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Plutonium Disposition Now! (U)

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PLUTONIUM DISPOSITION NOW!

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ABSTRACT

A means for use of existing processing facilities and reactors for plutonium disposition is described which requires a minimum capital investment and allows rapid implementation. The scenario includes interim storage and processing under IAEA control, and fabrication into MOX fuel in existing or planned facilities in Europe for use in operating reactors in the two home countries.

Conceptual studies indicate that existing Westinghouse four-loop designs can safely dispose of 0.94 MT of plutonium per calendar year. Thus, it would be possible to consume the expected US excess stockpile of about 50 MT in two to three units of this type, and it is highly likely that a comparable amount of the FSU excess plutonium could be deposed of in a few VVER-1000's. The only major capital project for this mode of plutonium disposition would be the weapons-grade plutonium processing which could be done in a dedicated international facility or using existing facilities in the US and FSU under IAEA control. This option offers the potential for quick implementation at a very low cost to the governments of the two countries.

INTRODUCTION

During the next several years, approximately 50 metric tons (MT) of weapons-grade plutonium will be removed from the US nuclear stockpile and also about the same amount from the former Soviet Union (FSU) and declared surplus to military needs. The existence of this surplus material has been termed as a "clear and present danger" by the National Academy of Sciences' (NAS) Committee on International Security and Arms Control (CISAC) and the Committee has recommended prompt actions in the disposition of this material[1]. The ultimate disposition of the plutonium in these weapons must satisfy at least three different goals:

1. Preclude re-use by the super powers.
2. Prevent environmental damage from plutonium contamination.
3. Prevent proliferation from diversion to terrorist groups or non-weapons states.

To meet these goals, the CISAC endorsed the so-called "Spent Fuel Standard." The objective of the "Spent Fuel Standard" is to provide physical protection against the diversion of weapons material by terrorists and to make the material as inaccessible for weapons use as the much larger and growing quantity of plutonium that exists in spent fuel from commercial reactors. In order to achieve this standard, the Committee endorsed two options for further evaluations:

- Use in a once-through fuel cycle in existing or modified nuclear reactors.
- Vitrify with high level waste (HLW).

The second option has been evaluated conceptually[2], and is now being investigated in further detail by the DOE Surplus Fissile Material Control and Disposition Project. Initially it was expected that this option could be implemented with only slight modification to the planned high level waste vitrification program and facilities[3]. Reference 2 indicates that these modifications are costly (>$1 billion) and would either cause substantial delays in the planned HLW program or be delayed until after 2013 for implementation.

Studies of the options for plutonium disposition[1,3,4,5,6] have concluded that light water reactors (LWRs) provide a very effective means for rapid deployment of existing technology to reduce the proliferation threat of these materials. This paper describes results of studies performed by the Westinghouse Electric Company (WEC) and the Westinghouse Savannah River Company (WSRC) of Westinghouse reactor designs for use in plutonium disposition. A scenario is then presented for use of existing reactors for plutonium disposition which requires a minimum capital investment and allows rapid implementation since for the most part existing facilities are utilized.

WEAPONS-GRADE PLUTONIUM DISPOSITION IN PRESSURIZED WATER REACTORS

Plutonium disposition can be achieved by first fabricating the weapons-grade plutonium into a mixed-oxide (MOX) fuel form and then irradiating in either advanced or existing PWRs to a depleted level similar to commercial spent fuel. Neutronics studies pertaining to safety related core design using 100% weapons-grade MOX fuel demonstrate the feasibility of a small plutonium disposition reactor of 600 MWe capacity called the PDR600, a large plutonium disposition reactor of 1400 MWe capacity called the PDR1400 and a typical four-loop modified Westinghouse reactor.

The fundamental advantage of the PWR designs for plutonium disposition is that the technology is mature and has been demonstrated to be highly reliable as proven by performance trends over the last thirty years[6]. Also, considerable effort has been invested in enhanced designs that include advanced safety features. MOX fuel form that is used or planned for the use for plutonium

recycling in power reactors in several European countries and Japan is well-developed. MOX fuel incorporated in power reactor cores has behaved outstandingly well and assemblies irradiated to high burnup have demonstrated that MOX fuel can satisfy the general trend towards a progressive increase in discharge burnup[7].

Weapons-grade plutonium is characterized by its isotopic composition as indicated in Table I. For comparison, a typical isotopic composition of spent commercial reactor fuel is also shown in Table I. This provides a target then in applying the 'Spent Fuel Standard' to denature weapons-grade plutonium through usage as MOX fuel. It may be noted, however, that reactor-grade plutonium could also be used to make crude nuclear weapons[1]. The higher levels of plutonium isotopes, Pu-240 and Pu-242, only limit the efficiency and capacity of the material for weapons use. The criteria for loading and burnup of weapons-grade MOX fuel is then controlled by the desire to use as much material as possible without compromising the overall operational and safety characteristics of the design. Certainly the self-protecting objective can be met very quickly through short irradiations but the potential for production of useful power is compromised. Also, the potential exists for improved fuel designs which replace the depleted uranium with other materials (e.g. ZrO_2-ac, SRO-gm, be,, W)[8,9] to eliminate the production of additional plutonium during irradiation. Fuels of this type offer the potential for annihilation of the major portion of the plutonium and should be considered for ultimate disposal of this material, but will require further development and demonstration. Current results are based on applying the well-developed MOX fuel technology in such a way as to maximize plutonium disposition in a PWR.

Table II describes important core characteristics of the three reactor types[10,11,12]. The PDR600 design is based on the AP600 design with the differences being the fuel and cladding type and the control rod configuration. The design is based on the EPRI ALWR utility Requirements Document and is an elegant combination of innovative safety systems that rely on dependable natural forces and proven technologies. The PDR600 core consists of 145 fuel assemblies. Each assembly has a 17x17 fuel rod array with 24 guide tubes and one instrument tube. The normal Zircaloy-4 cladding is replaced by 304 stainless steel to maximize plutonium enrichment. Zircaloy-4 cladding could be used, but would require additional burnable absorbers (BAs). The equilibrium core loading uses 6.6 w/o in total plutonium content with a loading of 896 pyrex BAs to reduce peaking and soluble boron. To further reduce the soluble boron concentration, zirconium diboride integral fuel burnable absorbers (IFBA) with a loading of 3.0 mg/inch is used in all fuel rods. One-third of the core is discharged every cycle at 13,300 MWD/MTM consistent with the discharge burnup being 40,000 MWD/MTM. There are 69 rod control cluster assemblies (RCCA) made of silver-indium-cadmium in the PDR600.

The PDR 1400 has a large core consisting of 257 fuel assemblies. The feed enrichment for the equilibrium cycle is kept at 6.6 w/o in total plutonium. To compensate for the highly reactive fuel, zirconium diboride coating in the form of IFBA with a loading of 3.0 mg/inch is used in all fuel rods in the reference design as was the case for the PDR600. In addition, a heavy loading of pyrex BAs (1312 total) is used to reduce power peaking and soluble boron concentration to an acceptable limit. The number of RCCA is increased from 77 in the reference advanced PWR design to 101 in the PDR1400.

The four-loop Westinghouse core contains 193 fuel assemblies. An equilibrium cycle core model has been developed using 64 feeds. A small number of pyrex BAs (total number 288) are used to control power peaking, but no IFBAs are needed. The objective is to use maximum amount of weapons-grade MOX assemblies such that the shutdown margin is just met with the existing number of control rods (Total number 53). This homogeneous MOX core design uses a total plutonium fraction of 3.19 w/o in MOX assemblies. Table II gives the core design data for a typical four-loop Westinghouse plant using 100% weapons-grade MOX core.

The core physics results include information on soluble boron concentration, peaking factors, Doppler and moderator reactivity coefficients, boron, xenon and control rod worths, shutdown margin and delayed neutron parameters. The results are summarized in Table III. These results indicate that the core design for weapons-grade plutonium disposition can be achieved with minimum changes in the present safety and licensing criteria of advanced or existing PWRs. The reader is referred to Reference 9 for more detailed discussion of the analyses.

WEAPONS PLUTONIUM DISPOSITION OPTIONS

The total investment required to dispose of 100 MT of weapons-grade plutonium and the rate of that disposition depends on the length of the program, the reactor lifetime and the size of the reactor chosen. Table IV shows a compilation of these factors and their effects. The program lengths designated in the table would be the most likely depending, respectively, on whether national policy places the highest priority on rapid disposition (25 years), current reactor lifetimes are utilized (40 year life) or evolutionary reactor lifetimes are utilized (60 year life). Each of these program schedule lengths include nine years to design and construct the initial reactor. An implication of the shortest program length is that although this is the most expeditious campaign, many years of useful reactor life remain and these plants would either need to be converted to a new mission or liquidated.

The PDR600, being the smaller reactor, would obviously require more reactors and have the lower disposition rate. Using a 40 year reactor lifetime as the accepted basis, three PDR600s would be required and they would each dispose of plutonium at the rate of 0.85 MT per calendar year. For the same lifetime, two PDR1400s would be required and they would each dispose of plutonium at the rate of 1.79 MT per calendar year. If the full, projected design lifetime of 60 years is used as the basis, then just two PDR600s or a single PDR1400 are required. Disposition rates would be increased only slightly with the longer lifetimes. All data shown is based on feeding 6.6 w/o plutonium to each cycle.

Existing four-loop Westinghouse designs will consume 0.94 MT of plutonium using the 100% weapons-grade MOX core per calendar year. Considering that many of the Westinghouse four-loop plants have considerable time left on their operating licenses (30 to 40 years), it would be possible to consume the expected US excess stockpile of about 50 MT in two units or the combined US and FSU excess stockpiles of about 100 MT in three or four commercial units.

RAPID DISPOSITION SCENARIO

Following the NAS recommendation for decisive action to deal with the "clear and present danger" of weapons plutonium, use of existing facilities must be maximized. This is possible through international control under IAEA (International Atomic Energy Agency). Under this disposition scenario, excess weapons plutonium from both the US and FSU would be placed under IAEA control in interim storage either in the two home countries or in a neutral country as soon as possible. This is consistent with the proposed immediate action by NAS. Then plans should be made for the conversion of the weapons pits to plutonium oxide powder either in the home countries in existing facilities under IAEA control or in a new or existing facility in a neutral country.

After the material has been converted to powder, it could be shipped to the BNFL fuel fabrication plant that is being built at Sellafield in the United Kingdom and converted to mixed oxide fuel. This facility is currently planned to begin operation in 1997. BNFL has indicated strong interests in supporting an effort of this type. Alternatively, the MELOX plant under construction by COGEMA at Marcoule, France is scheduled for operation in 1995. No contacts have been made with COGEMA but it is likely that there would be substantial interest in this effort. The reader should consult Reference 13 for a more extensive survey of world-wide MOX experience and existing or planned facilities for MOX fuel fabrication.

The fuel would then be used in existing LWR's in the two home countries in order to satisfy energy needs and to defer the requirements for uranium fuel until it is needed at some future date. The fuel would be provided free of charge to selected utilities in the home countries and would be used under IAEA

control. After irradiation, the spent plutonium fuel would be dealt with in the same way as uranium based fuel and become part of the consideration for disposal of spent fuel or partially separated for annihilation if the accelerator concept is developed for actinide disposal.

As shown in the previous section, Westinghouse four-loop existing reactors have significant capacity for plutonium consumption. Although detailed studies have not been performed, it is likely that VVER-1000 reactors in the FSU would have similar capacity. Considering that many of the Westinghouse four-loop plants in the US have considerable time left on their operating licenses, it would be possible to consume the expected US excess stockpile of about 50 MT in two to three units, and it is highly likely that a comparable amount of the FSU excess plutonium could be deposed of in a few VVER-1000's.

The only major capital project for this mode of plutonium disposition would be the weapons-grade plutonium processing which could be done in a dedicated international facility or using existing facilities in the US and FSU under IAEA control. For instance, the New Special Recovery facility at the Savannah River Site was built for plutonium scrap recovery and was never used. An estimate of approximately $200 million has been made for upgrading this facility for weapons grade processing[6]. This option offers the potential for quick implementation at a very low cost to the US and FSU governments and provides a means for future destruction of these materials through development of an advanced fuel form[8,9] or in conjunction with other longer term options such as the accelerator for actinide disposal.

CONCLUSIONS

Following the recommendation of the NAS Committee on International Security and Arms Control, it is possible to use existing facilities under IAEA control to quickly begin the disposal of weapons-grade plutonium in both the US and the FSU. This scenario is also consistent with the strong desire of the FSU to extract value from the material and will allow further study and consideration of annihilation options. Support and cooperation by the world community for this option is recommended in order to solidify the significant strides that have been made toward world peace by the ending of the Cold War in the early 1990's.

Table I
Plutonium Isotopics

Isotope	Fraction of Total (w/o)	
	Weapons-Grade	Reactor-Grade
Pu-238	0.05	0.1
Pu-239	93.6	59.0
Pu-240	5.9	23.0
Pu-241	0.4	13.0
Pu-242	0.05	4.9

Table II
Core Description
(all dimensions cold)

Design Parameters	PDR600	PDR1400	Existing Four Loop Westinghouse Reactor
Core Power, MWth	1933	4100	3565
Fuel Assemblies, Total	145	257	193
Feed Assemblies	48	85	64
Fuel Assembly Configuration	17x17	17x17	17x17
Fuel Rods/Assembly	264	264	264
Enrichment, w/o Pu Total	5.5,6.6	6.6	3.19
Fuel Loading, MTM	66.8	118.3	89.1
Fuel Rod Diameter, cm (in)	0.950 (0.374)	0.950 (0.374)	0.950 (0.374)
Fuel Rod Cladding Material	SS304	SS304	Zircaloy-4
Fuel Rod Active Height, m (ft)	3.66 (12.0)	3.66 (12.0)	3.66 (12.0)
Burnable Absorber Type	Pyrex, IFBA	Pyrex, IFBA	Pyrex
Control Rod Material	Ag - In - Cd	Ag - In - Cd	Ag - In - Cd
Total Control Rod Clusters	69	101	53
Avg Linear Power Density, kw/m	13.45	16.08	18.64
Cycle Length, MWD/MTM	13,300	13,300	11,000
Discharge Burnup, MWD/MTM	40,000	40,000	33,000

Table III*

Safety Characteristics of Westinghouse Reactor Designs

	PDR600	PDR1400	Existing Four Loop Westinghouse Design
HFP, BOL, Eq Xe, C_B (ppm)	947	1045	1651
Peak $F_{\Delta H}^N$, BOL/EOL	1.30/1.31	1.34/1.36	1.41/1.27
Peak Baseload F_Q^N, BOL/EOL	1.64/1.57	1.70/1.66	1.68/1.47
Axial Offset Range, BOL/EOL (%)	-9.9/-5.6	-9.4/-5.1	-1.3/-5.6
$\varphi 1/\varphi 2$, BOL/EOL	25.2/21.7	26.1/22.6	13.2/10.3
HFP, BOL, Eq Xe MTC (pcm/°C)	-34.7	-38.9	-38.7
HZP, BOL, No Xe MTC (pcm/°C)	-15.1	-13.0	-9.7
HFP, EOL, Eq Xe MTC (pcm/°C)	-44.3	-50.0	-76.0
HFP, BOL, Boron Coef. (pcm/ppm)	-2.7	-2.6	-4.7
SDM Requirement (%$\Delta\rho$)	1.6	1.6	1.3
Calculated SDM (%$\Delta\rho$)	5.3	3.2	1.33

* Definition of Symbols

BOL - Beginning of Life
EOL - End of Life
C_B - Critical Boron Level
Eq Xe - Equilibrium Xenon
No Xe - No Xenon
$F_{\Delta H}^N$ - Nuclear Enthalpy Rise Hot Channel Factor
F_Q^N - Nuclean Heat Flux Hot Channel Factor
HFP - Hot Full Power
HZP - Hot Zero Power
MTC - Moderator Temperature Coefficient
SDM - Shutdown Margin
$\varphi 1/\varphi 2$ – Fast to Thermal Flux Ratio

Table IV

Plutonium Disposition Rate

(Disposition of 100 Metric Tonnes)

		PDR600			PDR1400		
Program Length (yr)	Reactor Life (yr)	Number of Reactors	Reactor years	MT Dispositioned per Reactor-Yr	Number of Reactors	Reactor Years	MT Dispositioned per Reactor-Yr
25	16	9	126	0.79	4	58	1.72
49	40	3	117	0.85	2	56	1.79
69	60	2	116	0.86	1	55	1.81

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