DEEP UNDERGROUND REACTOR (PASSIVE HEAT REMOVAL FROM A LWR WITH A HARD NEUTRON ENERGY SPECTRUM)

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ABSTRACT

In this paper, I discuss the advantages of siting deep underground a high- conversion reactor with a Pu -Th fueled tight- fueled assembly, wherein the fuel has a long burn-up period. By putting this reactor far under the ground, heatcan be removed passively not only during a steady-state run and also in emergencies, such as loss of coolant and loss of on-site power; hence, the safety of the reactor can be much improved. Also, the reactor can be built near a consumer area, and the evacuation area around it accordingly minimized. This approach reduces the cost of generating electricity by eliminating the container building and shortening transmission lines.

INTRODUCTION

The concept of a high- conversion light water reactor using a high concentration of Pu-fuel tight-lattice was proposed in the Nuclear Energy Research Initiative (NERI) Program [1]. This reactor has a hard neutron- energy spectrum close to that of an Na-cooled fast reactor , so that a high burn-up of fuel can be obtained. A reactor with uranium fertile material has a positive water-coolant void coefficient; thus, to obtains a negative void-coefficient, a pancake-type flat core configuration is needed, or a fuel assembly with a neutron-streaming void section[2]. The latter option reduces neutron economy. The use of thorium fertile material, however, provides a negative void-coefficient without having a neutron-leaky core configuration; the neutron economy accordingly is improved and a higher burn-up of fuel attained compared with a reactor with uranium fertile materials. However, the pumping power required to circulate the water coolant has to be substantially increased to remove the high-density heat from a tight- latticed fueled core. During steady operation, the flow of the coolant can be maintained by increasing the pumping power several times above that of the regular LWR. But, during emergencies, such as an outage of on-site power or loss of coolant , heat removal becomes serious problem. This accident scenario has been analyzed in detail, and an experimental study on heat removal from a tight lattice is planned in the Japanese research program.

PASSIVE HEAT REMOVAL

To withstand an emergency of loss of pumping power, a passive cooling system is needed to remove heat, such as using the natural circulation of the coolant. Here I propose using a tight-latticed water reactor embedded in a deep underground location, where it will be cooled by the natural circulation of the water. A high pressure difference between the inlet and outlet in the narrow water channel of the tight lattice is generated by the difference in gravity force between the low density of boiled water and the high- density water condensed after the steam passes through the steam turbine. To achieve such a high- pressure difference, the vacuum condenser must be located far above the boiling water reactor. The pumping-pressure difference needed to circulate water in a regular BWR and PWR are, respectively, 2 atm and 1.5 atm, equivalent to a 20 -15 meter difference in water height. For our high conversion (HC) LWR with a tight lattice, the difference in pumping power is increased several times; a water height of more than 80-60 meters is needed to naturally circulate coolant water. By putting the reactor deep underground, there is enough space to get such a high pressure difference between the inlet and outlet, relying on the density difference between the steam section and the water which is condensed after passing through the steam turbine and condenser; in our configuration, both are located far above the reactor vessel.
By locating the reactor even deeper , the pressure imposed on the pressure vessel is increased by the gravitational force of the surrounding earth. A water pressure of 100 atm and 150atm for a BWR and a PWR can be provided, respectively, by the earth's pressure at a depth of 400- and 600-meters.

The passive cooling system using natural circulation conventionally proposed is operated in an environment wherein there is not enough pressure, so that the steam -water state is not well defined and some instability might be created. Hence this is not necessarily a safe operation. By operating at a high enough pressure, these nonlinear effects can be eliminated, and we can safely operate the reactor deeper underground. From this point of view, there are many advantages to the concept of a deep underground reactor. Due to the pressure of earth's gravity, the pressure vessel itself can be thin; thus, the reactor would be much lighter than that of a regular LWR operated on the earth's surface. A huge heavy crane would not be required to move this reactor and it could be constructed with a modular-type design.

Using super-critical steam was suggested as being a highly efficient way for generating electricity [3] This particular underground reactor would require 25 atm pressure that can be readily achieved by the earth's pressure if the reactor were placed at 1000 meter depth where the pressure is 26 atm. A higher value can be obtained by providing a thick pressure vessel .

A DEEP UNDERGROUND FACILITY

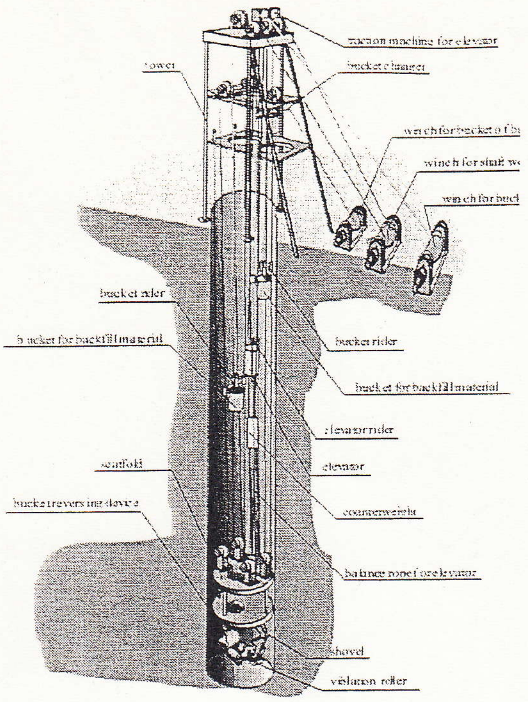
The deep underground geological storage of high- level waste has been studied extensively. . The Yucca Mountain Repository is about 300 meters depth, and a tunnel of more than tens of kilo-meters long is planned. [4]

A super-Kamiokande detector with a 50- meter high and 40-meter diameter water-tank has been installed 1000 meters deep in a mountain in Kamioka mine in Japan to measure neutrino oscillations.. Many other high-energy facilities, such as the Homestead(USA), and Grand Sasso (Italy), have been used for such high-energy experiments.

The cost of the digging a large hall underground is not as expensive as digging above ground. I was informed that in Japan the cost of a 10- x 20- meter tunnel is about 10,000 dollars per 1 meter depth, although this depends on geological features. Nevertheless, the cost of the digging in hard rock deep underground is cheaper than excavating in shallow but fractured rock.

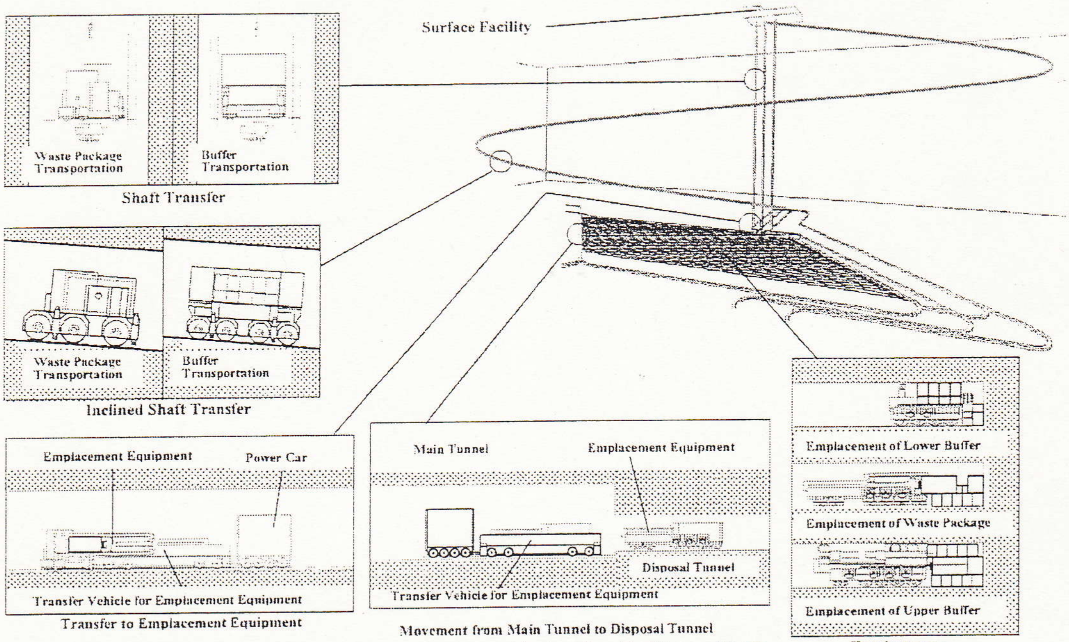
LAYOUT OF A DEEP UNDERGROUND FACILITY. (EMBEDDED REACTOR ,TUNNELING SYSTEM)

In reference[5], I discussed installing a single reactor in a vertical hole (like Fig.1), but transporting and placing the reactor's components, such as the pressure vessel, then might require using a large crane. It will be not suitable for installing large power systems composed of many reactors, turbines, and electric generators. For such installation, the tunneling method developed for large HLW geological storage (fig.2) will be more appropriate. By adopting the configuration of having a few stratified layers in this tunneling system (fig.3), then the turbines, vacuum condenser, and generators can be installed in the upper level, whilst the dump tank for emergency cooling can be installed in the bottom layer below the reactor. Due to siting the entire system underground , there is adequate room for these separate installations. Furthermore, a deep under--ground site is much safer as regards earth-quakes because the movement there is far less than near the surface.



Schematic view of backfilling of a shaft

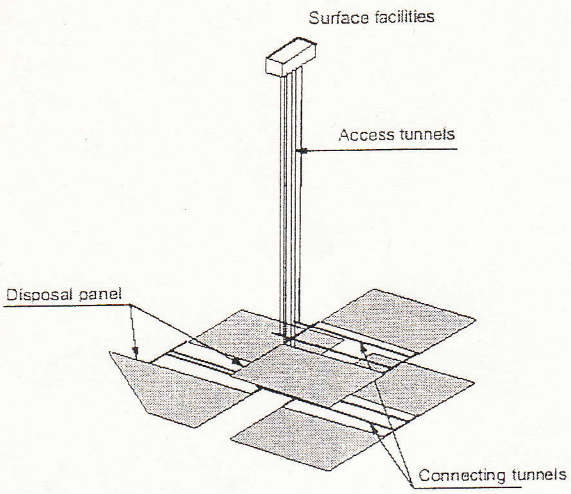
Fig 1



In this diagram, conceptual methods for transport in shaft and incline are shown to aid understanding of the differences. When the repository site is decided, the optimum method will be selected in accordance with the geological and environmental conditions.

Transportation / emplacement operation in the underground facilities (disposal tunnel horizontal emplacement concept)

Fig.2



Multiple-layer layout

Fig.3

To utilize the high pressure of earth's gravity, the reactor vessel and cooling pipes should be surrounded by the primary- and secondary- containment and embedded into the rock. The space between these containments are filled with gaseous , liquid, or solid materials, so that the pressures from earth's gravity are directly imposed on the reactor vessel and the coolant- channel pipes. This arrangement differs from that proposed by others, notably Sakharov and Teller, for an underground reactor in which both the reactor and piping are sited in the space excavated in the rock. As filling materials, gases, liquids, and solids have been considered. These materials should not be corrode the container's surface, and should be thermal insulators. Helium gas might be ideal because of its large sized atom, and because it has a smaller neutron capture cross- section than does nitrogen or CO_2. But it might require a larger volume than a liquid, such as water, liquid CO_2 , or liquid N_2. Since our reactor and coolant channel pipes will be repairable, and are not embedded permanently in the ground, as in Sakharov and Teller's concept, these gases and liquids can be removed easily thereby creating sufficient space for repairing the reactor by robotic machine. A good candidate for the solid material might be sand or concrete grout.Sand can be easily removed, as can concrete grout using a suitable tool.

Since the high pressure caused by earth's gravity is imposed on the reactor vessel, it can be thin and light. Hence, a small locomotive can transport the reactor's components to the site , instead of having to construct the reactor in placee, which takes long time. The components are manufactured in the factory, and transported into the deep underground site through the tunnel. (fig 2). The reactor can be installed in a similar way as the glassified HLW (fig. 4) although the hole must be a little bigger. The technology involved will be similar to that employed for geological storage.