Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Can Geological Radioactive Waste Disposal Sites Be Used as EGS Sites?

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Keywords: Radioactive waste disposal, EGS, Deccan flood basalts, granites, geothermal systems, canister, nuclear power, repository

ABSTRACT

With growing concerns about climate change, countries are compelled to seek clean energy sources like geothermal and nuclear for socioeconomic development and to reduce carbon dioxide emissions. Geothermal and nuclear energies appear to be in the front line since these two sources can supply base load power and mitigate global warming. An inherent problem with nuclear energy is the safe disposal of the highly radioactive waste in geological formations due to the large amount of heat generated by the transuranic radioactive waste. The temperatures often reach 250°C around the canisters. When stored in geological formations, these canisters generate energy that could possibly be utilized to generate power using binary technology, similarly to Enhanced Geothermal Systems (EGS). A conceptual design to extract the heat generated by the canisters using heat exchangers and generate electric power is given here. Removal of heat increases the safety of the canister and the surrounding geological Formation and simultaneously providing uninterrupted power supply to the rural masses. Considering India's granite occurrence and the volume of high level waste generated by the nuclear power plants, this methods seems to be viable and make India energy independent.

1. INTRODUCTION

The first nuclear power plant in the world started operating in 1950, and about 436 commercial power plants are currently operating in 56 countries, generating 372,000 MWe of electricity and accounting for nearly 15 % of electricity worldwide. The power generated is reliable, free from CO_2 emissions, and supplies base-load power like geothermal power plants. France leads the world in nuclear power generation, generating nearly 75 % of its electric power in this manner (http://www.world-nuclear.org).Nuclear power is growing significantly in Asia, and about 111 nuclear power stations currently generate electric power there. In the near future, large growth is expected in countries like India, China and Korea. Large quantities of nuclear waste are generated in these nuclear power plants that are disposed of safely in geological repositories. However, monitoring of the geological disposal sites is essential to avoid disasters due to accumulated heat near the waste containers and thermal reactions within the geological formations that host the waste containers. A concept to utilize the heat generated by the waste in the repositories similarly to Enhanced Geothermal Systems (EGS) that utilize the radioactive heat generated by granite at greater depths is presented in this paper.

2. POWER SCENARIO IN INDIA

India gets its electric power from fossil fuels, hydropower, renewable energy, and nuclear sources, as shown in Table 1. Coal-based thermal power plants supply the largest share of electricity. Although the geothermal potential is very high, this has not yet been exploited (Chandrasekharam and Chandrasekhar, 2010). However, in recent years, M/S GeoSyndicate Power Pvt. has initiated projects to generate 20-50 MWe of power from the Puga and Godavari geothermal areas. However, acute demand for power is compelling the country to double its power output in the next couple of years by burning an additional 263 million tonnes of coal and emitting 870 million metric tones of CO_2, as shown in Figure 1. After signing the Kyoto Protocol, India is obliged to seek CO_2 free energy sources to meet the increasing demand for power and to reduce CO_2 emission by 5 %. Although renewable and nuclear sources contribute about 10% of India's electricity together, geothermal and nuclear are considered the most reliable sources that can supply base load power and enhance the per-capita electrical power consumption from 631 to 1000 kWh (Chandrasekharam and Chandrasekhar, 2010a). Unless the contribution of renewables is increased, the growth in power production (with reduced CO_2 emission) will not exceed 4 % in the future. When used in tandem, EGS and nuclear power can meet this demand increase and foster India's energy independence (Chandrasekharam and Chandrasekhar, 2010b).

Table 1. Power generation from various sources

Plant/Fuel type		MWe		Percent	
Thermal		**90895**		**64.4**	
	Coal		**75002**		**53.1**
	Gas		**14691**		**10.4**
	Oil		**1201**		**0.9**
Hydro		**35209**		**24.9**	
Nuclear		**4120**		**2.9**	
Renewable		**10855**		**7.6**	
Total		**141080**			

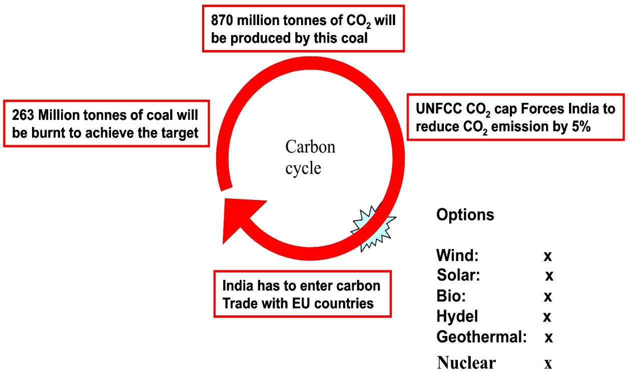

Figure 1. The carbon cycle- India's options for increasing its power output: 5% reduction in CO_2 forced India to enter into carbon trade with the EU although renewable options to compensate the 5% reduction in CO_2 are available.

3. NUCLEAR POWER OPTIONS

India has an ambitious plan to generate 20,000 MWe of power from nuclear power plants by the year 2020, thereby increasing the nuclear contribution from 2.9 % to 25 % of total power use (http://www.world-nuclear.org). The amounts of power generated by various types of nuclear reactors are given in Table 2. Low, intermediate and high levels of waste generated by the reactors correspond to 84, 14 and 2% respectively. High waste levels (amounts of transuranic radioactive waste > 5000 m^3) have the highest content of radioactive material (Ramana et al., 2001).

Table 2. Power and waste generated by different types of nuclear reactors in India up to 2000

Reactor	Power MU	Waste (m^3) *
RAP1	11047	2735
RAP2	18588	1924
MAP1	16414	1620
MAP2	14891	1418
NAP1	10465	1013
NAP2	10471	810
KAP1	9027	700
KAP2	8034	500
TAP1	28663	3875
TAP2	28502	3875
TOTAL	156102	18470
	1Unit = 1 kWh	

(Modified from Ramana et al, 2001). * Low and Intermediate level waste

4. WASTE DISPOSAL AND HEAT GENERATED BY THE CANISTERS

There is a clear understanding that every country involved in nuclear power generation is ethically and legally responsible for its own waste and that it will be disposed in a proper manner following the prescribed safety standards for the disposal of high-level waste in geological formations (IAEA, 2004, 2006). Countries involved in nuclear power generation are thus designing suitable repositories in geological formations to dispose of this high-level waste (Choi et al., 2000, Robert et al., 2002). Nuclear waste generated in nuclear power plants that contains medium to high levels of radioisotopes are disposed of in deep geological strata after placing the waste in canisters made of material that ensures no leakage and is resistant to chemical reactions. Deep geological disposal concepts are all based on placing the waste canisters in specially engineered facilities located deep (often 400-900 m) underground in carefully chosen geological strata (Winograd, 1981, Angino, 1977). The principal types of host formations generally chosen are sedimentary (e.g. clay formations), crystalline (e.g. granite), and volcanic (basalts) rocks and salt domes. The reason for choosing underground disposal sites in geological formations is due to the long lifetime of the waste and long period of isolation from the biosphere required for this waste. Disposal of high-level waste is beset with the problem of radiogenic heat. As a consequence of this heat production, attention has to be paid to several factors including the thermo-mechanical and physiochemical properties of the host rock (Utsugida, 1986). A typical canister design for high-level waste disposal is shown in Figure 2. Several canister designs are available and are used depending on the repository site specifications (Choi et al., 2000).

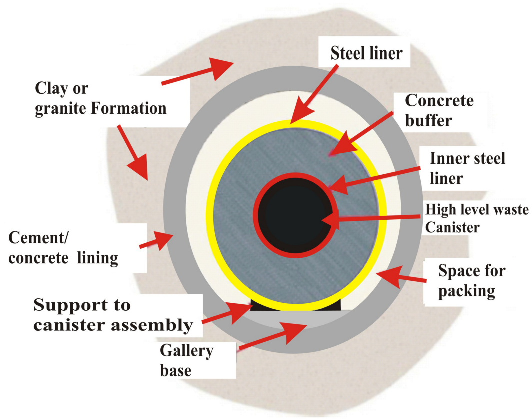

Figure 2. A typical canister design for hosting high-level nuclear waste (modified after Craeyea et al., 2009). The canisters can be placed horizontally or vertically in the host geological formations.

Some repositories contain a single large canister to hold large volumes of waste (as shown in Figure 2), and some contain clusters of small canisters packed into a larger one (Choi et al., 2000). The most challenging problem imposed by disposing of high-level waste in geological formations is the containment of heat generated this waste. Low-level waste that generates low amounts of heat can be handled easily compared to high-level waste. It is reported that the heat generated per unit volume by a canister containing a volume of 2.09 m^3 of high-level waste decreases with time and varies from 235 W/m^3 in the first year of emplacement to 224 W/m^3 in the second year. The heat generated per unit area by a canister with the same volume of high-level waste is given over a span of 20 years in Table 3. The temporal increase in temperature of a single canister with 2.09 m^3 of high-level waste is shown in Figure 3.

Table 3. Heat generated by canister containing 2.09 m^3 of high level waste in a repository (Utsugida, 1986)

Years after burial	Heat generation per canister W/canister	Heat generation rate per unit area W/m^2
1	481	3.7
5	438	3.4
10	390	3
20	312	2.4

5. REPOSITORIES AS EGS SOURCES

The amount of heat generated by a small volume of high-level waste is several orders of magnitude higher than the heat generated by high heat generating granites (3 – 7μ W/m^3), as can be seen when comparing this value to those in Table 3 (Chandrasekharam and Chandrasekhar, 2010b). The main problem with the repositories hosting high-level waste is the temperature increase over a period of time, as shown in Figure 3. If this temperature is controlled by some mechanism, then the repositories may become safer, and disposal sites may not pose the serious problems that are now feared. It is possible that these high-level waste repositories can be utilized as heat sources and that electric power can then be generated using binary cycle technology. This high-level waste can be considered an anthropogenic EGS source, and suitable canister designs can be developed with built-in heat exchangers within the canisters. A rough schematic design of such a canister is shown in Figure 4. Considering the amount of heat generated by a small volume of high level waste, as shown in Table 3, the capability of such small volume of the waste to generate high amounts of electric power is quite possible. Since the heat generated from the canister is removed constantly by circulating water, the thermo-mechanical properties and physico-chemical reactions of the formations hosting the canister can be controlled for long periods of time. Thus, the power plants built over such repositories can be online continuously for periods of 50 years and above, as shown in Figure 3.

6. CONCLUSIONS

India's granite is well-suited to host high-level nuclear waste, so it is possible that this method of utilization of growing amounts of high-level nuclear waste can be implemented to lift the socio-economic status of its rural villages (Chandrasekhar and Chandrasekharam, 2008, Chandrasekharam and Chandrasekhar, 2010b). Pilot power plants using the above method could be installed in certain arid states like Karnataka and Rajasthan (e.g. drought prone districts like Bellari and Raichur in Karnataka and Jodhpur in Rajasthan), where excellent granites are exposed and the groundwater table is located at greater depths. This seems to be an effective and sound way of high-level waste disposal in a manner acceptable to the population. If this proves to be true, a similar method could be adopted by all countries generating high-level waste to enhance the per-capita consumption of electric power as well as the GDP. Since the repositories are monitored constantly like any other power plants, nuclear waste disposal sites might be able to be made

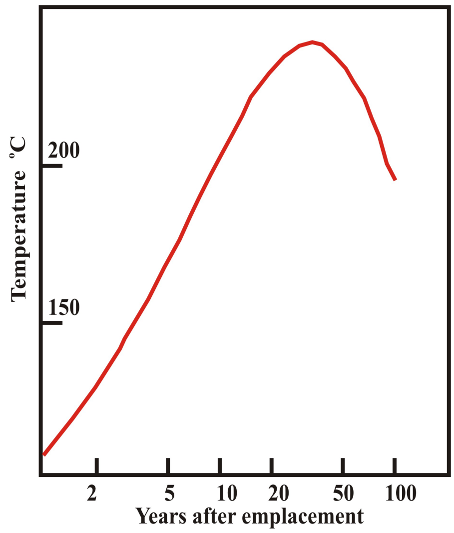

Figure 3. Temporal temperature change around a canister containing a volume of 2.09 m^3 of high-level nuclear waste in a repository (modified after Utsugida, 1986)

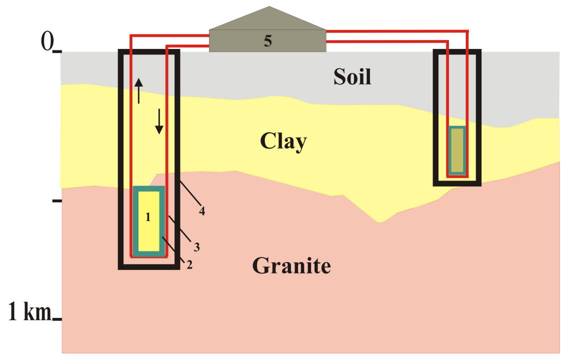

Figure 4. Schematic diagram showing the utilization of a high-level waste disposal site as an EGS site. 1. High level canister, 2. Heat exchanger, 3. Water circulating tube, 4. Repository wall, 5. Binary power plant.

relatively harmless. If developed, these plants, together with EGS resources, could produce carbon free power for millions of people and contribute to the energy independence of developing countries (Chandrasekhar and Chandrasekharam, 2009, Chandrasekharam and Chandrasekhar, 2010b).

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