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ABSTRACT

Described are problems and techniques for safe disposal of radioactive waste. Degrees of radioactivity, temporary storage, and long-term permanent storage are discussed. Included are diagrams of estimated waste volumes to the year 2000 and of an artist's conception of a permanent underground disposal facility. (SL)

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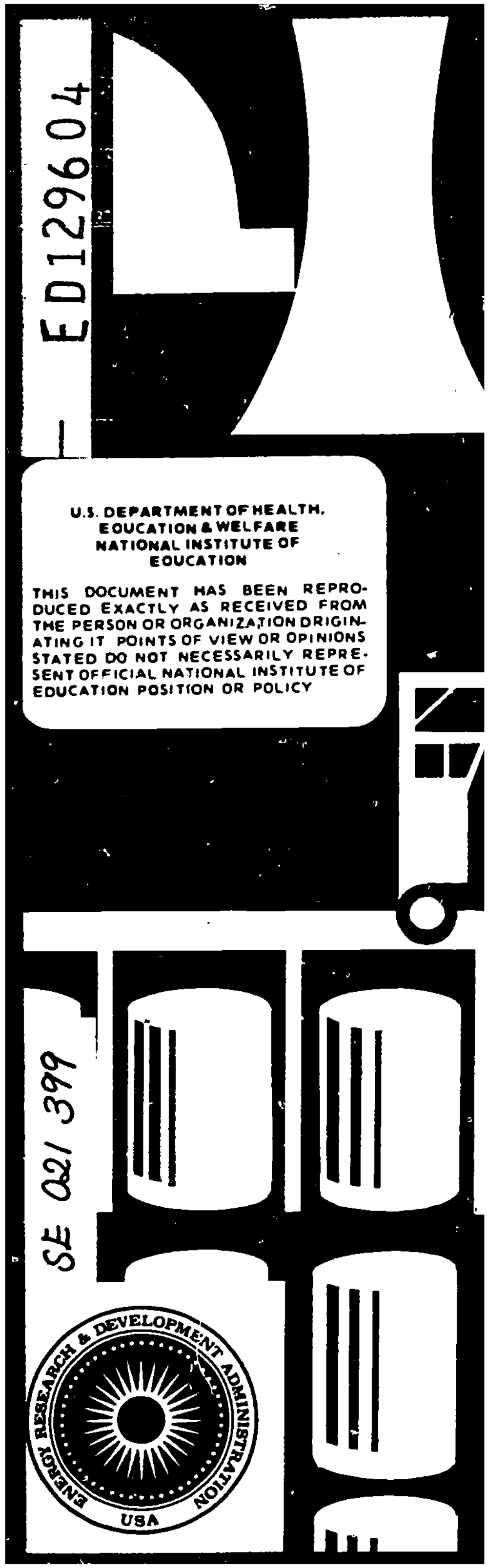

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Joseph M. Dukert is an author and consultant who began writing professionally about science and technology even before he received his B.A. degree in journalism from the University of Notre Dame in 1951. For 2 years he was Assistant Director of Public Information at that University. Later he did graduate work in international relations at Georgetown University and was one of three U.S. Fellowship students during the first academic year of the Hopkins School of Advanced International Studies in Bologna, Italy.

For several years he was Public Relations Director for the Nuclear Division of the Martin Marietta Corporation, and later he developed a program that interpreted the company's basic research work in physics, mathematics, metallurgy, and the biosciences to a diverse group of audiences, which included the general public.

He has been executive producer for several movies, one of which received a "Cindy" as the best industrial sales film of the year. Another of his films was chosen as the outstanding television newsreel film of the year at the Rome Film Festival.

He is the author of three popular science books, *Atompower* (Coward-McCann, 1962), *This is Antarctica* (Coward-McCann, 1971), and *Nuclear Ships of the World* (Coward-McCann, 1973), numerous booklets, magazine and newspaper articles, and movie and TV scripts.

introduction

Like every step forward in man's history, the development of peaceful nuclear power has produced some new problems while helping to solve older ones. One "new problem" is deciding how best to dispose of the radioactive "ashes" from nuclear reactors. Long before the first power reactor started up, engineers and scientists had formulated safe techniques for handling such wastes, but they knew that even better methods could and should be developed. During the first few decades of the Nuclear Age, they have continued to improve on earlier systems.

With more than 200 commercial nuclear power plants now built or definitely planned in the United States, it's important to understand that the immediate problem of storing their wastes safely *has* been resolved, and that the Energy Research and Development Administration (ERDA)—which absorbed the research and development programs of the U.S. Atomic Energy Commission in January 1975—is embarked on a program for choosing the optimum system to dispose of long-lived radioactive waste permanently.

It's clear that a permanent solution is needed. Compared with the unused solids and gases produced by a power plant burning coal or oil, a nuclear reactor leaves only a *miniscule residue* of waste from the fission process, but the potential hazards from some radioactive wastes could remain for hundreds of thousands of years if they were not disposed of effectively.

Concerns are easy to arouse and hard to allay in a situation like this, especially in view of the limited public understanding of radioactivity. Some people are content to accept official assurances without question, but others are equally willing to believe scare stories—even if they have little factual or technical basis. The purpose of this background review is to explain in layman's terms ERDA's approach to management of high-level commerical waste—why things are done, as well as what and how.

High-Level Radioactive Waste: Safe Storage and Ultimate Disposal

by Joseph M. Dukert

"High-level radioactive waste" is perhaps the most misunderstood term in the public lexicon of nuclear energy. To define it the handiest way to start might be by saying something about what it is *not*.

First, high-level wastes should not be confused with the extremely dilute radioactive effluents that nuclear power plants may discharge as a part of day-to-day operation. On the contrary, power plants are *never* permitted to release high-level wastes to the environment. Nor are such wastes buried at nuclear power plant sites, or at any of the U. S. nuclear industry's half dozen commercial burial grounds. Strictly speaking, you might say that high-level radioactive wastes don't even *exist* at the power plants where electricity is generated. But that last statement deserves a little amplification.

Waste is the unusable material left over at the end of an operation. Fuel elements are the only source of high-level radioactivity in a nuclear power plant, but they themselves are not waste when they are removed from the reactor. For a load of nuclear reactor fuel, the end of the line need not be the generating station but a chemical reprocessing plant.

That's where unfissioned uranium fuel, the valuable plutonium formed during reactor operation, and perhaps a few useful radioactive by-products can be removed from the "spent" fuel elements. Only the residue from those processing steps is truly "waste," and only after that stage of the nuclear power cycle do we have to worry about safely disposing of it.*

This particular distinction is more than semantic. So long as reactor fuel elements remain intact, any major amounts of radioactivity that appear within them stay sealed inside. They are physically and/or chemically locked into the fuel material itself and also "canned" within the fuel cladding that surrounds it. It is only in the heavily shielded cells of a reprocessing plant that the fuel elements are cut open by

*To allow for further study of safeguards questions, the Nuclear Regulatory Commission has not yet decided whether or when to authorize full-scale recycling of plutonium in commercial reactors, so the possibility technically exists that the entire fuel bundle would require long-term storage or disposal. Aside from the economic penalty and loss in natural resources that such an approach would involve, however, the general principles governing safe disposal of that greater bulk would undoubtedly be similar to those described in this booklet.

remote control and the radioactive material inside is dissolved so that the chemical work on it can begin. That's when the unusable substances really become "waste", and that's also the first point at which high-level radioactivity reaches a physical and chemical form that would have even a remote likelihood of entering the general environment.

There is a vast difference in the degree of radioactivity between reprocessing plant wastes and the low-level effluents from a power plant. The latter normally contain less than one millionth of a curie per gallon, while the former are measured in hundreds or even thousands of curies per gallon (for definitions of terms, see the box on Radioactive Decay on pages 4 and 5). Everybody agrees that the very high-level waste cannot be diluted sufficiently so that it could be released to the air or water. It must be isolated from man's air supply, his drinking water, and his food chain for a suitable period of time—namely, until radioactive decay renders it harmless.

A certain amount of contaminated trash also develops at any nuclear operating site—old protective clothing, filters, etc.—but this booklet won't deal with those items because their disposition is relatively easy. Depending on the nature of these wastes, they may be sealed in concrete or simply boxed, and then shipped to one of the approved commercial sites around the country for land burial.

Fuel elements that have spent several years producing energy in a power reactor, on the other hand, are highly radioactive because of fission products distributed within the material inside their cladding. Nevertheless, this spent fuel can be moved to the reprocessing plant without too much difficulty by using specially designed shipping casks. High-level radioactivity raises the temperature of surrounding material, so each thick-walled shipping container has its own built-in cooling system. The entire fuel element is encased in a virtually indestructible cask that is built to survive a fire, collision in transit, or other severe accidents. But even if that safeguard should fail, the nature of the fuel form itself would tend to avoid any spread of radioactivity.

The liquid wastes at a reprocessing plant are a different matter. Liquids are always harder to package and harder to handle. For the most part, these liquids are corrosive too. And in some cases their radioactivity level is so high that the liquid could boil for several decades unless cooled continuously. The Federal Government's experience with high-level wastes at its own plutonium production facilities shows that liquid radioactive wastes can be stored safely if adequate engineering precautions are taken and if the tanks are kept under constant surveillance; but this is only an interim measure. It is done—either by government or private processors—only at the point where the wastes originate.

During its entire history, the U. S. Atomic Energy Commission never shipped high-level liquid wastes from one installation to another, and ERDA has no intention of doing so either. Nor is there much likelihood that the Nuclear Regulatory Commission—which took over AEC's regulatory responsibilities in January 1975—would ever allow commercial fuel reprocessors to transport such material. In 1971, AEC announced the following ground rules and timetable for the nuclear fuel reprocessing industry; these remain in effect:

> Reprocessors will be permitted to store high-level liquid wastes temporarily in approved containers, but no more than a 5-year backlog of newly generated waste will be allowed to accumulate before the material is converted to an acceptable solid form. The commercial reprocessors aren't restricted to using the specific solidification processes that the government has demonstrated, but their end product will have to meet rigorous standards. It must be a stable solid, which won't revert to liquid or gas in

what is radioactive decay?

In certain atoms, the nucleus is unstable. It has more energy than it needs. Nature's way of putting things in order is for part of the nucleus to break away and thus release some of this excess energy. The nucleus thus changes into a completely different element. The process is called radioactive decay, and the energy given off is called nuclear radiation.

Radioactive atoms in our own bodies and all around us decay constantly. No harm is done so long as the radioactivity doesn't become too concentrated. It's a process that's been going on since the beginning of time. Some nuclear radiation is more penetrating than others, but all radiation can be blocked by shielding, by distance, or by a combination of the two.

The unit of measurement for all radioactivity is the *curie*, which indicates a certain number of nuclear disintegrations per second. The curie isn't a measure of weight or volume; it might represent the total radioactivity in a teaspoonful or in a tubful of liquid. In fact, the weight and volume of radioactive material usually are not noticeably affected by this decay, although the number of curies gradually decreases.

Each radioisotope has a characteristic "half-life", which indicates how long a piece of it will take to decay. No matter what quantity of the material you start with at any given time, you can be sure that half of its atoms will have disintegrated by the end of a single half-life. The period for various radioactive substances varies from split-seconds to millennia.

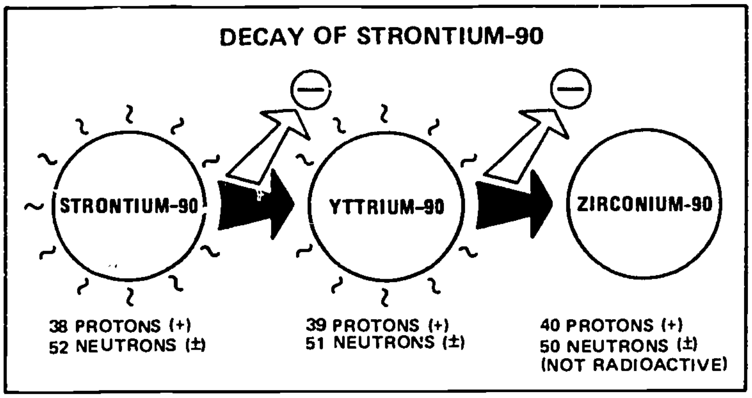
Clearly, the materials with shorter half-lives emit more radiation in a short time, but they also stabilize more quickly. Those with longer half-lives tend to radiate less vigorously, because it takes longer for a given percentage of their nuclei to disintegrate.

Radioisotopes generate heat spontaneously, because the energetic particles given off by decay slow down as they pass through the material surrounding them. Their energy-of-motion turns into thermal energy, and the material itself becomes warm or even hot. A single pound of strontium-90 and its "daughter" yttrium-90 (see diagram on page 6) give off as much heat in a year as you would get by burning half a ton of coal. Of course heat production and radioactivity both decline in time. At the end of that year the pound of material would contain fewer curies and would be generating proportionally less heat energy.

It should be noted that a pound of strontium-90 is quite a substantial amount in terms of radioactive waste. It would represent more than 100,000 curies, with a peak thermal output of over 400 watts. In contrast, the *mixture* of reactor wastes that a commercial reprocessing plant might turn over to ERDA for storage and eventual disposal would probably contain fewer than 1000 curies per pound.

Much of the radioactivity in spent fuel disappears before it even goes to a reprocessor. It is normal to let such fuel bundles cool in a deep pool of water at the reactor site for 3 or 4 months before shipping, and during that time about 99.9% of the original radioactivity vanishes through decay.

During 20 half-lives a million curies of any material will decay to less than 1 curie--so that if high-level liquid wastes containing radionuclides at one million times the permissible drinking water concentration were to be stored in liquid form, nearly 600 years would be required for strontium-90 (with a half-life of about 30 years) and half a million years for one kind of plutonium (with a half-life of 24,000 years) to decay to this obviously acceptable level. Standards might be less restrictive for insoluble solids, but long-term isolation (by conventional standards) will be required. Fortunately, nuclear wastes are compact enough (or can be made so) to make this feasible.



As electrons leave the nucleus (beta decay), neutrons are converted into protons and the atom becomes a different element.

the presence of high radiation or reasonably high temperatures. It has to be chemically stable too, which means that it won't decompose, explode, burn, or become corrosive. Research and development is continuing on solidification techniques (stressing products that resist being leached away or dispersed in any other manner); and it's always possible that even better forms for solid waste will be discovered.

Counting such solidified material, a commercial firm will be allowed to store up to 10 years' accumulation of waste at the reprocessing site, but within 10 years after fuel elements have been processed, the resulting high-level waste must be shipped (in solid form and in sealed metal capsules) to a government facility designated to handle it. Transporting the solidified waste (which will have lost part of its original radioactivity during the temporary storage period) will be just as safe as shipping spent fuel elements.

The first commercial reprocessing plant for nuclear reactor fuel did not begin operation until 1966, and only a small amount of fuel had actually been reprocessed at the time the AEC ground rules went into effect. That plant has been shut down for several years now, pending federal approval for modification and expansion. Another reprocessing plant is seeking a license to begin operation now also, but shipments of solidified high-level commercial wastes probably won't begin until sometime in the 1980s. By that time, ERDA expects to have at least one of two alternatives ready for the material. One is to [illegible] steel canisters in concrete vaults or in steel casks at or near the surface, where they and their radioactive contents would be monitored continuously. This technique is usually called retrievable surface storage. The other is to put such canisters far beneath the surface of the earth in geologic formations, such as bedded salt, chosen especially for this purpose. The latter method would be used only on a pilot basis until results from laboratory and earlier field experiments can be checked on a broader scale. Although the surface storage would be designed for 100 years, the geologic program would be aimed at completing the pilot phase and having disposal available in something like two or three decades.

With either alternative it will still be possible to remove the wastes for storage or disposal in some other fashion if that seems desirable in the years to come. Disposal, indeed, has a very special meaning that ERDA doesn't apply at all to waste-handling methods like these, which are reversible. Burial in salt could become a form of disposal, but only if the storage rooms and access tunnels were refilled and the plastic salt formation allowed to reseal itself. But confining the material on the surface is still called storage.

Why is such a long-term view necessary? Why are the fuel reprocessors—and, ultimately, the electric utilities and their customers—to be charged by the Federal Government for such elaborate waste handling procedures? The answers lie in the nature of nuclear waste itself.

When an atomic nucleus fissions inside a reactor, it splits into smaller fragments. Every nucleus doesn't split in precisely the same way, so scores of quite different "fission products" may be formed inside a single homogeneous fuel pellet. Some have very short radioactive "half-lives", and so they essentially vanish within minutes or hours or days. The unstable nuclei don't actually disappear completely; rather they are transformed by radioactive decay into different *kinds* of nuclei, which, in turn, may or may not be radioactive themselves. According to the rules of nature, all radioactive atoms eventually pass through different stages of decay until they reach one where they will no longer be subject to radioactive disintegration. Sometimes that takes a long, long time.

Consider strontium-90, for instance. It's a fairly common fission product, and its half-life is more than 28 years. That means that if any given amount of it is allowed to sit for that length of time (e.g., dissolved in a tank of liquid or solidified inside a vault) it will still be giving off half as much radioactivity and heat at the end of nearly three decades. In another 28 years it will have dropped to one-quarter of its original level; 28 years after that it will be down to one-eighth, etc. If we start out with a substantial concentration of a fission product like this, it's clear that a century or so of storage won't solve everything, although within about 300 years all but one-tenth of 1% of the radioactivity will have disappeared.

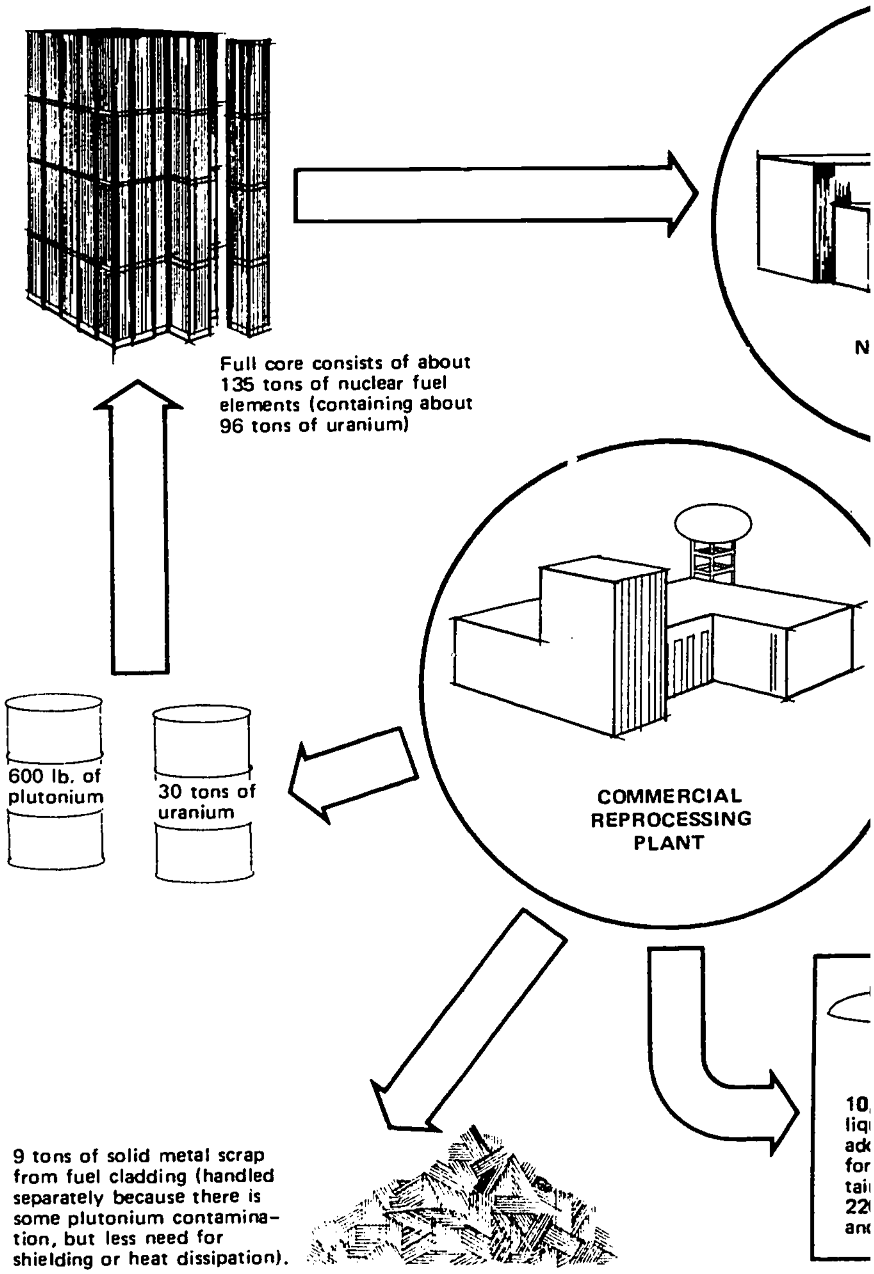
Aside from fission products, however, there is another component of nuclear waste that poses an even longer-term problem. It is the heavier radioactive nuclides that are formed when the nucleus of an atom like uranium absorbs a neutron "bullet" inside the reactor instead of being split apart as a result of its impact. Some of these big new nuclei decay very rapidly, like most fission products, but some others have radioactive half-lives of thousands of years.

The most important of these "heavy" radionuclides is plutonium, and this brings us back to the reprocessing plants themselves and the reason they are needed.

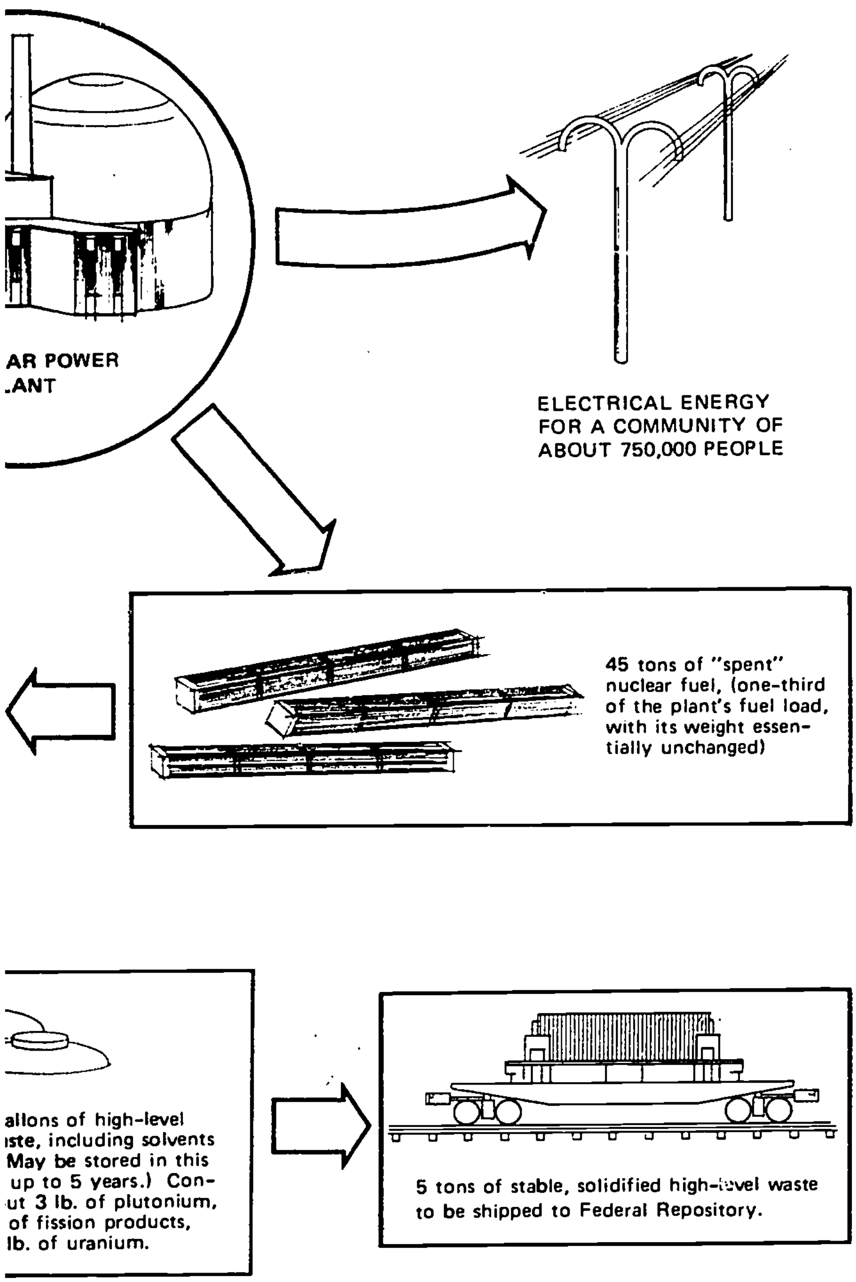
In order for a nuclear reactor to operate, a certain amount of fissionable fuel material must be present in its core. Otherwise, an energy-releasing chain reaction simply couldn't take place. As a typical reactor functions, the amount of uranium in its core decreases steadily. Some of it changes into plutonium, but a greater percentage is usually split into fission products as the nuclear "binding energy" holding the uranium nucleus together is released. Plutonium is also fissionable, so a certain percentage of that newly formed material joins in the chain reaction to extend the reactor's output.

Fission products, on the other hand, act like a damper on the reaction. They soak up extra neutrons without releasing any appreciable amount of energy in return. As fission products build up, the reaction tends to bog down. Eventually, there comes a time when it is more efficient and more economical to replace spent fuel elements with fresh ones than to leave them in the reactor and try to produce more fissions within the remaining fuel.

Many power reactors are designed so that a portion of the core is replaced annually, and after the first few years a pattern develops in which each individual fuel element spends 3 or 4 years producing power before being removed and shipped to a reprocessing plant. The point is that at this time the fuel matrix still contains *some* of its original fissionable uranium. It also contains fission products and a considerable amount of unfissioned plutonium, which is potentially valuable as a fuel for other reactors. The job of the chemical



The fuel cycle associated with 1 year's operation



ypical 1000-electrical-megawatt nuclear power plant.

reprocessor is to pull out as much of the valuable items—including plutonium—as he can within practical limits.

As the fuel cycle diagram on pages 10 and 11 indicates, all but a tiny fraction of the plutonium may be recovered for reuse, and these methods are being improved. Yet the small amounts of plutonium and similar materials that slip through into the waste provide a disposal problem because of their extremely long half-lives.

As in the instance above (where a distinction had to be made between spent fuel and waste), there is an important reason for distinguishing between the two major types of radioactive material found in the wastes of reprocessing plants. Most fission products emit radiation that is quite penetrating. In order to block this radiation relatively heavy shielding is required. Plutonium, on the other hand, generally decays by emitting "alpha particles". This type of radiation can be stopped by a comparatively simple shield—even a piece of paper. And the alpha wastes produce very little heat.

The biological danger from plutonium develops only if it actually gets into the human system by being inhaled or absorbed by the body in some way.* Obviously there are many ways of preventing this, but it has always seemed

*The fact that plutonium's hazards are confined to cases where ingestion takes place is pointed up sharply by its use in "heart assist" devices, and eventually, perhaps, in a nuclear-powered mechanical heart. Plutonium-238, a form whose shorter half-life (less than 90 years) makes it a greater heat producer than most of the plutonium found in reactor wastes, can be used to generate a small electric current continuously for mechanical devices implanted directly into the body. The same technique and fuel were used in several scientific instrument packages left on the moon by Apollo astronauts. Sealed in a suitable container, the plutonium for an implanted power source cannot be absorbed by the patient's body cells, and thus is harmless.

advisable to take multiple precautions. If it should be ingested, some plutonium would tend to remain in the system like certain chemical poisons (e.g., lead and mercury) rather than being evacuated by natural processes. Under those circumstances, its radiation could do severe damage.

Contrasted with what "might happen", the *actual* safety record is reassuring. *Tons of plutonium have been produced and handled by workers in the U. S. weapons program since 1945, and there has never been a single fatality from plutonium poisoning.* But the safety record was not achieved by chance, and the wisest course in regard to alpha wastes seems to be to treat them as cautiously as the more intensely radioactive fission products by isolating them from the environment until they decay.

Unfortunately, the half-life of plutonium-239 (the radioisotope that accounts for between 60 and 70% of all the plutonium in spent fuel) is about 24,000 years. That's why deep burial in dry salt formations has been under study since the early days of nuclear power. Geological evidence indicates that such burial could seal off the wastes until all potential danger from them had passed.

There is a common misconception that enormous amounts of nuclear waste are involved. In reality, fuel reprocessing for all commercial nuclear power plants, which are expected to operate between now and the end of this century, will only produce between 30,000 to 60,000 tons of high-level waste in solid form. (The weight may vary, based on the solidification process used.) Even after it has been packaged in small containers to facilitate shipping, storage, and ultimate disposal, its volume would be very small compared to other types of solid waste. Metal scrap (from fuel cladding) represents a somewhat greater volume than the compressed high-level waste, but the metal "hulls" are far easier to handle because of lower heat output and radiation.

experience with noncommercial waste

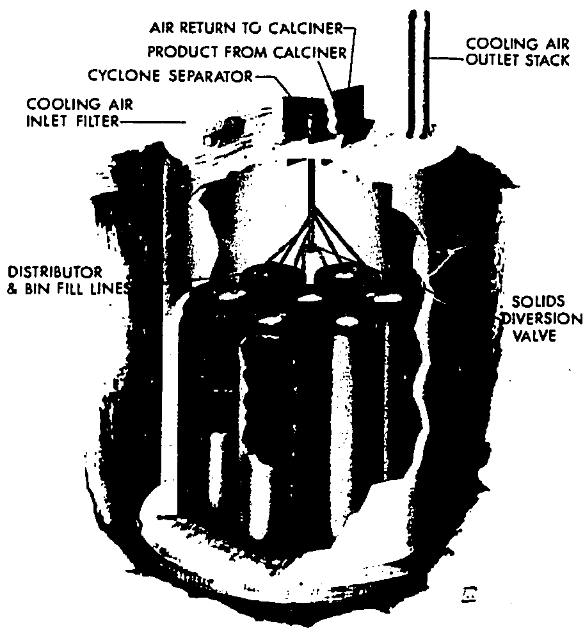
As part of this country's weapons program, the Federal Government has been reprocessing reactor fuel and storing the resultant wastes for about 30 years. Much of what it has learned can be helpful to the nuclear power industry, but there are differences.

The prime purpose of the giant production reactors at Hanford, Washington, and Savannah River, South Carolina, is to produce plutonium, rather than to generate usable heat. With power reactors the opposite is true. In each case, this led to the design of different types of fuel elements. Furthermore, the older facilities generally neutralize the acid in their liquid waste so it can be stored in ordinary steel tanks. That increases the volume, however, and also changes its chemical composition. Commercial reprocessors thus far have indicated a willingness to make the higher capital investment in *stainless steel* tanks that can hold the original *acid* wastes safely.

During the early years, AEC did not take time to reclaim excess uranium from its waste stream. This was done later, after several years in storage. Still later, liquid wastes were removed from the Hanford tanks again when high-heat-producing fission products like strontium-90 and cesium-137* were separated from the rest of the material for segregated storage.

Gradually ERDA is solidifying the liquid wastes it still holds at various locations it took over from AEC. The goal is to reduce the backlog of liquid wastes to a "working inventory" level by the late 1970s.

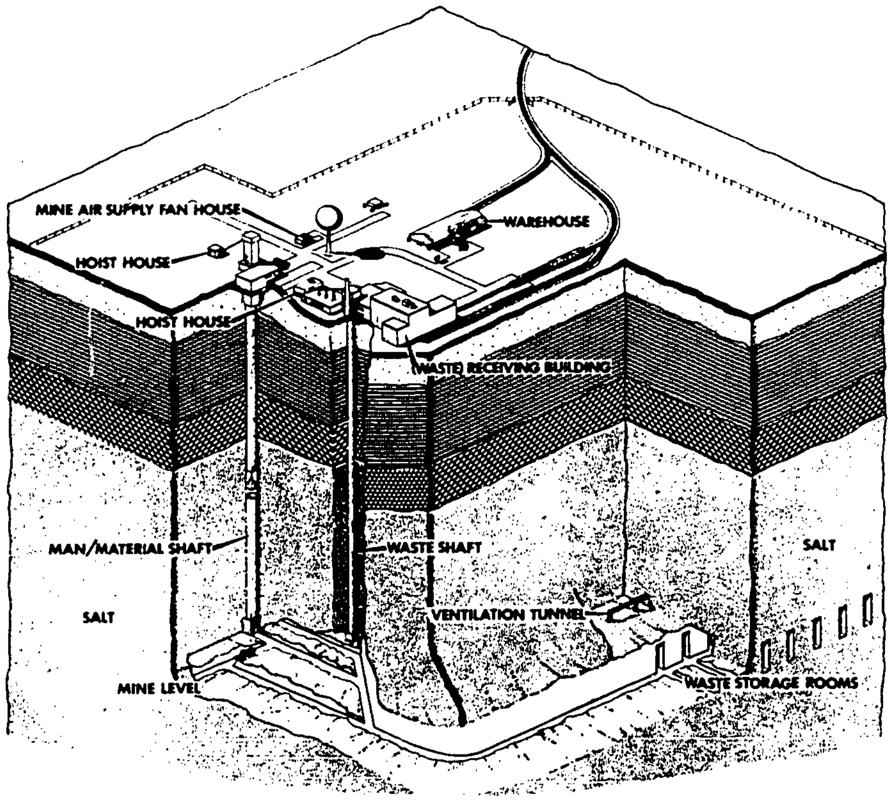
*When safely encapsulated, fairly large quantities of these materials (thousands of curies at a time) have found practical uses as sources of heat and radiation. However, the total market demand for such special applications is still limited.



This underground concrete vault at the Idaho Nuclear Engineering Laboratory stores highly radioactive solid wastes from nuclear fuel processing. This is one of six 12-foot diameter tanks that will hold 40,000 cubic feet of solid wastes.

ERDA's reprocessing plant at Idaho Falls handles other specialized reactor fuel. It stores the high-level wastes in acid form (as commercial plants do) and has routinely solidified them after about 2 years interim storage. While operating this facility, the AEC also developed and demonstrated three other solidification processes for power reactor fuel wastes, and details of the technology have been made available to private industry.

Although liquid waste storage by AEC was always regarded as merely an interim measure, it has proved to be a safe method. Leaks developed in some of the first tanks, but the volume of liquid that escaped has been small. The radioactivity has been retained in the soil near the tanks, either by absorption of the liquid or ion exchange. No leakage to the soil has taken place from the more modem tank-within-a-tank design at Hanford and Savannah River or from the stainless steel tanks at Idaho.



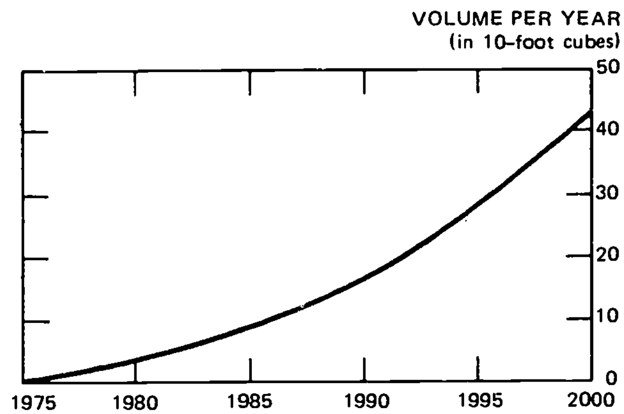
This cutaway is an artist's concept of a possible pilot plant to confirm the concept of using underground bedded salt to dispose of solidified high-level radioactive waste. The waste would be placed in salt beds about 1000 to 3000 feet underground, and would always be retrievable during the pilot plant operation.

Several different techniques have been demonstrated successfully for solidifying high-level liquid wastes. First, the liquid may simply be evaporated. Another method, used primarily since the early 1960s at the Idaho Nuclear Engineering Laboratory near Idaho Falls, involves heat-treating the solid material to produce sand-like grains at the same time the liquid is being extracted. To decrease its solubility, a solid might be heated further to produce a ceramic. It could be mixed with other materials and processed into a new compound, or it could be incorporated in either metal or glass. Solid wastes may arrive at Federal Repositories in different forms from the various commercial reprocessing plants, but in each case they are likely to occupy only about one-tenth of the volume of the liquids from which they were derived.

At the ground-level repository for commercial wastes, the plan is for a single receiving and transfer facility to check over and accept waste canisters as they arrive by rail or truck. The adjoining storage structures will be uniform and relatively small, and capacity will be added only as needed. Naturally, some storage space would always be kept open on a standby basis in case the waste had to be removed from a module for any reason.

The metal cylinders of waste that will be shipped by commercial reprocessors to the surface storage site or to a pilot geological repository may vary in size, but generally they will be 10–15 feet long with diameters from 12 to 24 inches. A single filled canister could weigh several tons. The limiting factor will be the amount of heat it generates, with each container being restricted to a few thousand thermal watts. Recently produced wastes are hotter and will have to be shipped in smaller volumes; those that have been given more time to decay before packaging can be handled somewhat more easily and more efficiently.

Permanent disposal of radioactive wastes in salt formations was recommended by a special committee of the National Academy of Sciences–National Research Council as early as 1957, after 2 years of study. The salt-burial approach was endorsed by each successive advisory panel created by NAS–NRC to examine progress in the field, and this disposal technique is still the most promising of all those suggested so far. The present ERDA program is focused on studying several other likely formations (such as domed salt and



Estimated high-level waste which will result from all commercial reprocessing operations in the United States (based on AEC projections of growth in the nuclear power industry as of 1974 and a tenfold reduction in waste volume through solidification after aging.)

granite) to bring knowledge about them up to a par with the knowledge of bedded salt. The next step would be to pick a formation and site for a *pilot plant*.

For example, if salt is chosen, after each metal cylinder containing wastes is set into place, the space above it will be filled by a removable shield plug (instead of crushed salt) that would fuse into the surrounding salt. For the same reason, a metal sleeve will line the hole; and the technique for removing a can of stored waste will actually be tested. Extensive instrumentation will measure temperature, pressure, radiation effects, and any positional change in the waste capsules or the surrounding mass.

Samples of rock and salt from around the storage area will also be examined periodically. As in the case of the surface vaults, the pilot geological repository will be monitored continuously. Because the metal waste containers would eventually deteriorate, it is likely that some will be ruptured on purpose under controlled conditions after burial.

to study any possible interaction of bare solidified waste and the salt itself.

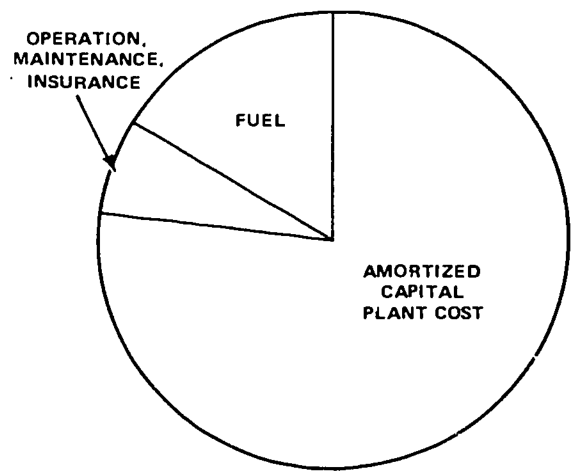
If enough evidence is developed to justify use of the pilot plant site for permanent disposal of wastes, this will be a relatively easy option to exercise. If long-term safety can't be demonstrated or if the operation fails to win public acceptance, the material can be removed to the existing retrievable surface storage facility for safe management there.

Salt beds appear to have many advantages for disposal. They have lain relatively undisturbed for millions of years and are likely to remain that way. Thick layers of this salt would be good protective shields against the radiation of the waste. And salt has a "plastic" property, so that if it were heated—as it would be by the waste—it would "flow" to relieve the heat stress, but would fuse so that the net movement of waste would be nil.

The AEC used an abandoned salt mine near Lyons, Kansas, to test salt under simulated conditions of high-level waste disposal, and the results were generally favorable. But serious questions were raised—not about the basic idea of using bedded salt, but about using that specific mine. A major uncertainty was the effect of plans of a nearby working mine to expand the use of water to mine its salt. So the AEC began looking at other salt bed sites for a possible pilot salt repository, and evaluating other geologic media also.

Overall, federal officials have made it clear that their primary objective is to assure safety in radioactive waste management, rather than to keep costs at an absolute minimum. ERDA plans to charge reprocessors a one-time fee when solid wastes are accepted at a Federal Repository, and this will be intended to cover the projected costs of long-term storage and ultimate disposal. Although the exact rate structure cannot be drawn up until site selection and design work are complete, the charges are unlikely to be burden-

BREAKDOWN OF GENERATING COSTS
(Typical New 1000-MW Nuclear Plant)

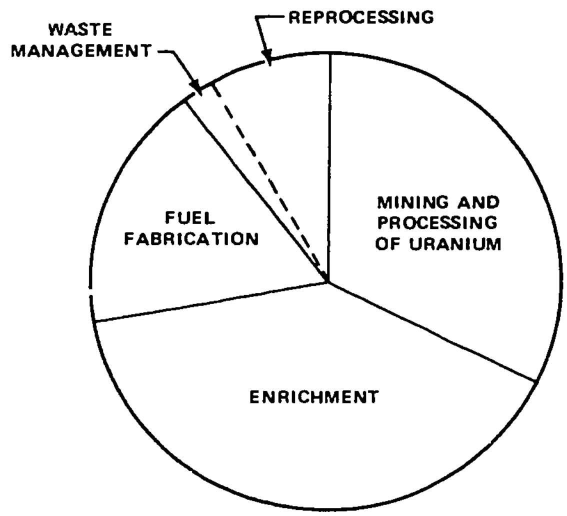


some when pro-rated among the vast quantities of electric power supplied by generating plants over a period of years.

As an indication, several generalized studies have estimated that the costs for solidification, shipping, and storage in a geological repository would amount to from .03 to .10 mills per kilowatt hour of electricity produced. That would be a small fraction of 1% of the retail price of electricity to most U. S. householders at present.

The AEC's (and now ERDA's) approach to radioactive waste management has been a complex combination of long-range planning, concern for environmental protection, and step-by-step progression. At the very beginning of the Nuclear Age, the Federal Government was faced with decisions that might affect the earth and its inhabitants hundreds of thousands of years from now. It began by developing the techniques of guarded liquid storage that would ensure safe storage for decades at least and that could

BREAKDOWN OF FUEL COSTS*
(Typical New 1000-MW Nuclear Plant)



*Ignoring the value of plutonium and uranium that can be recycled after reprocessing.

be extended if necessary. Simultaneously it pursued research and development on solidification and handling methods that now have reached the stage where the technology of retrievable surface storage makes it safe and practical. One system of ultimate disposal (burial in salt beds) seems acceptable, and other alternatives are still considered possible when certain technology becomes available.

Few people consider the fact that this entire planning exercise—unique in human history—has had to be compressed into a brief, crucial period that could very well be completed in our lifetime. If it becomes possible in the 21st century to meet energy needs entirely through the nuclear fusion process (or through solar devices, geomagnetism, ocean currents, or via some other, yet-unanticipated energy scheme), the problem of high-level radioactive wastes could dwindle or disappear along with the widespread use of fission reactors.

For comparison, think of the fossil-fuel era, now barely a century old, yet already recognized by many as a transitional period. Practically no coal was burned before 1850. Wood had been used for almost all fires since the days of the cave man, and there was still no such thing as an electrical generating plant to require any sort of fuel. Oil made its first significant appearance as an energy source only after 1900. Natural gas made its start around 1920, and its supply days are already considered numbered.

Nuclear power as we know it now presents another, badly needed energy option. Its impact on the environment compares favorably in most respects with fossil fuel; and, with the prospect of nuclear fuel recycling starting on a substantial scale in the 1990s, its resources are much greater. But the lessons of the recent past would indicate that the fissioning of uranium and plutonium may be a major source of energy for only a relatively short time—probably decades rather than centuries.

The technology for handling and storing commercial wastes on an interim basis for 100 years or more exists and has been demonstrated. Surface storage facilities can still be made ready in plenty of time for the first shipments of solidified waste from the reprocessing plants during the 1980s. The final volume of all high-level wastes from power plants will be small enough so that geologic disposal could be used easily if pilot operations show that this is the best way to handle its permanent disposal. As a backup, research on other alternatives is continuing.

If ERDA used some of the waste from reprocessing facilities in the 1980s as "feed" for a geologic pilot repository it could store the remainder in retrievable surface storage facilities capable of receiving *all* the commercial waste at any time. Alternately, all of the waste could go directly to a geologic repository.

The Energy Research and Development Administration is required by law to prepare detailed advance safety analyses and environmental impact statements for its developmental and operational waste handling facilities, and to publish and circulate them to other interested agencies and groups before each major step. Its own environmental impact statements about the retrievable surface storage and pilot geologic repository become a matter of public record and face careful review.

Early in 1975, ERDA announced that it would expand its original environmental review before requesting funds for a surface storage facility—which had always been recognized as only an interim measure. A great many individuals and groups will have further opportunity to comment on and criticize the final approach this country takes in solving the disposal problem for high-level commercial nuclear wastes.

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- ENVIRONMENT AND SAFETY—Investigation of health, safety, and environmental effects of energy technologies, and research on managing wastes from energy production.
- NUCLEAR ENERGY—Expansion of medical, industrial and research applications; advancement of reactor technologies for generating electricity, especially the breeder concept; and production of nuclear materials for civilian needs.
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