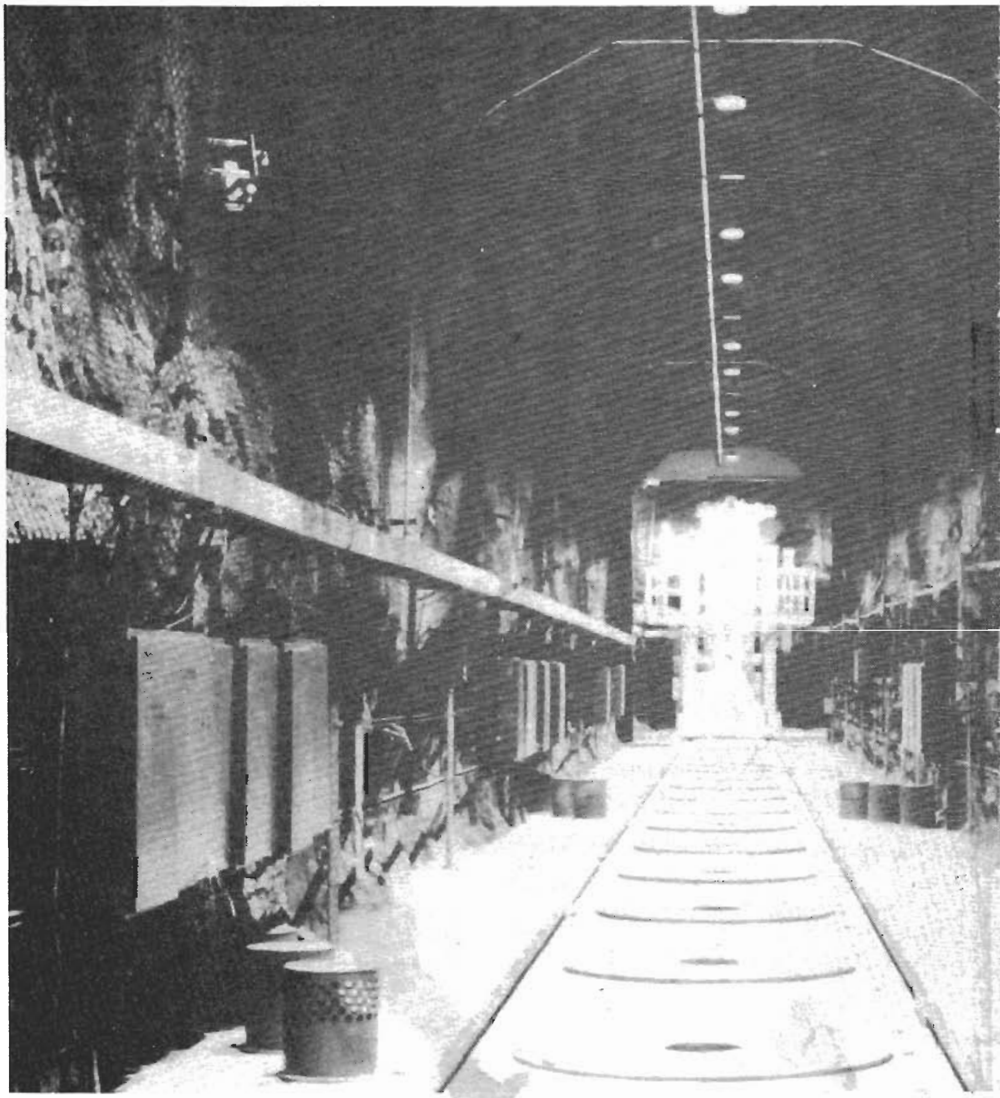
Nuclear Wastes

Roger Allan finds some hot things in the nation's garbage can



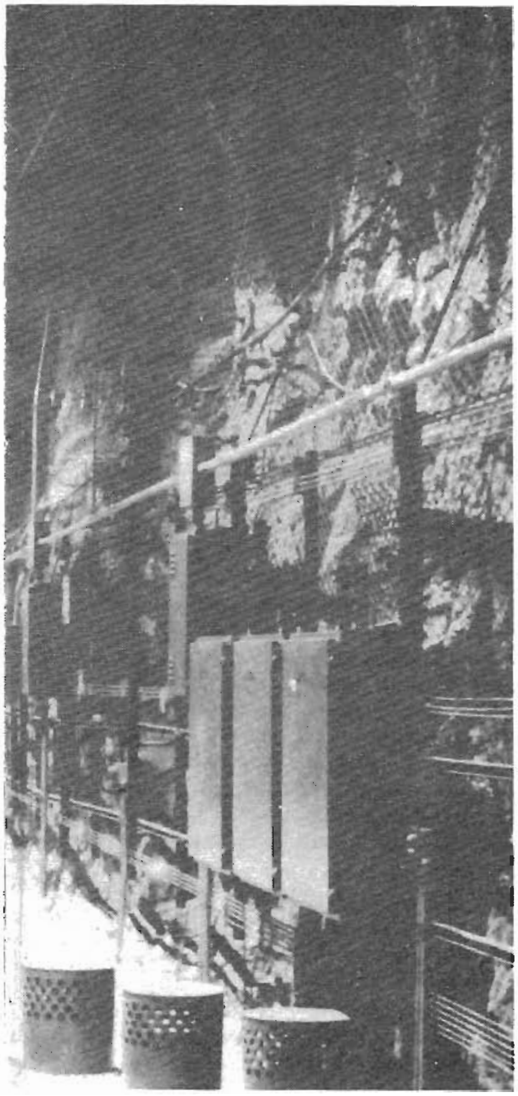
Actual spent fuel assemblies have been placed 1400 feet below the surface at the Nevada test site to evaluate granite's response to heat and radiation (All illustrations, courtesy of U.S. Department of Energy).

THERE ARE essentially three types of radioactive wastes: high level, transuranic and low level. Transuranic wastes (TRU) are those containing isotopes above uranium in the periodic table of chemical elements. They are the by-products of fuel assembly and weapons fabrication and of reprocessing operations. Customarily, while their radioactivity is greater than 10 nanocuries per gram (1 nanocurie = 37 disintegrations/second), they give off very little heat. As such, they can customarily be handled by ordinary methods not requiring remote control. For many years they were disposed by burying in shallow trenches, but since 1970 have been placed in retrievable storage. Low level wastes (LLW) contain relatively little radioactivity and require little or no shielding. These wastes customarily come from medical applications, university laboratories and such mundane items as household smoke detectors which use the heavy artificial isotope americium-241 (half life: 432 years).

High level wastes are those resulting from the reprocessing of spent fuel from a reactor, either defense or commercial. Within a year or so of removal of spent fuel from a reactor, most of the short lived isotopes have decayed away, the cesium-137 and strontium-90 that remain providing most of the heat and radiation of the wastes. At the beginning of 1982 there were about 9,000 tons of spent fuel assemblies from commercial nuclear power plants in temporary storage. These spent fuel assemblies occupy 104,000 cubic feet of space — about the equivalent of one football field covered two feet deep. Each nuclear power generating plant generating a million kilowatts of electricity produces about 33 tons (390 cubic feet) of spent fuel assemblies each year. By the year 2000, the accumulation of spent fuel from commercial nuclear power reactors is projected to total about 950,000 cubic feet.

The spent fuel taken from a reactor after it has operated for a year is highly radioactive, with a surface radiation dosage in the millions of rems per hour (400 rem/hour being lethal to a human being). Most of the heat and radiation decays away after about five years of storage, but spent fuel remains potentially dangerous for much longer periods of time. This danger exists because exposure to even low levels of radiation over sufficiently long periods of time coud cause harmful health effects. Also, some of the waste products could be chemically poisonous if ingested. However, spent fuel is not explosive from either a chemical or nuclear standpoint.

Customarily, the spent fuel rods are stored in facilities at the reactor sites in pools flooded to a depth of thirteen feet with ion-free water. The water provides a medium for dissipating the heat generated by the spent fuel rods, with its depth designed to prevent contamination to reactor workers.



The difficulty with all this is the amount of spent fuel produced (number of bundles), the half-life of the isotopes, and the lack of a permanent storage program. All the designers of reactors built in the late 50s, 60s and early 70s expected that the water pool storage facilities to be built on site would only be a temporary stop-gap measure, pending the construction of a permanent long term storage or reprocessing facility. And in fact, a facility, the Barnwell Nuclear Fuels Plant, was constructed in South Carolina for this purpose. However, for political and economic reasons, the Carter Administration in 1976 closed the facility, believing that in so doing it might urge other countries to do likewise, thereby decreasing the world's production of military grade plutonium, a by-product of the process.

As such, the nuclear power facilities were caught in a bind; they were producing spent fuel rods at the rate of 60-180 per reactor per year (depending on the design), and when it is remembered that the US and Canada combined have 82 operating reactors, with another 104 either on order or under construction, they rapidly started to run out of space to put them. Their first attempt at dealing with this problem was to decrease the distance between spent fuel rods in the retaining pools from 20 inches to 12 inches. While this increased the number of rods that could be held by a pool, it also increased the amount of heat generated, reaching the design maximums for the pools, a bit like putting a quart in a pint pot. The second method of dealing with the rods was to ship them to the retaining pools of nuclear facilities still under construction, in the hopes that by the time the facility was finished someone would come up with a better idea. Needless to say, a process for the long term (centuries, 500-1000 years minimum) storage, isolation or disposal of HLW was increasingly become a matter of concern, and while it would be wrong to suggest that the nuclear industry is currently choking on its own waste products, the time is drawing nearer when such a reality will occur.

There are, broadly speaking, three ways that HLW can be dealth with: holding them for decay, diluting and dispersing them, or concentrating and containing them. Holding them for decay is relatively simple: one merely shrouds the material with adequate protective layers, sits back and waits. It is fine for such things as iodine-131 which has a half-life of 8 days, after which the radioactive components have reduced to the level where one can virtually flush it down the toilet without there being any danger to the public or the environment. An example of diluting is the controlled release of krypton-85 gas into the atmosphere, it being a side product of the chemical processing of spent fuel. The gas has practically no chemical or biological action, and the volume of the atmosphere is so huge that the krypton concentration rapidly falls to unreadably low levels.

But neither of these methods are useful for those high-level wastes which are solid or liquid and toxic for long periods of time such as tritium (half life: 12.3 years), carbon-14 (half life 5730 years), plutonium-239 (half life: 24,131 years), or the two big ones in volume, strontium-90 (half life 28.8 years) and cesium-137 (half life: 30.2 years). These two dominate the radioactive components of spent fuels for the better part of a millenia. Customarily, protection from them is considered to require a time span of at least 500 years, preferably 1000 years.

The first question that must be addressed in dealing with this matter is whether these types of high-level wastes should be either stored or disposed. Arguments in favour of storage are that handling is safer after decay has taken place, that further research and development may lead to better ways of getting rid of these wastes, and that some new important use for the radioisotopes may be found by future generations. An argument against storage is that there may be an accidental release of radioactivity, contaminating the biosphere. Arguments in support of disposal (that is, the final action, with no intent to recover or transfer the material at a later date) are invariably based on the idea that disposal is final and requires no further action. Arguments against disposal are predicated on the question of whether or not the disposal process is safe. Over the years, a number of proposals have been forthcoming, with one, deep bed incarceration, seemingly becoming the only truly viable alernative, and the subject of much research in Canada and the United States.

Basic Methods

An overview of some of the methods: The first is underground storage in tanks. This is useful if the wastes (particularly defense wastes dating back to the primitive methods employed during the Manhattan Project) are liquid or sludge. There are a number of such facilities scattered around North America. While the original tanks developed leaks, contaminating the surrounding area, modern tanks are made of steel and sit inside metal lined concrete boxes that have a monitored and filtered air flow through them. Cooling water passes through coils in the tank to prevent boiling, and a condenser returns water evaporated from the wastes. Measuring devices include liquid level gauges, thermocouples for sensing temperature, and detectors for determining radioactivity in the air. The main advantage of such a system is that with careful attention leaks can be detected and fixed. The main disadvantage is that the instrumentation must be extremely accurate, the cost of maintaining the facility over hundreds of years is prohibitive, and in the event of an earthquake the tanks would rupture. It is considered "long term" temporary storage, i.e. storage for decades until something better becomes available.

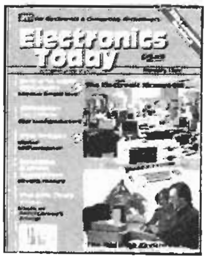
A second approach is surface storage, of which there are three types. The first is water bed storage, used by nuclear power facilities as outlined above. The second is an air cooled vault placed just below the ground. Air is forced through the spaces in the concrete and cools the containers of solidified waste. The third type consists of an above-ground silo, with air flowing by natural convection up through the space between the container and a concrete biological shield. Canada uses the first method for spent fuel rods from power reactors, and the third method for more dangerous radioactive wastes. The advantages of these systems is that they are retrievable and relatively easily monitored. Their disadvantage is that they are prone to human and mechanical error, and are very expensive to maintain. All three methods are considered to be "long term" temporary storage.

A third generic approach involves seabed disposal, and consists of dumping wastes into the ocean either as a liquid or contained in concrete canisters. While it has been used from time to time over the years, particularly for the disposing of liquids, it currently is considered non-viable for environmental reasons. This system is predicated on the belief that the vast volume of water in the oceans will dilute the toxic radioactive particles to below dangerous levels. There are two adjunctive seabed disposal methods. The first consists of drilling large holes in areas that are free from water currents and seismic disturbances. Into these holes a machine would place canisters of wastes followed by plugs of inert materials. In a variation of this idea, canisters mounted with fins (a bit like bombs) would be dropped into areas that had deep beds of sedimentary material. The canister would "plow" into the sediment and be buried. While there are still partisans of this approach, it is now customarily considered to be a last ditch method due to the inability of locating the canisters, and the lack of knowledge as to how the radioactive material would flow through sediment if one of the canisters fractured. However, research continues in this vein, research in which Canada takes part.

Fractionation, while not in itself a method of disposal, is a way in which the volume of material can be reduced. Essentially, spent fuel is reprocessed, and most of the uranium and plutonium removed for further use. Further, the other fission products, such as strontium-90 and cesium-137, can be removed. The net effect is to reduce the volume of fission products by some 90%. While the remaining 10% is very highly radioactive, composed of products with very long half-lives, it helps in that one doesn't have as much of it to deal with.

Transmutation is an esoteric process, akin to the medieval alchemist's desire to change one substance into another, preferably gold, albeit brought up to date. It is now theoretically possible through neutron bombardment, but at a prohibitive cost. As applied to nuclear wastes, transmutation would involve irradiation of wastes by neutrons as in a fission reactor or in some future fusion reactor. The neutrons are absorbed to produce new isotopes that may have very short half-lives or be stable. The process thus supplements natural radioactive decay as a way to eliminate the isotope by shortening its half life. Although studies show that transmutation is feasible, it seems to be a more expensive choice than any of the others. If fission reactors are used to produce neutrons to transmute wastes, new wastes would be continually generated, analogous to a puppy chasing its own tail. It might be better to use charged particle bombardment as in high-energy particle accelerators. Also, fusion reactors, possibly available in the next century, might supply enough neutrons to transmute wastes. However, for the time being, it has no practical advantage.

Another somewhat off the wall disposal method involves ice-sheets. It is based on the belief that the further away from habitation such toxic radioactive wastes are placed the better, analogous to the old adage of "out of sight, out of mind'. There are three versions of ice-sheet disposal. The first would be to place waste-filled containers on racks sitting on the top of the ice itself. A second would fix the canisters in the ice, suspended by cables, with markers to show the waste location. The third, and oddest, proposal involves the canisters melting their own way down through the ice-sheet by the heat produced by the wastes themselves, eventually settling on the bedrock. Water would freeze above them, forming a plug. There are many reasons why these methods are not being actively investigated. The only place for them to occur would be in the Antarctic (the Arctic is floating); there are international legal problems as to who owns the Antarctic; there is only a short period of the year when access to the region is possible, and transportation would be difficult. Further, there is some thought that the ice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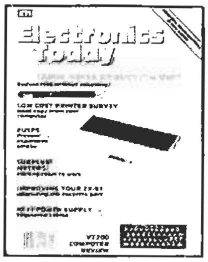
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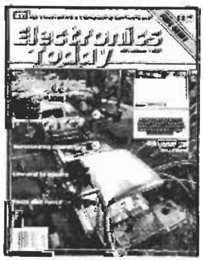
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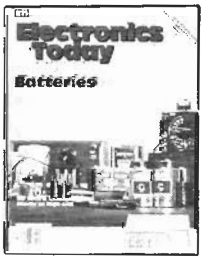
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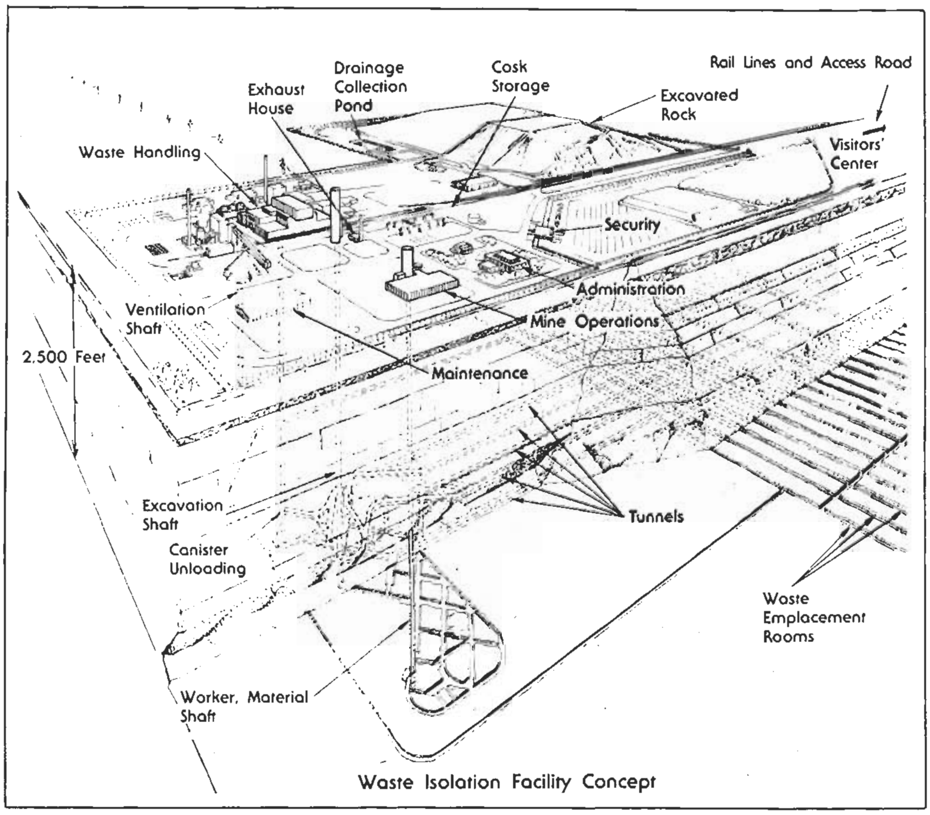

The storage of wastes in deep shafts would be an elaborate undertaking.

sheets and bedrock are separated by a water layer produced by the great weight of the ice-sheet itself (analogous to the water layer produced under an ice-skaters skate). As such, the canister would be exposed to water that is directly connected to the sea, and hence provides a possible means of contaminating the biosphere. While this process looks pretty on paper, no one is taking it seriously.

Another esoteric process for disposal is in space — essentially either just bunging it out of earth orbit into the black void, placing it on the moon, or putting it into orbit around the sun or even plunging it into the sun. The difficulties are tremendous. For a start, the shielding of the wastes adds a tremendous weight penalty, enormously increasing the launch costs. Further, there is the danger that a mission might have to be aborted, involving the dispersal of the wastes over the earth as the rocket disintegrated. Legally, who owns the moon? And as for plunging them into deep space, what if it should bump into another life form? The only serious studies of this method involve the space disposal of isolated special nucleotides, thereby decreasing the volume of high level toxic nuclear wastes.

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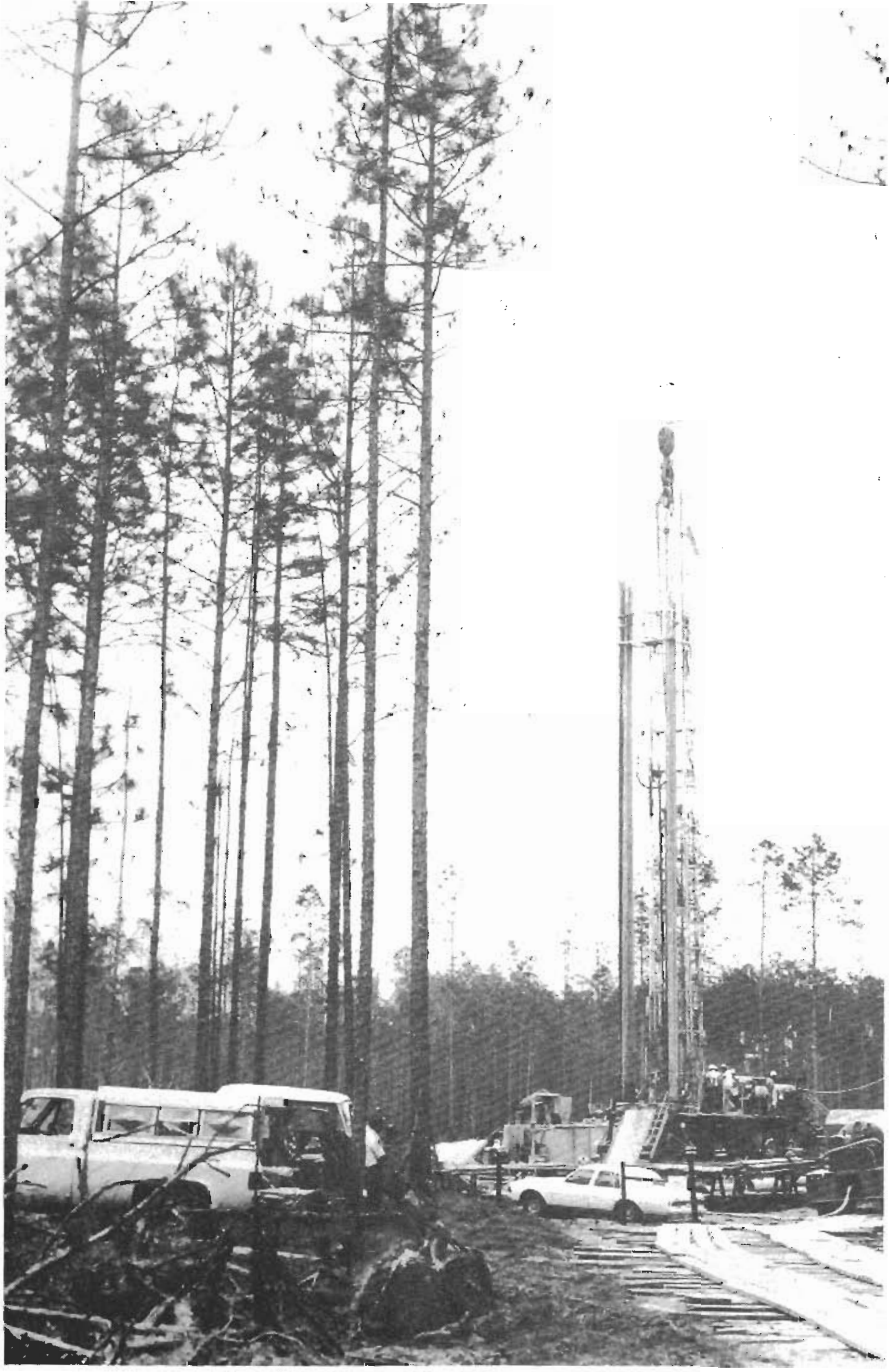

Drilling in the American south to evaluate salt domes as potential repository sites.

comes in a number of forms, under the general heading of geologic disposal. They are six in number.

Firstly, the placement of solid wastes in very deeply drilled holes, say 6 or 10 miles deep. Canisters would be lowered into the hole and stacked in a column several miles high, the hole then being plugged. Its apparent advantage is the waste's remoteness from water and the biosphere. Its advantage is that holes of that diameter have not been drilled to date to that depth, and the geology of rock at that depth is unknown.

Second is a variation of ice-sheet melting process, though in this case it involves rock melting. Solid or liquid wastes are poured down a hole, say 3000 metres deep. The heat from the radioactive decay melts the rock, the wastes mixes with the rock and any liquid present boils away; escaped vapour is caught and treated. The mass of rock would eventually cool after about a thousand years, and the resulting rock would be resistant to further change. It is not being seriously considered.

Thirdly, there is a process which involves the pumping of liquid wastes into geologic structures causing hydrofracture along fault lines in rock shuch as shale, similar to the process sometimes used for getting oil out of rocks. This system has been used on occasion by both the US and USSR to dispose of liquid defense wastes. It is not considered very good as it is not suitable for all types of wastes, as the geology of the area must be very carefully known, as the area could never be mined or drilled, and as there is always the risk that the liquids would percolate through the ground water to the surface, contaminating the biosphere.

Fourthly, double walled tunnels could be mined transversely through mountains. Remotely controlled conveyors would fill the tunnels with canisters of radioactive wastes, and remotely monitor them. An air flow through the tunnels would dissipate the heat. This method appears good for storage, but not adequate for permanent disposal due to high cost and the threats of earthquakes and landslides.

Fifthly, island isolation. No one is taking this method seriously, other than pie-in-the sky types. Essentially, it consists of finding a remote island and dumping the stuff there, posting a "Keep-Out!" sign, and sailing away.

Sixthly, and most promisingly, is the placement of waste canisters in a mined cavity, not in transverse shafts as in method four above, but in transverse drifts at depth. This method being studied by at least fifteen countries, including Canada and the United States.

The first step is the determination of which type of rock is most suitable, and have included studies of granite, crystalline rocks, volcanic rocks such as basalt and tuff, salt, shale and various types of clay. Initially, in laboratory tests over the past twenty odd years, several of the above types of rock were viewed as acceptable for geologic waste isolation. In the US, various types of salt domes (in Louisianna and Mississippi), salt beds (in Texas and Utah), basalt (in Washington) and tuff (in Nevada) have proven the most promising. In Canada, research is centring around the utilization of plutons. Plutons are large homogeneous formations of hard rock many kilometres across and found in great number throughout the Canadian Shield. They are believed to have remained essentially unchanged since the molten rock welled up through the earth's crust and solidified billions of years ago. They contain no valuable minerals, and are unlikely to be used for anything, ever.

The repository which would be built into either a pluton in Canada, or probably a salt dome in the US, would resemble a large mining complex. It would combine two types of industrial facilities — a waste handling facility at the surface and a large mine constructed 2,000 to 4,000 feet below the surface. A central area of about 400 surface acres (in the US design, not much different from the Canadian) will contain buildings and other repository facilities during the 30 to 40 year operating period. The waste handling facility will contain the equipment to handle high-level waste or spent fuel. Canisters of solidified high-level waste would be unloaded from shipping casks and transferred to a shielded cell. The integrity of the cask would be inspected, and then the canister would be lowered through the waste shaft to the emplacement level and moved to the final location by a shielded transport vehicle.

The underground area of the repository, in the US design, would cover approximately 2000 acres. Seperate shafts with elevators will lead below ground for personnel and equipment and for lowering nuclear waste canisters. Other shafts will provide ventilation. Tunnels will spread out into the underground area. Canisters of solidified high-level waste will be lowered to the repository emplacement area where a transport vehicle will carry them into a tunnel for emplacement by lowering them into holes drilled into the tunnel floor.

In addition to the geologic barriers that surround the repository, various types of engineered barriers would be used to contain the waste, i.e. the canister, liner and absorbent packing material. As each storage zone is filled, the holes, tunnels and shafts would be backfilled and sealed. However, provisions in the US design would be made to provide for retrievability of the waste canisters for up to fifty years. Following closure, attempts to alert future generations of the existence, importance and danger of the repositories would be made, including surface symbols, records in public libraries, and computerized information.

As an experiment to determine the feasibility of this waste disposal system, the US National Waste Terminal Storage Program (part of the Department of Energy) in conjunction with the Lawrence Livermore National Laboratory undertook to build a small facility on part of the Nevada Test Site (primarily used for the testing of weapons). Commencing in 1978 with conclusion expected later this year, the project, code named **Climax,** was designed to see if the computer models of how high-level radioactive wastes would react underground were in fact accurate. While the final report has not yet been written, it is believed that the theoretical calculations match the experimental data as to the effect of heat, water movement and such like.

In Canada, an Underground Research Laboratory (URL) is being constructed near Lac du Bonnet, Manitoba, 300-500 meters deep in the crystalline rock formation known as the Lac du Bonnet batholith, on a site leased for 21 years from the Manitoba government. Its purpose is similar to the **Climax** project, but more suited for Canadian Shield conditions. Excavation for the URL began in 1983, with 1986 being the date of commencement for the underground experiments. In the year 2000 the shaft and boreholes will be sealed and an evaluation of whether this is a practical method of waste disposal will be made. If the report is favourable, then an enlarged, permanent centre will be built in one of the plutons, probably in Ontario.

But until then, the high-level wastes just remain in temporary water pools year after year after year.....

In the future it is expected that more and more spent fuel will be transferred between reactor sites, central fuel storage sites and reprocessing plants. Since accidents are inevitable, safety considerations require that the containers be designed to withstand impact, fire and immersion. The shipping cask is specifically designed to withstand a series of conceivable events: a 30-foot fall onto a flat, hard surface (as if the cask were dropped from an overpass onto a concrete highway), a 40-inch fall onto a metal pin 6 inches in diameter (as if the cask hit a sharp corner of a bridge abutment), a 30-minute exposure to a fire at a temperature of 1475°F (as if a tank of gasoline ruptured in an accident and a fire ensued) and complete immersion in water for 8 hours (as if the cask rolled off into a creek). Such a cask has been designed and tested. Shown here is part of the testing procedure in which a cask was mounted on a rail car and crashed into a concrete wall at 80 miles per hour. The cask survived with only light scratches on its outer surface.