snake River Plain System, Idaho.* Water-Resources Investigations Report 94-4257. DOE/ID-22120. Idaho Falls: US Geological Survey. 1995.

USGS, 1995b — US Geological Survey. Water Resources of Idaho. *1995 Water Use Hydrologic Unit Estimates.* http://idaho.usgs.gov/public/water.use.1995.h8.html. 1995. (Viewed January 10, 2001).

USGS, August 1995 — Bartholomay, Roy C., Brennon R. Orr, Michael J. Liszewski, and Rodger G. Jensen. *Hydrologic Conditions and Distribution of Selected Radiochemical and Chemical Constituents in Water, Snake River Plain Aquifer, Idaho National Engineering Laboratory, Idaho, 1989 Through 1991.* Water-Resources Investigations Report 95-4175. DOE/ID-22123. Idaho Falls: US Geological Survey. August 1995.

USGS, October 1995	Bartholomay, Roy C., Linda M. Williams, and Linford J. Campbell. *Radionuclides, Stable Isotopes, Inorganic Constituents, and Organic Compounds in Water from Selected Wells and Springs from the Southern Boundary of the Idaho National Engineering Laboratory to the Hagerman Area, Idaho, 1994.* Open-File Report 95-718. DOE/ID-22124. Idaho Falls: US Geological Survey. October 1995.
USGS, November 1995	Tucker, Betty J., LeRoy L. Knobel, and Roy C. Bartholomay. *Chemical Constituents in Water from Wells in the Vicinity of the Naval Reactors Facility, Idaho National Engineering Laboratory, Idaho, 1991-93.* Open-File Report 95-725. DOE/ID-22125. Idaho Falls: US Geological Survey. November 1995.
USGS, September 1996	Bartholomay, Roy C., Linda M. Williams, and Linford J. Campbell. *Radionuclides, Stable Isotopes, Inorganic Constituents, and Organic Compounds in Water from Selected Wells and Springs from the Southern Boundary of the Idaho National Engineering Laboratory to the Hagerman Area, Idaho, 1995.* Open-File Report 96-496. DOE/ID-22130. Idaho Falls: US Geological Survey. September 1996.
USGS, March 1997	Williams, Linda M. *Evaluation of Quality Assurance/Quality Control Data Collection by the U.S. Geological Survey for Water-Quality Activities at the Idaho National Engineering Laboratory, Idaho, 1994 Through 1995.* Water-Resources Investigations Report 97-4058. DOE/ID-22136. Idaho Falls: US Geological Survey. March 1997.
USGS, April 1997	Bartholomay, Roy C., Betty J. Tucker, Daniel J. Ackerman, and Michael J. Liszewski. *Hydrologic Conditions and Distribution of Selected Radiochemical and Chemical Constituents in Water, Snake River Plain Aquifer, Idaho National Engineering Laboratory, Idaho, 1992 Through 1995.* Water-Resources Investigations Report 97-4086. Idaho Falls: US Geological Survey. April 1997.
USGS, June 1997	Bartholomay, Roy C., Linda M. Williams, and Linford J. Campbell. *Radionuclides and Chemical Constituents in Water from Selected Wells and Springs from the Southern Boundary of the Idaho National Engineering Laboratory to the Hagerman Area, Idaho, 1996.* Open-File Report 97-360. DOE/ID-22141. Idaho Falls: US Geological Survey. June 1997.
USGS, December 1997	Bartholomay, Roy C., LeRoy L. Knobel, and Betty J. Tucker. *Chemical and Radiochemical Constituents in Water from Wells in the Vicinity of the Naval Reactors Facility, Idaho National Engineering Laboratory, Idaho, 1994-95.* Open-File Report 97-806. DOE/ID-22143. Idaho Falls: US Geological Survey. December 1997.
USGS, January 1998	Tucker, Betty J. and Brennon R. Orr. *Distribution of Selected Radiochemical and Chemical Constituents in Perched Ground Water, Idaho National Engineering Laboratory, Idaho,1989-91.* Water-Resources Investigations Report 98-4028. DOE/ID-22144. Idaho Falls: US Geological Survey. January 1998.

USGS, February 1998	Bartholomay, Roy C., *Distribution of Selected Radiochemical and Chemical Constituents in Perched Ground Water, Idaho National Engineering and Environmental Laboratory, Idaho, 1992-95.* Water-Resources Investigations Report 98-4026. Idaho Falls: US Geological Survey. February 1998.
USGS, December 1998a	Bartholomay, Roy C., Linda M. Williams, and Linford J. Campbell. *Radiochemical and Chemical Constituents in Water from Selected Wells and Springs from the Southern Boundary of the Idaho National Engineering and Environmental Laboratory to the Hagerman Area, Idaho, 1997.* Open-File Report 98-646. DOE/ID-22152. Idaho Falls: US Geological Survey. December 1998.
USGS, December 1998b	Colello, Joseph J., Jeffrey J. Rosentreter, Roy C. Bartholomay, and Michael J. Liszewski. *Strontium Distribution Coefficients of Basalt Core Samples from the Idaho National Engineering and Environmental Laboratory, Idaho.* Water-Resources Investigations Report 98-4256. DOE/ID-22153. Idaho Falls: US Geological Survey. December 1998.
USGS, 1999	Bartholomay, Roy C., Brian V. Twining, and Linford J. Campbell. *Radiochemical and Chemical Constituents in Water from Selected Wells and Springs from the Southern Boundary of the Idaho National Engineering and Environmental Laboratory to the Hagerman Area, Idaho, 1998.* Open-File Report 99-473. DOE/ID-22161. Idaho Falls: US Geological Survey. 1999.
USGS, February 1999	Anderson, S.R., Mel A. Kuntz, and Linda C. Davis. *Geologic Controls of Hydraulic Conductivity in the Snake River Plain Aquifer at and near the Idaho National Engineering and Environmental Laboratory, Idaho.* Water-Resources Investigations Report 99-4033. DOE/ID-22155. Idaho Falls: US Geological Survey. February 1999.
USGS, July 1999	Pace, Mary N., Jeffrey J. Rosentreter, and Roy C. Bartholomay. *Strontium Distribution Coefficients of Basalt and Sediment Infill Samples from the Idaho National Engineering and Environmental Laboratory, Idaho.* Water-Resources Investigations Report 99-4145. DOE/ID-22158. Idaho Falls: US Geological Survey. July 1999.
USGS, August 1999	Knobel, LeRoy L., Roy Bartholomay, Betty J. Tucker, Linda M. Williams, and L. DeWayne Cecil. *Chemical Constituents in Ground Water from 39 Selected Sites with an Evaluation of Associated Quality Assurance Data, Idaho National Engineering and Environmental Laboratory and Vicinity, Idaho.* Open-File Report 99-246. DOE/ID-22159. Idaho Falls: US Geological Survey. August 1999.
USGS, October 1999	Knobel, LeRoy L., Roy C. Bartholomay, Betty J. Tucker, and Linda M. Williams. *Chemical and Radiochemical Constituents in Water from Wells in the Vicinity of the Naval Reactors Facility, Idaho National Engineering and Environmental Laboratory, Idaho.* Open-File Report 99-272. DOE/ID-22160. Idaho Falls: US Geological Survey. October 1999.

USGS, November 1999 — Orr, Brennon R. *A Transient Numerical Simulation of Perched Ground-water Flow at the Test Reactor Area, Idaho National Engineering and Environmental Laboratory, Idaho,1952-94.* Water-Resources Investigations Report 99-4277. DOE/ID-22162. Idaho Falls: US Geological Survey. November 1999.

USGS, 2001 — US Geological Survey. *National Handbook of Recommended Methods for Water Data Acquisition, 11.M. GLOSSARY.* http://water.usgs.gov/pubs/chapter11/chapter11M.html. 2001. (Viewed September 13, 2001).

WGRFC, 2001 — West Gulf River Forecast Center, Fort Worth, Texas. National Oceanic and Atmospheric Administration. *Glossary of Hydrologic Terms - C.* http://www.srh.noaa.gov/wgrfc/glossary/c.html. 2001. (Viewed September 12, 2001).

Wick, 1980 — Wick, O.J., ed. *Plutonium Handbook, A Guide to the Technology.* La Grange Park, IL: American Nuclear Society, 1980.

Wood *et al.*, August 2000 — Wood, T.R., D. Bates, C.W. Bishop, G.L. Heath, J.M. Hubbell, L.C. Hull, R.M. Lehman, S.O. Magnuson, E.D. Mattson, J.M. McCarthy, I. Porro, P.D. Ritter, M. Roddy, J.B. Sisson, and R.P. Smith. *Deficiencies in Vadose Zone Understanding at the Idaho National Engineering and Environmental Laboratory.* Idaho Falls: Idaho National Engineering and Environmental Laboratory. INEEL/EXT-99-00984. August 2000.