Available online at www.sciencedirect.com
ScienceDirect

NUCLEAR SCIENCE AND TECHNIQUES

Nuclear Science and Techniques 19 (2008) 117–120

# Challenges in spent nuclear fuel final disposal: conceptual design models

Mukhtar Ahmed RANA*

*Physics Division, Directorate of Science, PINSTECH, P.O. Nilore, Islamabad, Pakistan*

**Abstract** The disposal of spent nuclear fuel is a long-standing issue in nuclear technology. Mainly, $UO_2$ and metallic U are used as a fuel in nuclear reactors. Spent nuclear fuel contains fission products and transuranium elements, which would remain radioactive for $10^4$ to $10^8$ years. In this brief communication, essential concepts and engineering elements related to high-level nuclear waste disposal are described. Conceptual design models are described and discussed considering the long-time scale activity of spent nuclear fuel or high level waste. Notions of physical and chemical barriers to contain nuclear waste are highlightened. Concerns regarding integrity, self-irradiation induced decomposition and thermal effects of decay heat on the spent nuclear fuel are also discussed. The question of retrievability of spent nuclear fuel after disposal is considered.

**Key words** Spent nuclear fuel disposal, Conceptual design models, Self-irradiation induced decomposition, Thermal effects

**CLC number** TL24

## 1 Introduction

The problem of disposal of high-level nuclear radioactive waste, e.g., spent nuclear fuel (SNF), is not new and needs urgent attention due to its increasing volume worldwide. It is now one of the most important but controversial problems of nuclear technology. Only safe and successful solution of this problem would guarantee the long future of nuclear power. It is extremely difficult for policy-makers worldwide to develop a consensus on how to approach towards the startup policy for final disposal of high-level nuclear waste. The disposal of SNF is now gaining momentum[1-9] due to the need for more electricity with minimal emission of $CO_2$ and other greenhouse gases to limit global warming.

Urgency for solution of final disposal of high-level nuclear waste is due to complications involved and multidisciplinary nature of the problem, which will take long time (decades) to reach the stage of final disposal even after the practical startup of the final disposal site. Fig.1 shows the cycle of spent fuel, which is the main high-level nuclear waste. This simple schematic is based on the well-known facts and details are given by a number of authors[3-5]. The next section gives compact details about composition of forms of SNF. In section 3, sequence of nuclear fuel disposal activity is specified along with description of major aspects of long-term nuclear waste radiation effects on containment materials, and major issues of spent nuclear fuel disposal are discussed with state of situation and references. Paper ends with leading conclusions.

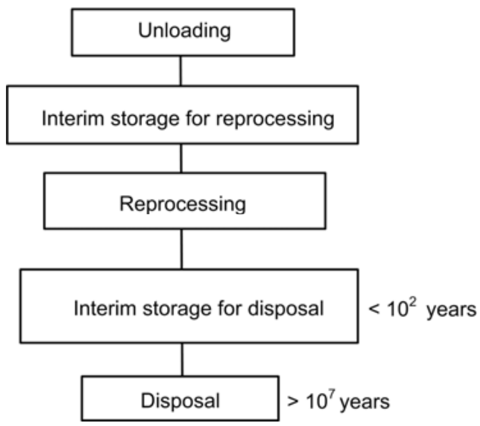


**Fig.1** Spent nuclear fuel cycle.

* Corresponding author. *E-mail address:* mukhtar.ahmedrana@manchester.ac.uk
Received date: 2007-12-29

## 2 Spent nuclear fuel: composition and forms

SNF shows almost a complete spectrum of radioactivity. Some of elements in SNF will remain radioactive for hours to a few years, whereas others for thousands to millions of years. Rate of change of any of radioactive nuclei in SNF can be represented by

$$\frac{\mathrm{d}N_i}{\mathrm{d}t} = \left.\frac{\mathrm{d}N_i}{\mathrm{d}t}\right|_{\mathrm{form}} - \left.\frac{\mathrm{d}N_i}{\mathrm{d}t}\right|_{\mathrm{decay}} \quad (1)$$

whereas concentration or number of a specific species of nuclei at any time are given by

$$N_i(t) = N_i(t_0) + \int_{t_0}^{t} \left.\frac{\mathrm{d}N_i}{\mathrm{d}t}\right|_{\mathrm{form}} - \int_{t_0}^{t} \left.\frac{\mathrm{d}N_i}{\mathrm{d}t}\right|_{\mathrm{decay}} \quad (2)$$

where $t_0$ is the starting time and $t$ is any time afterwards. It is clear from the equations that composition of SNF will continue changing, but in a quite deterministic way assuming initial composition of SNF is known. It is an important point to be considered while selecting containment materials and disposal site.

Fig.2 shows general composition and forms of fission products and transuranium elements, which are most important in evaluation of disposal activity. This figure is based on results by Buck *et al*[10]. It is clear from Fig.2 that SNF is a very special type of waste due to high percentage of rare earth elements in it along with a quite considerable percentage of radioactive gases. These are very different characteristics from those of human safe environment. Major chemical alterations in SNF are gaseous and thermal evaporation, oxidation and dissolution of fuel pellets, and precipitation of secondary phases in changing spent fuel. These changes, based on well-known facts and results from Poinssot *et al*[11] and Ewing[5], are represented by a schematic in Fig.3.

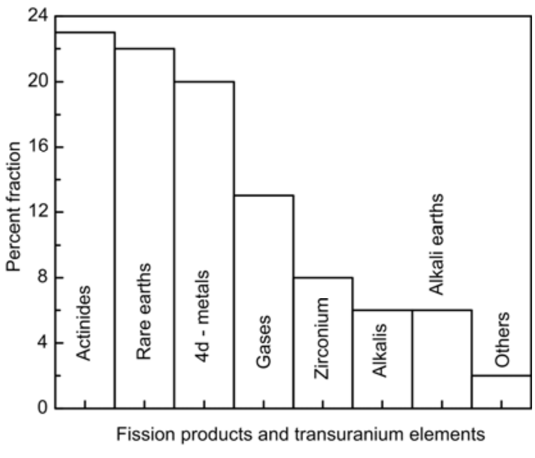


**Fig.2** General composition and forms of fission products and transuranium elements[10].

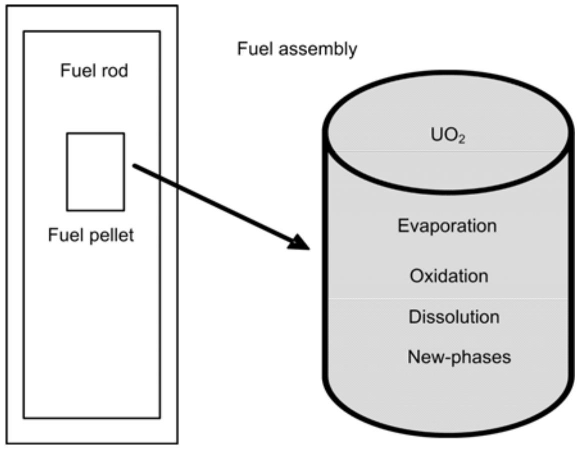


**Fig.3** Long-time alterations/changes in SNF[5,11].

## 3 Disposal of spent nuclear fuel

The issue of disposal of SNF or high-level nuclear waste has been evaluated for decades now by nuclear scientists worldwide[5-12]. Considered options for SNF disposal include burial in ocean floor polar or ice hills, space disposal, keeping in interim storage facilities and more importantly, deep underground burial in special geological formations. Deep underground burial is being considered as the safest in available options. Fig.4 shows compact summary and implementation sequence of research areas involved in the most important geological nuclear waste disposal. Despite the investigations cited above and others[13-19] on materials and geology, correlated research activities are required for successful geological nuclear waste disposal, especially coupled investigations on underground geological formations, seismology and hydrology. Effects of radiations on confinement materials in final disposal are very important. Fig.5 shows expected radiation effects on containment materials to be used in nuclear waste disposal.

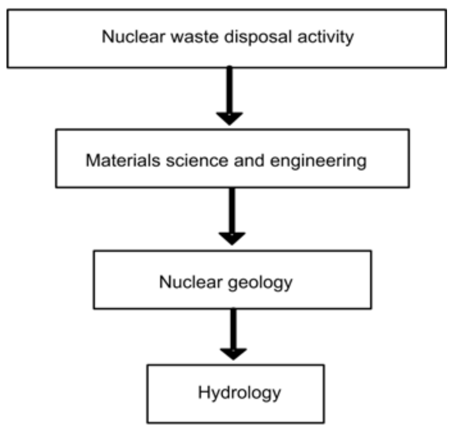


**Fig.4** Compact summary and implementation sequence of

research areas involved in geological nuclear waste disposal.

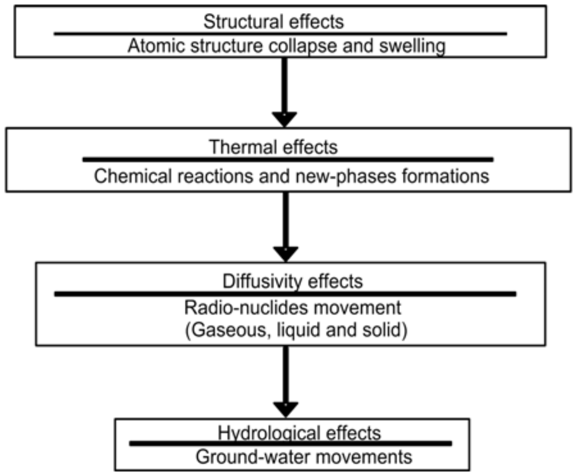


**Fig.5** Radiation effects on containment materials and environment.

It is aimed here to highlight the major problems in the disposal of high-level nuclear waste like processed or un-processed spent nuclear fuel. Problems involved are extremely complicated and requires conceptual, materials and other technical developments. Feared by complications, it is sometimes treated as unsolvable problem, which has imposed dark shadows on the future of nuclear power. To keep nuclear technology in work in future, related scientific community is working very hard to cope with the problems. Solution of this problem will bring conceptual and material developments, which will help in overall development of science and technology. Table 1 is composed of a brief discussion about major issues and problems involved with disposal of SNF.

**Table 1** Brief discussion about major issues and problems involved with final disposal of SNF

| Issue | Comment / State of the situation / Reference |
|---|---|
| High strength radiation environment | Initial radiation strength per unit SNF depends on burn of the fuel, but extremely high for any living being without best available shielding arrangements[20]. |
| Radioactivity decay time scale | Geological time scale: up to millions of years. |
| Forms of radiations | Various types of radiations including charged and neutral particle rays, and electromagnetic radiations. |
| High heat deposit | Decay of radioactive elements in SNF is accompanied with the release of energy, most of which is transformed into heat. SNF is a heat source, which can harm integrity of its disposed packages. |
| Gaseous nature of radioactive products | 13% of fission products and transuranium elements are gases, which have higher danger of leakage and mobility to the objectively safe environment. |
| Dirct disposal of SNF versus its reprocessing | Direct disposal of SNF will be cheaper[21]. |
| Transmutation | Decreases the danger level of SNF, but does not solve the problem completely. Final disposal will still be needed[20]. |
| Retrievability after disposal | Ideally, it is required. But, assurance is difficult due to involvement of unexpected natural happenings like earth-quakes. |

Disposal of SNF can only be successful by implementing multiple barrier[20] strategy to confine the disposed waste and its effects far from safe environment to which living beings have or may need to have contact in future. Fig.6 gives an overview of possible barriers to confine the disposed high level waste. Most important of natural barriers is a solid stable crystalline rock far from earthquake related fault lines. Engineered barriers include corrosion-resistant containers possibly of copper alloys and disposal architecture.

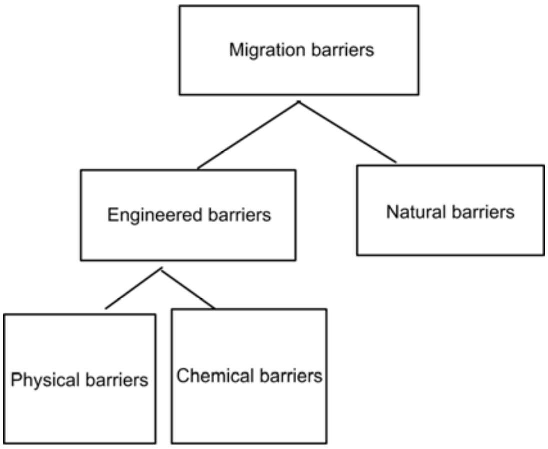


**Fig.6** Migration barriers in repository design.

## 4 Conclusion

State of the situation regarding spent nuclear fuel disposal is described comprehensively. It is concluded that composition of spent nuclear fuel will continue changing with time, which needs to be considered in evaluation and design of disposal materials and facilities. Conceptual model description of major issues of spent nuclear fuel disposal is given along with scientific discussion and comments with focuses of materials, geology, seismic and hydrology aspects.

## 5 Acknowledgment

Financial support from Higher Education Commission of Pakistan under Post Doctoral Fellowship Program 2007-08 is gratefully acknowledged.

## References

1 Ewing R C. Nature, 2007, **445:** 161-162.
2 Brown V. Science, 2007, **315:** 174-174.
3 Farnan I, Cho H, Weber W J. Nature, 2007, **445:** 190-193.
4 Delay J, Rebours H, Vinsot A, *et al.* Phys Chem Earth, 2007, **32:** 42-57.
5 Ewing R C. Elements, 2006, **2:** 331-334.
6 Sailor W C, Bodansky D, Braun C, et al. Science, 2000, **288:** 1177 -1178.
7 Fetter S. Bull At Sci, 2000, **56:** 28 -38.
8 Ewing R C. Can Miner, 2001, **39:** 697 -715.
9 Ewing R C, Weber W J, Lian J. J Appl Phys, 2004, **95:** 5949-5971.
10 Buck E C, Hanson B D, McNamara B K. Waste Environ, 2004, **236:** 65-68.
11 Poinssot C, Ferry C, Lovera P, *et al.* J Nucl Mater, 2005, **346:** 66-77.
12 Dowson J, Darst R. Environ Politics, 2006, **15:** 610-627.
13 Utsunomiya S, Ewing RC. Radiochim Acta, 2006, **94:** 749 -753.
14 Shoesmith D W. J Nucl Mater, 2000, **282:** 1-31.
15 Kleykamp H. J Nucl Mater, 1985, **131:** 221-246.
16 Kleykamp H. J Nucl Mater, 1979, **84:** 109-117.
17 Janeczek J, Ewing R C, Oversby V M, *et al.* J Nucl Mater, 1996, **238:** 121-130.
18 Grandstaff D E. Econ Geol, 1976, **71:** 1493-1506.
19 Finch R J, Ewing R C. J Nucl Mater, 1992, **190:** 133-156.
20 Wiles D R. The chemistry of nuclear fuel waste disposal. Montréal: Polytechnique International Press, 2006.
21 Bun M, Fetter S, Holdren J P, *et al.* Report DE-FG26-99FT4028: the economics of reprocessing versus direct disposal of spent nuclear fuel. Harvard University, Cambridge MA02138, USA, 2003.