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Comments:

April. 2, 2002

Dr. Mori
JAIF. Inc.
Vice President

1-5-20, Numa Sakuraga Oka,Fujisawa,
JAPAN 251-0027

JAIF.
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Dear Dr. Mori,

I should have come to you in JAIF to apologize in person for my great mistake, regarding the date of my lecture, but I write you instead since I did not have the opportunity. I truly regret having missed the opportunity to give my lecture at JAIF during my stay in Japan and hope that you will forgive me.

Thank you also for your kind suggestion. I contacted Mr. Takeda at Dowa Co. who came to Sokendai at Hayama, and we had a fruitful discussion about the deep underground reactor. He taught me about the practice of civil and mine engineering and gave me many valuable suggestions.

After the Sokendai symposium. I visited the Kamioka mine company which built the super-kamiokande site and got a great deal of information about the construction of big vaults in the Kamioka mine. Mr.K.Tsurumi who is the Directing General Manager at the Kamioka Mine & Smelting Company kindly agreed to meet with me on a national holiday, and gave me valuable information along with a videotape on the mine and super kamiokande.

Visiting the super-kamiokande gave me even greater confidence in the concept of a deep-underground reactor. Although the idea may not be readily accepted by the public, building a reactor deep underground would be more economical than building one on the earth's surface.
Future reactors, not only high conversion light water reactors but also many other types of reactors, such as HTGR which has been promoted recently, should be placed deep underground.

I am enclosing a copy of the paper, which I plan to submit to the upcoming ANS meeting in Florida, and others. I would appreciate it very much if you would read it, and give me your comments.

During my stay in Tokyo, I had the opportunity to participate in a conference on the foundation of quantum mechanics held at Waseda Unviversity. Prof. Ojima and Prof, Takahashi of the architecture department have been active for the last 20 years in metropolitan underground city planning. I visited them and discussed the deep underground reactor with them. They felt that my proposal of a 500-1000m depth was too deep for their purpose.

As you are working on the new initiative for metropolitan city planning, this is extremely important for future of Japan. I am going to continue on this subject more than my efforts to accelerator driven reactor proposed decade ago.

I hope you will continues to support this enterprise for creating a peaceful civilization which uses nuclear energy wisely.

Thank you for all your help, and I am looking forward to see you in the not distant future.

Sincerely,

Hiroshi Takahashi

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PS. I will sent this by mail and E-mail.

Embedding Materials and Economy for a Deep Underground Reactor

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Abstract - I proposed embedding the high-conversion LWR, studied in the NERI program, about 500-1000 meters deep underground. At such depths, the earth's gravity force passively removes heat using the natural circulation of the reactor coolant; then, even a nuclear-power plant with very tight-lattice fuel assembly can be operated safely. Safety is ensured by embedding the reactor vessel and other components, such as coolant ducts, in casing containers and filling the space between the container and the vessel with embedding material. I describe suitable embedding materials that can be easily removed to allow access to the reactor and coolant components. , Finally, I discuss the key economic aspects of building a reactor deep underground.

I. INTRODUCTION

In NERI program, we highlighted the value of a high-conversion light water reactor (LWR) that uses a high concentration of tight-lattice Pu fuel [1][2]. This reactor, with its hard neutron-energy spectrum close to a Na-cooled fast reactor, ensures a high burn-up of fuel. The reactor with uranium fertile material has positive water-coolant void coefficient, so to get a negative void coefficient, a pancake-type flat core configuration must be used, or a fuel assembly with a neutron-streaming void section that reduces the neutron economy. Using thorium fertile material provides the negative void coefficient without the need to have a neutron-leaky core configuration. Also, the neutron economy is improved and the burn-up of fuel is higher than in the reactor with uranium fertile materials. However, the pumping power of the water coolant must be substantially increased to remove the high-density heat from tight-latticed-fueled core. In the steady operation, coolant flow can be maintained by increasing pumping power several times above that of the regular LWR. During emergencies, such as outage of on-site power or loss of coolant, the removal of heat becomes serious problem. Detailed analyses of this accident scenario have been made, and experimental studies of heat removal from a tight lattice are planned in Japanese program.

The high pressure-difference between the inlet and outlet in the narrow water channel of the tight lattice is provided by the difference in gravity force between the low density of boiled water and the high density of the water condensed after the steam passes through out the steam turbine. To get this high-pressure difference, the vacuum condenser is located far above. The pumping-pressure difference circulating water in the regular BWR and PWR are, respectively, 2 atm and 1.5 atm which is equivalent to a 20 –15 meter difference in water height .For the high conversion (HC) LWR with a tight lattice, the difference must be several times greater: here, a difference in water height of more than 80-60 meter is needed to naturally circulate coolant water. By putting the reactor deep underground, enough space can be provided to get a satisfactory high-pressure difference between the inlet and outlet, steam turbine and condenser, both of which are located far above the reactor vessel.

By locating the reactor deeper, the pressure imposed on the pressure vessel is increased by the gravitational force of surrounding earth. At a depth of 400 meters and 600 meters, the earth's pressure generated a water pressure of 100 atm and 150atm, suitable for a BWR and a PWR, respectively. .

In the conventional model proposed for a passive cooling system using natural circulation, it is operated in an environment where the pressure is insufficient, the state of the steam is not well defined, instability is created, and so, it is not necessarily a safe operation, even though it is a passive one. . By operating at a high enough pressure, these nonlinear effects are eliminated, and the reactor can be safely operated deep unde ground. From this point of view, there are many advantages in the concept of the deep underground reactor. Due to pressure from earth's gravity, the walls of the pressure vessel can be thin;

thus, the reactor can be much lighter than a regular LWR operated on the earth's surface. A huge heavy crane is not required to move this reactor, and its design can be of the modular type.

II. EMBEDDED REACTOR

A.Sacharov and E. Teller [3] proposed constructing nuclear power plants underground to protect against radiation hazards; Russian nuclear power plants generating plutonium and electricity are operated underground near Enisei River(Krasnoyarsk). Instead of putting the reactor in an underground space, I proposed [4] embedding the above high-conversion LWR at 500-1000 meter depth.

In my concept, in contrast to Teller's underground reactor, the reactor and components will be accessible for repairs or fuel exchange; the reactor can be designed with large burn-up so that fuel exchanges should be infrequent. The reactor vessel and coolant ducts will be surrounded by a reasonably sized container, and the containers are embedded in the ground. The space between container and the components are filled with embedding materials during its regular operation. . These spaces are wide enough so that after voiding or draining the filling materials, a person or a robot could get in to do repairs or exchange the fuel.

There are many possibilities for these materials, from He gas, CO2 gas, water, salts, bentonite, fine sand, gravel, tar, to concrete. For easy access, although it is likely to be infrequent, a liquid, such as light water, or fine sand can be drained without difficulty. Water is most convenient liquid but it requires good thermal insulation. Due to the smallness of the movements of the earth of the deep underground in an earthquake, a simple structure can support the rigidity of the reactor and coolant ducts. He gas also is a good candidate for a filling material but good preventive measures are needed against leakage due to the small He molecule. Carbon oxide gas can be liquidified at high pressure and because it has a larger molecule than He gas, and it is less likely to leak. Both have a small neutron-capture cross-section. To prevent the contamination of the c groundwater and the surrounding rock with radioactivity due to neutron leakage from the reactor core, the embedding material chosen should have small neutron capture and act as good shielding for neutrons.

Salt is an easily handled embedding material because it can be liquidified by injecting water;, however, corrosion of the vessel and container material becomes a serious problem, especially in high-pressure environments. Fine sand can be easily drained, but its solidification due to high pressure must be prevented. Tar is solid at low temperatures but can be liquidfied in high temperatures so it could be drained by increasing the temperature, although it is hard to do the work in the unsuitable environment underground.

Nevertheless, utilizing a combination of these materials with suitable structural materials, reasonable embedding conditions can be attained for getting high pressure for reactor system.

By encasing not only the reactor and coolant ducts, but also the turbine, a high-pressured working fluid can be obtained for generating the electricity with high efficiency. This approach reduces waste heat and stabilizes the thermo-hydraulic system. The outlet of the turbine and condenser section should be at low pressure which is maintained by a rather thick pressure container unless these components are located near the ground's surface.

Embedding the entire reactor system prevents guillotine-type rupture of the coolant ducts and the other serious accident conditions encountered in reactors operated on the earth surface. The earth's pressure is directly imposed on the reactor, and so the thickness of the pressure vessel and the coolant ducts can be reduced, even at high pressure; this enhances the thermal efficiency. The reactor vessel can be manufactured in a factory and transported to the site by light transport equipment. Further, by adopting a modular type reactor, the costs of construction can be lowered substantially by assembly on site, even for large-capacity plants.

Installing a nuclear facility deep underground affords good protection to the public, and it can eliminate need for the containment building. Seismic hazards are reduced. Thus, the area of emergency evacuation also can be minimized, and there is possibility of constructing the NP near a consumer area; accordingly, the expensive construction of lengthy high-voltage electricity-transmission lines can be avoided.

The deep underground environment has been studied in relation to the geological storage of high-level radiation waste, such as the Yucca Mt. Project [6]. The technology for these projects has been well explored Figures I. 1- 6 are taken from a paper on the JNC program[7]; its geological storage concept can be extended to deep underground reactors. In the high-energy physics field, underground science laboratories [8] are planned, such as the Homestake Gold Mine in South Dakota where R. Davis carried out solar neutrino experiments. The Super-Kamiokande[9]

(Japan) and the Gran Sasso (Italy) underground facilities, are now among the main facilities studying elementary particle physics.

III ECONOMY OF DEEP UNDERGROUND REACTOR, TRANSMISSION LINE, CONTAINER BUILDING, EMERGENCY COOLING SYSTEM, AND EVACUATION

The high cost of underground construction has been a critical feature in considering building a reactor deep underground. However, in the Homestake gold mine, more than 500 miles of tunnel has been laid under in depth of 5000 feet. Kamioka mine has 1000 km lengths of tunnels, and Sado gold mine has 500 km long tunnels.

The Kamiokand facility has a cylindrical water tank 41.4 meters high, 39.4 meters in diameter that can support 50,000 tons on pure water. Some 11,200 photomultipliers tubes of 50cm diameter were constructed under Mozumi-ko, by Kamioka Mine company, in 1993-1998, at 1000m underground. The cost of this construction was US$ 77 million (104 oku-yen2002)

The cost of the digging large hall in underground is not unduly expensive. In Japan, the cost of digging the about 10x20 meter size tunnel was about 10,000 dollars per 1 meter depth, although this depends on the geological conditions.

The deep underground geological storage of high-level waste has been studied. Although the Yucca mountain deep-storage facility is about 300 meter deep there are plans to build a tunnel of more than tens of miles.

Thus, the concern that it will be very expensive to construct a deep underground facility is misleading, and indeed, building reactors underground becomes a realistic proposition. The above data are for constructing large facilities in hard rock mountains, but comparably, building deep underground in hard rock will be not as expensive as the cost of shallow underground construction where the rocks are fractured or soft. .

To protect the public from radiation due to fall out from radioactive releases from regular nuclear- power plants, the reactor is enclosed in a container building. By putting the reactor underground, the radiation field becomes very small, and so the evacuation around it can be minimized.

Thus, NPs can be built near consumer areas and, consequently, transmission line can be shortened so substantially lowering the coats of electricity generation. The cost of transmission lines is very substantial, especially those in densely populated area where land is expensive. It was estimated that the expense of installing transmission lines more than 400 Km long is more than the cost of power plant itself.

Although installing many facilites underground, such as the steam turbine, and vacuum condenser, is more costly than building them on the earth's surface, but not having to constructing long transmission lines and the double-walled container building and the other facilities associated with having a seismically strong structure, ensures that, overall, cost of the constructing the reactor in deep underground might be less expensive. A detailed cost evaluation still is required.

IV. USE OF MOUNTAIN REGIONS (HORIZONTAL LAYOUT).

Although I discussed the deep underground in the above which assume it will be built near populated area at sea level, if the reactor is built in high mountain area such as super- Kamiokande, the deep underground can be accessed by through horizontal tunnel, and the reactor container can be accessed with regular vehicle. Although the mountain region is far from the city. There are many candidate sites for building the reactor. Horizontal one is easy access and it is convenient to transport to heavy equipment such as thick pressure vessel. Drainage of the underground water is simple without high power pump. Turbine section can be located near surface without elaborated installation in deep underground

Figure II.1 shows the Homestake gold mine vaults which was digged the ore from surface. These will be used also by constructing the reactor in the bottom of vaults and embedding by filling the earth above it . we can restore the earth environments.

Figure II.2 shows the layout of the Homestake gold mines.

Figure III.1 shows the Kamiokande ditector of neutrino and proton decay.

Figures III.2-7 show the Kamioka Mine and the equipment used for mining the lead and zink ore. These will be used for building the deep underground reactor .

There are many vaults left over in the old mine (Some of the coal-mine near Essen in Germany can be utilize for this purpose although it is not deep.) which are waiting to be restored. These will be used also by constructing the reactor in the bottom of vaults and embedding it by filling the earth above it.

There are many transportation tunnels which can be utilized by making side tunnels without heavy investment, although they are mostly located in far from the metropolitan area.

V. OTHER TYPES OF REACTOR

In the above we discussed the BWR type reactor with tightly bounded fuel assembly, but the deep underground reactor concept can be applied to many other type of reactors. For PWR type reactor, by using the heat exchanger section where the steamed water is generated, we can use the earth gravity in the same way as BWR.

It has been proposed to use super-critical steam for gaining high efficiency of electric generation[10] , 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 achieved by providing thick pressure vessel .

High temperature gas cooled reactor (HTGR) without container which has been promoted recently can be run with good protection of public by running in the deep underground reactor with high performance of the electricity generation due to high pressure and high temperature. Gas turbine can be smaller than the steam turbine, it can be installed in smaller space than the steamed turbine.

VI. CONCLUSIONS

The operation of a nuclear power plant in underground provides a proper heat removal with natural circulation of coolant water without the expensive container building. This natural water-coolant circulation can remove any concerns about on-site electricity black out; also, the storage facility for emergency cooling water can be built far above the reactor because there is sufficient space available in a deep underground installation.

The deep under ground is seismically resistive, and the construction of facility is not expensive as it has been assumed due to harder rock than the shallow underground.

The deep underground site minimize the evacuation area, and by locating the reactor close to populated area, transmission line is shortened, and many reactors operation (modular type reactor) as the nuclear park reduces the cost of building big facility. By embedding the reactor into earth, the facility becomes for seismically solid, the many component such as pressure vessel becomes light and can be transportable. By proper choice of the embedding material the reactor and the other components can be accessed by voiding them without difficulty. Use of the mountainous area for nuclear facility should be considered as the alternative option for easy to access and building in future.

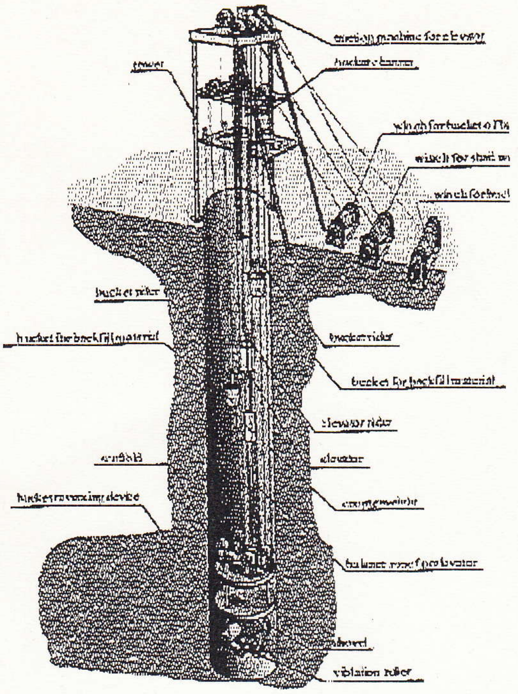
Here, I have focused on the light water reactor, but this concept can be applied to the gas-cooled reactor that requires a high pressure, and doubtless, it will apply to many other types of reactors.

A concern that it is very expensive to construct a deep underground facility is misleading, and indeed, the construction of reactors deep underground becomes a more realistic proposition, especially in view of the September 11th attack on the World Trade Center Twin Towers.

Also,for defending people from nuclear hazards should a nuclear power plant be bombed, it would be wise to build future reactors deep underground.

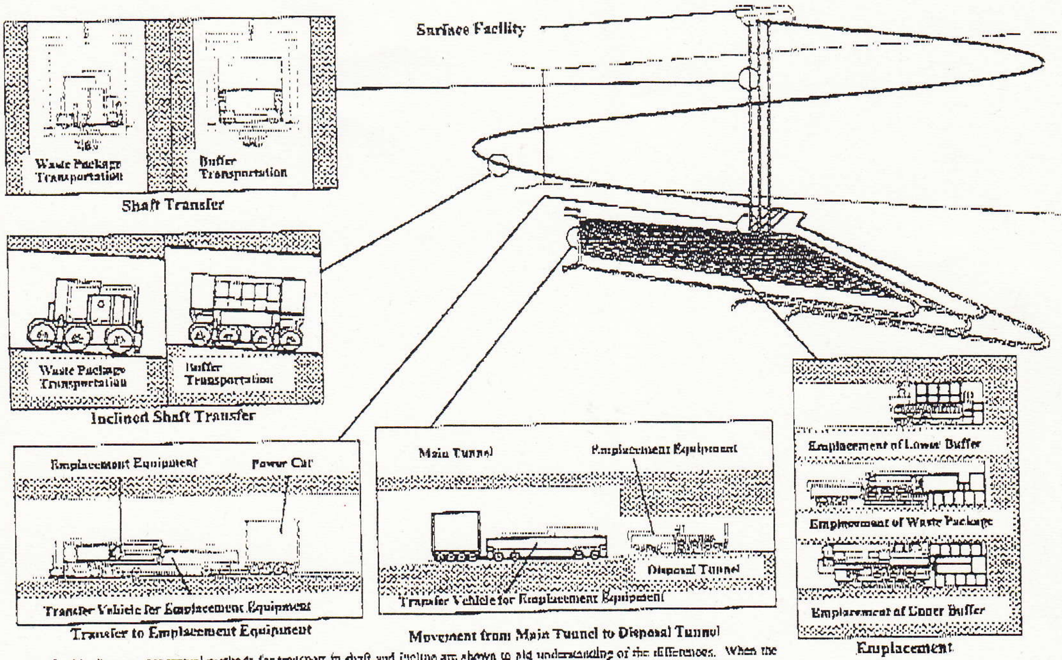
ACKNOWLEDGEMENT

The author would like to express his thanks to Drs. Kawata B.D.Chung, J. Herczog, .U.Rohatgi, Prof.Davis and Prof. B.W.Lee Mr. Tsurumi for their valuable discussion .The figures of describing the HLW storage, Underground science laboratory , and Kamioka Mine which are used in this paper are provided from reports from JNC [7], University of Washington State [8] and Kamioka Mine company [9] the author would like to special thanks to these organizations allow me to use these figures.



Schematic view of backfilling of a shaft

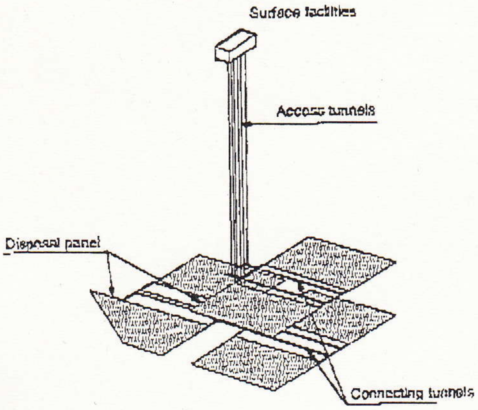
Fig. I.1. This type of shaft (access tunnel (Fig.I.3) can be used for transporting the reactor vessel and components in the vertical layout.



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.

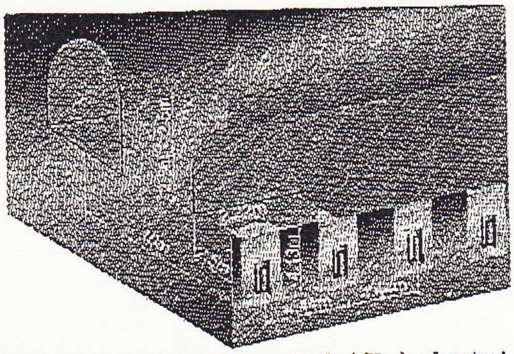
Fig I. 2. Transportation/emplacement operation in the underground facilities (disposal tunnel horizontal emplacement concept) * Japan Nuclear Cycle Development Institute " H12: Project to establish the scientific and technical basis for HLW disposal in Japan [7] Second progress report on research and development for the geological disposal of HLW in Japan.

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



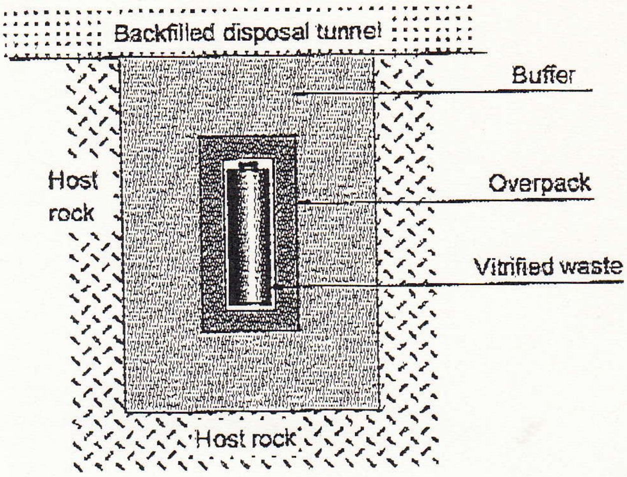
Multiple-layer layout

Fig.I.3 Many layers will be serve as placement of reactor, fuel exchange, turbine, electric generator, vacuum condenser, and emergency cooling storage and its dump.



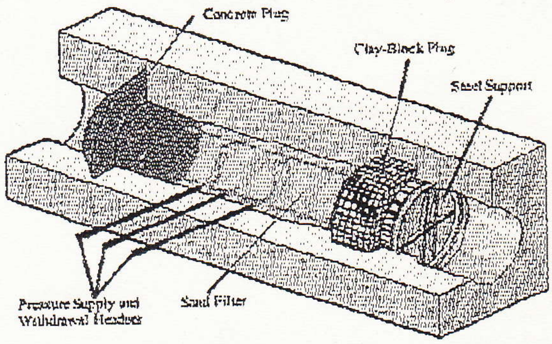
(a)Disposal pit vertical emplacement method (Hard rock system)

Fig.I.4 Instead of waste, the reactor vessels will be placed with more wide dimensions.



Vertical emplacement concept

Fig.I.5



Schematic view of Tunnel Sealing Experiment (TSX)

Fig.I.6 To protect the each tunnel from accident propagation, the above type sealings are installed.

IV. USE OF MOUNTAINE REGIONS (HOLIZONTAL LAYOUT, VAULT).

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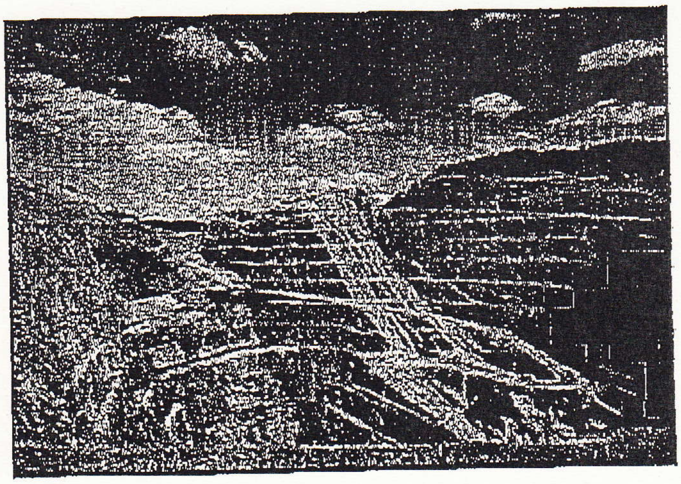

Fig.II.1Homestake mine vault(open pit)

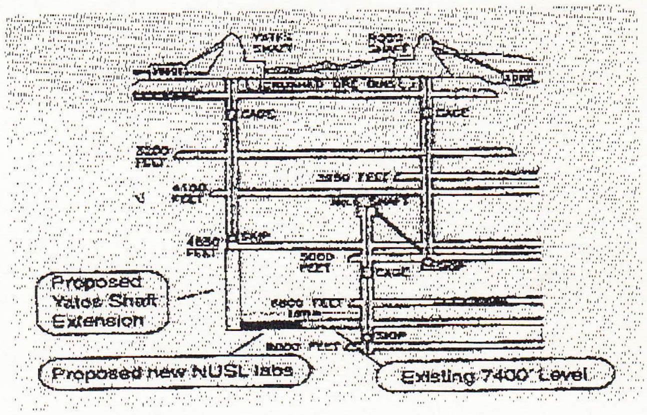

Fig.II.2 Homestake mine vertical layout

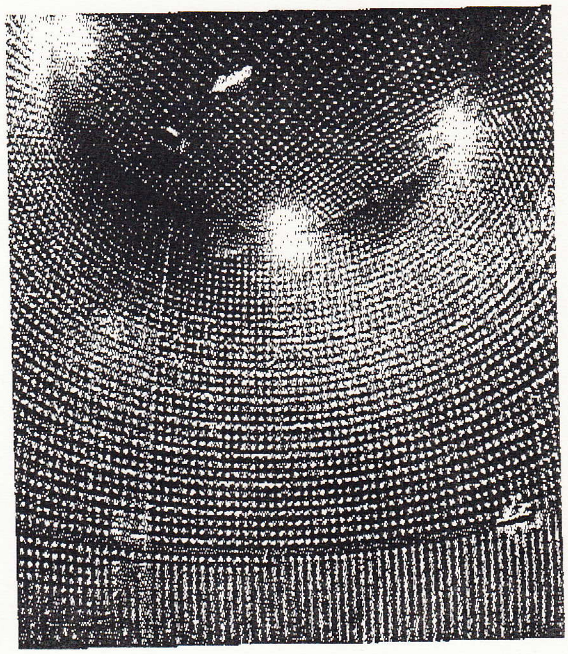

Fig.III.1 Super Kamiokande Ditector.

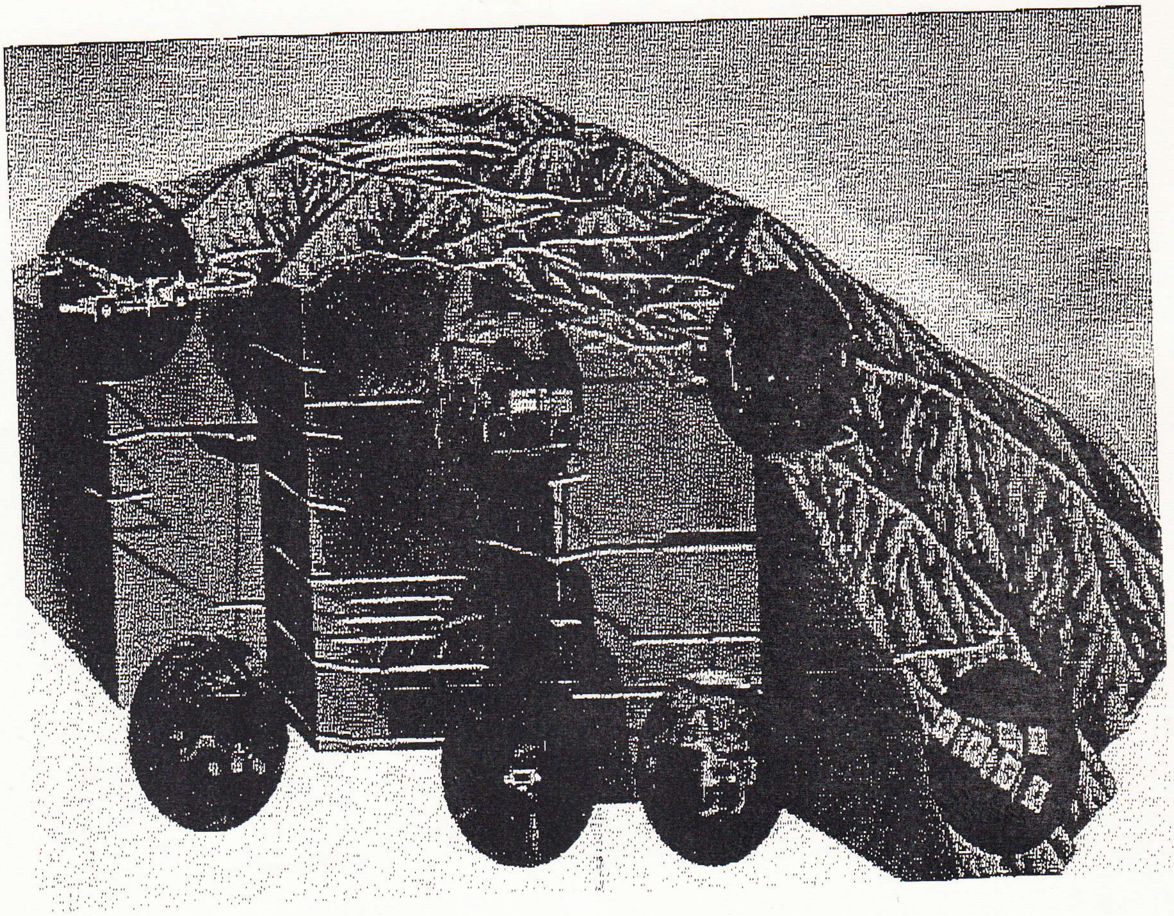

Fig.III.2 Kamioka Mine

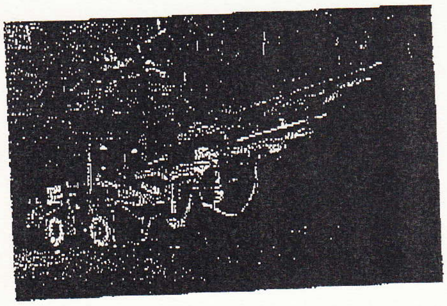

Fig. III.3 Mobile Jumbo Machine

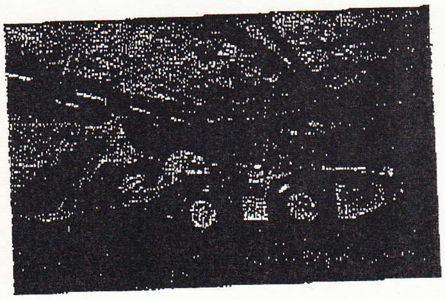

Fig.III.4 Load Haul. Dump(6.5 m^3 volume)

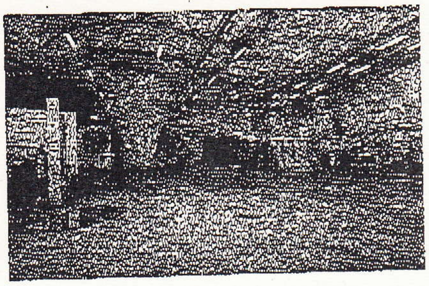

Fig. 5 Workshop for repair

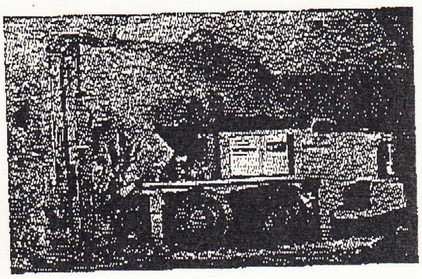

Fig. III.6 Oil-pressured long hold drill machine

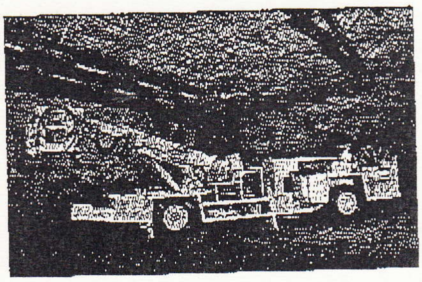

Fig. III.7 AN-FO truck continuous explosive supply