The use of minor actinides and a small power proton accelerator for fast reactor with a high breeding gain.[1]

(Alternate Ways to Dispose of High Level Waste: The Merits of the Antartic Icefield, the Moon, and Outer Space)

Hiroshi Takahashi
Brookhaven National Laboratory
Upton, New York, 11973
Tel 516-282-4099

ABSTRACT

We propose the use of a proton accelerator to run a slightly subcritical fast breeder and incinerator of minor actinides, and also the use of minor actinides to make a high burnup fuel, which can be burned in a reactor with a non-flattened core with a ratio of height to diameter (H/D= 1). By injecting medium-energy protons into a subcritical assembly, and by supplying external neutrons produced by spallation and by high-energy fission reactions, the reactor can be operated in a safer condition than a reactor operated in a critical condition. The safety problems associated with super-criticality, which might be created by factors, such as a positive Na-void coefficient and fuel bowing, can be alleviated.

The metal-fueled fast breeder has small decrement in the reactivity of power and burn-up; the reactivity decrement of the oxide fuel reactor can be reduced substantially by mixing the MA of ^{237}Np with the oxide-fuel. Thus, these reactors can be operated at a sub-criticality of k=0.99 with small beam proton power of 15 mA and 1 GeV energy (15 MW). This slightly subcritical condition makes the power distribution more or less flat, which is important from the point of view of reactor safety. MA can be also used for achieving highfuel burn-up.

This reactor requires a small inventory of fissile material and has large breeding gain. Thus, we suggest using Np-237 to improve the characteristic of the fast reactor rather than simply incinerating this valuable commodity. Because of its small requirement for beam current, the cyclotron can be used instead of the linear accelerator, and the linac can be used for running many reactors by splitting the high current beam.

In the appendix we discuss alternative way to dispose of high level waste into the Antarctic icefield, the moon and outer space.

I. Introduction

Accelerator technology has been developed extensively in the last few decades, and now has the potential to play an important role in the nuclear fuel cycle.(1)

We studied the concept of an accelerator-breeder(2),(3) (fuel producer) in connection with a program of non-proliferation of nuclear material. In that study, fission in the target was

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suppressed; the injection of a proton beam power of 300 MW (1 .GeV, 300 mA) into a depleted uranium target produced 1.0- 1.5 tons of plutonium yearly.

When an assembly of a fast reactor with k=0.99 is used as a target, 300 MW of proton beam power can produce more than 6 tons of fissile material if the beam is first split and injected into many target assemblies. However, a large initial inventory of fissile material is required for these reactors.

Recently, ANL promoted the use of the metal-fuel fast reactor(4) instead of the oxide-fuel reactor, because the former is inherently safer. Pirometallurgical fuel processing is much more economical than aqueous fuel processing which generally has been employed. Another advantage of this metal-fuel reactor over the oxide-fuel reactor is that there is only a small swing in reactivity during fuel burn-up, so that very few control rods are required to control excess reactivity; alternatively, the reactivity-worth of a single control rod can be reduced. Thus, the probability of having an accident after withdrawing a control rod is reduced. Because this metal-fueled fast reactor shows only a small decrement in reactivity, it is suitable for use in a reactor assisted by a small power proton accelerator because it can be run at sub-criticality (k = 0.99) without many control rods.

However, although a large reactivity swing can be regulated by the control rods, the insertion of a control rod into the core region creates a higher peak of power distribution, which is not desirable from the safety point of view.

To deal with the problem of disposal of long-lived, highly radioactive waste, plans have been made to permanently store it in a stable geologic formation, such as the Yucca Mountain in Death Valley. However, there is concern that such geologic formations might change over millions of years. Therefore, alternative approaches to dealing with the waste have been studied that would separate the long-lived nuclei from high-level waste by transmuting the former into short-lived or non-radioactive wastes.

The use of fast neutrons is an effective way to incinerate minor actinides (MA) because of the high ratio of fission-to-capture neutron reactions.

When the neutron spectrum is hard enough, an assembly composed of ^{237}Np, which does not cause fission of the thermal neutrons, becomes critical in a large volume of the target assembly. However, the lifetime of neutrons in this hard spectrum is very short, and the delayed neutron fractions from ^{237}Np fission(5) are much smaller than those from ^{23}*U fission.

Therefore such a ^{237}Np- fueled reactor must be controlled more carefully than a regular fast breeder w'hich has a large amount of ^{238}U fuel. To alleviate the problem of criticality, we proposed to use the proton accelerator to generate external neutrons to run the ^{237}Np-fueled reactor in a subcritical condition.

II. A Fast Breeder Assisted by Proton Accelerator

A high-current proton beam, which is required for a fission-suppressed fuel producer, has to be spread at the entrance of a "Hohlraum" pie-shaped target by a magnetic field(1), and then is injected into the large surface of the main target; this approach reduces radiation damage to the fuel elements, and flattened the power distribution in the target.

For neutron economy, a side enclosure is installed to capture neutrons created near the target's surface. But, even using with geometry, a large leakage of neutrons cannot be prevented. Also, to maintain the power distribution in the injected proton beam more or less flat, the energy of the protons must be kept high, so that they can penetrate deep inside the target.

These problems can be solved if we use a non-fission suppressed target which has k value close to 1 (for example, k= O.99). In such a case, the target is so close to Critical that the proton beam power can be kept small, and hence, easier to inject into the target. Also, because the condition of k=0.99 lengthens the path of neutron migration in the target, the distribution of neutron flux will be close to that of a regular reactor. Thus, it is not necessary to pay special attention to ensuring deep penetration of the proton beam nor to injecting it into a widespread area, as is the case for the fission-suppressed target.

Recently, a group of researchers at the Central Research Institute for Electric Power Industry (CRIEPI)(6,7) analyzed a U-Pu-Zr ternary alloy fuel with a U-Zr-blanket fast breeder. Their analysis indicated that this reactor has a high potential to enhance passive safety because of the advantageous thermal and neutronic characteristics of the fuel. The fuel temperature during operation can be kept well below the boiling point of sodium, because of the high thermal conductivity of the designed alloy and the sodium-bonded fuel element.

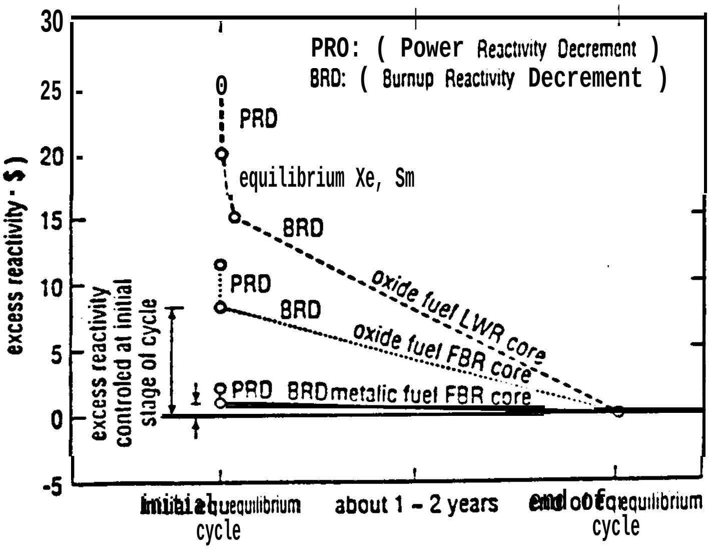

Figure. 1 Excess reactivity oxide- and metallic- fueled core. (initial cycle and time variation) (from ref.7).

Figure 1 shows the power reactivity decrement (PRD) and burn-up reactivity decrement (BRD) for metallic fuel, oxide fuel, and for the LWR. The LWR shows a large decrement in reactivity. To control excess reactivity, a burnable poison absorber is used, in addition to the control rods. The oxide-fuel fast reactor has 3$ PRD and 8$ BRD. To compensate for this excess reactivity, several control rods are required. In contrast to these reactors, the metallic fuel has an extremely small decrement of 1$ for PRD and another 1$ for BRD. Consequently, only a few control rods are required in the metallic-fueled reactor, and both the economy of neutron breeding and the distribution of the power flux are improved. Furthermore, the probability of having an accident related to the control rod is decreased. These small reactivity decrements are caused by the hardening of the neutron spectrum in the metal-fueled fast reactor compared to the oxide-fueled reactor. This hard spectrum, in turn, makes the inner conversion ratio high, the neutron life-time and the absolute values of the doppler- coefficient small, and the sodium density coefficients large. Thus, more careful control is required than in a reactor with a soft neutron spectrum.

When a medium-energy proton is injected into a subcritical assembly with a multiplication factor, k, the total number of fissions, N_{fiss} , can be expressed as(s):
where N_h = the total number of fissions due to high-energy proton reactions, S_h = the number

$$N_{fiss}-N_h+s_h\frac{k}{\nu(1-k)} \qquad (1)$$

of neutrons produced by the high-energy proton reaction (spallation, high-energy fission, and evaporation), and ν = the number of neutrons per regular fission. As shown in Eq. (1), when the k value of the reactor is close to 1 (slightly subcritical condition), the second term becomes the dominant term, and a small number of neutrons from an external source can induce a large number of fissions.

Thus, by providing external neutrons to the subcritical fast reactor(8), *many* of the safety problems associated with criticality can be alleviated and we can make the operation of this reactor safer than that of the regular fast reactor, which is always operated in the critical condition.

The degree of sub-criticality should be determined by taking into account the safety of the reactor. If we choose a small k value, then the chance of having accident associated with super-criticality can be avoided. However, we should consider another important factor, that of large peaking factor resulting from the non-flat distribution of power. When the k value of a target is small, the targeet must have a "Hohlraum" pie-shaped geometry, as is the case for a fission-suppressed target, to make the power distribution flatter and more uniform. This kind of geometry worsens the neutron economy, because a large number of neutrons leak out from the proton-injected surface which is needed to reduce radiation damage to the fuel element. This kind of geometry can be avoided by choosing a k value for the target assembly as close to 1 as possible.

When the k value of the target is 0.99, then, to run a large-capacity, fast reactor like the 3.3 GWt, the proton-beam current needed is small, with a value of only 15-20 mA for 1 Gev proton energy (15-20 MW); This value is 1/20-1/15 times less than for a fission-suppressed target where a proton accelerator of 300 mA and a 1 GeV energy (300 MW) beam is needed to produce 1. or 1.5 tons of Pu. When the fast breeder has a breeding ratio of 0.3, about 6 tons of Pu can be produced by running twenty such breeders with a 300 mA 1 GeV proton accelerator, although a large initial inventory of fissile material is required. Because only a 15 mA proton beam current is required to run a single breeder, the proton beam can be injected vertically from the top of the reactor into a small center target assembly with an area of about 300 cm^2. The target assembly can be the same as that of the metal-fueled assembly, except it should not contain any Pu fissile material, to avoid excess fissions caused by low-energy neutrons.

The metal-fueled reactor does not have upper and lower blanket regions because the internal conversion is so high. The upper part of the fuel element is occupied by a gas-ventilation section for fission products. Thus, medium-energy protons can be injected into *the* reactor from above the ^{238}U target assembly, as shown in Figure 2.

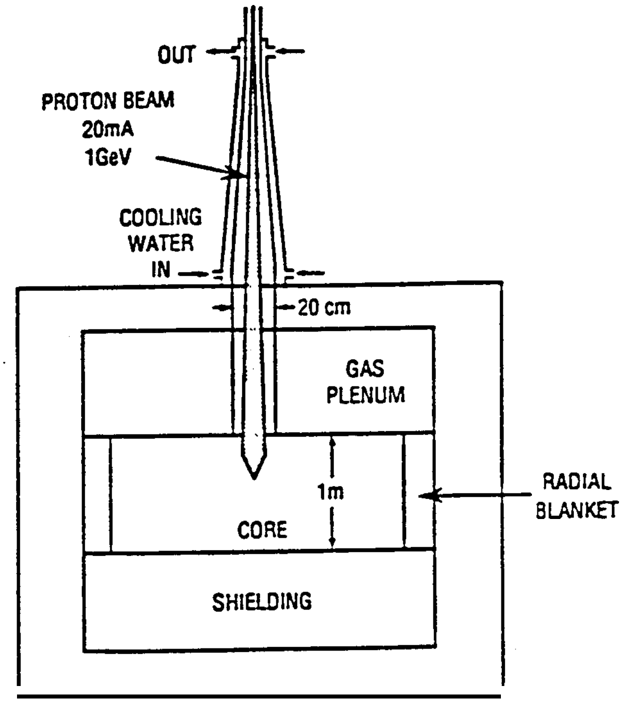

Fig.2 Overview of a fast breeder (or Incinerator) assisted by proton accelerator.

However, the shielding region should be removed so that medium-energy protons can penetrate deep inside the target section, where neutrons are effectively produced by the spallation and the following the high-energy fission of ^{238}U.

Another approach is to use a windowless liquid Pb-Bi target (Figure 3), as was adopted in LANL's thermal incinerator target.(9) Liquid Pb-Bi is pumped upward through the outer channel and is turned downward, after which it falls by gravity, forming a meniscus below the turning point.

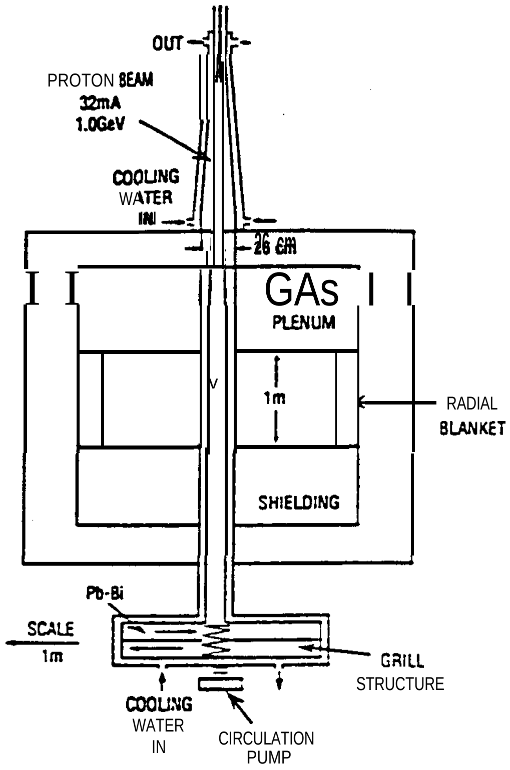

Fig.3 An Overhead view of the flowing Pb-Bi Eutectic Target for fast breeder (or Incinerator) assisted by proton accelerator.

The Pb-Bi target requires a somewhat higher current than the ^{238}U target, because the neutron yield from the liquid Pb-Bi target is smaller than that from the ^{238}U target.

III. Incinerator assisted by proton accelerator.

As discussed in the previous section, the oxide-fueled reactor has a large power-reactivity decrement of 3$ and a burn-up reactivity decrement of $8. Therefore, the large number of control rods is needed to control the large excess reactivity installed at the beginning of the fuel cycle. This shortcoming can be alleviated by mixing minor actinides, such as ^{237}Np, with the MOX fuel. When ^{237}Np captures neutrons, it is converted to ^{238}Pu and to ^{239}Pu which result in fission, even by low-energy neutrons. Also, mixing the ^{237}Np with MOX fuel hardens the neutron spectrum, giving a smaller decrement in burn-up reactivity and in the absolute value of doppler coefficient, but a large sodium density coefficient. This trend makes the overall decrement in reactivity small, so that the number of control rods required in the oxide-fuel fast reactor can be reduced.

Recently, a group at the Power Reactor Nuclear Fuel Corporation (PNC)$^{(10)}$ extensively studied the effects of mixing the minor actinides of (^{237}Np) with MOX fuel in the oxide-fuel reactor.

	Reference Core (No MA-loaded)	Homo. MA Loading Core
Pu Enrichment (Inner Core/Outer Core)	15.3/19.3 Wt%	16.2/19.6 Wt%
Burnup Reactivity Loss	3.31% $\Delta\rho$	1.88% $\Delta\rho$
Control Rod Worth (BOEC, 33cm Insertion of Primary Rods)	1.67% Ap (LOO)*	1.46% $\Delta\rho$ (0.87)”
Doppler Coefficient	-1.05 x 10^{-2} Tdk/dT	-7.08 x 10^{-3} Tdk/dT
Coolant Density Coefficient ($\Delta\rho$/100% Density Change)	-1.73 x 10^{-2}	-2.50 x 10^{-2}
Prompt Neutron Life Time	0.406 µsec	0.338 µsec
β_{eff}	3.71x 10^{-3}	3.47x 10^{-3}

*) Values in Parentheses Denote Relative Control Rod Worth

Table I. Core characteristics of MA-loaded cores. (from ref. 10).

Table I compares the calculated results of the nuclear characteristics of a homogeneous MA-loaded cores with the reference core, which has no MA loading Their calculation shows that the spectrum of neutron flux with MA loading becomes harder than that of the reference core. A calculation was made for a homogeneous mixture of 5 % MA with MOX fuel. The group at PNC also calculated the effect of the ratio of MA to MOX fuel on the reactivity change in an infinite medium, and found that the decrement in burn-up reactivity becomes almost zero when 9% MA is mixed with the MOX fuel; therefore, the decrement in reactivity of this reactor can be reduced in this way. This finding suggests that the oxide-fuel fast reactor can be run in a slightly subcritical condition of $k=0.99$ without the many control rods using the proton accelerator in the same way as the metal-fueled reactor.

The target assembly in the oxide-fueled incinerator is almost the same as the metal-fueled breeder discussed above; the ^{238}U target might be replaced by ^{237}Np, which yields more neutrons than the ^{238}U.

The advantage of a small decrement in reactivity comes from hardening of the neutron speed-um. This hardening results in the need for more careful control of the reactor than is the case for a reactor with softer-neutron spectrum. The use of the proton accelerator becomes important for safe operation of the reactor.

IV. Sub-criticality

Figure 4 shows the relative power change due to the step wise reactivity insertion in the critical reactor calculated by point reactor kinetic model. The figure indicates that even with only a small reactivity insertion of 0.6-0.8/3, the power increases as much as 10 times and 10^3 times the normal power within 5 sec after insertion: this calculation does not include the negative doppler coefficient of the fuel element. The reactivity of the fast reactor, especially one with MA fuel, has to be controlled very carefully in the critical operation.

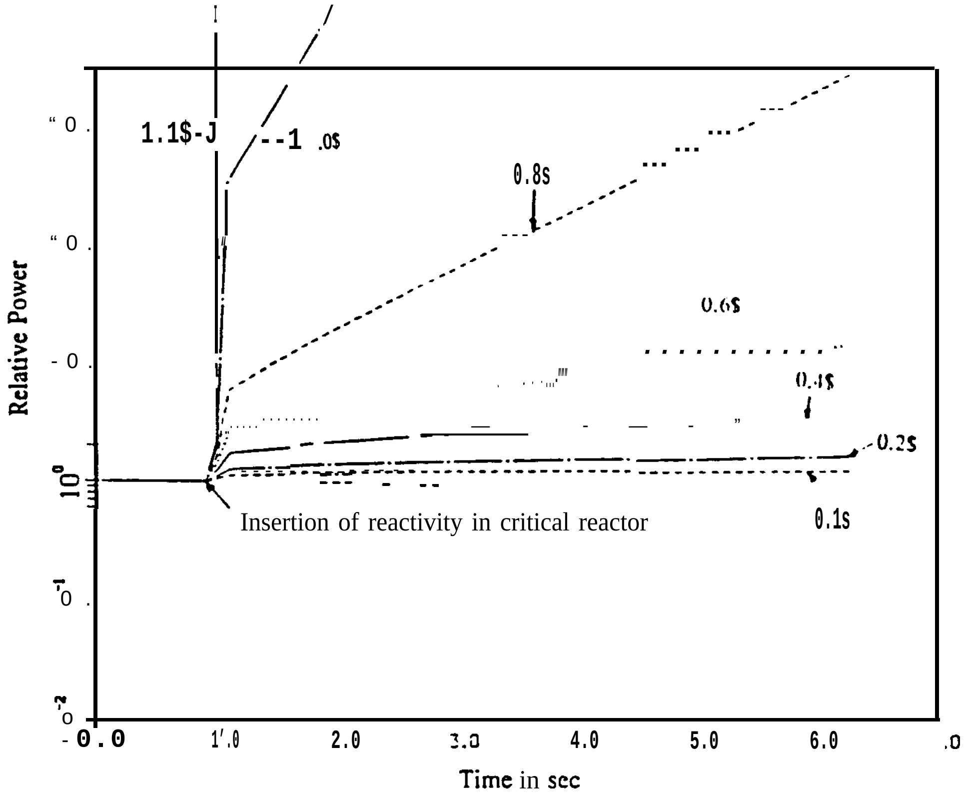

Figure 4. Relative power change in a critical reactor,

When the reactor is operated in the subcritical condition, the insertion of small reactivity does not cause a power excursion.

Figure 5 shows the power change of subcritical reactors operated with spallation neutrons which the initial subc-riticality are -3, -6,-12, and -24$, the reactivity of 1.1$ are step wisely inserted at 1 see, and the proton beam is shut down at 2 sec.

Power increase is at most less than 44 % in the case of initial sub-criticality of -3$. Thus, a subcritical reactor can be operated in more relaxed condition than the critical reactor. The safety of the reactor associated with criticality can be greatly improved, and also the subcritical reactor is more economical because it does not require the safty equipments to reduce this risk. For comparison, figure shows the level of decay heat.

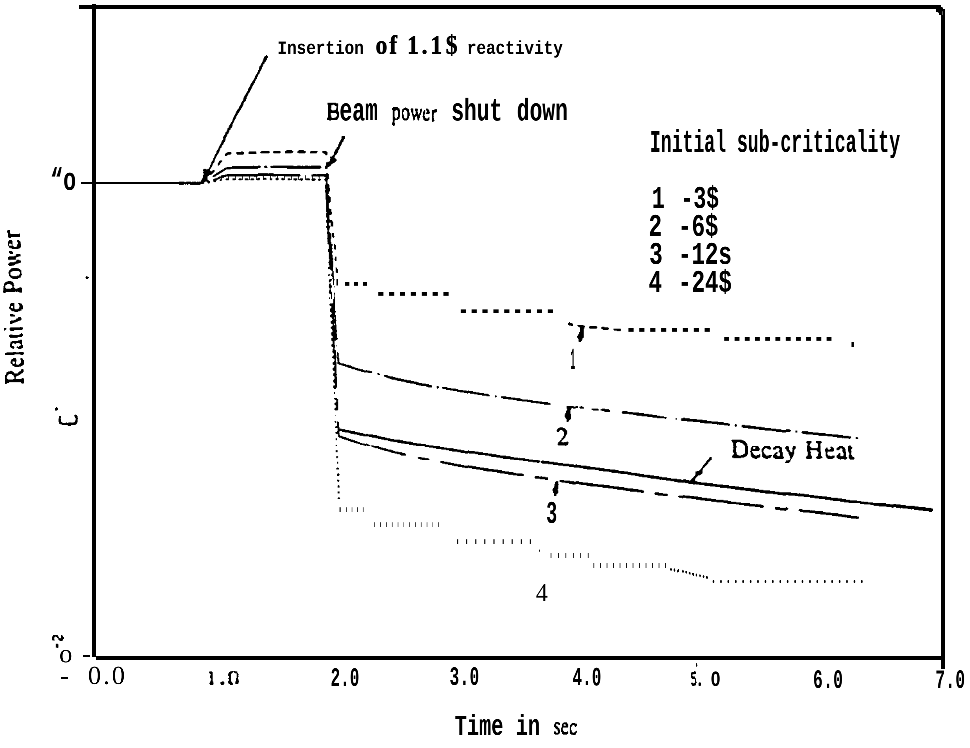

Figure 5. Relative power change in subcritical reactor.

V. Core geometry (flatness)

To reduces the positive reactivity caused by decreasing of Na density, the fast reactor has flattened core with D/H = (Diameter of core / Height of core) = 2, is used for a regular reactor. For the MA transmutor using a metal-fueled reactor(1 1), a ratio of D/H of 5-6 is adopted to maintain its inherently safe characteristics. This leaky reactor requires a large inventory of fissile material to compensate for large neutron leakage. And this makes the linear power rate very high, so that the removing heat from the flattened core becomes more difficult; also, the breeding gain becomes small.

Because the small insertion of reactivity does not have a great effect in the subcritical reactor, the positive Na-coolant coefficient is not as important as in the critically operated reactor. Thus, we can adopt the solid core geometry of D/H $\approx$ 1, which reduces neutron leakage. Therefore the inventory of the fissile material can be reduced, the internal breeding gain becomes large and the fuel can be burned for a long time without reprocessing provided that the fuel withstand radiation damage, or that the accumulation of fission products does not affect the metallurgic properties of the fuel.

VI. Beam expansion and radiation damage

A small beam current has another advantage, that of shortening the beam expansion section. To reduce radiation damage to the target material, a proton beam with low luminosity has to be expanded using combination of dipole and quadruple magnets for achieving a flat distribution at the top instead of Gaussian distribution. The length of the beam expansion section for a high current beam becomes long when a conventional magnet is used. This causes trouble with shielding in the beam expansion section; when beam is inserted vertically, as in the case shown in figures 1 and 2, the reactor must be situated deep underground, increasing the cost of construction.

An other disadvantage of running a high subcritical assembly is the sharp gradient of flux distribution, which is of more concern from the safety point view than the criticality problems. To avoid this sharp distribution of power, the proton beam must be spread, requiring a long beam-expansion section.

Another problem in using the high current of beam is the radiation damage to the target and surrounding materials. The spallation neutron energy is high, and the high-energy charged particle created by spallation reaction damages the material. When we use the high current beam, frequent replacement of the component is required and plant efficiency is reduced substantially.

Radiation damage to a solid target, like tungsten material, is higher than to the window material because of the high intensity of high-energy neutrons and charged particle.

VII. Use of MA to increase the fuel burn up.

The metal-fuel fast reactor has small reactivity swing so that it does not require MA for long bum-up time. Due to the presence of Na as coolant and covering material of the core, refueling the fuel takes more time and is a more complicated procedure than in the LWR. Therefore, it is desirable to make infrequent fuel exchanges. Because the addition of MA can change the reactivity swing to positive, we can lengthen fuel bum-up provided that the metallurgic properties of the fuel are not greatly changed by the accumulation of fission products.

By adding MA to give a concentration of more than 10% of the Pu fuel, we can also make reactivity swing of the oxide fuel positive and bum the oxide fuel for much longer. Oxide fuel can accommodate more fission products than the metal fuel due to its material properties. However it requires a higher concentration of MA than the metal fuel; consequently a higher MA inventory is needed.

VIII. Accelerator

Because the target assembly of the fast breeder and incinerator is slightly subcritical, k= O.99, a proton beam power only of about 15-20 MW is required to run the fast reactor at about 3.3 GWT. Small beam powered protons can be accelerated using the so-called “multistage-parallel” cyclotron arrangement(9-2) instead of using the linear accelerator.

The linear accelerator has a higher efficiency of conversion from electric power to beam power than the cyclotron accelerator. A high current beam of 250-300 mA, accelerated by a linac, can be split by a laser, gas jet (foil)(13), or time wise as pulse, and several fast breeders and incinerator reactors can be operated with only the small additional cost of an accelerator (see Figure 6).

IX. Conclusion

We propose to use a proton accelerator to run a slightly subcritical fast breeder and incinerator of minor actinides. By injecting medium-energy protons into the subcritical assembly and by providing external neutrons produced by spallation and by high-energy fission reactions, the reactor can be operated in a safer condition than a reactor operated at criticality. The safety problems associated with super-criticality, which might be created by factors such as a positive Na- coolant coefficient and a sudden recovery of fuel bowing, can be alleviated. Further, the extra sub-criticality can allow a more flexible choice of structural material and a more flexible operation.

The metal-fueled fast breeder has a small decrement in reactivity of power and burn-up; by mixing the MA of ^{237}Np with the oxide-fueled reactor, the decrement of reactivity can be reduced substantially. Thus, these reactors can be operated at a sub-criticality of k=O.99 with a small beam proton power of 15-20 mA and 1 GeV energy (15-20 MW). This slightly subcritical condition produces a power distribution that is more or less flat, which is important from the point of view of reactor safety.

The linear accelerator has a higher efficiency of conversion from electric power to beam power than the cyclotron accelerator. A high current beam of 250-300 mA, accelerated by linac, can be split by a laser, gas jet (foil),or time wise as pulse, and several fast breeders and incinerator reactors can be operated with only the small additional cost of an accelerator.

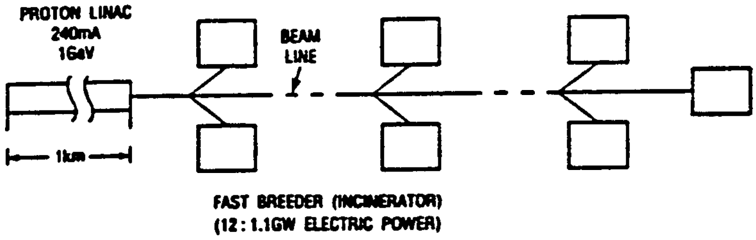

Fig.6 Fast breeder (or incinerator) park.

^{237}Np is very valuable fertile material for improving the neutronic characteristics of the oxide-fueled reactor, such as power and bum-up reactivity decrements. MA material should be used efficiently in this way, rather than simply incinerating it.

X. APPENDIX

In the main text, we discussed the use of the minor actinides to improve the characteristics of a nuclear reactor, especially the fast neutron reactor. However, the problem remaining is that of radiation hazard due to the fission products. To solve this problem, in this appendix, we will discuss various alternative ways.

There have been several studies on the transmutation of high-level radioactive wastes produced from nuclear reactors into short-lived nuclei using the neutron created by spallation, fission or fusion reactions. Although transmutation of minor actinides by fission processes produces energy, so that an energy balance can be easily achieved, to transmute the fission products themselves requires a substantial amount of energy. Thus, to transmute the Cs-137 fission product by thermal neutrons with an incineration rate of 2-3 half-year life-time, a very high thermal neutron flux of the order of 10^{17}/cm^2/sec is needed; this high thermal-neutron flux cannot be obtained by present nuclear reactors.

Recently, Russian scientists(14,15) proposed to isolate HLW in outer space or in the deep earth crust by self-heating. However, the isolation of HLW in outer space using a rocket might disturb astronomical observations because of its local radiation source. Further, injection of the HLW into the sun requires a rocket with more than 35 km/see velocity to carry the FP, and the mass ratio of the total mass to payload mass becomes very high when a 1,100 chemical rocket with hydrogen-oxygen fuel is used. Thus, these alternatives are not economical unless a nuclear propulsion rocket can be developed.

Isolation of HLW into the deep earth crust requires a container made from material which has a higher melting temperature than the earth's crust to preventing the radioactive material dispersing during its passage through the crust.

We propose here a new approach of disposing of the medium- and long-lived fission products of Sr-90, Cs-137, Tc-99 and 1-129 into the Antarctic ice-field, outer space, and on to the back face of the moon.

At first, we must separate type I FP, which is composed of Sr-90 and Cs-137, from the type 11 FP which is composed of Tc-99 and 1-129. Type I FP has 30 years half-life and produces a lot of heat; type II FP has long half-life of more than 10^5 years and the heat production is not high in type I. Also Tc is soluble to water.

We can dispose of type I FP by enclosing it in a rather thin capsule and putting it in an earth pit at the bottom of the Antarctic ice field by melting through the ice.
The heat produced by the FP initially will melt the ice, but it soon will be frozen over again. The radiation will be shielded by thick ice, and will be confined in a small region. A speed at which the FP container melts through the ice will depend on the size and weight of the quantity of FP. Because the half-life of type I FP is 30 years, within 300 years after disposal, the level of radiation will be reduced by a factor 0.5 10-10-3. This approach does not incur the cost of removing the earth as is the case for a geological stable deposition so that it will be very economical.

Concerning damage to the container due by crushing the glacier pressure, the recent discovery of the ancient (5000 years ago) ice-man who was embedded in a pit hole under the glacier suggests that the FP I container in the pit hole will maintain its integrity. Even if the container is ruptured and radiation material leaks, the frigid temperature of the environment will freeze the FP. Since type I FP is not soluble in water, any material that has leaked out will not migrate, and the environmental problem will be minimum. The antarctic ice field is far from regions of human habitation and activity, and furthermore, the area is under international jurisdiction.

Concerning the cosmic neutrino experiment that is being carried out the antarctic ice field, the place selected for disposal of FP-I will be far from the experimental area, so that it will not disturb the experiment. The anti-neutrinos released in the beta-decay process of FP-I will not disturb the experiment.

If the second type of fission products, (type II FP) such as Tc-99 and 1-129, can be dispersed uniformly into space in the solar system, the radiation level will be so small that the astronomical observations will not be affected, as would be the case of isolation using a rocket. A energy corresponding to about a 35 km/see velocity of FP II nucleus is in the order of 1 to 2 kilo electron-volt, so that the FP can be accelerated by small-energy accelerator instead of using the medium-energy accelerator considered in transmutation. Nuclei ejected with this velocity will remain inside solar space the radius of which is about the distance between the sun and earth. However, the energetic nuclei cannot be ejected directly from the earth's surface into outer space because the kinetic energy of nuclei would be soon lost by ionizing the air surrounding the earth; they should be ejected from a space ship or from the moon to avoid the ionization loss. To mitigate the effect of the magnetic field on the charged particles, the neutral-beam technology developed for SDI might be used. The efficiency of an accelerator providing the ejection energy to the particles might be so high that the energy consumed for dispersing the FP-II in outer space will be mostly that needed to launch the FP-II using a rocket or putting it on the Moon surface. The energy consumed in launching the FP-II nuclei will be small compared to the nuclear transmutation energy, in the order of a few tens MeV, using the accelerator.

To prevent the disturbance of astronomical observations, a homogeneous dispersion of FP-II is need as I proposed above, but if FP-II is put on to the back surface of the moon which never faces the earth, astronomical observations from the earth will not be disturbed, and it will not be necessary to eject the material into outer space. On the moon, there is no atmosphere and the moon is geologically stable, so that the radioactive nuclei cannot be transported to other locations by natural forces. The moon will be controlled by an international organization, so that every nation can have access this deposit site. To prevent any spread of FP due to rare events, such as a meteorite falling on the deposit site (although the radius of contamination area will be limited because there is no atmosphere), the some underground deposition might be required. To reduce any impact due to a meteorite falling, the site may be covered by moon soil. This operation can be complementary to the operation to take out the He-3 material which can be used in a future fusion program.

At present, we have discussed the elimination of weapon-grade plutonium produced in Russia. Rather than incinerate this plutonium by fission, which creates FP, it would be better to store the plutonium on the moon, so that it can be used later to produce more fissile material with fast breeder when a large energy generation is demanded.

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