DISPOSAL OF NUCLEAR WASTE: A GLOBAL SCENARIO

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ABSTRACT

Many nuclear power plants around the world are nearing the end of their operating lives. For example in United States where most nuclear power plants are approaching the end of the operational time period allowed in their licenses. Locally the Ginna power plant, 20 miles northeast of Rochester, on Lake Ontario, is attempting to deal with these issues. The close of the cold war has left us with radioactive waste from decommissioned nuclear missiles. The disposal of radioactive waste from nuclear power plants and nuclear missiles is as politically intense an issue as the plants and missiles themselves. By analyzing various sources of nuclear waste and their disposal, very easily we can assess the global scenario.

Key Words: Nuclear waste, Radioactive waste, Earth crust, Nuclear reactor, Radioactive Elements, Disposal methods

INTRODUCTION

Now a days the disposal of nuclear waste is becoming a concern. Many nuclear power plants around the world are nearing the end of their operating lives. This is particularly true in the United States where most nuclear power plants are approaching the end of the operational time period allowed in their licenses. Locally the Ginna power plant, 20 miles northeast of Rochester, on Lake Ontario, is attempting to deal with these issues. The close of the cold war has left us with radioactive waste from decommissioned nuclear missiles. The disposal of radioactive waste from nuclear power plants and nuclear missiles is as politically intense an issue as the plants and missiles themselves. Yet the three issues have remained curiously separate in spite of their close physical ties.

Few debates on nuclear waste disposal discuss the opportunities to close nuclear power plants or get rid of nuclear weapons a disposal site would afford. Radioactive wastes are those waste which contain radioactive chemical elements that do not have a practical purpose. They are sometimes the product of nuclear processes, such as nuclear fission.

Sources
Radioactive waste comes from a number of
sources. The majority originates from the nuclear fuel cycle and nuclear weapon reprocessing. However, other sources include medical and industrial wastes, as well as naturally occurring radioactive materials (NORM) that can be concentrated as a result of the processing or consumption of coal, oil and gas, and some minerals.

**DISCUSSION**

**Nuclear fuel cycle**

Waste from the front end of the nuclear fuel cycle is usually alpha emitting waste from the extraction of uranium. It often contains radium and its decay products. Uranium dioxide concentrated from mining is not very radioactive only a thousand or so times as radioactive as the granite used in buildings. It is refined from yellow cake ($\text{U}_3\text{O}_8$), then converted into Uranium hexafluoride gas. As a gas, it undergoes enrichment to increase the U-235 content from 0.7% to about 4.4%. It is then turned into a hard ceramic oxide ($\text{UO}_2$) from assembly as reactor fuel elements.

**Medical**

Radioactive medical waste tends to contain beta particle and gamma ray emitters. It can be divided into two main classes. In diagnostic nuclear medicine a number of short-lived gamma emitters such as technetium-99m are used. Many of these can be disposed of by leaving it to decay for a short time before disposal as normal trash. Other isotopes used in medicine, with half-lives in parentheses:

- Y-90, used for treating lymphoma (2.7 days)
- I-131, used for thyroid function tests and for treating thyroid cancer (8.0 days)
- Sr-89, used for treating bone cancer, intravenous injection (52 days)
- Ir-192, used for brachytherapy (74 days)
- Co-60, used for brachytherapy and external radiotherapy (5.5 years)
- Cs-137, used for brachytherapy and external radiotherapy (30 years)
Table 1: Common radioactive isotopes produced during nuclear reactions

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life</th>
<th>Isotopes</th>
<th>Half-life</th>
<th>Isotopes</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strontium-89</td>
<td>54 days</td>
<td>Zirconium-98</td>
<td>65 days</td>
<td>Niobium-95</td>
<td>39 days</td>
</tr>
<tr>
<td>Ruthenium-103</td>
<td>40 days</td>
<td>Rhodium-103</td>
<td>57 minutes</td>
<td>Rhodium-106</td>
<td>30 seconds</td>
</tr>
<tr>
<td>Iodine-131</td>
<td>8 days</td>
<td>Xenon-133</td>
<td>8 days</td>
<td>Tellurium-134</td>
<td>42 minutes</td>
</tr>
<tr>
<td>Barium-140</td>
<td>13 days</td>
<td>Lanthanum-140</td>
<td>40 h</td>
<td>Cerium-141</td>
<td>32 days</td>
</tr>
</tbody>
</table>

Year to century-scale half-life*

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life</th>
<th>Isotopes</th>
<th>Half-life</th>
<th>Isotopes</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen-3</td>
<td>12 years</td>
<td>Krypton-85</td>
<td>10 years</td>
<td>Strontium-90</td>
<td>29 years</td>
</tr>
<tr>
<td>Ruthenium-106</td>
<td>1 year</td>
<td>Cesium-137</td>
<td>30 years</td>
<td>Cerium-144</td>
<td>1.3 years</td>
</tr>
<tr>
<td>Curium-224</td>
<td>17.4 years</td>
<td>Plutonium-238</td>
<td>85.3 years</td>
<td>Americium-241</td>
<td>440 years</td>
</tr>
</tbody>
</table>

Longer half-life

<table>
<thead>
<tr>
<th>Isotopes</th>
<th>Half-life</th>
<th>Isotopes</th>
<th>Half-life</th>
<th>Isotopes</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technecium-99</td>
<td>$2 \times 10^6$ years</td>
<td>Iodine-129</td>
<td>$1.7 \times 10^7$ years</td>
<td>Plutonium-239</td>
<td>24000 years</td>
</tr>
<tr>
<td>Plutonium-240</td>
<td>6500 years</td>
<td>Americium-243</td>
<td>7300 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Half-lives of the order of years to decades of isotopes of elements that can seek tissues organs biologically (being akin to other elements chemically) are the most hazardous from point of view of radiation. For example, $^{90}$Sr, being chemically akin to Ca, can seek the bone and lodge itself there for years causing radioactive damage to surrounding tissues.

Industrial
Industrial source waste can contain alpha, beta, neutron or gamma emitters. Gamma emitters are used in radiography while neutron emitting sources are used in a range of application, such as oil well logging.

Naturally occurring radioactive material
Processing of substances containing natural radioactivity; this is often known as NORM (Naturally Occuring Radioactive Material). A lot of this waste is alpha particle-emitting matter from the decay chains of uranium and thorium. The main source of radiation in the human body is Potassium-40 ($^{40}$K). Radioactivity is of two types i.e. natural radioactivity and artificial radioactivity.
Fig. 2: Nuclear fuel cycle
Natural radioactivity
Over the eons, the surface of the earth and the terrestrial crust happens to be an enormous reservoir of primordial radioactivity. Small amounts of radioactive materials are contained in mineral springs, sand mounds and volcanic eruption.\footnote{7}

Artificial radioactivity
Radioactivity was discovered about a hundred years ago. Following the Second World War and discovery of the fission process, human activity added radioactivity artificially to the natural one. Two main source have been: (a) the civilian nuclear programmes, including nuclear power production, medical and industrial applications of radioactive nuclides for peaceful purposes, and (b) the military nuclear programme, including atmospheric and undergoing nuclear-weapon testing and weapon production. Table 1: showing some common radioactive isotopes.

Nuclear fuel cycle: As stated earlier, civilian nuclear operations lead to radioactivity. The story of uranium from its mining to its use in reactors and thence of chemical processing and accumulation of radioactive waste is covered by what is referred to as ‘nuclear fuel cycle’.Fig-2 shows how nuclear fuel cycle runs in nuclear reactor. The activities comprising mining, processing, fuel fabrication and ultimately use of fuel in nuclear reactors result in power generation. Reprocessing spent fuel helps in recycling plutonium for fuel fabrication. The byproducts in this activity are enriched fissile material useful for fuel as well as for weapons, depleted uranium used for DU shells, the actinides and radioactive waste.

Types of nuclear waste
Nuclear waste is classified into following 4 categories as shown in Fig. 3

\begin{tabular}{|c|c|c|c|}
\hline
Types & Low level waste (LLW) & Intermediate level waste (ILW) & Transuranic waste (TRUW) & High level waste (HLW) \\
\hline
\end{tabular}

\textbf{Fig. 3:} Types of nuclear waste

\textbf{Low level waste (LLW):} is generated from hospitals and industry as well as the nuclear fuel cycle. Commonly, LLW is designated as such as a precautionary measure if it originated from any region of an ‘Active Area’, which frequently includes offices with only a remote possibility of being contaminated with radioactive material. Such LLW typically exhibits no higher radioactivity than one would expect from the same material disposed of in a non-active area, such as a normal office block.

\textbf{Intermediate level waste (ILW):} It contains higher amount of radioactivity. It may be solidified in concrete or bitumen for disposal. As a general rule, short-lived waste
(mainly non-fuel materials from reactors) is buried in shallow repositories, while long-lived waste (from fuel and fuel-reprocessing) is deposited in deep underground facilities. **Table 2.** showing sources and contents of different types of nuclear waste.

**Table 2 : Sources and contents of nuclear waste**

<table>
<thead>
<tr>
<th>Types</th>
<th>Source</th>
<th>Contents</th>
<th>Disposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLW</td>
<td>Hospitals, Industries and Nuclear-fuel cycle</td>
<td>Papers, Rags, Tools, Filters etc</td>
<td>Shallow land burial</td>
</tr>
<tr>
<td>ILW</td>
<td>Radioactive operations or Process</td>
<td>Resins, Chemical sludge, Metal reactor fuel cladding</td>
<td>Deposited in deep underground</td>
</tr>
<tr>
<td>HLW</td>
<td>Nuclear reactor</td>
<td>Fission products and Transuranic elements</td>
<td>---------</td>
</tr>
<tr>
<td>TRUW</td>
<td>Elements having atomic number greater than uranium</td>
<td>Alpha-emitting transuranic radionuclides</td>
<td>---------</td>
</tr>
</tbody>
</table>

**High level waste (HLW)**: It is produced by nuclear reactors. It is highly radioactive and often thermally hot. LLW and ILW accounts for over 95% of the total radioactivity produced in the process of nuclear electricity generation.

**Transuranic waste (TRUW)**: As defined by U.S. regulations is, without regard to form or origin, waste that is contaminated with alpha-emitting transuranic radio nuclides with half-lives greater than 20 years, and concentrations greater than 100 nCi/g (3.7 MBq/Kg), excluding High Level Waste. Elements that have an atomic number greater than uranium are called transuranic.

**Disposal of nuclear waste**

Disposal of nuclear of nuclear waste is done in different layers of earth crust such as continental crust, seabed etc.

**Geological disposal**

Geological disposal in deep geological formations whether under continental crust or under seabed as a means of radioactive waste disposal has been recognized. The deep geological sites provide a natural isolation system that is stable under hundreds of thousands of years to contain long-lived radioactive waste. High-level radioactive waste is disposed in host rocks that are crystalline (granitic, gneiss) or argillaceous (clays) or salty or tuff.

**Sub-seabed disposal**

Seabed disposal is different from seabed dumping which does not involve isolation of low-level radioactive waste within geological strata. The Seabed Burial Proposal envisages drilling these ‘mud-flats’ to depths of the order of hundreds of meters, such bore-holes being spaced apart several hundreds of meters. The high level radioactive waste contained in canisters, to which we have referred to earlier, would be lowered into these holes and stacked vertically one above the other interspersed by 20 m or more of mud pumped in.
Subductive waste disposal method

This method is the state-of-the-art in nuclear waste disposal technology. It is the single viable means of disposing radioactive waste that ensures non return of the relegated material to the biosphere. Subduction is a process whereby one tectonic plate slides beneath another and is eventually reabsorbed into the mantle. The subductive waste disposal method forms a high-level radioactive waste repository in a subducting plate, so that the waste will be carried beneath the earth’s crust where it will be diluted and dispersed through the mantle.

Transmutation of high-level radioactive waste

This route of high-level radioactive waste envisages that one may use transmutational devices, consisting of a hybrid of a subcritical nuclear reactor and an accelerator of charged particles to ‘destroy’ radioactivity by neutrons. The fission fragments can be transmuted by neutron capture and beta decay, to produce stable nuclides. Transmutation of actinides involves several competing processes, namely neutron-induced fission, neutron capture and radioactive decay.

CONCLUSION

The disposal of radioactive waste from nuclear power plants and nuclear missiles is as politically intense an issue as the plants and missiles themselves. Therefore the disposal of nuclear waste is become a concern. On the basis of their sources nuclear waste is of various types therefore their disposal is also done by different ways. The main disposal site of these waste is the earth crust. The different layers of earth crust is used for disposal of nuclear waste i.e. deep geological formations whether under continental crust or under seabed.

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