THE SOUTHEASTERN NEW MEXICO RADIOACTIVE WASTE DISPOSAL PILOT PLANT*

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INTRODUCTION

The need for a radioactive waste repository is not predicated upon public acceptance of nuclear power: the need already exists. Wastes from the chemical processes associated with plutonium production have been accumulating within the AEC/ERDA complex since World War II. The nuclear power reactor fuel cycle is plugged with 2000 metric tons of spent fuel awaiting reprocessing, and the backlog is growing rapidly. Clearly, there will be a radioactive waste repository; the only questions to be answered are where and how big it--or they - - will be.

Scientists recognized from the beginning that the toxic by-products from the nuclear fuel cycle would have to be isolated from the biosphere for almost aeonian times. In 1954, the AEC asked the National Academy of Sciences to consider the problem of waste isolation and to recommend a practical means for its accomplishment. The Academy recommended burial of the wastes in stable geologic formations, and pointed out that bedded-salt deposits offered the additional advantages of plasticity, high thermal conductivity, and isolation from flowing water. Over the next 15 years, Oak Ridge National Laboratory carried out a modestly funded effort to develop the technology for bedded-salt storage of high-level wastes. In Project Salt Vault, spent fuel elements (but not actual solidified high-level waste) were buried in an existing salt mine at Lyons, Kansas, and the response of the salt was monitored in an elaborately instrumented experiment. Data from this experiment provided the basis for ORNL's conceptual design of a pilot plant repository to be located at Lyons.

For both technical and political reasons, plans for the pilot plant were abandoned in 1971, and ORNL undertook the design of a facility (then known as the Bedded Salt Pilot Plant) sited in the virgin salt beds of southeastern New Mexico. This program, too, was aborted when the AEC opted for retrievable surface storage of wastes; the intent was to buy time for the development and demonstration of other disposal concepts. Retrievable surface storage came under attack on the grounds that it offered an unacceptable potential for environmental pollution and that it was really an evasion of the federal government's obligation to find a permanent solution to the waste disposal problem. Interest in the southeastern New Mexico repository was revived in late 1974. ERDA (the transition from AEC to ERDA occurred in October, 1974) decided that ORNL should investigate the broad aspects of waste disposal in all potentially suitable geologic media, and that Sandia Laboratories should carry out the conceptual design of the New Mexico facility. Sandia's charter for this work specified that the repository, now known as the Radioactive Waste Disposal Pilot Plant, should accommodate all categories of ERDA-generated waste and that its design should permit later conversion for the storage of commercial wastes.

Sandia's formal responsibility for the RWDPP design began in April, 1975.

NUCLEAR WASTES

Figure 1 is a simplified representation of the nuclear fuel cycle, showing the wastes generated in

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each step. In the uranium mining and milling operation, only a few tenths of a percent of the ore is removed (as U_3O_8), and the tailings constitute a truly monumental waste volume. There are no hazardous nuclides in the tailings that were not present in the ore to begin with; the hazard - - and it must be emphasized that the hazard is very small - - lies in their greater proximity to man's environment. Isolation of mine tailings has not been practiced in the past, but methods for stabilizing the waste piles to prevent erosion and subsequent uptake into the biosphere are under investigation.

The second step of the fuel cycle includes conversion of (solid) U_3O_8 to (gaseous) UF_6, and enrichment of the uranium by gaseous diffusion or centrifugal isotope separation. No fuel reprocessing plants are now in operation, so there is no uranium "feedback" into the fuel cycle. Therefore, only virgin uranium - - uranium which has not been contaminated by the highly radioactive by-products of the fission process - - enters the enrichment plant. At present, then, the waste from enrichment plants exhibits only a very low level of radioactivity. This waste, which can best be described as trash consisting of rags, paper, protective clothing, etc., can be disposed of by simple surface burial.

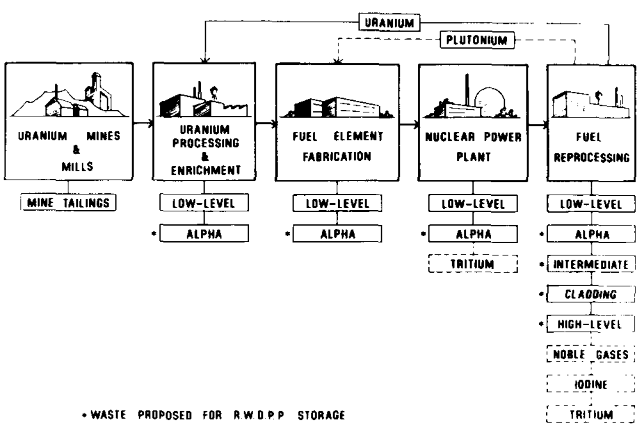

FIG. 1 THE NUCLEAR FUEL CYCLE

Later, with uranium recycle, the waste from enrichment plants will be contaminated beyond the limit for surface burial, and isolation in a repository will be required. This "hotter" waste is variously called alpha waste, transuranic waste, or TRU waste, because of its contamination by transuranic alpha emitters produced (in reactors) by neutron capture in heavy elements. Before shipment to a repository, alpha waste will be incinerated, compacted, and fixed in concrete or bitumen. It will be packaged in plastic-lined steel drums or large fiberglass-coated plywood boxes. External radiation and contamination levels will be low enough to permit contact handling and storage by conventional warehouse methods.

Fuel element fabrication plants, like enrichment plants, produce low-level waste now and will produce alpha waste after uranium recycle begins. Waste contamination levels will increase when plutonium recycle begins, but no changes in handling or storage procedures will be required. (Plutonium is one of the transuranic "contaminants" produced by neutron capture in uranium fuel elements. It happens to be uniquely valuable as a man-made reactor fuel; it's the product of uranium-cycle breeder reactors.)

Virtually all of the waste produced in nuclear power stations is in the low-level category. However, a problem arises in verifying that the contamination level is below that prescribed for surface burial and, as a practical matter, suspect material is treated as alpha waste.

Light water reactors, particularly pressurized water reactors, produce tritium in their coolant systems. At present, the tritium is released to the atmosphere but, with the tendency toward tighter control of effluents, it will undoubtedly be recovered as a waste product in the near future. Because of its short half-life (12 years) and because of its recovery as tritiated water, tritium is an unlikely candidate for storage in a salt-bed repository.

Fuel reprocessing plants produce every type of radioactive waste except, of course, mine tailings. Low-level, alpha, and tritium wastes have already been adequately discussed in this paper. There are several categories of intermediate-level waste. One is similar to alpha waste: general trash contaminated with alpha emitters, but with additional fission-product (intermediate-mass β and γ emitters) contamination which prevents contact handling of the waste packages. This so-called α - β - γ waste requires light shielding during transport and remote handling during emplacement.

Another type of intermediate-level waste is composed of the residual salts from a secondary waste stream in the solvent extraction process by which uranium and plutonium are recovered from spent fuel. The physical properties of this waste are not well-defined for either of the two commercial reprocessing plants now nearing completion, but it is clear that shielding and remote handling will be required, and that decay heat will be a consideration in the emplacement of the waste canisters in salt.

The primary waste stream from the solvent extraction process contains virtually all of the fission products and transuranic nuclides, and most of the unrecovered uranium and plutonium, from the spent fuel. When high-burnup fuel from a power reactor is reprocessed within a few years after discharge from the reactor, the resulting waste is intensely radioactive and has a very high thermal power density; this is the high-level waste. In general, ERDA fuel experiences lower burnup than power reactor fuel. Also, most of the ERDA solvent extraction waste has now aged - - and decayed - - for times up to 30 years. For the purpose of storage in a repository, then, ERDA "high-level" waste constitutes a third category of intermediate-level waste. It is still hot, thermally and radioactively, but less so than commercial high-level waste. Several solidification processes are under development; one proposed by the Savannah River Plant involves stabilization of the liquid waste in concrete. The resulting solid has a thermal power density of about 0.5 watt/liter - - a value much lower than that characteristic of commercial high-level waste.

Solid waste forms for commercial high-level waste must have a high thermal conductivity to facilitate heat dissipation. All solidification processes begin with calcination of the liquid waste to a granular solid, which then serves as the feed material for a secondary fixation process. In present state-of-the-art solidification technology, the final waste form is a glass containing roughly one part (by weight) of calcine to two parts of glass frits. The power density of the glass can be controlled by choosing the age - - i.e., the time out-of-reactor - - of the liquid waste and by adjusting the composition of the glass. For salt-bed storage, the power density of solidified high-level waste will be limited to about 25 watts/liter.

Almost all contemporary nuclear power stations are designed around light water reactors - - reactors in which the primary coolant is ordinary water. Light water reactor fuel rods consist of small ceramic (UO_2) cylinders stacked and clad in zircalloy tubing. In fuel reprocessing plants, the fuel rods are chopped into short (3-5 cm) pieces, and the fuel material is dissolved in nitric acid. This leaves the empty cladding hulls, which constitute a separate waste category. They are highly radioactive from neutron activation of the zircalloy itself and from surface contamination by residual fuel material. The bulk density of uncompacted hulls is very low, so that direct disposal makes for inefficient use of storage space in a repository. Mechanical compaction is unattractive because of the pyrophoric nature of the ziracalloy. Volume reduction by smelting is technically feasible, but expensive. Reclamation of the zircalloy for re-use as fuel cladding is not practical because of the stringent quality control requirements, and there are no other major uses for which these requirements can be relaxed. At present, the physical form of the cladding waste is undecided but, whatever its form, it will be similar to intermediate-level waste in its heat generation and radiation effluent characteristics.

As in the case of tritium, noble gases (specifically, ^{85}Kr) and iodine (^{129}I) will undoubtedly be recovered as disposable wastes within a few years. The ^{85}Kr has only a 10-year half-life, and long-term isolation in an underground repository is probably not justified. On the other hand, ^{129}I has a 1.6×10^7-year half-life, and a solidified waste form such as KI may well become a candidate for salt-bed disposal.

REPOSITORY SITE GEOLOGY

Salt, particularly bedded-salt, has been a leading candidate for storage of nuclear waste since publication of a National Academy of Sciences Report in 1957.[1] The particular factors which recommend bedded-salt for this purpose are plasticity, high thermal conductivity and ease of mining. Plasticity is important for its potential role in maintaining the integrity of a disposal site over periods of perhaps hundreds of thousands of years. The thermal conductivity of rock salt (12×10^{-3} cal/cm-sec-°C) is high compared to that of most geologic media, and should prevent temperature buildup beyond about 200°C around properly designed high-level waste canisters. The decrepitation point of salt is about 250°C; the melting temperature is about 800°C. Mining operations are commonly undertaken in bedded-salt with favorable extraction rates from the points of view of time and desired density of waste storage.

Bedded-salt deposits of southeastern New Mexico (Fig. 2) have some specific features that are advantageous to this program. Recognizable continuous flat bedding through much of the basin generally aids site characterization and mining operations. Salt horizons are found there with the properties of adequate thickness, proper depth, purity, and distance from dissolution fronts and aquifers. Estimates of adequate thickness (about 80 m) of salt are based on a combination of thermal properties of waste and salt. This is readily met within the Salado and Castile Formations, but is further limited by general requirements for mining operations less than about 900 m deep. The purity of salt in southeastern New Mexico varies with depth; nearly monomineralic halite is found within the Castile Formation. The Salado Formation has a more varied assemblage of evaporite minerals associated with halite, and is increasingly clay-rich toward the surface. Included water content in salt in two holes drilled in 1974 (by ORNL) shows no predictable patterns with respect to stratigraphic position. In general, the included water content is about 0.5 percent but varies from nil to about 5 percent. Dissolution fronts in the area under exploration are shown in Fig. 3. Estimated rates of lateral solutioning of evaporites are about 10-13 km/million years.[2] Vertical rates have likewise been estimated at 100 m/million years.[3] These are average rates, and it must be kept in mind that short-term rates may be substantially higher or lower. Horizontal and vertical buffer zones will be established around the repository to preclude dissolutioning during the necessary period of isolation. It will not be possible to avoid penetrating aquifers during exploration for and development of the repository. The Magenta and Culebra dolomites, aquifers above the salt penetrated by ORNL and Sandia Laboratories, showed no measurable flow in the previous area of exploration but can normally be expected to contain water. Deep water-bearing strata, such as the Bell Canyon Formation of the Delaware Mountain Group, will be avoided in future drilling operations. Hole plugging research at ORNL and mining operations existing in the area indicate it is quite possible to seal off these aquifers should they bear water at a site

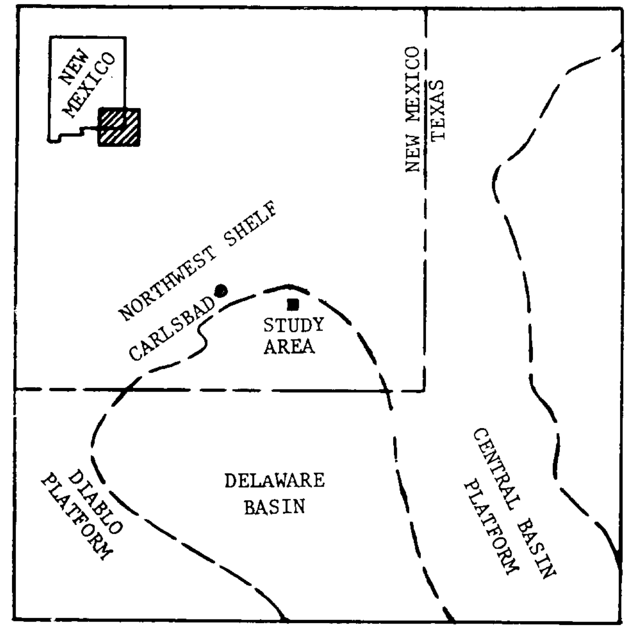

FIG. 2 - STUDY AREA LOCATION IN SOUTHEASTERN NEW MEXICO

selected. Exploration efforts guiding selection of a site for the pilot plant are taking all of these factors into account.

Economic factors in southeastern New Mexico are important in site selection. Two potential resources whose recovery might be directly affected are potash and petroleum. Areas that are being considered strongly for siting are in and around the potash district in the northern part of the Delaware Basin. Exploration efforts are concentrating on areas with marginal to uneconomic reserves of potash ore in today's market. Estimates of the area to be occupied by the repository, including the buffer zone, range from 25-75 square kilometers (10-30 square miles). It has not yet been established whether or not potash mining above a repository is permissible. Petroleum resources under a potential site may be more difficult to estimate. RWDPP exploration efforts are concentrating on areas that have shown no significant petroleum resources. Favorable structures are being avoided. Dry holes are an asset to this project, though it is probably desirable to avoid numerous drill holes which may have penetrated through the salt and could introduce solutioning if not plugged properly. It has also not been determined that exploration for, and extraction of, petroleum resources that might be found below a pilot plant or repository would be

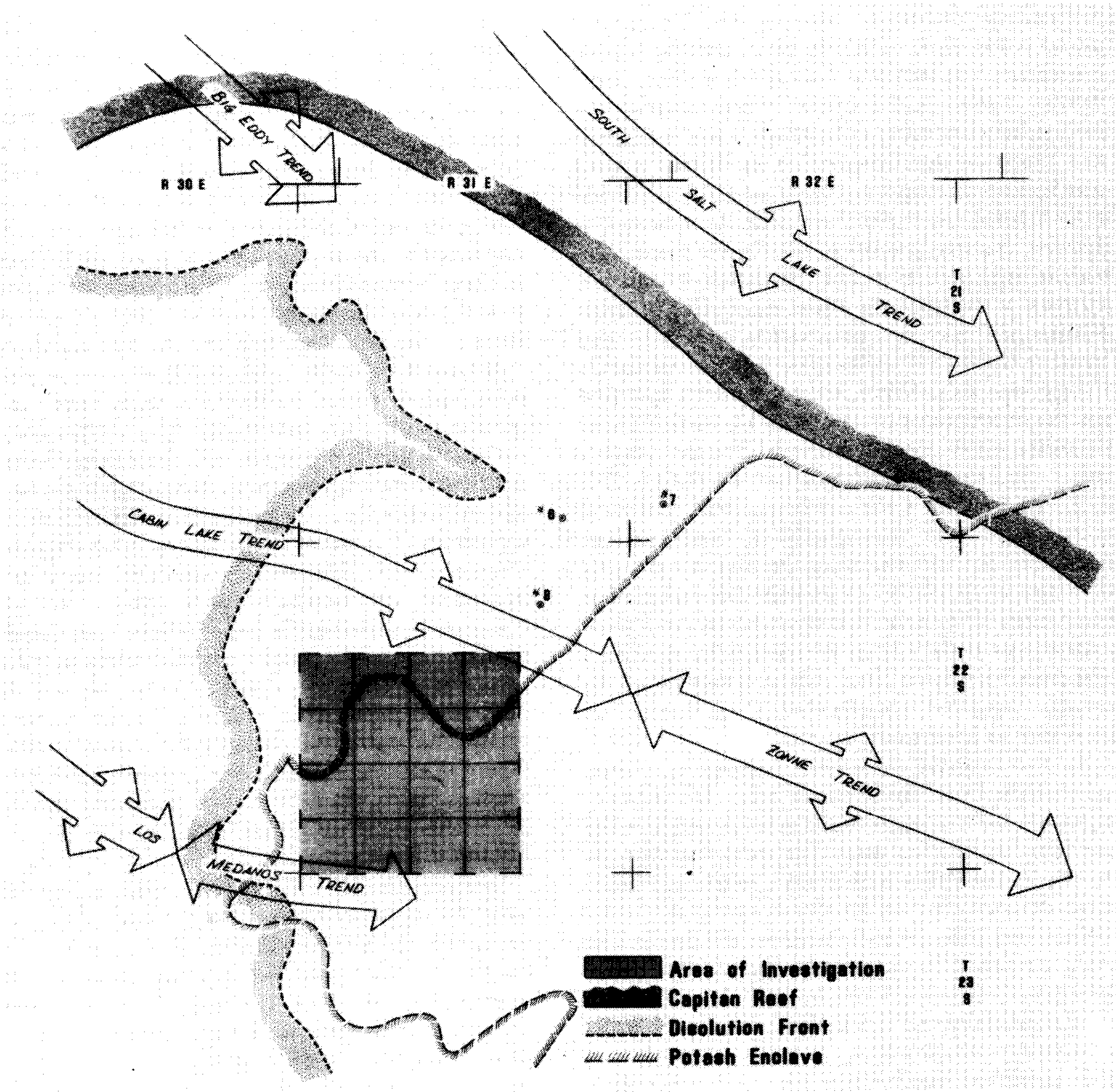

FIG. 3 – GEOLOGIC FEATURES AND STUDY AREA LOCATIONS IN SOUTHEASTERN NEW MEXICO

prohibited, although operations would probably be excluded from the surface area and buffer zone of the repository. In both cases, the value of the resources and impact on the total economy would have to be weighed against the value of, and necessity for, a permanent repository for radioactive waste.

The general geologic setting of the Delaware Basin, and associated reef-to-back-reef facies, has been summarized a number of times.[4,5] Various special aspects have been investigated and reported too extensively to list here. Some of the details of investigations already conducted by either ORNL or Sandia Laboratories will be discussed below in the context of known geology as reported in the references cited above.

An area previously explored by ORNL through two drill holes is shown in Fig. 3. Nothing particularly abnormal was noted during this investigation; dips of 25° in core from the Castile Formation was believed indicative of minor local flexure. Sandia Laboratories, when assigned the project for disposal of radioactive waste in bedded-salt, reopened the investigation by drilling a third core hole on what appeared to be a hydrologic divide at a corner of the exploratory area. As indicated in *Science*, the stratigraphy of the Castile Formation encountered directly below the Salado Formation appears to be from the lower part of the Castile Formation.[6] Bed dips observed in core were very high (up to 70° - 80°) in the lower Salado and Castile Formations. In addition, brine containing dissolved gas was encountered in the Castile Formation under pressures greater than hydrostatic. The gas is highly toxic; it has a general composition of 50% CO_2, 25% H_2S, and 25% CH_4. Isotopic and chemical composition of the gas/brine and various formation/aquifer waters in the region are being obtained in an effort to explain this and similar encounters in the area. It is desirable to avoid these occurrences mainly from the viewpoint of mining and repository operational safety. If they cannot be entirely avoided, predictability is obviously necessary to operations.

As also reported in *Science*, exploration efforts are shifting from the previous area. The primary argument for moving is the structural setting in the previous exploration area. The local structure, as shown in boreholes and seismic work, precludes mine development on a 3% or less grade while maintaining adequate salt thickness and purity. The toxic gas found in the previous borehole is below anticipated operating levels by several hundred feet stratigraphically, but this buffer is questionable in a structurally complex area.

A trenchant observation has been made that waste canisters of known practical materials are reactive with salt. The salt itself is therefore considered to be the ultimate containment medium for the waste. The primary geologic problem concerning containment is: how long would it take for the nuclear waste to reach the biosphere? Effective consideration of this problem requires detailed examination of potential pathways of the waste to the biosphere, salt solutioning rates, and reactions of waste materials with evaporite minerals.

It is necessary geologically to consider the following pathways of waste to the biosphere: tectonics and solutioning (which is related to tectonics). The tectonic history of the area has been explained by concepts ranging from piston-like action of the basin relative to the reef to a stable basin with changes in water level during deposition. Tectonics within salt near the reef have not been explained to the satisfaction of all geologists. There has been limited faulting within the basin; this aspect is being investigated by deep and shallow seismic surveys and interpretation to aid site selection. Assessment of seismic risk is ongoing to provide information about earthquake magnitude and ground motion for structural design of facilities.[2] Estimates are being made of solutioning factors which acknowledge potential climatic changes such as a pluvial change. The minimum distance from the repository to solution fronts will be established by this estimate. Horizontal solution rates are dependent on similar factors. The effect of epeirogenic movement is more difficult to evaluate, though the area in general is not eroding at rates comparable to large uplift. As far as can be determined, there is no reason to expect massive epeirogenic movement within the required lifetime (about 0.25 million years) of a possible repository. Similar basins, like the Salina, have maintained large-scale integrity about twice as long as the Delaware Basin.

Interactions of radionuclides with evaporite minerals are difficult to predict. Interactions might be expected through gaseous, liquid, and solid phases of the systems. Investigations of the migration and retention of normal formation gases such as Ar or H_2S provide insight to the behavior of gaseous phases. Experimental work is planned to clarify these answers. The waste material may also be soluble in geologic time. Brine inclusions with less than 10% gas migrate toward a heat source such as radioactive waste canisters, and would eventually form a radioactive solution saturated with respect to salt. It is important to know distribution coefficients of fission products with evaporite minerals to model exchange behavior from this solution. This information will soon be obtained empirically. Modeling of solid state diffusion is also being undertaken with existing computer codes to determine movement in geologic media.

RWDPP DESIGN CONSIDERATIONS

The various types of nuclear waste can be divided into two broad categories: those which are amenable to contact handling (the alpha waste), and those which require shielding and/or remote handling. This leads to a natural division of the repository into two facilities, one designed for the more or less routine warehousing of alpha waste and the other designed around the much more sophisticated handling equipment required for the hot wastes. In a steady-state fuel cycle, the volume of alpha waste generated will be two to three times that of all the other waste types combined. The storage density in the hot facility will necessarily be much lower than in

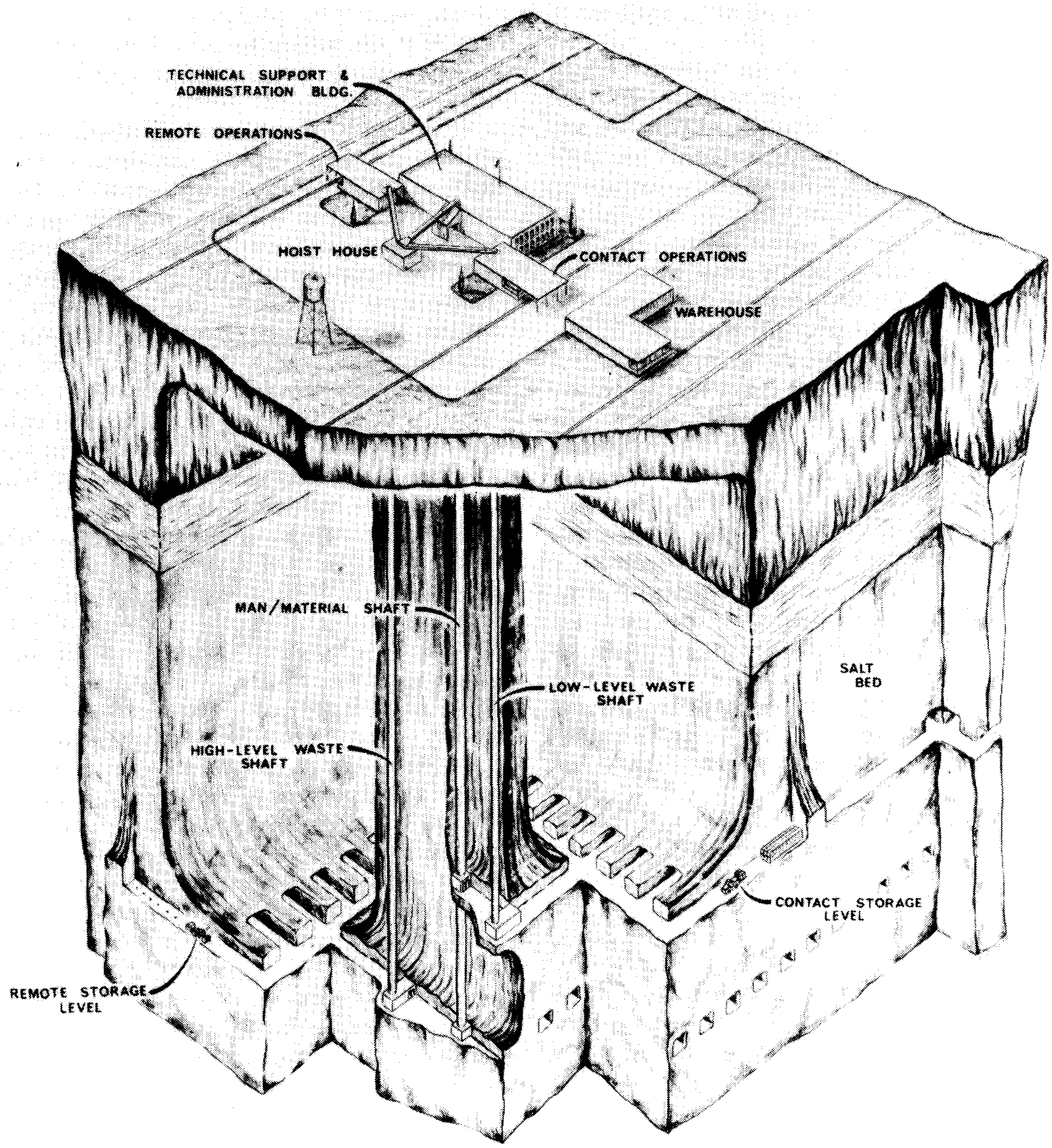

FIG. 4 R.W.D.P.P. BI-LEVEL TERMINAL-STORAGE

the alpha facility, so that the mined areas in the two parts of the repository will be roughly equal. In one conceptual design, the hot storage area is mined at about the 800-meter level and the alpha facility is directly above it, at about 700 meters. As shown in Fig. 4, the only common feature of the two storage areas is the man and materials shaft; air locks at both levels provide complete isolation, so that even a major spill in one facility will not affect operation of the other.

On both storage levels, waste packages will be stored in long (hundreds of meters) drifts with cross-sectional dimensions tailored to package size and method of emplacement. As implied by the "pilot plant" designation, the first few years - - perhaps up to 20 - - of operation will be devoted to demonstrating operational techniques and observing the behavior of the waste and the salt storage medium. During this period, the capability for retrieving any or all waste packages will be maintained. There are two reasons for this: first, it is conceivable that some unforeseen circumstance may arise during the demonstration period which makes it necessary or desirable to move the waste to a different disposal site; second, there may be a payoff in one of the current programs aimed at waste utilization (sterilization of municipal sewage, for example) which makes the waste a resource instead of a liability. Barring either of these eventualities, the RWDPP will be converted to full status as a repository at the end of the pilot plant phase of operation. (This is not to imply that the wastes will no longer be retrievable, but in routine repository operation, the drifts will be completely backfilled with salt as they are used, and recovery will be more difficult.)

In the alpha facility, waste boxes and drums will be stacked - - neatly, to increase utilization of the storage volume - - by ordinary warehouse methods. No special shielded or remotely operated equipment will be required. Since alpha waste generates essentially no thermal power, backfilling to promote heat transfer will not be necessary; however, a statistically significant number of waste containers will be covered with salt so that degradation of the containers and waste form in a repository (as opposed to a pilot plant) environment can be observed.

The ultimate size of the alpha facility - - or, for that matter, the high-level facility - - cannot be determined at this time: it will depend on how much nuclear power and, therefore, how much waste is generated in the future, and on what fraction of that waste is stored at the RWDPP. Some perspective on plant size may be gained by noting that, on the basis of a recent forecast of the growth of nuclear power, about $10^6 m^3$ of alpha waste will have been produced by the year 2000. If this were all stored at the RWDPP, the surface area above the alpha storage facility would be about 4 km^2, or nearly one square mile.

High-level waste canisters will be unloaded from their shipping casks in a surface-level hot cell, lowered (without shielding) to a subsurface hot cell, and transferred to a special shielded transporter which carries individual canisters to the storage site. The transporter will be designed to emplace the canisters in previously prepared one-canister cavities, and to insert precast shield plugs; the emplacement operation will be controlled by an operator in the shielded transporter cab. Storage arrays with both vertical and horizontal canister orientations are under consideration. Canister spacing is calculated to limit the areal power density to 370 kw per hectare (150 kw per acre).

Three high-level waste storage drifts containing some 300 canisters will be dedicated to experiments aimed at defining the long-term behavior of the waste. Core samples will be taken periodically to determine the condition of the canisters and the solidified waste, and to measure the extent of migration of the toxic nuclides. Sooner or later, in months or years but certainly no longer than tens of years, metallic canisters will disintegrate; they will not provide a permanent barrier between the waste and the salt. In order to accelerate the migration experiments, degraded waste forms — glass monoliths without canisters or even ground-up glass — will be included in the test matrix. Migration distances are expected to be only of the order of centimeters so that recovery of the waste, if necessary, can be accomplished by overcoring.

The cladding waste and intermediate-level wastes will be stored in separate drifts of the high-level facility using, to the extent possible, the same equipment used for high-level waste. Emplacement techniques will vary, depending on the thermal power and radiation effluent of the waste. For the least active α - β - γ waste, for example, it may be possible to stack the containers in the manner used for alpha waste and use loosely packed salt backfill for radiation shielding. Solid billets of cladding waste, on the other hand, may require an emplacement technique only slightly less sophisticated than that used for high-level waste.

Accurate records showing the location of each waste container will be maintained, and the recovery procedures developed for use during the pilot plant phase of operation will permit retrieval of any designated waste container with minimum perturbation of the surrounding containers. After conversion of the RWDPP to repository status, any retrieval operation would involve remining the backfilled storage drifts or mining new drifts parallel to the storage drifts.

PROGRAM CHRONOLOGY

It was noted earlier that Sandia Laboratories undertook the conceptual design of the RWDPP in April, 1975, and that in late 1975 an exploratory area previously selected by ORNL was abandoned when unacceptable geologic structure was encountered in a drill hole. Recent activities have been concentrated on the identification of alternative sites for further exploration. Seismic surveys and photogeologic studies have centered on an area about 10 km southwest of the original site, and several additional drill holes are planned.

Tentative site confirmation will be made in June, 1976, and the conceptual facility design will be completed by June, 1977. An architect-engineer selected by ERDA will be responsible for the engineering design. Construction will be carried out in two phases, with site preparation and installation of utilities beginning in the spring of 1978, and construction of the repository proper beginning in early 1979. Facility operation, by a contractor to be selected by ERDA, is scheduled to begin in January, 1983.

CONCLUSION

Any rational program for achieving energy independence in the United States must rely heavily on nuclear power. Despite the glowing predictions of those who promote fusion power, solar power, geothermal power, etc., these technologies are simply not ready for commercial exploitation today — and they may not be ready for several decades. Only coal and nuclear power are ready, and coal can't do the job alone.

Legitimate technical criticism of nuclear power is healthy; it keeps the industry honest. Perhaps the most valid criticism has been the government's failure to take the initiative in "closing the fuel cycle" by providing a repository for nuclear wastes. This lack of initiative does not connote a lack of interest or a failure to recognize the seriousness of the problem; until now, it has simply been a question of fiscal priorities.

It is unfair to infer that the present support of waste management programs is another case of "too little, too late". But it's not too early, either. The maturation of the nuclear power industry demands that repositories become available on a time scale that coincides with the startup of the commercial fuel reprocessing plants. That's what the RWDPP is all about.

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