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Trends in Effective Nuclear Waste Management Procedures: Options for Nigeria's Emerging Nuclear Power Industry

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Abstract

Nigeria's current dismal national power generation capacity provides impetus for the present quest by the federal government to exploit alternative energy sources for beneficial domestic and industrial usage. A critical component of this strategic endeavour is the effort to exploit the potential of the atom for purposes of nuclear power generation. However, the nuclear industry is confronted with diverse challenges; prominent among these is the problem of ionizing radiation management. In this paper, we examine the nuclear fuel cycle and the challenges of efficient radioactive waste disposal procedures and techniques, highlighting the underlying principles for the various procedures, the current global scientific and technical issues in radioactive waste management and the risk of terrorist attack on spent fuel storage facilities. Our findings indicate that in spite of the challenges of the nuclear industry, effective nuclear fuel management procedures are available making nuclear energy a viable alternative for purposes of national energy security.

Keywords: Nuclear waste management, Geological disposition, High Level Waste, Radioactive waste, spent fuel.

1. Introduction

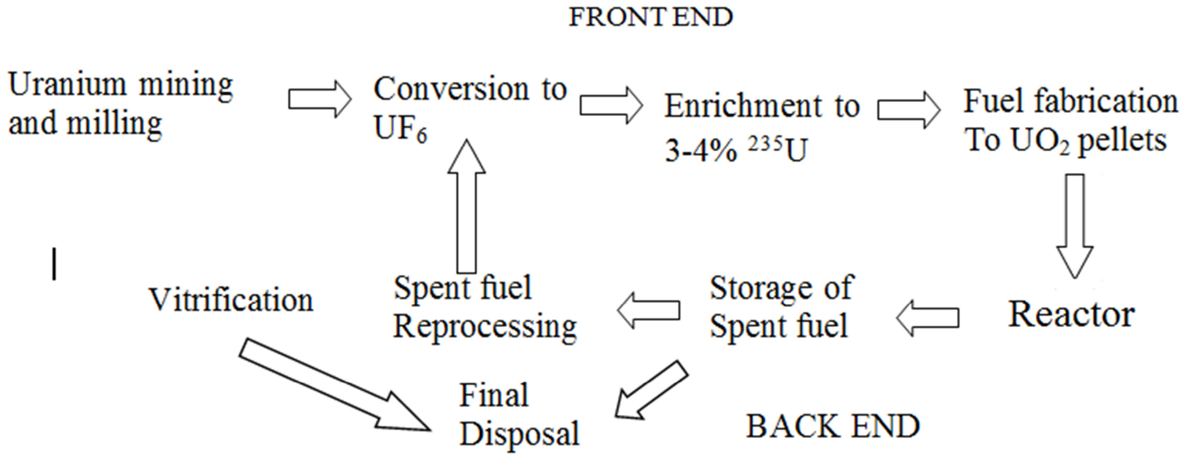
Waste generation is an unavoidable consequence of the advancement of human societies and innovations in science and technology. Waste exists wherever cities and communities of people are found and it has been the focus of various anthropological investigations (Gonzalez, 2003). Though man is sometimes not worried about the waste he generates, however for the protection of lives and the preservation of the habitat, waste has to be properly managed. Research and development into the peaceful uses of nuclear science and technology has led to widespread applications in research, medicine, industry and the generation of electricity by nuclear fission since the beginning of the 20th century (Williams, 2003). All parts of the nuclear fuel cycle produce some radioactive waste (World Nuclear Association, 2009). The radioactivity of all nuclear waste diminishes with time so that all radioactive waste decays eventually into non-radioactive elements (i.e. stable isotopes) because all radioisotopes contained in nuclear waste have a half-life. Depending on the half-life of the particular radioactive element present, the spent fuel could remain hazardous for as long as hundreds of thousands of years or even for millions of years (Nuclear Information and Resource Service, 2007). To remove nuclear waste successfully from the environment requires complex treatment and management.

2. Nuclear Fuel Cycle

The nuclear fuel cycle is composed of procurement, preparation, utilisation and ultimate disposition of the fuel (Lamarsh, 1983). The fuel cycle begins with the mining of uranium, uranium enrichment and manufacture as nuclear fuel (IAEA Bulletin, 2008) which is then delivered to a nuclear power plant. Uranium concentrations in sea water is about 0.003ppm and in the rocks of the earth's crust about 4ppm, and is incorporated into many mineral ore, as uraninite (UO_2) or pitchblende (U_3O_8) or as secondary minerals (complex oxides, silicates, phosphates, vanadates). U_3O_8 is a stable complex oxide: $U_2O_5.UO_3$ (World Nuclear Association, 2007).

There are two main divisions of the nuclear fuel cycle, namely front end and back end. The front end consists of those parts of the fuel cycle which precede the use of the fuel in the reactor while the back end of the fuel cycle consists of the parts related to the fuel after it has been used and then withdrawn from a reactor (El-Wakil, 1971). The stages that make up the front end of the nuclear fuel cycle are mining and milling, conversion, enrichment and fuel fabrication. After uranium has been used in a reactor to produce electricity, it is known as spent fuel and may undergo a further series of steps including temporary storage, reprocessing, and recycling before eventual disposal as waste. Collectively these steps make up the back end of the fuel cycle.After it has been used in the power plant the spent fuel may be recycled in which case it is sent to a reprocessing plant or if it is not to be recycled it is sent to a final repository (Gudowski, 2000) for disposition. The recycling procedure can reprocess about 95% of spent fuel to be used again in the nuclear power plant (Heighway, 1994).

The nuclear fuel cycle can be illustrated as follows:



The nuclear fuel cycle can also be 'open' , in which the fuel is used once and then sent for storage without reprocessing (IAEA Bulletin, 2008) or 'close' in which the fuel is used, reprocessed and used again.

3. Radioactive Waste Management

The diverse and varied applications of radioactive substances in industry, research and medicine, as well as their use in nuclear power plants to generate electricity lead inevitably to the incidence of radioactive waste generation (IAEA, 2003).

3.1 CLASSIFICATION OF RADIOACTIVE WASTE

Radioactive waste classification differs between nations; however international conventions and practise delineate the following three broad groups of radioactive wastes (Baisden and Choppin, 2007):

i. Low Level Waste
ii. Intermediate Level Waste
iii. High Level Waste

Uranium is the major fuel in most nuclear power reactors and high-level wastes (HLW) are the products of the 'burning' of uranium fuel in a nuclear reactor (Nuclear Energy Agency, 1994). This type of waste is made up of fission products and transuranic elements produced in the reactor core. Transuranic elements are man-made elements that are heavier, that is, higher in atomic number than uranium and Plutonium is the major element in most TRU waste (Environmental Protection Agency, 2011). Others are americium and curium. HLW is the 'ash' generated from 'burning' uranium and due to its very high temperatures and high radioactivity, it requires both cooling and shielding. A large proportion of the total radioactivity, more than 95%, from nuclear power generating plants come from HLW (Nuclear Energy Agency, 1994). There are two distinct kinds of HLW: Used or spent fuel itself, and separated waste from reprocessing the used fuel.

Intermediate-level wastes (ILW) also exhibit a certain level of radioactivity requiring shielding. Its major constituents are chemical sludge, resins, metal fuel cladding, and also contaminated substances from reactor decommissioning (Nuclear Energy Agency, 1994).

The last class of nuclear waste, low-level waste (LLW), results from medical and industrial applications, as well as from the nuclear fuel cycle. Its main constituents are paper, rags, tools, clothing, filters, *etc*, containing small quantities of predominantly short-lived radioactivity (Nuclear Energy Agency, 1994).

3.2 Management of Radioactive Waste

A nuclear power plant generating 1000 MW (e) releases about 30 t of spent fuel annually (Gonzalez .A.J., 2003). International practise gives each country ethical and legal responsibility for the nuclear wastes generated within its territory (Baisden and Choppin, 2007).Before reprocessing or final disposal, spent fuel can be safely stored for long periods in wet or dry facilities. Such facilities have in some cases already been in operation for over 30 years.

Various options for nuclear waste disposal and management have been proposed (Buser, 2003). In the case of high level waste (HLW), the following options have been proposed: Dispersal in oceans under special conditions; partial containment through disposal in deserts or special zones; containment through disposal in deep geological formations; sub-sea-bed disposal; disposal in subduction zones; disposal in Antarctica ice; transmutation and space disposal.

3.2.1 Dispersal in Oceans under special condition

This method entails filling containers made of borosilicate glass which has the capacity to prevent any nuclear radiation from leaking out with nuclear waste. The container is further enclosed in another water-tight metal container and dumped into the ocean. There is a speculation that a minor quantity of radiation does manage to escape from these containers despite their being said to be leak-proof.

3.2.2 Partial Containment through disposal in deserts or special zones

In this method, radioactive waste sealed in steel casks the size of elephants is filled in chambers chiselled into salt formations millions of years old in deserts. An example of this is the scrubby desert in south-eastern New Mexico. Experts argue that Water does not filter through salt, so it cannot pick up radioactive material and spread it. Also, unlike granite salt does not crack. Instead, pressure makes it act like a plastic that heals its own fractures and fills voids. Technical experts worry that problem could arise from nearby oil and gas drilling deep below the salt beds. (Inquirer, 2011).

3.2.3 Disposal in Geological Formation

In this method of waste disposal, the waste is enclosed in very strong, corrosion-resistant, metallic containers and put in underground chambers (the repository) at depths between 250m and 1000m. The whole system is constructed in such a way that the waste is intact and undisturbed for thousands of years (Voiland, 2002). Before being placed in any geologic repository, the liquid and solid HLW will most likely be vitrified, or incorporated into a glass matrix and then sealed in canisters, fabricated from zirconium or zircalloy (Montgomery, 1992). Currently in all countries, deep geological disposal is being adopted as the means for permanently isolating HLW from man's environment (Gordon et al, 1989). One of the reasons for this is that the existing knowledge is such that decisions regarding containment parameters and site selection will be based upon very sound geologic, hydrogeologic, geophysical and geochemical principles that have long-standing empirical roots. Natural analogues can be used to predict the longevity of various types of metal containers (Krauskopf, 1988). The response of HLW to variations in temperature, pressure, pH, geologic setting, and groundwater flow can be predicted using computer that can be developed, particularly in geographic information systems (GIS) environment. Acceptable geologic sites must be situated away from areas of any recorded tectonic activity, and in low permeability rocks (Krauskopf, 1988). Sites where the potential of ore deposits or hydrocarbon accumulations exists must also be avoided, as well as rocks with fracture and breccia zones, where the mobility of groundwater is high (Krauskopf, 1988). The sensible heat from radionuclide decay would be more rapidly dissipated if rocks of high thermal conductivity are selected (Krauskopf, 1988).

Morsleben - Germany

3.2.4 Sub-seabed Disposal

This method involves burial of HLW beneath a stable abyssal plain and burial in a subduction zone beneath the ocean floor within the thick clay sediments (200 to 500 feet) that cover large expanses of the relatively deep (3 to 4 miles) mid-oceanic regions. The waste is carried slowly downward into the Earth's mantle. The technical considerations, legal barriers in the Law of the Sea, and also because in North America and Europe, sea-based burial has become abomination due to fear of widespread contamination in event of a repository leak, sub-seabed method of radioactive waste disposal is currently not being seriously considered (Nadis, 1996). There is also the question of the impact of ocean currents and the interaction of radionuclides with salt in the event of canister leakage (Krauskopf, 1988)

3.2.5 Disposal in Subduction Zones

Subduction zones occur at active convergent plate boundaries, where the less dense continental oceanic crust subducts the more dense oceanic crust. (Montgomery, 1992).The movement of one section of the Earth's crust below another is marked by an offshore trench, and earthquakes occur adjacent to the inclined contact between the two plates. A mountain chain parallel to the trench is formed by the crumpling and uplifting overriding plate. Deep sea sediments may be scraped off the descending slab and incorporated into the adjacent mountains. Part of the oceanic plate may begin to melt as it descends into the hot mantle. The formed magma migrates upwards, some of it reaching the surface as lava erupting from volcanic vents. The idea for this option is to dispose wastes in the trench region such that they would be drawn deep into the Earth. However, as it is a form of sea disposal, it is therefore not permitted by international agreements and has not been implemented anywhere. (World Nuclear Association, 2010).

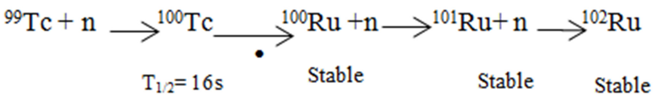
3.2.6 Disposal in Antarctic Ice

HLW could be contained in Ice-sheets, in regions where ice-thickness reaches several thousand feet, conceivably providing a remote, low-temperature environment. (Nuclear Power Procon, 1988). Skeptics argue that the stability of the ice sheet would be compromised because radioactive decay not only creates new species of radionuclides (daughter products), but also transforms kinetic and electromagnetic energy into sensible heat. Also, the world's oceans could also be polluted since ice has properties of flow; splitting masses of ice containing radionuclides could eventually enter the hydrosphere.

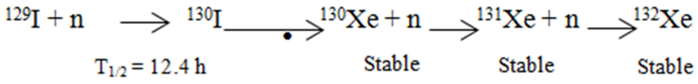
3.2.7 Transmutation

Transmutation is basically the capture of a neutron or several neutrons followed by beta decay until a less toxic (shorter-lived) or stable nuclide is formed. For technetium and iodine, the transmutation can be accomplished in thermal reactors through the following pathways (Baisden and Choppin, 2007):

^{99}Tc ($T_{1/2}$ = 2.13 x 105 a)



^{129}I (T1/2 = 1.6 x 107a)



The option is not feasible for ILW and existing HLW. Problem areas of transmutation are partitioning (separation of long-lived radionuclides from wastes, typically by chemical means) and processes for making radionuclides into suitable physical and chemical forms for transmutation. For this option to be used on a large scale in future, it would require technological advances and major nuclear programmes (Cummings et al, 1996).

3.2.8 Space Disposal

This method of HLW disposal recommends the launching of rockets containing encapsulated HLW into space away from the earth; maybe directing it into the sun. Some rather serious problems associated with this proposed method include: high cost and the risk associated with the occasion of launch failure. (Montgomery, 1992). A failed launch could prove to be catastrophic because waste dispersed in the atmosphere would be so large.

In the case of ILW/LLW the waste management options are:Releases in air and water; partial containment through sea dumping in canisters or drums; burial of wastes; seepage of liquid waste streams in pits, trenches, cribs, ponds, basins; direct injection; containment through controlled long term storage or disposal in caverns.

3.2.9 Releases in air or water

Gaseous wastes can be released to the atmosphere but before release, they are filtered, compressed to take up less space, and then allowed to decay for some time period. On elapse of the required time, the gases will be sampled. If the required limits are met, the gases will be then released to the atmosphere. The gases can sometimes be reused in specific areas of the plant (USNRC, 2003). Liquids are processed by filtering, demineralising, evaporation leaving the solid impurities (which are then processed as solid radioactive waste), and/or storing the liquid for a time period to allow the radioactive material to decay to remove the radioactive impurities.

After processing, the water will be sampled. If the required standards are met, the water can be released to the environment or placed in the storage tanks for use in the plant or be. If the standards are not met, the sample will be reprocessed.

3.2.10 Partial containment through sea dumping in canisters or drums

This method involves dropping canisters of LLW and ILW wastes from a ship (sea dumping) (Parliament, 2009)

LLW and ILW Containers

3.2.11 Burial of wastes

Waste containers like carbon-steel drums, liners, and boxes and high-integrity containers (HICs) are used in the burial of LLW. They are placed in a disposal facility with soil or cement backfills. Carbon-steel drums, boxes, or HICs when used with concrete modules improve the long-term integrity of the package. Steel is used primarily for the disposal of short-lived nuclides. Carbon-steel containers are inexpensive, but can undergo both uniform corrosion and pitting corrosion within the soil and cemented systems. The life-time of carbon-steel containers in a disposal system is expected to be short (few years or longer). HICS are more durable LLW container and are used for the disposal of long-lived high-activity waste. HICs can be made from reinforced concrete, corrosion-resistant metal alloys, high-density polyethylene (HDPE), or polymer-coated metals (Tang et al, 1990).


FPH's LILW Repository, Loviisa, Finland


RAWRA's Richard mine, Czech Republic

Seepage of Liquid Wastes Streams in Pits, Trenches, Cribs, Ponds, Basins

This method involved discharging contaminated process water and liquid into cribs, trenches, French drains, ditches, and ponds (Anderson, 1974).

Tumble tipping of waste into a Trench

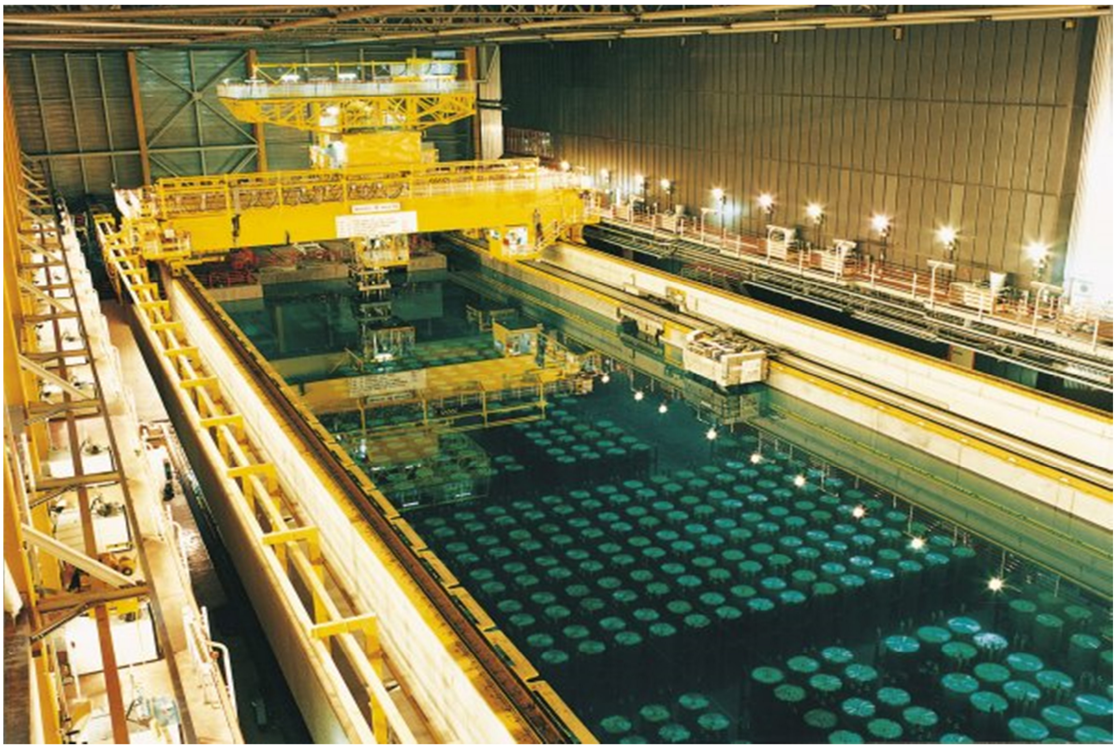
3.2.12 Direct Injection

This method entails injecting liquid radioactive waste directly into a layer of rock deep underground that has the characteristics to trap the waste minimizing any further movement. To achieve this firstly, there must be a layer of rock (injection layer) porous enough to accommodate the waste and permeable enough, acting like a sponge to allow easy injection. Secondly, there must be impermeable layers above and below the injection layer that act as a natural seal. Geological features that limit horizontal or vertical migration could provide additional benefits as in the case of injection into layers of rock containing natural brine groundwater. The high density of brine (salt water) would reduce the potential for upward movement. Direct injection has been implemented in Russia and the USA (World Nuclear Association, 2010).

3.2.13 Containment through controlled long term storage

Long-term above ground storage involves specially constructed facilities at the earth's surface that would be neither backfilled nor permanently sealed. Hence, this option would allow monitoring and retrieval at any time without excessive expenditure. In this method the nuclear waste is first is put in an intermediate and/or temporary storage facility, under strict safety conditions. This facility normally is a large wet storage reservoir, located next to the reactor. The wet storage reservoir is filled with boric acid, which helps to absorb some of the radiation given off by the radioactive nuclei inside the spent fuel elements. Inside this large wet storage reservoir the high-level radioactive isotopes become less radioactive as they decay and also generate less and less heat. Hence, the final disposal of HLW is delayed to allow its radioactivity to decay. Less than one thousandth of its initial radioactivity remains forty years after removal from the reactor and it is much easier to handle. Thus for at least this length of time canisters of vitrified waste, or spent fuel elements assemblies, are stored in large wet storages in special ponds, or in dry concrete structures or casks (Moeller et al, 2011).

There are several proposed developments of reprocessing technologies . One technology under development would separate plutonium along with the minor actinides as one product. This however cannot be simply put into MOX fuel and recycled in conventional reactors; it requires fast neutron reactors which are as yet few and far between. On the other hand, it would make disposal of high-level wastes easier.



Storage pond for used fuel at the Thermal Oxide Reprocessing Plant at the UK's Sellafield site (Sellafield Ltd)

Table 1: Waste Management for Used Fuel and HLW from Nuclear Power Reactors [3]

COUNTRY	POLICY	FACILITIES AND PROGRESS TOWARDS FINAL REPOSITORIES
Belgium	Reprocessing	• Central waste storage at Dessel • Underground laboratory established 1984 at Mol • Construction of repository to begin about 2035
Canada	Direct disposal	• Nuclear Waste Management Organisation set up 2002 • Deep geological repository confirmed as policy, retrievable • Repository site search from 2009, planned for use 2025
China	Reprocessing	• Central used fuel storage at Lanzhou • Repository site selection to be completed by 2020 • Underground research laboratory from 2020, disposal from 2050
Finland	Direct disposal	• Program start 1983, two used fuel storages in operation • Posiva Oy set up 1995 to implement deep geological disposal • Underground research laboratory Onkalo under construction • Repository planned from this, near Olkiluoto, open in 2020
France	Reprocessing	• Underground rock laboratories in clay and granite • Parliamentary confirmation in 2006 of deep geological disposal, containers to be retrievable and policy "reversible" • Bure clay deposit is likely repository site to be licensed 2015, operating 2025
Germany	Reprocessing but moving to direct disposal	• Repository planning started 1973 • Used fuel storage at Ahaus and Gorleben salt dome • Geological repository may be operational at Gorleben after 2025
India	Reprocessing	• Research on deep geological disposal for HLW
Japan	Reprocessing	• Underground laboratory at Mizunami in granite since 1996 • High-level waste storage facility at Rokkasho since 1995 • High-level waste storage approved for Mutsu from 2010 • NUMO set up 2000, site selection for deep geological repository under way to 2025, operation from 2035, retrievable
Russia	Reprocessing	• Underground laboratory in granite or gneiss in Krasnoyarsk region from 2015, may evolve into repository • Sites for final repository under investigation on Kola peninsula • Various interim storage facilities in operation
South Korea	Direct disposal	• Waste program confirmed 1998 • Central interim storage planned from 2016
Spain	Direct disposal	• ENRESA established 1984, its plan accepted 1999 • Central interim storage probably at Trillo from 2010 • Research on deep geological disposal, decision after 2010
Sweden	Direct disposal	• Central used fuel storage facility – CLAB – in operation since 1985 • Underground research laboratory at Aspo for HLW repository • Osthammar site selected for repository (volunteered location)
Switzerland	Reprocessing	• Central interim storage for HLW at Zwilag since 2001 • Central low & ILW storages operating since 1993 • Underground research laboratory for high-level waste repository at Grimsel since 1983 • Deep repository by 2020, containers to be retrievable
United Kingdom	Reprocessing	• Low-level waste repository in operation since 1959 • HLW from reprocessing is vitrified and stored at Sellafield • Repository location to be on basis of community agreement • New NDA subsidiary to progress geological disposal
USA	Direct disposal but reconsidering	• DoE responsible for used fuel from 1998, $32 billion waste fund • Considerable research and development on repository in welded tuffs at Yucca Mountain, Nevada • 2002 decision that geological repository be at Yucca Mountain was countered politically in 2009

4. RISK OF TERRORIST ATTACK ON SPENT FUEL STORAGE FACILITIES

The risk of terrorist attack on highly radioactive spent fuel cannot be totally dismissed, but the probability is very low. This is because spent fuel assemblies in pools or dry casks are large and heavy (National Research Council, 2006) and as such too large to be handled by a single individual. An insider may be able to remove single rods from the pool, but being able to get it out of the plant under normal operating conditions will prove difficult in deed.

5. CONCLUSION

Transmutation and space disposal were proposed after reprocessing of spent fuel became available. Opinions on the proposed strategies however soon converged towards geological disposal in continental formations or under the sea-bed (Buser, 2003).Nuclear waste management through geologic disposal have experienced considerable advancement, especially in the technical areas concerning the understanding, characterization and quantitative modelling of the natural and engineered safety-barrier systems. Most National programmes of radioactive waste management continue to support deep geologic disposal as a necessary and feasible technology, despite some countries postponing implementation of repositories while others are evaluating other options available for waste disposal (OECD/Nuclear Energy Agency, 1995).

Geological disposal remains the only long-term solution available. After four decades of study, geological disposal remains the only scientifically and technically credible long-term solution available to meet the need for safety without reliance on active management. It also offers security benefits because it would place fissile materials out of reach of all but the most sophisticated weapons builders. As in all scientific work, progress in achieving geological disposal has been marked by surprises, new insights, and the recognition that for even the best-characterized sites, there always will be uncertainties about the long-term performance of the repository system. Providing convincing evidence that any repository assures long-term safety is a continuing technical challenge. Nevertheless, a well-designed repository represents, after closure, a passive system containing a succession of robust safety barriers. Our present civilization designs, builds, and lives with technological facilities of much greater complexity and higher hazard potential.

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