# DEEP UNDERGROUND REACTOR (PASSIVE HEAT REMOVAL OF LWR WITH HARD NEUTRON ENERGY SPECTRUM )

Hiroshi Takahashi
Brookhaven National Laboratory, Upton, New York, 11973
Tel 631-344-4099,Fax 631-344-7650, e-mail takahash@bnl.gov

ABSTRACT

To run a high conversion reactor with Pu -Th fueled tight fueled assembly which has a long burn-up of a fuel, the reactor should be sited deep underground . By putting the reactor deep underground heat can be removed passively not only during a steady-state run and also in an emergency case of loss of coolant and loss of on-site power; hence the safety of the reactor can be much improved. Also, the evacuation area around the reactor can be minimized, and the reactor placed near the consumer area. This approach reduces the cost of generating electricity by eliminating the container building and shortening transmission lines.

## 1. INTRODUCTION

The concept of a high conversion light water reactor using a high concentration of Pu-fuel tight-lattice has been proposed in Nuclear Energy Research Initiative (NERI) Program [1]. This reactor has a hard neutron energy spectrum close to that of an Na-cooled fast reactor , and high burn-up of fuel can be obtained. A reactor with uranium fertile material has a positive water-coolant void coefficient, thus to get a negative void-coefficient, it is required a pan-cake-type flat core configuration or a fuel assembly with a neutron-streaming void section which reduces neutron economy [2]. The use of thorium fertile material, however, provides a negative void-coefficient without having neutron-leaky core configuration; the neutron economy accordingly is improved and a higher burn-up of fuel can be obtained compared with a reactor with uranium fertile materials. However, the pumping power of water coolant has to be substantially increased to remove the high-density heat from a tight latticed fueled core. During steady operation, coolant flow can be maintained by increasing 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 studied analyzed in detail and an experimental study for heat removal from a tight lattice has been planned in the Japanese research program.

## 2 PASSIVE HEAT REMOVAL

To withstand an emergency case of loss of pumping power, a passive cooling system, such as heat removal using the natural circulation of the coolant, has been studied. I propose here using a tight-latticed water reactor embedded in a deep underground location, so that it is cooled by the natural circulation of the water. The 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 steam turbine. To obtain such a high pressure differenc, 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 which is equivalent to a 20 -15 meter difference in water height. but 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, we can provide enough space to get such a high pressure difference between the inlet and outlet using the density difference between the steam section and the water which is condensed after passing through the steam turbine and steam condenser which in our configuration 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 which is 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, even in the passive state. By operating at a high enough pressure, these nonlinear effects can be eliminated, and we can obtain safe operation of 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 can be thin;, thus the reactor would be much lighter than that of a regular LWR operated on the earth surface. A huge heavy crane would not be required to move this reactor and it could be constructed with a modular-type design.
It has been proposed to use super-critical steam for gaining high efficiency of electric generation [3] , this reactor requires 250 atm water pressure, this can be achieved by the earth pressure in the 1000 meter deep under ground: 260 atm. The more high water pressure can be obtained by providing thick pressure vessel .

## 3 A DEEP UNDERGROUND FACILITY

Deep underground geological storage of high level waste has been studied. The depth of the Yucca Mountain Repository is about 300 meters depth, so that a tunnel more than tens of kilo-meters long is planned. [4]
To measure neutrino oscillation, a super-Kamiokande detector with a 50 meter high and 40-meter diameter water-tank is installed 1000 meters deep in a mountain in Kamioka mine in Japan. Many other high-energy facilities such as the Homestead(USA), 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 the cost of a 10x20 meter tunnel is about 10,000 dollars per 1 meter depth in Japan, although this depends on geological features. Nevertheless, the cost of the digging in hard rock deep under-ground is cheaper than excavating in shallow but fractured rock.

## 4 LAYOUT OF DEEP UNDERGROUND FACILITY. (EMBED REACTOR ,TUNNELING SYSTEM)

In the paper, of reference[5] I discussed the single reactor installed in the vertical hole, but the transportation of the reactor components such as pressure vessel might requires large crane, and it will be not suitable to installation of large power systems composed of the many reactors, turbines and electric generators. For this installation, the tunneling type developed for large HLW geological storage will be more suitable. By adopting the few stratified layers in this tunneling system , turbines, vacuumed condenser and generators can be installed in the upper level, and dump tank for emergency cooling can be installed in the bottom layer than reactor. Due to the underground installation, enough rooms for these installations is available. The deep under-ground is much more safe for earth quake because of small movement than near surface.

To utilize the high pressure of earth gravity the reactor vessel and cooling pipes are are surrounded by primary and secondary containment and embedded into the earth rock. The space between these containments are filled with gas , liquid or solid materials so that the earth gravity pressures are directly imposed to the reactor vessel and the coolant channel pipes. This is different from the underground reactor which had been proposed by the others where the reactor and piping are sit in the space excurvated from the earth rock. As the filled materials, gas, liquid or solid has been considered. These materials should not be corrode the container surface, and should be thermally insulated. He gas might be ideal because for large size atom and has small neutron capture cross section than nitrogen or $CO_2$. But it might requires the some larger volume than liquid such as water, liquid $CO_2$ , liquid $N_2$. Since our reactor and coolant channel pipes will be repairable, and are not embedded permanently in ground as Dr Teller's concept, the these gases and liquids can be removed easily so that we can create enough room for repairing these by robotic machine. As the solid material, sand or concrete grout might be good candidate. The sand can be easily removed, concrete grout also can be removed by suitable tool without difficulty.

Since the high pressure by the earth gravity is imposed in the reactor vessel, it can be thin and light, so that small locomotive can transport these reactor components, therefore instead of construct the reactor on site which takes long construction time, these are manufactured in the factory, and can be transported to the deep underground site though the tunnel. shown in the figure 1. The reactor can be installed in the similar way as the glassified HLW although the hole must be little bigger than this. Technology will be similar to the geological storage.

In the safety analysis of the reactor built above ground reactor, LOCA type accident caused by guillotine type coolant pipe rupture has been extensively studied, but our pipes are embedded in the earth the possibility of occurring the guillotine type rapture is remote and even when pipe is ruptured the sudden loss of coolant can not be occurred, due to whole system is tightly embedded in to the earth and the coolant has no space to escape from the pipe.

The outermost container are directly embedded in earth rock it provide high earth pressure on the container, thus the pressure difference between reactor pressure vessel and the container becomes small, we can use thin shell. But sudden depression of the inner pressure cause the collapse of the pressure shell, we have to keep good control of pressure for thin shell container. When some thicker shell is used pressure balance is not necessary to be so refined, pressure balance can be maintained by using the gas compressor.

In this stratified layers concept of reactor installation, the fuel exchange might be done with the similar way as the conventional power plant by using the one level above of the reactor by opening up space above the reactor, and filling the water for radiation shielding.

To make easy accesses for repairing and maintenance, some tunneling can be open after depressurizing the section. The plugging section for the tunnel can be done similar way as developed in the HLW storage facility. As shown in figure 3.

## 5 ENVIRONMENT ANALYSIS. CONDENSER COOLANT

Earth surrounding the reactor might becomes radioactive due to high neutron fluxes leake out from the reactor, especially the accelerator driven reactor, high energy particle beam is involved, they will make the surrounding rock radioactive unless these are well shielded. To prevent these radiation to be leak out to above ground, some shielded container should be installed surrounding the underground reactor, and also the hydro-analysis of the underground water movement should be studied in more rigorously than the analysis of HLW storage.

To condense steam to water, a large amount of the water is required; this is supplied from ground surface. Thus this under ground reactor should be located near sea or river. The power of pump to circulate water for condensing steam in the deep ground will not be so large because of siphon effect of water. The mountain range with lake can be used with horizontal tunneling. As shown in figure 4.

## 6 ECONOMY OF THE DEEP UNDER-GROUND REACTOR , TRANSMISSION LINES,CONTAINER BUILDING'S EMERGENCY COOLING SYSTEM AND EVACUATION

To protect the public from radiation hazards in the fall out of radioactive elements, regular nuclear power plants, a container building for the reactor is provided. By putting the reactor into the deep underground, the radiation field generated from the radiation fallout would be very small, and we could minimize the evacuation area

Thus, we could build a NP near a consumer area and thereby shorted the transmission lines. This would entail substantial reduction in the cost of electricity generation. Generally the cost of transmission lines is very substantial, especially establishing lines in densely populated areas where the cost of land is high; it was estimated that the construction of a transmission line of more than 400 Km is greater than the cost of building the power plant itself 8] .

Although installing each components, such as steam turbine and vacuum condenser in the deep underground is more expensive than building them on the earth's surface, by not having to construct long transmission lines and a double-walled container building and other facilities associated with having a seismically strong building structure, lowers the overall cost of the constructing reactor in the deep underground. However, a detailed cost evaluation is still required.
To remove decay heat after an accident, emergency-cooling borate d water is stored in the container building; in the case of the tight-lattice reactor, the height of the cooling water must be considerable to get the needed high pressure; also it is very vulnerable for seismic protection.
When the reactor is the deep underground the emergency borated water also can be stored underground where the movements of an earth quake is smaller than at shallower depths. Also there is enough room to store a huge amount of water high above the reactor and so water under high pressure can be provided to cool the tight latticed reactor. Also to protect against re-criticality of the core due to its melting, a large pool of water can be provided under an underground reactor without difficulty.

Installing a nuclear facility in under deep underground ensures that public are well protected. We can eliminate containment building and reduce the seismic hazards avoiding the strong earth motions at the surface. The area of emergency evacuation , which concern closed down the Shoreham NP near BNL in the last decade, also be minimized; thus there is possibility of constructing the NP near a consumer area, and the
expensive construction of high voltage electricity transmission lines can be lessened. Therefore , building a deep underground reactor might be more economical than building the nuclear power plant on the above ground. Although it might be very difficult to obtain public acceptance in the present political climate, it might be wise to built future reactor deep underground.

## 7 CONCLUSION

The construction of a nuclear power plant underground was proposed by A.Sakharov and E. Teller 7] for protection against radiation hazard, and Russian Pu and Electric Generation nuclear power plant is operated in Enisei river[8]. However, my proposal for a deep underground reactor uses earth's gravity force to provide passive heat removal using natural circulation of the reactor coolant; such a nuclear power plant can be operated more safely.
The high pressure drop required for heat removal from the tight latticed fuel reactor can be supplemented by use of earth's gravity. This natural-water-coolant circulation can eliminate concerns about an on-site electricity blackout. The storage facility for the emergency coolant system can be built far above the reactor because there is enough space available in a deep underground installation.

The capability of removing heat, not only during steady-state operation but also in accidents involving a loss of coolant or an outage in on-site power is essential especially for the HC reactor with tight latticed fuel assembly. By putting the reactor deep underground and removing heat passively, public safety is ensured.
Also the deep underground reactor is imposed by high earth pressure by embedding it earth rock, the pressure vessel and the coolant pipe can be thin so that they can be manufactured in the factory and can be it can be transportable by small locomotive thus the building cost can be reduced substantially than the regular reactor . By using the modular type design and installing them in the stratified layer tunneling system, the capital cost can be reduced further. Also for defense purposes in protecting people from nuclear hazards created by smart bombing of nuclear facility, future reactors should be built in deep underground.

Here, I have discussed mainly the light water reactor, but this concept equally can be applied to gas-cooled reactors which require high pressure, and it will apply many other types of rectors such as liquid metal cooled Na, or Pb cooled reactor. Although these not require the high pressure for running a reactor, For electricity generation using steam turbine, it requires very high pressure to get high efficiency. A high pressure provided by earth gravity is beneficial for these reactors too.

The horizontal installation of large power plants can use many technologies developed for deep geological storage of HLW which has been studied by many countries for back end of the fuel cycle. But to promote the nuclear energy, the research on the front end is crucial and the deep underground reactor concept might be served for this purpose.

8 ACKNOWLEDGEMENT

The author would like to express his thanks to Dr. B.D.Chung , Dr. J. Herczog, Dr.U.Rohatgi, Dr. S.Mtsuura, Dr.Y.Yamazaki, Prof. Davis and Prof. B.W.Lee for their valuable discussion.

REFERENCE

[1] T. Iwamura et. Al. " Research on Reduced-Moderation Water Reactor (RMWR) JAERI_research Report, 99-058 ( In Japanese).

[2] Hiroshi Takahashi , Upendra Rohatgi , Tom Downar"A Proliferation Resistant Hexagonal Tight Lattice LWR Fueled Core for Increased Burnup and Reduced Fuel Storage Requirements" Progress report of NERI: Aug.1999 to May, 2000

[3] Y. Oka " Physics of supercritical- pressure light water cooled reactors " 1998 Frederic Joliot Summer school aug. 17-aug.26 1998 Cadarache , France.

[4] U. S. Department of Energy Office of Civilian Radioactive Management DOE/EISW 0250D-S " Geological Repository for the Disposal of Spent Nuclear Fuel and High- Level Radioactive Waster at Yucca Mountain Nye County, Nevada." May 2001

[5] " Second Progress Report on Research and Development for The Geological Disposal of HLW in Japan' JNC report

[6] H. Takahashi "deep underground reactor and transmutor (passive heat removal of lwr with hard neutron energy spectrum ) Susono Conference held at

[7] Edward Teller, Muriel Ishikawa,Lowell Wood, Roderick Hyde and John Nukolls " Completely automated nuclear reactors for long term operation II. ICENES 96.

[8] Informal meeting between US and Russia for Pu -reduction. at BNL Sept 2000.

Key words

1 Deep under ground reactor, 2 High conversion 3. Thorium, 4. Tight lattice LWR, 5 Embedded in earth, 6. High-pressure 7 Evacuations, 8. Near consumer 9. Safety