The legacy and future of radioactive waste management at the Millennium

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(Received September 7, 1999)

Wastes containing radioactive materials have been produced ever since ore recovery and processing began; however, such materials did not become of public concern until the large-scale activities involving uranium and thorium ores and nuclear fission during and after World War II. Efforts to provide disposal sites for radioactive wastes, especially those associated with nuclear weapons and nuclear energy, have been largely unsuccessful for the past 40 years or so and are nearing crisis proportions as the new millennium begins – its eventual resolution is believed to require greater reliance on stewardship and a larger governmental presence.

Introduction

Radioactive waste began to emerge as a significant issue during and shortly after World War II. Although legacy wastes associated with the mining and processing of various ores existed well before WW II, they did not receive much consideration until the waste products of fission introduced a myriad of public issues. These issues embrace a host of technical matters intertwined with social and psychological principles of risk, equity, and fairness. The purpose of this paper is to summarize these factors for major categories of radioactive wastes and to suggest how they may influence their management as the new millennium begins. The major categories of radioactive wastes to which these considerations apply are: Manhattan Project Wastes; Uranium Milling Wastes; Defense Wastes (TRU, High-level, and contaminants at sites); Commercial High-level Wastes; Low-level Radioactive Wastes; and Naturally Occurring Radioactive Materials (NORM).

Radioactive wastes contain two major categories of radionuclides, those specified by the Atomic Energy Act of 1954 as amended (AE Act materials) and Naturally-occurring and Accelerator-produced Radioactive Materials (NARM). AE Act materials are largely grouped into high-level and low-level wastes. The largest components of NARM waste is NORM, including a subcategory in which the radionuclide concentrations or potential for human exposure have been increased by human activities above levels encountered in the natural state; i.e., technologically-enhanced NORM, or TENORM.[2,3] Sources of TENORM are abandoned mine lands; radium in scales and sludges from oil and gas and geothermal energy production; sludges from water and sewage treatment plants; ash from burning coal or wood; and phosphogypsum wastes.[4,5]

Radioactive wastes that are present as site contamination may be subject to the Comprehensive Environmental Response, Compensation, and Liability Act of 1980,[6] or CERCLA. The Act, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, established a national program for remediation of sites and for responding to releases of hazardous substances into the environment. Sites that pose imminent threats to health or the environment are subject to "removal" actions, which are generally limited in duration. Sites that require a longer term evaluation and response are placed on the Superfund National Priorities List (NPL) and undergo a comprehensive Superfund remediation process.[13] Seventy-five of the sites on the NPL have radioactive contamination that will be remediated by DOE or DOD in partnership with the respective host state and EPA usually under a "Tri-Party Agreement".

Manhattan Project wastes

A general category of site contamination exists on some 46 sites due to national defense activities during and shortly after World War II.[7,8] These sites were assigned to the U.S. Department of Energy for restoration under the Formerly Utilized Sites Remedial Action Program (FUSRAP). (Congress also added two major sites that contain residual materials from processing thorium ores for rare earth elements and thorium metal.) Sites that contain these so-called FUSRAP wastes are not generally occupied but some sites do contain industrial or commercial activities. Radiation risks are directly dependent on the concentrations and amounts of radioactive thorium and radium present. These radionuclides are present in uranium residues, which exist in St. Louis, MO and Tonawanda, NY and are stored in silos at the Fernald, OH site. The dominant radionuclide is ^{230}Th (half-life of 75,400 years) because uranium and most of the ^{226}Ra were removed when the original pitchblende ore was processed. Most of the ^{226}Ra was required to be removed by Belgian Minerals, Co., the original owner of the pitchblende ore, but later became the property of the U.S.; these radium residues are currently stored in large underground silos at the Fernald, OH site. The uranium

0236–5731/2000/USD 17.00

Akadémiai Kiadó, Budapest
Kluwer Academic Publishers, Dordrecht

residues still contain ^{230}Th and future risks will persist and may well increase due to the ingrowth of ^{226}Ra and its decay products; if ^{230}Th were removed from the residues, this would preclude the ingrowth of ^{226}Ra and would significantly reduce future risks to the public.

Thorium residues from the processing of thorium ores represent potential radiation exposures due to ^{228}Ra and its gamma-emitting products. ^{232}Th, the parent of ^{228}Ra, has a half-life of 14 billion years, thus thorium represents a perpetual source of radioactivity in the waste residues. Over 200,000 cubic yards of soil contaminated with ^{232}Th residues exist beneath active public roadways where potential exposure is limited; active industrial properties contain more than 400,000 cubic yards beneath vegetative or paved surfaces and under buildings with actual human exposures well below 100 mrem/yr; and similar inactive industrial and other sites contain more than 600,000 cubic yards where access controls minimize onsite and offsite exposures. Radioactive constituents are distributed in large volumes of dirt and debris; therefore, most management alternatives involve near-surface management of earth-like material in dirt. Private property and residential sites generally contain small quantities of material with low concentrations, and many have already been cleaned up because of these factors. Removal of ^{232}Th from these wastes would greatly diminish their exposure potential and allow on-site or nearby management by land use controls because the principal product is radium-228 ($T_{1/2}$ = 5.7 y) and its gamma-emitting products would diminish to minimal levels in 20–30 years and close to zero in 50–60 years. Treatment could be expected to mix any remaining radioactivity which would enhance stability and by reducing future radiation exposures, allow more land-use options.

Manhattan project wastes generally consist of earthen materials that when stabilized near ground level tend to remain stable with potential radiation exposures on the order of background exposure (i.e., no imminent health threat), which will remain low if the materials are left alone. A stewardship philosophy in combination with technical systems and land use controls is important, therefore, in assuring that FUSRAP materials are in fact left alone and for informing future generations of potential risks. Such a philosophy suggests that DOE must increasingly become one of the nation's principal land stewards or at least assure that lands and materials for which it is responsible receive such stewardship. Such a role began with the transfer of large tracts of land to the U.S. Atomic Energy Commission for management of these unique reserves to meet national interests. Operations have yielded to other needs; however, the basic stewardship responsibility continues such that these lands are preserved in the public interest. Like previous generations, this generation of people need not assume a burden of guaranteeing the future of waste materials no matter what future people may do, but it does have a stewardship responsibility to transfer them intact to future generations and to provide intergenerational information about the material.

Uranium mill tailings wastes

Other legacy wastes similar to Manhattan Project wastes are the process tailings from milling uranium ore to recover uranium, initially for the buildup of the nuclear weapons program. These mining and milling activities began in the 1940s and expanded considerably as the nuclear power industry grew in the 1970's. The Uranium Mill Tailings Radiation Control Act (UMTRCA)[9] was passed in 1978 primarily to establish a remedial action program for 24 inactive uranium mill sites and some 5300 associated "vicinity properties" that became contaminated with unwise use of tailings as fill materials, etc. The UMTRCA remedial action program was carried out by DOE, but in accordance with environmental standards issued by EPA.[10,11]

Similar provisions were also provided in UMTRCA for 27 active uranium mill tailings sites, the operations of which are regulated by the U.S. Nuclear Regulatory Commission (NRC). Each site is required to have closure and stabilization plans by similar methods as a condition for license termination. Both programs are significant because previous to UMTRCA these materials were considered to be naturally-occurring and outside the purview of the AE Act.

Vicinity properties were included in the UMTRCA program if they contained uranium tailings in excess of 5 pCi/g of ^{226}Ra in the first 5 cm of surficial soils or/and 15 pCi/g in the top 15 cm or/and produced gamma exposure in excess of 20 μrem/hr. These values were chosen to preclude excess radon levels should structures be present and/or to limit public exposures of the public consistent with public radiation standards. Similarly, residual levels of ^{230}Th alone in soil were limited to 43 pCi/g to preclude exceeding 15 pCi/g of ^{226}Ra in the 1000 year compliance period.

Defense wastes

Defense wastes include radioactive materials at nuclear weapons production sites, national research laboratories, and military bases. The DOE facilities,[7,8] which have been self-regulated, are located in 30 states and territories and include 12 major sites; 10 national laboratories; and 41 other small sites in addition to the 24 UMTRCA and 46 FUSRAP sites. DOE has completed cleanup at one national laboratory, 25 FUSRAP sites, at all 24 UMTRCA sites and associated vicinity properties, and at 15 other small sites. The remaining 21 FUSRAP sites were transferred by Congress to the U.S. Army Corps of Engineers in 1997 presumably to hasten their cleanup but with little change in schedule, and in some cases, more delays.

The most important defense wastes are perhaps the transuranic (TRU) wastes from the nuclear weapons complex and the high-level wastes (HLW) produced in the production of plutonium and other nuclear materials. Most of these wastes are currently in storage at several of the major DOE sites; however, disposal has just begun (mid 1999) at the Waste Isolation Pilot Plant (WIPP), near Carlsbad, NM, and it is anticipated that such disposal will significantly reduce the inventory of TRU wastes at the various DOE sites. The WIPP site is located in bedded salt more than 2000 feet below the surface. TRU wastes are defined as those that contain alpha-emitting transuranic ($Z>92$) elements with half lives greater than 20 years and with concentrations in excess of 100 nCi/g.

Enormous quantities of waste material, some of which is highly radioactive or contains hazardous chemicals, or both, exist at the large DOE sites some of which are remote (e.g., the Nevada Test Site and the Hanford reservation). Such sites could be cleaned up and the materials stabilized on site such that their inaccessibility would provide an adequate level of protection of the public; however, institutional controls and environmental stewardship would need to be provided to maintain long-term isolation.

Site contamination also exists at Army bases, Army depots, Naval shipyards, Naval air stations, Marine bases, Air Force bases, National Guard bases, test ranges, and miscellaneous research and disposal facilities.[12,13] The Department of Defense (DOD) has identified 85 sites that have burial areas and 231 areas with "mixed wastes". Six nuclear power reactors, which were built to service remote installations, have been dismantled and 15 research reactors have been dismantled or deactivated. Plutonium-contaminated soil also exists due to a chemical explosion and fire involving a nuclear weapon accident that occurred at McGuire AFB, NJ in 1960. And, several sites are contaminated with low-activity depleted uranium, which because of its high density, is used as an armor supplement and in armor-piercing shells.

In the early 1950's, it was common practice within the DOD complex, and consistent with Atomic Energy Commission (AEC) policy and regulations, to place radioactive wastes in vertical pipe burial sites, shallow land waste burial sites, on-site landfills, and disposal pits. Radioactive wastes at such sites include electron tubes containing small amounts of radioisotopes, low-level wastes from nuclear weapons maintenance and operations, self-luminous instrument dials containing radium, radioactive sources and animal carcasses used in laboratory research activities, and contaminated soils from spills and nuclear weapons operations.[12]

The National Strategic Materials Stockpile (a multistate reserve of strategic ores for the production of fuel and weapons material) contains thousands of tons of thorium nitrate, and zirconium-bearing ore that contains 0.3 to 0.4% uranium and thorium, some of which has contaminated soil and equipment with radium, uranium, and thorium.

High-level radioactive wastes

The Nuclear Waste Policy Act of 1982 defined high level radioactive waste as spent nuclear fuel or the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid fission-product wastes produced directly in reprocessing and any solid material derived from such liquid waste.

Although it was originally planned that all reactor fuel would be reprocessed to recover unfissioned uranium and byproduct plutonium, this has not occurred for commercial nuclear fuel, primarily for economic reasons. Consequently, commercial high-level radioactive waste is mostly spent fuel. This fuel is currently in storage awaiting an operational Federal high level waste repository, at which point the fuel will be disposed intact (i.e., without processing). These fuel bundles were designed to contain the radioactive products of fission and the zircalloy cladding is quite stable and assures a high-integrity barrier to release of radionuclides.

High level wastes require long term isolation in deep, highly-stable geologic formations. The Act initially directed the selection of two sites for high level waste disposal in different geological media; however, Congress, for a number of reasons but primarily cost, changed this requirement and designated the Yucca Mountain site in Nevada as the sole site, subject to meeting EPA's standards and NRC's implementing regulations. Although crystalline rock (e.g., granite) and basalt have been studied, Congress, upon advice from government agencies and expert groups, determined that the welded volcanic tuff medium at the Yucca Mountain site should be selected. Environmental standards for high-level radioactive waste require that they be isolated in such a manner that very restrictive release limits not be exceeded for a period of 10,000 years after disposal.

Site investigation and development under the Nuclear Waste Policy Act has experienced considerable delays due to public opposition, legal challenges, and more geological studies, and the current schedule for operation is well past 2010, perhaps closer to 2020 unless Congress accelerates it. If, however, the Yucca Mountain Site can meet regulations, it can be expected to resolve disposal of high-level defense wastes and spent nuclear fuel from commercial nuclear plants.

Low-level radioactive wastes

Low-level radioactive wastes (LLRW) are defined by the Low-Level Radioactive Waste Policy Act (LLRWPA) of 1980 as radioactive material that is not high-level radioactive wastes, spent nuclear fuel, transuranic waste, or byproduct material as defined in Section 11 (e)(2) of the Atomic Energy Act. Regulations issued by the NRC (10 CFR 61) classify LLRW for near-surface disposal in three classes (A, B, C) based on concentrations of both long- and short-lived radionuclides. A fourth class, known as greater-than-class C (GTCC), consists of low-level wastes with concentrations of radionuclides greater than Class C wastes, which are generally not suitable for near surface disposal. Disposal requirements for GTCC wastes, which fall between defined low-level and high-level wastes, are uncertain; only that near-surface burial is not likely, presumably requiring disposal in the same way as high-level wastes.

Low-level waste management was, for various reasons, uniquely confined to Federal lands during the period from World War II to the 1950s. A few enterprising companies, with support of six states, sought privatization of waste disposal as a commercial, and presumably profitable, enterprise. Six sites were licensed and became operational between 1961 and 1972. Various events, mostly related to low revenues and public reactions when offsite releases were discovered, caused closure of the NY, KY, and IL sites thus shifting the entire burden of disposal to the sites in WA, SC, and NV.[14] The NV site closed in the mid 1980's; thus, only the WA (in the far west) site, which limits waste disposal to states in the Northwest and Rocky Mountain compacts, and the SC site (in the southeast) remain open. Since most low-level radioactive waste is produced in the central regions of the nation, a large portion of it is shipped long distances for disposal. No aspect of this situation echoes the desire to have the best site with optimal geology and arid conditions; access has been the key consideration.

Congress enacted the LLRWPA at the request of the National Governors Association which anticipated a crisis when South Carolina announced that it would close the Barnwell, S.C. site unless new sites were developed (S.C. considered it unfair to shoulder the nation's low-level waste burden alone, as appeared to be happening). The Act, which adopted the approach proposed by NGA, envisioned two or three new sites by 1986 and provided for interstate compacts to assure that low level waste would be managed on a regional basis (i.e., a new site would not automatically become a national site). Even with these provisions, no new site was even close to being developed, and Congress amended the Act in 1985 to establish firmer schedules and provided a series of increasingly burdensome surcharges on generators if states failed to meet specific milestones. Existing disposal sites were allowed to deny access beginning in 1996 to states in compacts that had failed to provide a disposal site by the deadline.

States, fearing loss of access to existing sites, began a serious effort in 1980 to implement the LLRWPA and to form interstate compacts. They also began siting processes that attempted to reflect local political interests which for the most part opposed a site in their state. Two forces thus became juxtaposed: providing access for generators, but keeping the site out of one's own state. In retrospect, it should have been obvious that these trends would prevent a new site, but eleven different compacts (and several go-it-alone states) were formed, host states were selected, and siting programs were developed, which was somewhat easy because nuclear utilities, which had a vested interest in assuring access to disposal, were tapped to pay the major costs of compact commissions. Meanwhile, as shown in Fig. 1, the volume of LLRW, which had increased steadily up to about 1980, decreased by more than a factor of 10 from 1980 to 1997, from 3.8 to 0.32 million cubic feet.[14] This decrease in volume occurred because the surcharges imposed by the 1985 amendments and site restrictions on generators were so onerous that it became cost-effective to separate wastes, increase storage time, and provide super-compaction. The activity levels probably decreased very little; i.e., the site had essentially the same source term, just distributed more compactly.

The various interstate compact commissions and unaffiliated states (see Fig. 2) have spent over $500 million in site studies and conceptual designs with no site entering the design and construction stage.

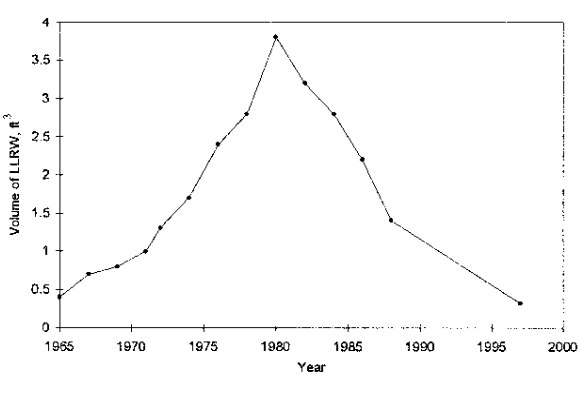

Fig. 1. Annual volume of LLRW (ft^3) disposed in the United States from 1965–1997

Fig. 2. Low-level radioactive waste compacts and independent states[15]

Designation of a site location was followed by intense local opposition, aided and abetted by statewide organizations and national anti-nuclear groups, such that no site has proceeded past the designation and investigation phase. Pennsylvania, California, Illinois, Nebraska, Ohio (preceeded by Michigan), North Carolina, Connecticut/New Jersey (as dual hosts), and Texas (the most recent) have all acted in good faith to secure sites only to be turned away at the final stages, typically by state political actions. Each had proposed disposal designs with supra-isolation features estimated to cost $600 million or more per site; these costs and the reduced waste streams also suggested that they would not be economically viable for a compact region. On the other hand, a single site that would accept LLRW from all states would be enormously profitable because disposal capacity is approaching a crisis. It is intriguing that no state has seized this opportunity to generate enormous funds to solve other state interests by managing a few hundred acres of land.

Many themes can be traced from events associated with LLRW over the past few decades; however, some of the major ones are:

Some 13 potential LLRW sites would be pursued by 11 compacts and the independent states (see Fig. 2), although 2 or 3 sites would be quite adequate. Since two of the existing sites could be expected to continue operation for another 10-20 years, one additional site could, if available, suffice for disposal of the greatly reduced volume of low-level radioactive waste for several decades.

States were quite willing to join compacts to gain its protections; however, as the process proceeded, political interests led to Michigan and North Carolina, both host states, being dismissed by their compacts because of lack of success in siting. Michigan was required to store waste for several years, but has since regained access to the Barnwell, S.C. site; North Carolina, the original host state for the Southeast compact, is still denied access to the S.C. site which continues to provide disposal to all states including the other Southeast compact states.

No new sites have been approved. Those states that have selected and investigated a particular site have experienced strong local opposition, supported in many cases by elected state officials, and have not been able to proceed past the conceptual design stage.

Parties who oppose current or potential waste sites have emphasized a concern about radiological risk; however, since no significant exposures have been recorded nor projected, the concerns are most likely social ones: equity, land values, inadequate information on actual risks, intergenerational concerns, and perhaps just fear of the unknown.

The State of South Carolina, which precipitated the low-level radioactive waste policy act of 1980 by threatening closure of its Barnwell site, has, depending on the Governor in office, tightened access, raised fees, and restricted access to generators in selected states. The surcharges allowed by the 1985 Act amendments have made the site very profitable to the state and this has probably affected its access policy. South Carolina limited access again in 1999 because of shrinking disposal capacity and is threatening early closure to all but Southeast compact members, except North Carolina, creating anew the anxiety for a new site(s).

Storage, volume reduction, and various on-site procedures have been adopted by generators, driven by costs and restrictions by disposal sites, to reduce the amounts of LLRW. This reduction, which is expected to be maintained, further reduces the need for new sites to no more than 2 or 3, certainly not the 13 or so that could be forecast by the number of compacts and individual states that, for various reasons, are expected to go it alone. The costs of the rigorous designs required to satisfy local concerns and the waste volumes, even with high fees, will not support that many sites which further restrains the viability, and unfortunately the performance of any new site. The first such site, if there is one, would probably need to reach beyond is current compact-protected area to assure a viable revenue stream, a circumstance that circulates back to the original issue – not being a "national site".

Surprisingly, illegal dumping has not occurred; this is perhaps due to the strict licensing and inspection programs of the NRC and agreement states.

Low-level waste siting has proven to be failure; all designations of new low-level radioactive waste sites have been turned away by local and state opposition, and the prospect of a new site(s) is now very remote. Congressional action will probably be necessary to change the situation; however, it appears that Congress is quite reluctant to address the matter again since it has already enacted schema devised by the states. Its reluctance may also be due to uncertainty on what will resolve the question and/or what the political consequences would be of a congressionally mandated solution. It is uncertain whether Congress will reexamine the LLRWPA; however, the events and circumstances as the new millennium begins suggest that it will not be resolved unless they do.

Naturally Occurring Radioactive Materials (NORM)

NORM wastes are subject to control by the states only since they are not AE Act materials. NORM wastes generally involve large volumes of soil or debris containing radioactivity at levels significantly greater than those that exist naturally. The mining and processing of mineral-bearing ores (e.g., uranium, phosphate, aluminum, copper, titanium, etc.) can lead to the accumulation of large volumes of waste with elevated concentrations of radium, which in addition to potential gamma-exposure, can produce elevated radon emissions. An example of such high-bulk technologically enhanced NORM residues are large piles at phosphate plants, which are called phosphogypsum stacks because the residues are largely gypsum. Other TENORM materials are radium accumulations in scale on the inside of pipes (and in piles or barrels of scale removed from pipes) associated with oil and gas pumping operations. Similarly, processing of groundwater by ion-exchange resins, granulated activated charcoal, etc., can produce sludges, resins, or charcoal that contain significant amounts of radium. These process materials are usually disposed in local landfills which may, under some circumstances, be considered NORM sites.

NORM materials have an interesting control history since neither AEC nor NRC have had control over them and state programs, which are based on broad public health authority, have been irregular and in some cases non-existent. Recent public concerns over low-level and high-level AE Act wastes have provided an impetus for states to deal with NARM materials presumably just because they are radioactive. It was perhaps this perspective that caused Congress to pass UMTRCA and bring FUSRAP sites under Federal responsibility even though the naturally-occurring materials they contained appeared outside the AE Act. The authority of the states for NARM, NORM, and TENORM has been extended considerably by RCRA and CERCLA and the Superfund act reauthorizations amendments (SARA); the Denver (CO) radium sites are a good example of state action under Superfund.

The Denver radium sites, which included some 31 separate locations, occurred because no regulations were in place to control radium and its use in the early years of this century. The National Radium Institute (NRI) was located in Denver, CO around 1912 for access to the Colorado Plateau's deposits of Carnotite ore which contained 1%–2% uranium; poor management of the substance itself and the byproducts of its processing and recovery have created long-term radiological problems. The NRI produced 8.5 grams of radium from approximately 1500 tons of ore until pitchblende ores (containing >50% uranium) became available from the Belgian Congo in the early 1920s. Other operations produced radium-containing medicines, tonics, cosmetics, pottery glazes, glassware, animal feed, and crop fertilizer. With the exception of Shattuck Chemical Co. which ceased radium operations in 1941 (but continued to process molybdenum and uranium until 1984) the radium processing and manufacturing plants went out of business in the 1920's and they, along with the radioactive tailings and unprocessed ore later used as fill and foundation material, were largely forgotten for the next fifty years. The sites were rediscovered in the late 1970's and placed as a single unit on the Superfund National Priorities List and slated for removal actions.

Cleanup, with one exception, for the Denver Radium sites consisted primarily of excavation, backfilling with replacement soil, and disposal of 230,000 cubic yards of contaminated soil at the Envirocare facility in Clive, Utah. The remedy for the Shattuck Chemical site was on-site stabilization of 50,000 cubic yards with cement and fly ash, which was determined to be the most appropriate because of the statutory preference of CERCLA for on-site remedies, the statutory preference for remedies involving treatment, and the high costs for permanent off-site disposal of contaminated soil. The Record of Decision for the Shattuck Chemical unit stated that " ... the location of the site in a metropolitan area should not dictate selection of an off-site remedy ..." Other contaminated material underneath roadways was left in place; however, the city of Denver was required to develop a health and safety protocol for street and utility workers who might need to dig in the area and to assess and properly dispose of any contaminated material at that time.

Remediation of the Denver Radium Sites relied on environmental stewardship as an effective measure and included provisions for institutional controls, maintenance, and monitoring. Also included are deed restrictions and annotations denoting that the property is a dedicated waste disposal site. The notations also restrict excavation, construction, groundwater use, and agricultural use, and provide for post closure maintenance of the cap and cover and for groundwater monitoring to detect releases from the site. The City of Denver sued EPA over the selected remedy in Federal court as provided in CERCLA, but EPA's decision was upheld.

Status and prospects at the Millennium

It is clear as the 20th century comes to a close that a myriad of activities have produced numerous sources of radioactive materials that are properly labelled as radioactive wastes. These wastes range from high-activity, potentially dangerous materials that are for the most part strictly contained to high-bulk, relativity benign materials that contaminate sites to various degrees. It is also clear that society has made much more progress in producing and using radioactive materials than it has in managing the waste byproducts.

Although it is generally agreed that it is desirable to isolate radioactive wastes, the means and criteria for doing so remain largely obscure. Potentially affected persons appear to insist that the material be put somewhere besides where they are or are likely to be and in a manner that it does not re-enter the environment. These perspectives have stymied many of the proposed management processes and proposed disposal locations. Consequently, essentially all of the high-level waste radioactive wastes produced since the 1940s remain in tanks or other forms at DOE sites, although solidification in borosilicate glass has begun, or in spent fuel storage at commercial nuclear reactor sites. Similarly, no new low-level radioactive waste sites have been approved for siting much less designed and constructed, and only two of the six sites licensed in the 1960s and early 1970s remain open; the other four have been closed because of capacity or inability to meet requirements. Several states have, as provided in the low-level waste policy acts of 1980 and 85, assumed host state responsibilities only to have those efforts thwarted when a site location appeared imminent. In the opinion of these authors, low-level radioactive waste disposal will probably require Congress to direct the setting aside of two or three large tracts of lands under Federal control in three regions of the country that assures regional access; provides long-term isolation and Federal land stewardship through BLM, the National Forest Service, DOE and/or HHS; and a fee structure that pays for optimal technical facilities for recycling and fixation of disposed materials, a trust fund, and shared revenues to states. Alternatively, such an approach could be taken by the administration or jointly with the Congress by simply citing the States' failure to produce any progress in more than two decades.

Strong opposition exists and can be expected to persist for the next few decades over high-level and low-level radioactive wastes associated with nuclear fission. Various groups insist that those activities that are vested in nuclear weapons and/or electricity generation by nuclear reactors be stopped, and although these perspectives appear to be rooted in values related to the wisdom and fairness of nuclear defense and patterns of energy use that are consumptive (wasteful) and based on non-renewable resources, they oppose their continuation without a solution to waste disposal. This approach has been so effective with respect to stalling nuclear weapons activities and nuclear power plants that these same groups pursue strong measures to block any low-level or high-level radioactive waste site, including resolution of legacy wastes. A dilemma appears to permeate these circumstances: the waste problem must be solved because of its threat to current and future generations, yet its very solution may allow nuclear weapons activities and/or the nuclear power industry to continue. This circumstance has persisted for several decades and will probably continue until it reaches a crisis and the Congress or the administration dictates a solution, perhaps not an ideal one, but one that is practical. Such a decision is likely to reflect a national interest on nuclear weapons and/or nuclear generation of electricity, and there are signs that such a decision may come sooner than many would expect. The Secretary of Energy recently opened the WIPP site in New Mexico despite significant opposition but after various concessions to state and local interests. The Congress continues to provide close oversight of the Yucca Mountain site but has become impatient with a continually lengthening schedule partially because nuclear utilities have built a sizable trust fund for resolution of spent fuel disposal which has not occurred (the site was congressionally mandated to open in 1998, which appeared to be a liberal schedule when adopted in the 1980s). Conversely, Congress appears reluctant, barring a catastrophe at one of the sites, to engage the technical and political issues relative to cleanup of DOE sites and can be expected to budget the necessary funds, but perhaps not on the requested schedules.

Cleanup of contaminated sites is experiencing similar difficulties with respect to siting, especially for sites containing FUSRAP (or Manhattan Project) wastes. The contaminated sites in Wayne and Maywood, NJ and St. Louis, MO have demonstrated that the only acceptable local solution is "remove and haul," which has been an option only because of the Envirocare site in Clive, Utah, which has been very profitable for its developers and the state of Utah. Even though disposal at the site appears to be relieving various local concerns and perhaps offering an advantage of consolidating disparate materials, the materials, which are covered near the surface and isolated for the near future, are potentially subject to challenge by future generations unless they adopt a different perspective relative to radioactive materials, land use, and stewardship.[16]

Assuring the continued stewardship of radioactive wastes is not only vital but a challenge to governmental and public institutions, which unfortunately has not yet been fully recognized and engaged by local and national entities. Stewardship has been and will continue to be an essential component of radioactive waste management. Despite many assertions about inadequacies of past radioactive waste management, the first and subsequent products of fission were isolated on Federal sites and have continued to be contained. Although some releases have occurred to the on-site environment and these were not what the public or anyone expected, exposures have been minimal. It is, considering the circumstances of wartime and the Cold War, overall remarkable that containment of radioactive waste products was established at the outset, and this policy has continued to govern Federal oversight and management of these materials. This policy also became part of the licensing program for research and commercial uses after the 1954 amendments to the Atomic Energy Act, which provided for non-Federal uses of nuclear and byproduct radioactive materials.

A troubling aspect of continued delay in waste siting is that, despite the political issues involved, the infrastructure and resources which currently exist to pay the large costs of disposal of wastes that already exist could be lost. If national defense and/or the nuclear power industry diminish significantly because low-level and high-level radioactive waste disposal is not resolved, it is uncertain whether the will or the funds would be available to manage the wastes which are no closer to final disposition than when they were first produced. If agreement to solve the waste issue hinges on stopping further generation, it is uncertain whether the types of isolation that could be accomplished technically now would in fact occur at that point. Most of the total waste is legacy waste from more than 50 years of weapons production and nuclear power development, continuing the weapons complex (which no longer uses nuclear reactors to produce plutonium) and the nuclear power industry, even with some modest expansion, will not increase the current waste volume, which must be managed with or without additional generation, by more than a factor of about two.

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Capt. Floyd L. GALPIN (USPHS-Ret) provided highly prized and appreciated counsel and wisdom on the status of low-level radioactive waste siting and management.

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