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Disposal of high level nuclear wastes: Thermodynamic equilibrium and environment ethics

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Abstract Contamination of soil, water or air, due to a failure of containment or disposal of high level nuclear wastes, can potentially cause serious hazards to the environment or human health. Essential elements of the environment and radioactivity dangers to it are illustrated. Issues of high level nuclear waste disposal are discussed with a focus on thermodynamic equilibrium and environment ethics. Major aspects of the issues are analyzed and described briefly to build a perception of risks involved and ethical implications. Nuclear waste containment repository should be as close as possible to thermodynamic equilibrium. A clear demonstration about safety aspects of nuclear waste management is required in gaining public and political confidence in any possible scheme of permanent disposal. Disposal of high level nuclear waste offers a spectrum of environment connected challenges and a long term future of nuclear power depends on the environment friendly solution of the problem of nuclear wastes.

Key words Nuclear Wastes, Thermodynamic equilibrium, Environment ethics, Policy making, Public confidence

1 Introduction

Nuclear energy, compared with hydral, coal, oil-gas and wind, has some special features, especially it is considered as a solution to climate change, abundant fuel and no dependence of supply on seasonal changes[1-4]. Safe development of nuclear power assures the state-of-the-art development in affiliated technology, which is considered attractive by developing countries. Further extension of nuclear power is barred by a still unresolved problem of nuclear waste management[5-11]. After many decades of active operation of nuclear power stations, a final successful policy of nuclear waste disposal has not yet been developed. High level nuclear waste (HLNW) disposal may have extremely serious implications if it fails due to engineering faults or natural disasters like high magnitude earthquakes leaking radioactive waste into the environment. Only a very limited number of countries like Sweden have finalized their policy about definition of nuclear wastes[12-14], abandoning the possibility of reprocessing, whereas the remaining nuclear world is still un-decided on whether they will dispose off as-taken-out spent nuclear fuel (SNF) or only reprocessed waste. So, the problem of nuclear waste disposal needs to be analyzed critically with the motivation of achieving a clear resolve to it. This paper outlines environmental aspects of disposal of high level nuclear wastes.

2 The environment and radioactivity dangers

Life is strongly linked to the safe environment. Undesirable changes in the environment can deeply harm life, so they must be monitored with precision to maintain life-fit environment. Considerable leakage of radioactivity into the environment can have serious implications. So, a major concern about nuclear technology is its safety. Two decades after the Chernobyl accident, picture of the harms caused to the environment in the accident is still far from completion.

Safety failures in nuclear technology can be disastrous. Earthquakes are a reality and are completely un-predictable to challenge the safety. Countries with nuclear technology consider earthquake factor in maintaining present nuclear technology and related

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facilities, and such future plans. In Fig. 1, fissures in the ground are visible in front of the Kashiwazaki nuclear power plant[15] after earthquake on July 17, 2007. According to an IAEA report, the amount of radioactivity released was very small and well below the authorized limits for public health and environmental safety. But, it was pointed out that the observations and conclusions relating to the behavior of the plant structures, systems and components still require validation through the valid procedure[16].

Fig. 1 Site around Kashiwazaki nuclear power plant after earthquake on July 17, 2007 [15].

Earthquake is an important consideration in site selection and design of a spent nuclear fuel storage or repository as it can release a great amount of radioactivity into the environment. Shaking table tests[17] may be employed to estimate the properties of the test frame at frequencies related to earthquake. Earthquake can cause tsunami in coastal areas[18,19]. The combination of a tsunami and failure in nuclear waste disposal site can potentially contaminate the environment at the scale of Chernobyl. So, history of earthquakes and their consequences at the disposal site under consideration need to be evaluated carefully. Trustworthy understanding about migration/leaching of radionuclides on earth surface and nature of traps for their accumulation[20-22] is essentially needed. Disequilibria of U-series and radiation induced effects in minerals may be used in safety analysis of nuclear waste disposal[23, 24].

3 Thermodynamic equilibrium

Thermodynamic equilibrium is a state of a system related to the minimum of the thermodynamic potential. Thermodynamic potential is the Helmholtz free energy (U–TS) for systems at constant temperature and volume whereas the Gibbs free energy (H–TS) for systems at constant pressure and temperature. U, T, H and S are, respectively, internal energy, absolute temperature, enthalpy and entropy. Minimum of thermodynamic potential is characterized by states of thermal equilibrium, mechanical equilibrium and chemical equilibrium of the system. Ideally, nuclear waste should be disposed in a way that it becomes in thermodynamic equilibrium with the environment and remains the same for almost forever without losing its original integrity.

Success probability of SNF disposal would increase by implementing multiple barrier strategy to confine the disposed waste and its effects far from safe environment to which living being have or may need to have contact in future[25]. Barriers play an important role to confine the disposed high level waste. Most important of natural barriers is a solid stable crystalline rock far from earth quake related fault lines. Engineered barriers include corrosion-resistant containers possibly of copper alloys (containing mainly copper along with Al: 5 %to 9%; Ni: 0.5 %to 4%; Fe: 0.5% to 4%; Mn: 0.1% to 3%; Ti: 0.001 %to 1%, Co: 0.001% to 1%; and B: 0.001% to 0.1% [26]) and disposal architecture. Regular drilled hole monitoring in buffer zone and leaching activity before and after earthquake can establish underground faults produced due to earthquake. Nuclear waste containment repository should be as close as possible to thermodynamic equilibrium, which means unlimited stability, similar to natural metal deposits within the Earth's Crust[27].

4 Environment ethics

Some of major considerations in evaluating ethical issues related to safety of nuclear waste disposal are clarity of the policies, policy awareness of individuals involved, natural response to nuclear fear/risk factor and valid legal system to sue charges. Central specific ethical issues are summarized as a set of disposal activity start-up questions[28-31]:

(1) Have the persons employed/involved given the free informed consent to the risk involved?

(2) Who bear major responsibilities in waste disposal and who is responsible for what?

(3) Are the distributions of risks and benefits equitable?

(4) Have individuals been informed about control over the risk?

(5) Are assessment about reliability of materials and methods involved are made?

(6) What are the third parties who can be held responsible for bringing in risk?

(7) Evaluation of costs and benefits of intervention measures?

(8) Are the plans of compensation for exposure to risk justified?

(9) How will an emergency be handled?

Generalizing theme build up by above questions, it may be said that issues like consent, equity, control and responsibility are essential ethical considerations for radiological protection policy[28].

It would be interesting to know how above issues or questions about nuclear waste disposal are incorporated in policy making and its implementation. Only thoughtfully critical and multiply reviewed process of policy analysis can achieve this. Ethical issues are closely linked with scientific or technical know how about procedures involved.

So, a trustworthy research is needed to finalize ethical aspects of high level nuclear waste disposal. Evaluation of risk faced by far-future generations due to present disposal of high level nuclear waste is also of great importance and equally valid ethical issue as for the case of present generation. Real problems are associated with predictions about level and nature of risks faced by future generations and their response to this problem, especially in case of disposal failures.

It would not be wise to ignore highly radioactive material and to hope that either nature or future generations of humans will not bring it into the biosphere somehow. In principle, we should ensure that even if detail of nuclear waste disposal is lost, it does not reach future generations, still they or their environment is not exposed to disposed waste at all. Nuclear waste disposal in one country can quite possibly affect biosphere in the neighboring countries. Pakistan's two neighboring countries (India and China) are among the countries seeking sizeable future nuclear energy programs[32]. Nuclear waste disposal is not a solely internal matter of any country. Activity of nuclear waste disposal may have strong local, regional and even global implications. Regional and global implications would become considerable for the cases of severe failures of disposal scheme.

5 Present and future perspectives

Although no repository around the globe is ready for geological disposal of nuclear wastes, some developments, mainly in conceptual and plan domains, were made in last couple of decades. Table 1 summarizes the present plans for high-level nuclear waste repositories. Tabulated details show the sensitivity of the subject and requirement of the decades-long considerations before start up of implementation of any disposal policy. In nuclear waste disposal matters, four considerations are very important which are radiation strength, mean life, environment contamination and traditional ethical values.

Table 1 Plans for high-level nuclear waste repositories [11]

Country	Geological medium	Estimated opening	Status
Belgium	Clay	2035 or later	Searching for site
Canada	Granite	2035 or later	Reviewing repository concept
Finland	Crystalline bedrock	2020	Site selected (Olkiluoto)
France	Granite or clay	2020 or later	Developing repository concept
Germany	Salt	Unknown	Moratorium on development
Japan	Granite or sedimentary rock	2030 or later	Searching for site
Russia	Not selected	Unknown	Searching for site
Sweden	Crystalline rock	2020	Searching for site
Switzerland	Crystalline rock or clay	2020 or later	Searching for site
United Kingdom	Not selected	After 2040	Delaying decision until 2040
United States	Welded tuff	2010	Site selected (Yucca Mountain)

Ethical values here refer to rightness or wrongness of our actions. Considering above discussion about high-level nuclear waste disposal, a long time in decades would be needed in evaluation of repository location, design and precautions before start up of disposal. Careful record keeping (including details of professionals involved) of all nuclear waste disposal evaluations should be practiced so that investigation of possible accident/emergency could be carried out with transparency.

Clear demonstration about safety aspects of nuclear waste management would help in gaining public and political confidence in any possible scheme of permanent nuclear waste disposal. A common public desire is retrievability of finally disposed wastes in case repository fails to isolate wastes from the live environment. Desire of retrievability is in direct contradiction with the principle of final disposal and adds serious complexities to the problem. Public resistance against nuclear waste repository[33] at Yucca Mountain is a typical example showing the complexities involved[34]. Fig. 2 shows a simplified picture of the Swedish plan for geological disposal of nuclear wastes[35]. Different objects in the figure, showing steps of the disposal procedure, are explained with the inset text. The figure differentiates high radioactivity wastes from low and intermediate radioactivity wastes which require different disposal procedures.

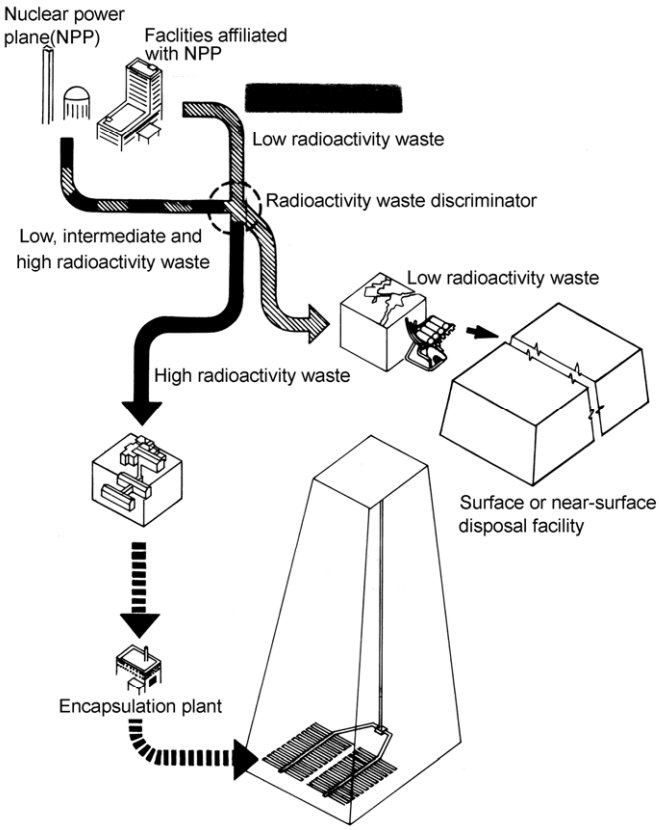

Fig. 2 A simplified picture of the Swedish plan for geological disposal of nuclear wastes.[35]

6 Conclusion

The radioactivity danger to the environment is one of the most important considerations of nuclear energy as it can cause a severe harm to the environment, which might not be repairable. Thermodynamic equilibrium of disposed nuclear waste in the repository is a guiding principal for the safe future of the environment and a clear demonstration about safety of nuclear waste management schemes is required in gaining public and political confidence. A trustworthy solution to the problem of final disposal of high level nuclear wastes is required for physical realization of plans of nuclear power plants around the globe.

References

1 Lee Y E, Jung Y B. Energy Conv Manage, 2008, **49**: 1951-1959.

2 Yanase T. Nucl News, 2007, **50**: 56-58.

3 Sovacool B K. Policy Sci, 2007, **40**: 101-122.

4 MacKerron G. Energy Policy, 2004, **32**: 1957-1965.

5 Ewing R C. Nature, 2007, **445**: 161-162.

6 Brown V. Science, 2007, **315**: 174-174.

7 Farnan I, Cho H, Weber W J. Nature, 2007, **445**: 190-193.

8 Delay J, Rebours H, Vinsot A, *et al.* Phys Chemis Earth, 2007, **32**: 42-57.

9 Ewing R C. Elements, 2006, **2**: 331-334.

10 Buck E C, Hanson B D, McNamara B K (authors). Gieré R, Stille P (Eds.). Energy, waste and the environment: a geochemical perspective. London: The Geological Socity of London Special Publication, 2004, **236**: 65-68.

11 Andersen P K, Ghassemi A, Ghassemi M. Encyclop Energy, 2004, **4**: 449-463.

12 Cederqvist L, Öberg T. Reliabil Engg Sys Safe, 2008, **93**: 1491-1499.

13 Bäckblom G, Martin C D. Tunn Underground Space Technol, 1999, **14**: 377-394.

14 Bäckblom G. J Nucl Sci Technol, 1998, **35**: 623-630.

15 IAEA report to the government of Japan about earthquake (July 17, 2007) damage at Kashiwazaki-Kariwa Nuclear. http://www.iaea.org/NewsCenter/News/2007/kashiwazaki-kariwa_report.html.

16 Power Plant prepared by IAEA Mission, 6-10 August 2007.http://www.iaea.org/NewsCenter/News/2007/kashiwazaki-kariwa_report.html.

17 Lestuzzi P, Bachmann H. Eng Struct, 2007, **29**: 1708-1721.

18 Ghosh A K. Nucl Engg Design, 2008, **238**: 1743-1749.

19 IAEA staff report, Risks to nuclear reactors scrutinized in tsunami´s wake: International Workshop on Hazards of External Flooding to Convene in India, 16 Aug 2005. http://www.iaea.org/NewsCenter/News/2005/tsunami.html.

20 Allard T, Calas G, Ildefonse P. Chem Geol, 2007, **239**: 50-63.

21 Smellie J A T, Karlsson F. Engg Geol, 1999, **52**: 193-220.

22 Petit J C. Radiochim Acta, 1990, **51**: 181-188.

23 Calas G, Allard T, Balan E, *et al*. MRS Proceed, 2004, **792**: 81-92.

24 Price P B, Walker R M. Appl Phys Lett, 1962, **2**: 23-25.

25 Wiles D R. The chemistry of nuclear fuel waste disposal, Canada Montréal: Polytechnique International Press, 2006.

26 Goto S, Kobayashi H, Hideo A, *et al*. Corrosion-resistant copper alloy, United States Patent 4830825, 1989.

27 Schwartz M O. Environ Geol, 2008, **54**: 1485-1488.

28 Oughton D H. Radiat Prot Dos, 1996, **68**: 203-208.

29 Weber W J, Ewing RC, Catlow C R A, *et al*. J Mater Res, 1998, **13**: 1434-1484.

30 Bradley D J, Frank C W, Milkerin Y. Physics Today, 1996, April Issue: 40-45.

31 Ewing R C, Weber W J, Lian J. J Appl Phys, 2004, **95**: 5949-5971.

32 Birol F. IAEA Bulletin, 2007, **48**: 16-20.

33 MacFarlane A. Bul Atom Scient, 2006, (5-6): 46-52.

34 US Department of Energy, Office of Civilian Radioactive Waste Management, Viability Assessment of a Repository at Yucca Mountain. Overview, Yucca Mountain Site Characterization Office (Las Vegas), Nevada, 1998.

35 Thegerström C. IAEA Bulletin, 2004, **46**: 36-38.