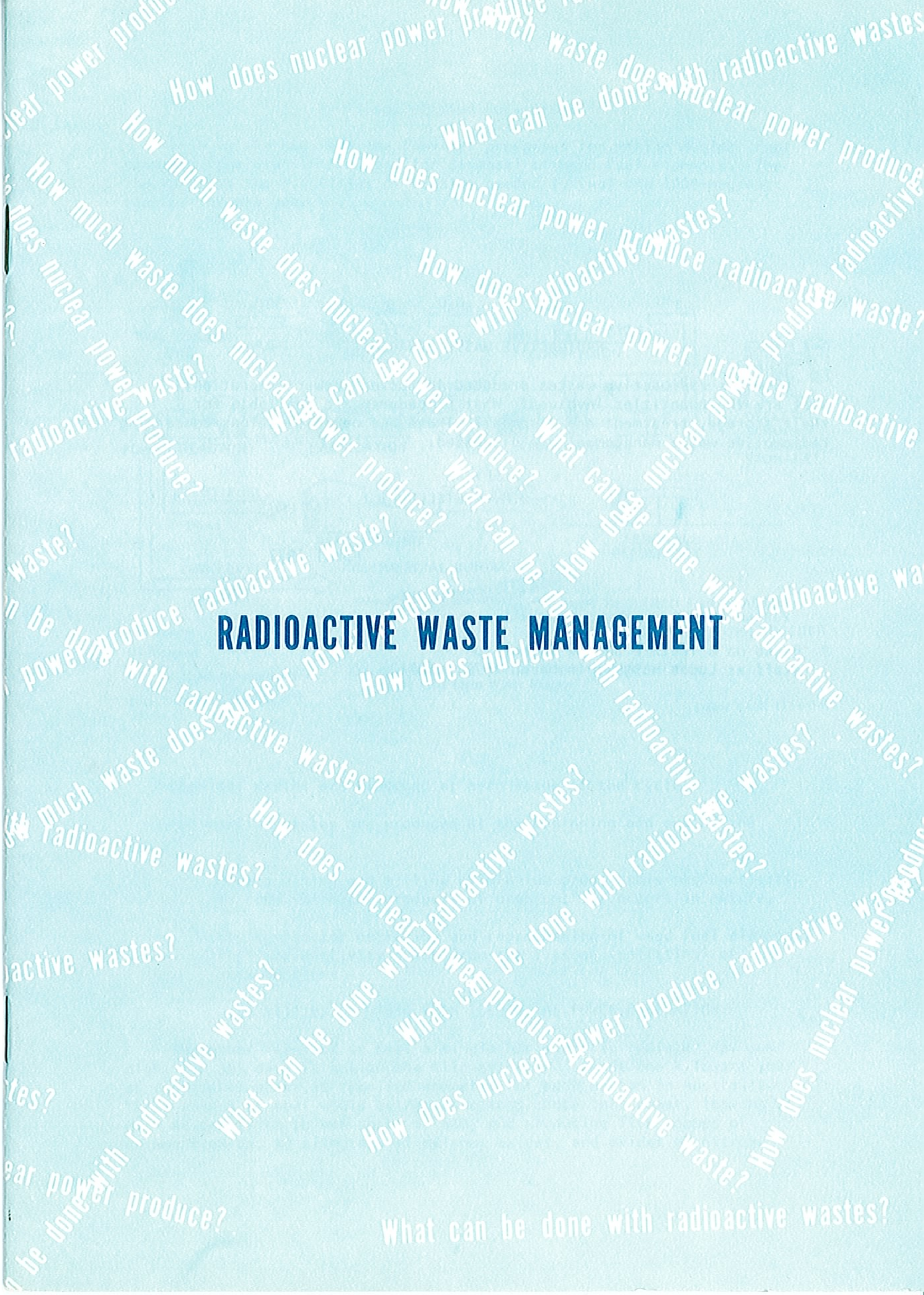

RADIOACTIVE WASTE MANAGEMENT

RADIOACTIVE WASTE MANAGEMENT*

How are radioactive wastes produced in nuclear power generation? What are the quantities involved? What procedures are available for their storage, treatment and disposal? These and other questions concerning radioactive waste management are discussed.

J.M. COSTELLO

April 1977

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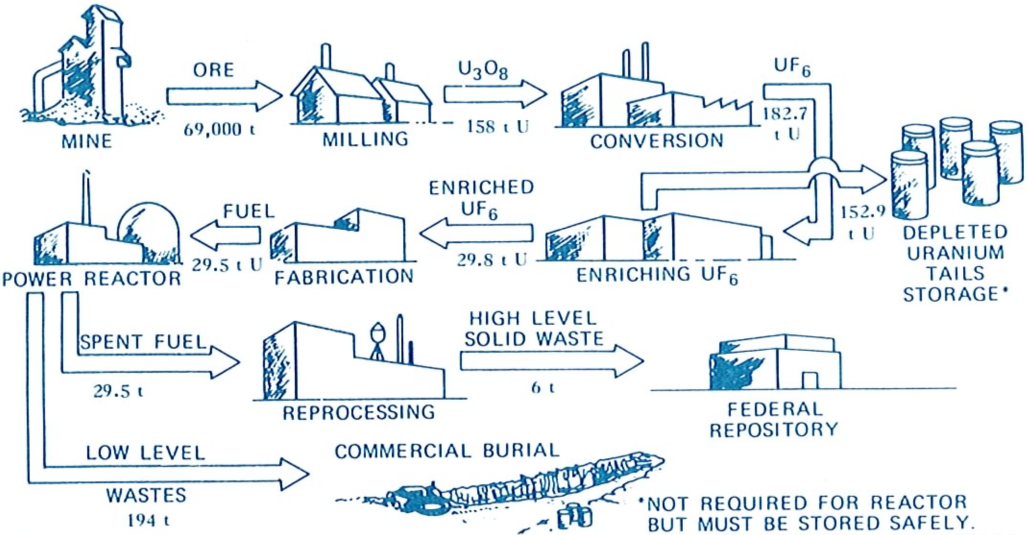
* Based on a lecture by the author to staff at Lucas Heights in March 1977. (DR12)

THE URANIUM FUEL CYCLE

This is the name for the chemical processes for making nuclear fuel elements from uranium ore, and for disposal of used fuel elements. The figure shows the quantities of uranium needed to fuel one 1000-megawatt reactor for one year.



*NOT REQUIRED FOR REACTOR BUT MUST BE STORED SAFELY. HAS VALUE FOR FUTURE BREEDER REACTOR BLANKET.

t – tonnes
U– Uranium
UF_6 – Uranium hexafluoride
U_3O_8 – Uranium oxide

Average Annual Fuel Materials Requirements for a Typical 1000 Mwe Light Water Reactor

(after WASH 1174–74)

Chemical wastes are produced at each stage of the cycle.

Radioactive wastes are produced at the beginning and end of the cycle:

- during mining and milling of uranium ores; this radioactivity is from the decay products of uranium; it occurs in nature;
- during reactor operation and reprocessing of used fuel elements; this radioactivity comes from the fission (splitting) of uranium atoms.

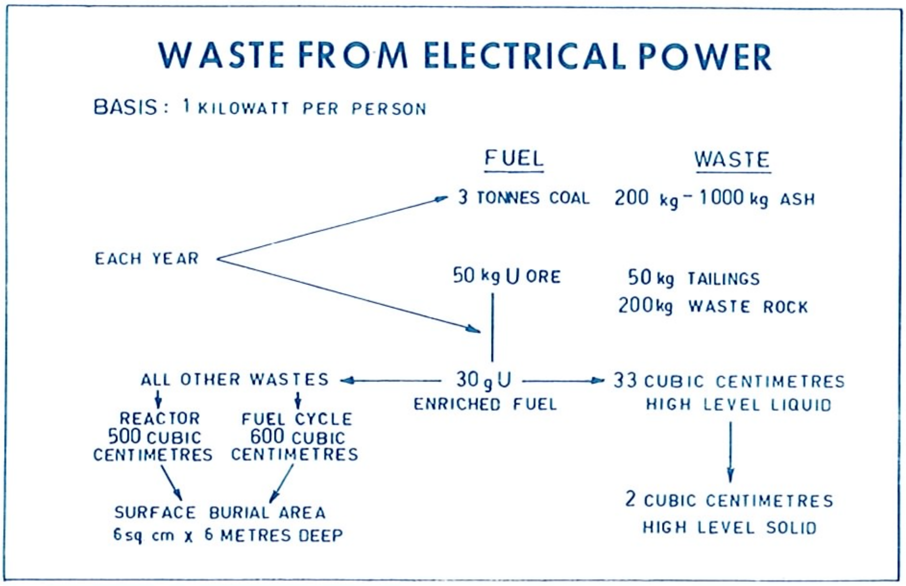
QUANTITIES OF WASTE FROM ELECTRICAL POWER GENERATION

The power required to heat a single bar electric radiator day and night for 365 days is called one kilowatt-year. About one kilowatt-year of electrical power is required annually for each person in Australia. Three *tonnes* of coal would be required to produce this power, leaving as much as one-fifth to one tonne of ash, and producing five tonnes of carbon dioxide, 40 kilograms of sulphur oxides, and oxides of nitrogen.

The same power could be generated in a nuclear reactor from 30 *grams* of enriched uranium, contained in a single pellet 2 cm long by 1.3 cm diameter.

The starting point for this pellet is a 30 cm cube of ore containing less than three parts per 1000 of uranium. Mining and milling wastes to produce a pellet from, for example, the Ranger Uranium ore body would be about 50 kilograms of finely ground ore 'tailings', and 200 kilograms of waste rock.

After use in the reactor, chemical treatment of the used pellet would produce 33 cubic centimetres of highly radioactive liquid waste, to be converted finally into two cubic centimetres of an insoluble glass 'high level' waste.



Production of the electricity used over a person's 70-year lifetime would give rise to about a teacupful of this waste!

Other wastes containing low concentrations of activity are also produced in nuclear power generation and by the nuclear fuel cycle. Typically, in the US and UK, these wastes are buried in shallow trenches and covered with soil.

METHODS FOR MANAGEMENT OF WASTES

Concentration and containment, and dilution and dispersion are both used in conventional (non-nuclear) industrial processes. The waste is either isolated from mankind or diluted to concentrations acceptable for discharge into the environment. Delay and decay is a principle unique to radioactive waste management; it means that the waste is stored and its radioactivity decreased through decay into stable substances.

PRINCIPLES OF RADIOACTIVE WASTE MANAGEMENT

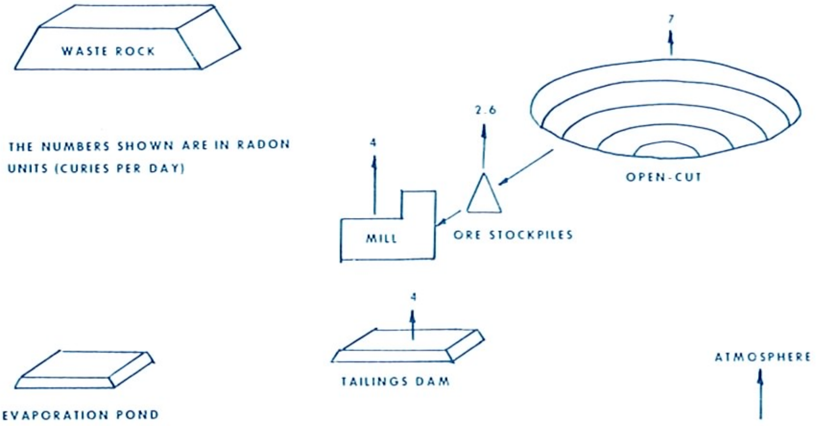
- CONCENTRATE AND CONTAIN
- DELAY AND DECAY
- DILUTE AND DISPERSE

WASTES FROM MINING AND MILLING OF URANIUM ORES

Airborne Wastes

Dusts containing silica and radioactive decay products of uranium are produced by blasting at the mine and during crushing at the mill. Concentrations of dust and radon gas in air at the mine are measured and personnel working time limited accordingly. (Radon is a gaseous decay product of uranium.) These wastes are managed by dilution and dispersion at the mine; similar wastes at the mill are removed in an extract system and returned to the process.

In evidence to the Ranger Uranium Environmental Inquiry it was stated that operations at the Ranger mine and mill would produce about 18 curies (a unit of radioactivity) of radon each day. This 18 curies may be compared with the hundreds of thousands emitted naturally each day from large land areas. Radon liberated from mining and milling operations cannot therefore be considered a global atmospheric problem.



NATURAL RELEASE		
	RANGER MINERAL LEASE (30 sq. km)	2.6
	NORTHERN TERRITORY (1,400,000 sq. km)	116,000
	AUSTRALIA (7,700,000 sq. km)	665,000
	WORLD LAND AREA (149,000,000 sq. km)	12,800,000

RADON ENTERING THE ATMOSPHERE

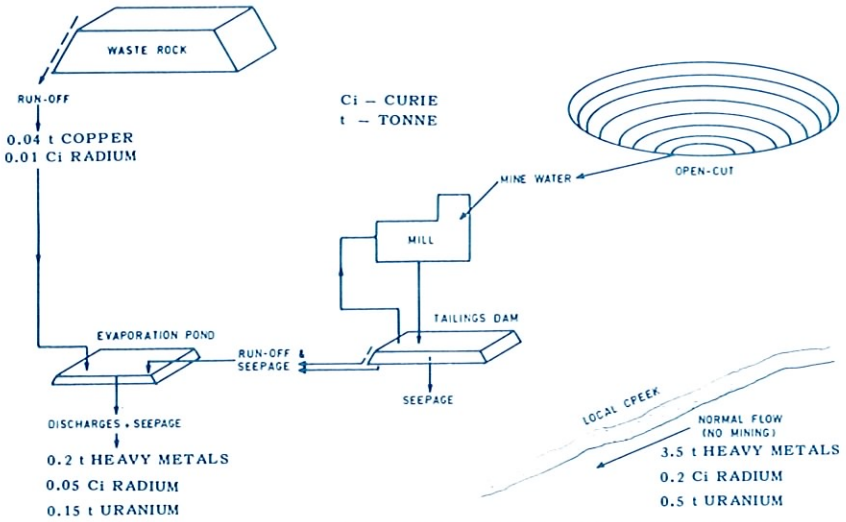
Although radon gas is much heavier than air, under normal atmospheric conditions there are no problems with its dilution and dispersion, one curie of radon occupies about one cubic millimetre (a sphere with the diameter of a full-stop!)

Liquid Wastes (from Mining and Milling)

Liquid wastes containing dissolved heavy metals (e.g. iron, copper) and radioactivity will be produced at the mill. Contaminated water will be generated through ground water seepage into the mine and by surface run-off from ore and waste stockpiles. Liquid and solid waste from the Ranger mill would be treated to remove most of the dissolved material, and discharged into a tailings dam, 120 hectares in area and 30 m high. The dam is designed to retain all solids and minimise seepage of liquid. The mill would re-use water from the dam and also water from the mine.

Surface water from stockpiles, and run-off and seepage through the foundations of the tailings dam, would be held and evaporated by the sun's heat in ponds. Discharges from these ponds would be made only during heavy rainfall, ensuring dilution of 100 times.

The amounts of heavy metals and radioactivity which would be discharged each year may be compared with the greater quantities already flowing down the local creek (before mining commences!). Dissolved heavy metals - not radioactivity - have the greatest potential for disfiguring the local environment.



(QUANTITIES PER YEAR OF CONTAMINANTS)

CONTAMINATED WATER AT URANIUM MINE AND MILL

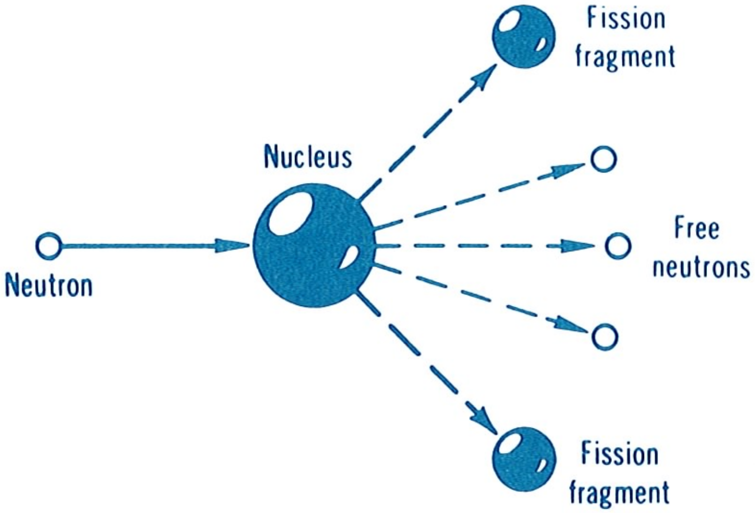
WASTES FROM CONVERSION, ENRICHMENT AND FUEL FABRICATION
(Refer to Page 1)

These stages of the fuel cycle operate on purified uranium, and their wastes will therefore be chemical in nature and contain very little radioactivity.

WASTES FROM REACTOR OPERATION

Large quantities of radioactivity are produced in a nuclear reactor through the fission (splitting) of uranium atoms. Most fission products have half-lives ranging from fractions of a second to about 30 years.

(A half-life is the time taken for half of an original set of atoms to decay. After 10 half-lives, only one thousandth of the original material will remain; one millionth will remain after 20 half-lives.)



A typical fission reaction

Neutrons produced in fission can also be absorbed by uranium atoms, producing 'transuranium' elements such as plutonium and curium. Plutonium isotope 239 has a half-life of 24,000 years.

Over 99.5 per cent of all the radioactivity produced in the reactor is retained inside the fuel and its metal sheath. Small quantities of low activity wastes produced are disposed of by burial.

The US is considering disposal of used fuel elements with little or no pre-treatment. This eliminates the possibility of theft of plutonium by terrorists or its use in nuclear weapons. However it would waste the residual energy contained in the used fuel. Alternatively this energy could be conserved by fuel reprocessing which segregates the highly radioactive waste for disposal.

WASTES FROM REPROCESSING USED FUEL

The used fuel assemblies, containing essentially all of the radioactivity from the fission reaction, are stored to permit very short-lived fission products to decay away. In reprocessing, the used fuel is dissolved and separated chemically into purified uranium, plutonium and a concentrated liquid 'high-level' waste solution, which contains over 99 per cent of the fission products and the 'transuranium' elements other than plutonium.

The fresh liquid waste from reprocessing may contain over 4 million units (curies) of radioactivity per cubic metre and generate heat at 15 kilowatts per cubic metre. It is convenient to allow the fission products (and heat generation rate) to reduce by delay and decay in storage for some time before converting the waste into an insoluble solid.

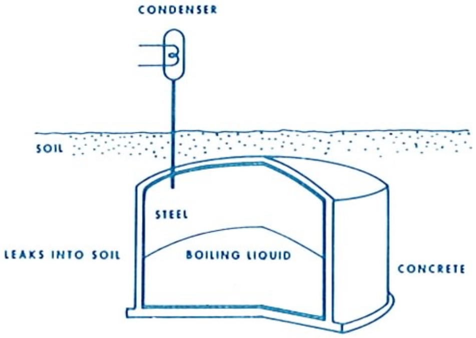
STORAGE OF LIQUID WASTE IN TANKS

The early type of tank used to store liquid waste from the US military program consisted of a concrete tank lined with mild steel and buried in the ground. Liquid waste, neutralised to remove acid, was allowed to boil from its own heat production. Steam was condensed and returned to the tanks.

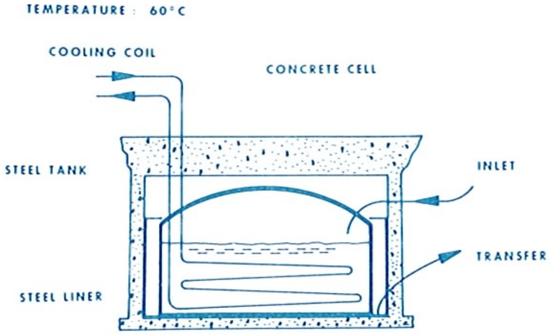
Over 10 per cent of tanks of this type have leaked, and more than 1000 cubic metres of waste containing large quantities of radioactivity has entered the ground.

However, a report by the US Comptroller-General has advised Congress that 'none of this material migrated far enough from the point of the leaks to be of any danger, nor is it considered likely to in the future'.

These tanks were built at a time when defence needs took precedence over environmental considerations. No more tanks of this type are to be built.



EARLY STORAGE TANK



MODERN TYPE OF STORAGE TANK

Modern tanks for wastes from nuclear power generation are made from stainless steel and placed in concrete cells which are lined with stainless steel - in effect, a double-walled tank. Fission heat is removed by water circulated through cooling coils. This type of tank has been used in the UK and France for many years without leakages occurring; however if leakage did occur, the waste liquid would be retained inside the cell and transferred, together with the contents of the tank, into a spare tank.

This system is safe for delay-decay storage of the waste, provided that

- continued supervision of the tanks is carried out
- a guaranteed supply of cooling water is available
- spare tankage is provided to cater for leakages.

Storage in liquid form is only an interim measure before waste solidification; there is no question of maintaining these or any other tanks under supervision for thousands of years.

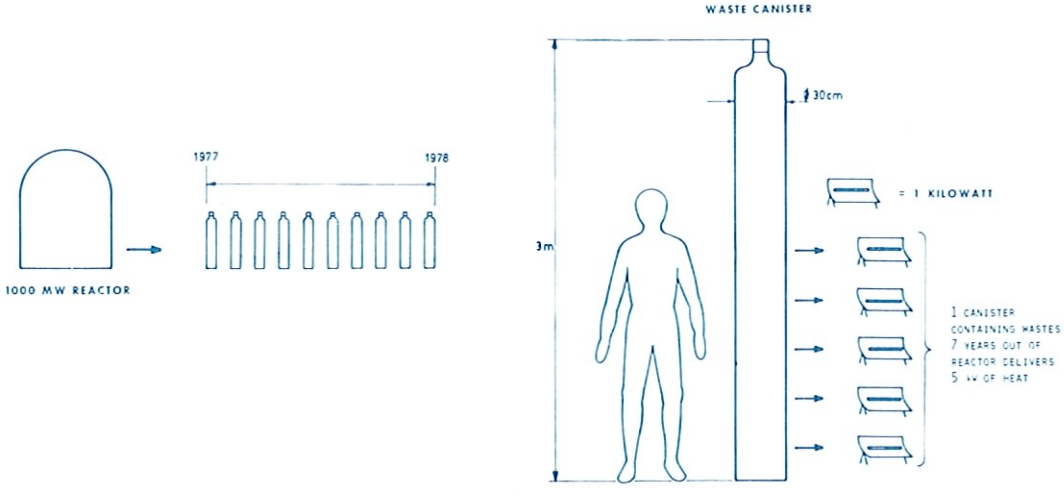
WASTE SOLIDIFICATION

Processes have been developed in the UK, US, France and Germany for conversion of the liquid waste into a stable, insoluble solid, such as borosilicate (Pyrex) glass. This is done by evaporating the solution and melting a mixture of the fission product solids with glass-forming materials.

Over 9000 cubic metres of waste solution has been evaporated at Idaho (US) and over 60 million units (curies) of radioactivity has been converted into a glass at Hanford (US) on a scale equivalent to solidifying wastes from 10 nuclear power reactors each year.

Molten glass will be poured into steel cylinders for solidification and handling. A cylinder will be nearly twice the height of a man and 30 cm in diameter.

Wastes from one year's operation of a reactor will fill 10 of these cylinders, each holding waste from about three tonnes of uranium.

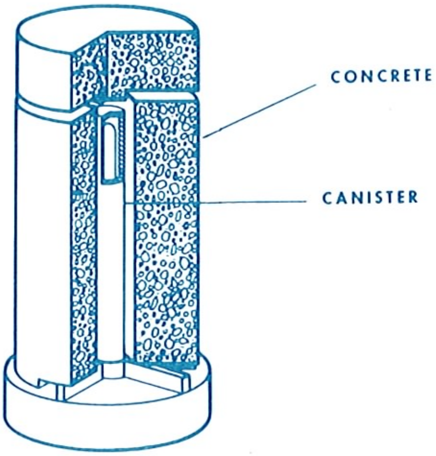


SOLIDIFIED HIGH LEVEL WASTE

The radioactivity in the glass will give out heat at a rate depending on the length of time that has elapsed since the fuel containing the waste was discharged from the reactor - typically, seven years after discharge, the heat rating of each cylinder will be five kilowatts (equal to five single bar electric radiators).

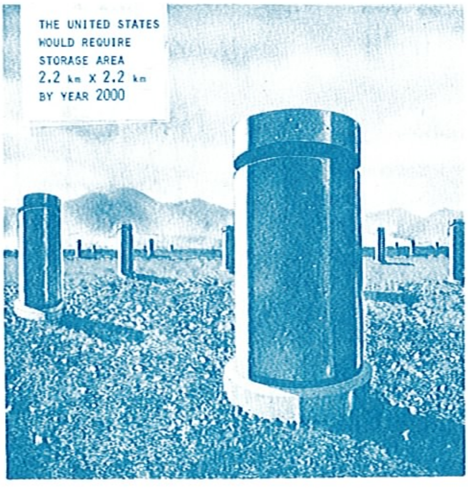
What is ultimately to be done with the cylinders of waste? Several countries, including the UK, believe that they should be stored, e.g. under water, and that their ultimate disposal should be deferred for as long as possible.

The cylinders must be shielded from living matter because of the intense radioactivity they contain. An early and very simple proposal made in the US involved the provision of individual concrete 'jackets' for each cylinder, with cooling by natural circulation of air between the two. For every reactor operating there would be produced each year, 10 monolithic blocks, each 5 m tall by 2.5 m diameter. This scheme is not as absurd as it might seem; it is estimated that the nuclear energy production of the entire US to the year 2000 would generate wastes needing an area of less than five square km for above-ground storage - 0.00005 per cent of US land area!



STORAGE

(from 'Managing Nuclear Wastes', A.I.F. 1976)



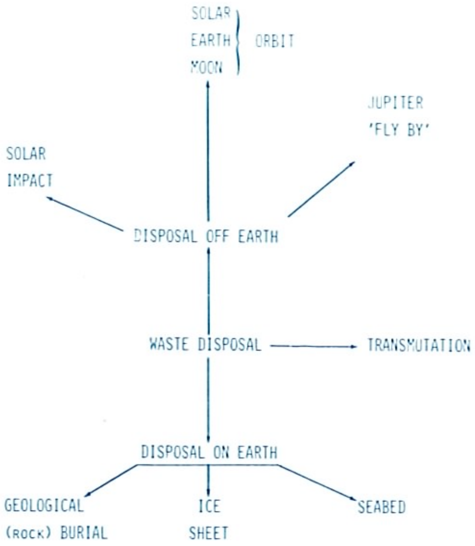
(after 'Managing Nuclear Wastes, A.I.F. 1976)

ULTIMATE DISPOSAL OF WASTE

Ultimate disposal of the wastes means their virtual isolation from man's environment for very long periods of time - 1000 years for fission products; over 240,000 years for some transuranium elements.

Several possibilities have been investigated, falling into three categories

- disposal by burial of all wastes,
- conversion of long-lived into short-lived wastes, followed by burial,
- extra-terrestrial disposal of the very long-lived wastes to a space orbit in the solar system, or by a bizarre 'Jupiter fly-by' to interstellar space!



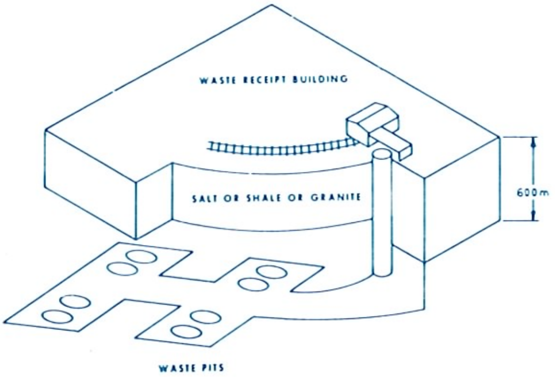
WASTE DISPOSAL ALTERNATIVES

GEOLOGIC DISPOSAL

Burial in deep geologic formations is the most likely method of ultimate disposal. Technically satisfactory and publicly acceptable disposal sites are being identified.

Burial in beds of salt, shale or granite appears to be technically satisfactory for isolation of the waste.

A dry, stable area is needed, free from earthquakes and volcanic action.



GEOLOGIC DISPOSAL

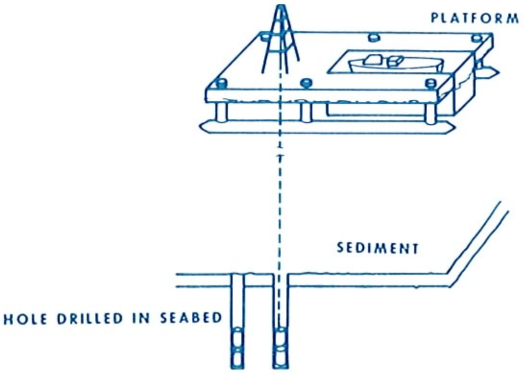
Salt beds at Karlsbad, New Mexico, are being studied with a view to construction of a pilot plant to demonstrate safe disposal.

A salt mine at Asse, Germany, has been used to store wastes of low activity for several years; tests to confirm the predicted effects from storage of highly radioactive wastes are planned.

BURIAL IN THE SEA-BED

Detailed studies have been proposed by Japan, the UK and US, on this method of disposal as a possible alternative to geologic disposal.

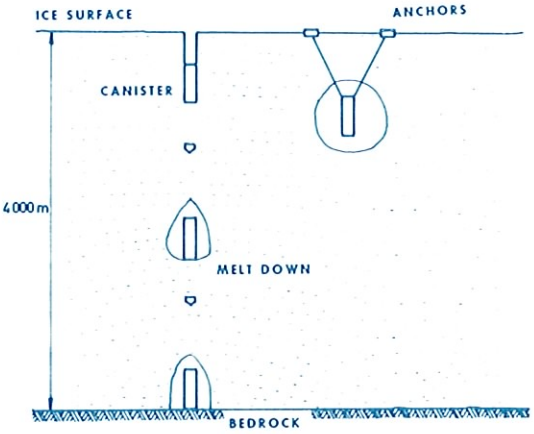
Disposal of wastes lowered from a floating platform onto the seabed or into holes drilled in the rock of the sea floor appears promising; however, much more information is needed on the ways in which waste might enter the food chain after the steel canister is corroded and the glassy solid contacted by sea-water.



SEABED DISPOSAL

DISPOSAL IN THE ICE SHEET

Burial of this waste in Antarctica is at present specifically prohibited by the Antarctic Treaty of 1959. Unless prevented by anchors, waste canisters would melt down through the ice.



DISPOSAL IN THE ICE SHEET

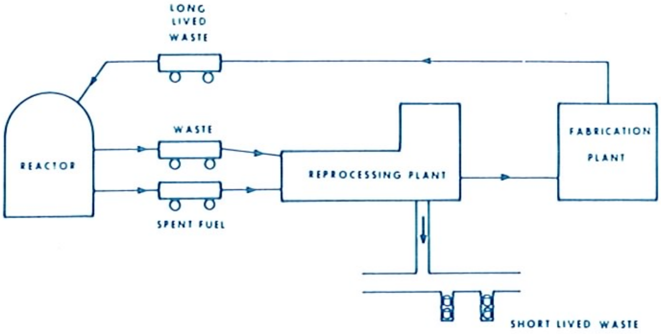
Insufficient evidence is available on the speed of ice movement, and on whether there is a static or moving layer of water between the ice and bedrock. Problems could be caused by wastes entering the food chain. One of the main advantages of Antarctica - the lack of use to date of the area by mankind, may not last if its mineral wealth is exploited.

EXTRA-TERRESTRIAL DISPOSAL

This method is not feasible with existing technology, as it would require development of a *guaranteed* system for preventing waste being vaporised into the atmosphere, in the event of a failure of the launching vehicle. Even so, it could be feasible only for the very long-lived transuranium wastes, and these cannot at present be separated to the required extent from the rest of the wastes.

TRANSMUTATION OF LONG-LIVED INTO SHORT-LIVED ELEMENTS

Again, this method is not realistic with today's technology; it would involve separation of the transuranium elements in the reprocessing plant at an efficiency not yet achieved followed by fabrication of the elements into 'fuel' for re-introduction into the reactor. There the elements would be split into shorter-lived fission products for disposal by burial.



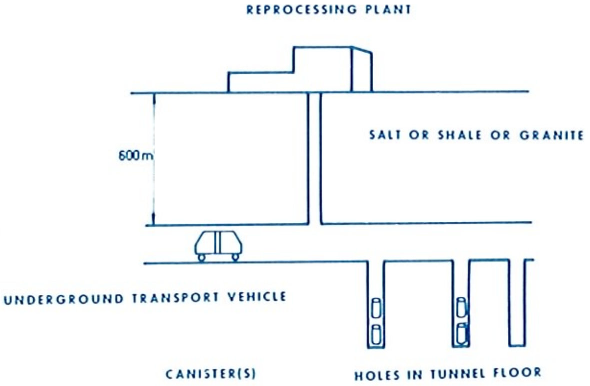
TRANSMUTATION

If transmutation could be achieved, it would reduce the time for delay-decay isolation of waste from 240,000 to 1000 years and eliminate the extreme long-term guarantees required for geologic burial.

SAFETY FACTORS IN BURIAL OF WASTE IN DEEP, DRY, GEOLOGIC FORMATIONS

Ideally, the glassified waste would be disposed of by lowering it into an excavated geologic bed lying deep below the reprocessing plant, eliminating the need for surface transportation.

Because of the heat continually emitted from the waste canisters, they will need to be spaced apart by at least 10 metres. Burial up to 600 metres below ground level is contemplated.



GEOLOGIC DISPOSAL

There are at least six independent barriers preventing the waste from re-entering man's environment. A stable, dry area remote from centres of population would be selected. The waste would be buried deep, away from mankind's activities.

SHELLS OF PROTECTION IN GEOLOGICAL BURIAL

1. DISPOSAL AREA REMOTE FROM POPULATION
2. DRY AREA SELECTED FOR BURIAL
3. BURIAL 600 METRES BELOW GROUND
4. INSOLUBILITY OF GLASSIFIED WASTE
5. ABSORPTION BY SOIL
6. TIME DELAY

If the site did not fulfil its expectation of dryness, water would enter and corrode the steel canister; the insoluble nature of the glass would permit only a very slow release of a continuously decaying amount of radicactivity.

Measurements have been made on glass containing both fission products and transuranium elements; the rate of activity release is equivalent to the glass taking more than a million years to dissolve! - by which time all the fission products will have decayed into stable elements.

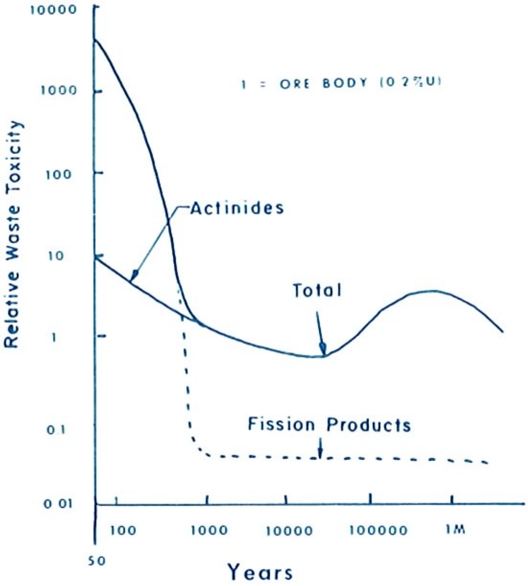
But what about the waste which does dissolve and move away? Suppose it spreads throughout the bed, to reach man's environment 600 metres above. First, the nature of most soils is to absorb radioactivity, and delay its rate of movement, allowing further time for decay.

Several models have been proposed for comparing the hazard from the waste with that from uranium ore deposits. The one shown assumes the canisters are buried at a mutual spacing of 10 metres. This dilutes the overall concentration of waste in the geologic bed by 1000 times.

The next step is to compare the relative toxicities of the waste with those of a naturally occurring ore body. This is done by calculating the volume of water in which the waste and the ore could be dissolved, for all constituents to be at their maximum permissible concentrations for drinking water.

If the radioactivity of uranium ore is taken as a measure of natural radioactivity, this calculation shows the waste to be at first, about 10,000 times more toxic than uranium ore.

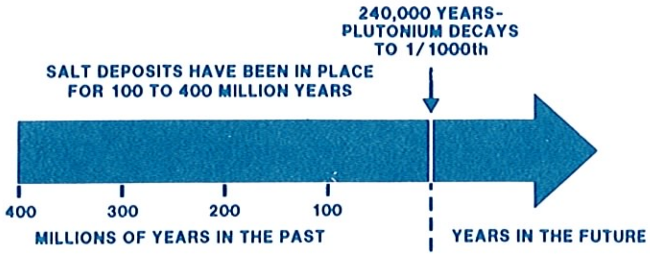
After the waste has been stored for 1000 years, the only radioactivity present comes from some long-lived fission products and transuranium elements, and the waste is of similar toxicity to uranium ore. It is this residual waste which requires very long periods of time (over 240,000 years) to decay into either atoms of uranium or non-radioactive elements. Thus the long isolation period is for waste of low toxicity.



COMPARISON OF BURIED WASTE WITH URANIUM ORE

Furthermore, this perspective means that there is no real need to remove the long-lived transuranium elements (such as plutonium) for special treatment.

The 240,000 years of isolation for buried waste is long in comparison with mankind's experience, but it is a negligible interval on a geologic timescale. Some salt beds were laid down hundreds of millions of years ago; they remained stable while the dinosaurs evolved and became extinct. Their presence today is proof that water has been excluded from the beds, and of their extreme stability.



TIME SCALES FOR GEOLOGIC STORAGE

Can we ever be sure that the wastes will remain safely in geologic burial? We can, on the basis of experience!

Two billion years ago in the Gabon region of West Africa, six nuclear reactors commenced operation in a concentrated deposit of uranium ore. The nuclear chain reaction, started spontaneously by the presence of water, continued for hundreds of thousands of years and finally ceased. During the long reaction, fission products together with transuranium elements, such as plutonium, were formed inside the ore body.

The radioactive products of these naturally occurring reactors have long since decayed into stable elements. These ultimate wastes have been discovered inside the ore deposit and, by their location, it is known that there was little, if any, movement of radioactive wastes during and after the nuclear reaction. Furthermore, the ore body was known to have contained water.

Compare this situation with that of burying wastes immobilised in Pyrex glass in a dry, geologic site far below ground level!

Commercial operation of waste solidification plant is planned in France by 1981, and for the mid-1980s in the UK and US. Siting of a geologic burial formation in the US is planned for 1978. By the mid-1980s it is expected to be receiving waste from commercial nuclear power stations.

To conclude - the technology for safe management of radioactive waste is already available. It now remains to gain public confidence by demonstrating ultimate disposal methods and their safety.

NOTES

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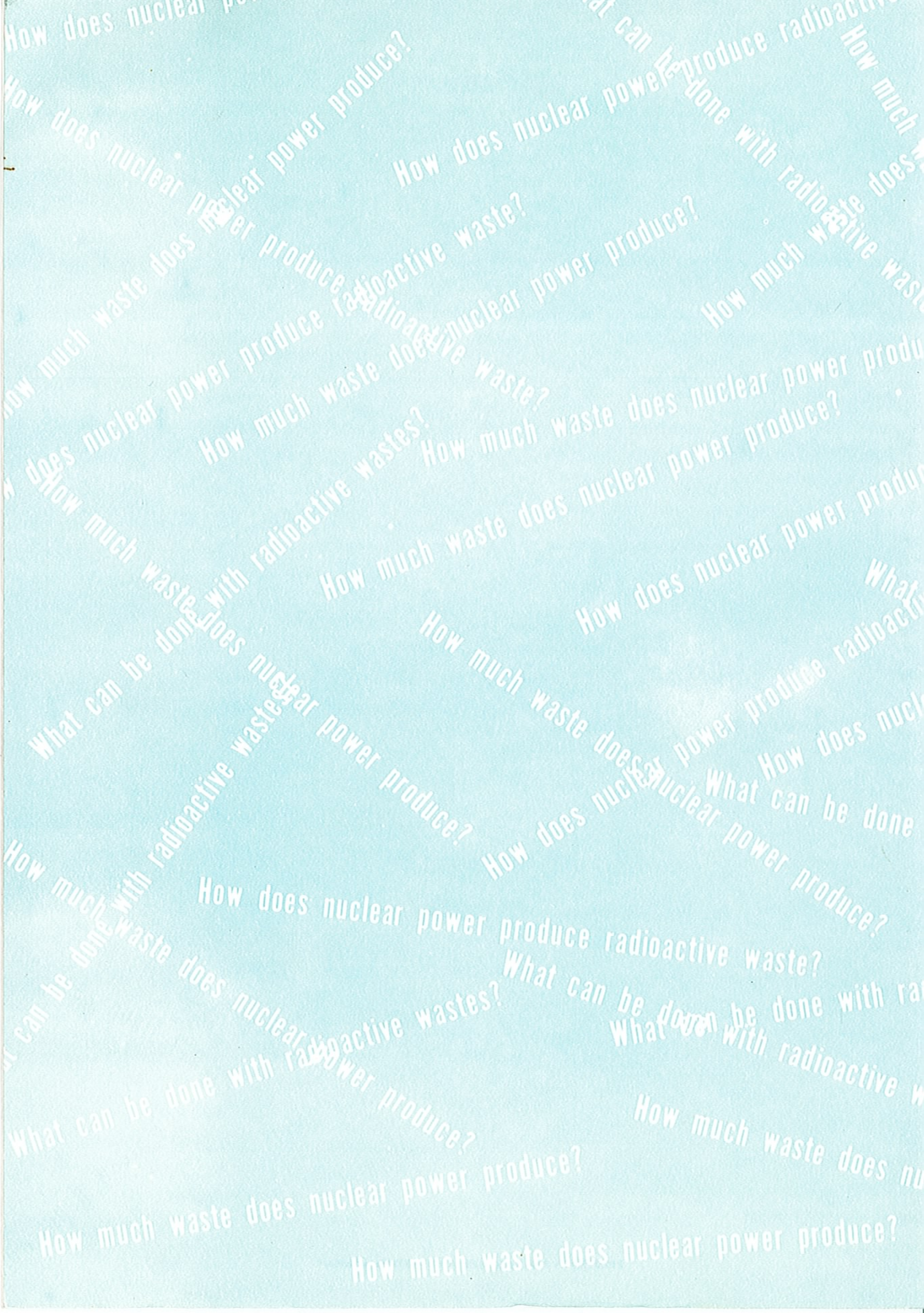
How does nuclear power produce radioactive waste?
How much waste does nuclear power produce?
What can be done with radioactive wastes?
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