

NUREG-0414

**SAFEGUARDING A DOMESTIC
MIXED OXIDE INDUSTRY AGAINST A
HYPOTHETICAL SUBNATIONAL THREAT**

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The additional annualized costs to do this are estimated at approximately \$1.3 billion for the MOX industry in the year 2000. This would approximately double the projected price of MOX fuel.*

6.4.3 Blending Methods

A simple way to blend UO_2 and PuO_2 is to mix the ceramic powders of each oxide mechanically. This mixed-oxide powder would be suitable for shipping without further mechanical or chemical alteration. The facilities for packaging the mixed-oxide blend and for loading and shipping would be little changed from those that would have been provided for unblended plutonium, except that larger container capacities would be required because of the UO_2 diluent. Mechanical blending would create no liquid or gaseous wastes. It would, however, involve an additional processing step in which plutonium particles might become airborne outside the processing equipment, and somewhat larger ventilation and high-efficiency particulate air (HEPA) filter systems might be required than without the blending steps.

An alternative to mechanical blending would be the coprecipitation of plutonium and uranium from aqueous solution. Formed in this way, the mixed oxide would be a solid solution of uranium and plutonium and each particle, no matter how small, would contain atoms of both elements in the desired concentration ratio. For a plant designed to produce pure PuO_2 , coprecipitation with uranium would require some extra process steps and create some additional contaminated waste streams. For a new plant designed from the start to produce diluted plutonium, the process could be simplified and the added cost lowered.

In making the master blend, it is possible that part of the uranium recovered and purified at the reprocessing plant could be directly recombined with the recovered plutonium. However, the recovered uranium would vary in isotopic enrichment from about 0.8 percent ^{235}U content to perhaps one or two percent (for fuel discharged before reaching full burnup). Because of these enrichment variations, economic considerations would favor not blending with recovered uranium, but returning it instead to the enrichment plant for upgrading to the enrichments desired for future use. Consequently, it is assumed that the fuel reprocessor would return the recovered uranium to the enrichment plant and would use natural uranium for blending with the plutonium.

6.4.4 Safeguards Benefits of Blending

Since PuO_2 separation could be within the capabilities of some malefactors, MOX blends cannot be regarded as self-protecting at any concentration. Accordingly, it is a basic premise of this assessment that lowering the concentration of plutonium through blending should not be used as a basis for reducing the level of safeguards protection. On the other hand, blending could provide additional protection against the threat of clandestine nuclear explosive manufacture in two important ways: first by increasing the difficulty of accumulating the mass of material needed to manufacture an explosive; and second, by increasing the amount of time a malefactor

*In the year 2000, 2,600 MT (metric tons) of MOX are projected to be fabricated into MOX fuel rods at a reference-estimated fabrication cost of \$200/kg fuel. (See Ref. 4, p. XI-26.) In addition, 10,900 MT of low-enriched uranium would be fabricated into fuel rods at a reference-estimated fabrication of \$95/kg fuel. (See Ref. 4, p. XI-15.) With the Puechl concept (Ref. 5), all 13,500 MT of fuel would need to be handled as MOX and would require fabrication at a reference-estimated cost of \$200/kg fuel. This represents a \$1.14 billion per year increment in fuel rod fabrication cost. There would be additional cost increases at reprocessing plants for fuel storage and mixing, and further cost increases for transportation, making an estimated total increment of approximately \$1.3 billion per year.

would need to manufacture an explosive after acquiring the requisite material. These two safeguards advantages of blending are discussed in the following subsections.

6.4.4.1 Mass Requirements

The mass required to make an explosive device from plutonium blends depends on whether the blend is used directly or is processed to concentrate the plutonium. It is theoretically impossible to make a nuclear explosive directly from blended plutonium and uranium oxides with a plutonium concentration below about four percent. At higher plutonium concentrations, the MOX blend could in theory be used directly in an explosive device.

The critical mass of unmoderated nuclear materials provides a relative measure of its direct usability for nuclear explosives. The critical mass for MOX blends depends on many variables, such as isotopic composition, impurities, outside reflectors, and, most importantly, density, i.e., whether it is in a powder or a compact solid state. These factors cause the bare sphere critical mass for reactor grade plutonium oxide (PuO_2) to vary from 30 to 70 kg. Bare sphere critical masses for MOX at 30 and 10 percent PuO_2 concentrations vary between 250 to 600 kg and 3,000 to 10,000 kg, respectively. As mentioned above, at four percent PuO_2 concentration and below, no unmoderated critical mass is possible.*

These critical masses suggest that for MOX blends with PuO_2 concentrations lower than the 20 to 30 percent range, impractically large amounts of MOX would be needed for direct manufacture of an illicit nuclear explosive. Although not essential, chemical separation of the PuO_2 would probably be preferred. Although no separation process will be perfectly efficient, it is obvious that separation could lead to substantially lower mass requirements, especially with dilute blends. Table 6.1 compares the weight of material of different blends (with and without separation) which would have to be stolen to have sufficient plutonium to form a bare sphere critical mass.

TABLE 6.1
WEIGHT REQUIRED TO FORM BARE SPHERE CRITICAL MASS

| Percent PuO_2 in Blend | Without Separation (kg) | With Separation ^a (kg) |
|--------------------------|-------------------------|-----------------------------------|
| Pure PuO_2 | 30 - 70 | 30-70 |
| 30% | 250 - 600 | 100 - 230 |
| 10% | 3,000 - 10,000 | 300 - 700 |
| 4% | None possible | 750 - 1,750 |

^aAll weights are 30 to 70 kg after separation into pure PuO_2 . These figures make no provision for losses during separation or the additional weight of containers.

Although separation would greatly reduce the amount of material required in the device itself, it is apparent that at the lower blend ratios, the weight and bulk of the required material before separation would be large and unwieldy.

*Data on critical masses were supplied by Dr. Robert Selden, Group Leader, B Division, Lawrence Livermore Laboratory.

The additional material required at lower blend ratios would present difficulties to outsiders intent on stealing weapon quantities in a single action, as well as to insiders trying to accumulate the needed quantities by repeated diversion of small amounts. The latter would be handicapped by portal monitors (both neutron and gamma types) whose ability to detect a fixed amount of plutonium in a moderate-sized package would be only slightly affected by blending.

The data in Table 6.1 indicate that blends would need to have concentrations as low as about 10 percent to have significant safeguards advantages. A successful explosive could be assembled directly, with an amount of 30 percent material that is not unreasonably large. At 10 percent concentration, the amount required for direct use in a crude explosive appears so large as to be impractical.

6.4.4.2 Separation Considerations

As indicated above, blending would virtually require malefactors to separate PuO_2 from the blended material to manufacture an illicit nuclear explosive. But this step would introduce an additional degree of difficulty and make the entire assembly operation more costly, more hazardous, and what is particularly important, more time-consuming to the malefactor.

In principle, one plutonium-bearing substance can be converted to another. Moreover, the general principles of plutonium chemistry are described in the unclassified literature, and a technically sophisticated person could learn the theory and basic principles involved in a chemical separation. However, there are substantial practical difficulties and dangers involved in working with plutonium because of its chemical, radiological and nuclear criticality properties. Acute plutonium poisoning, fire, explosions, acid burns and detection by the authorities are among the hazards that would be faced, particularly by a group lacking actual experience in plutonium conversion. In the United States, such experience has been virtually confined to Government-contracted or licensed facilities engaged in the production of nuclear weapons and plutonium-bearing nuclear fuels.

In spite of the difficulties involved, it is possible that a group of dedicated malefactors willing to take substantial risks might obtain the necessary equipment and technical knowledge to accomplish the separation (or enrichment) of plutonium blends. The magnitude of such an effort would depend on the uranium concentration, the amount of plutonium to be separated and the efficiency of the process used (see Ref. 4, Chapter IV, for a description of one separation method). To conduct the separation in a reasonable time, appreciable operating space, good chemical processing equipment, large quantities of supplies such as acid, and at least a several-man work force would be required. The effort might be a garage-size operation.

Experts do not agree on the time malefactors would need for the processing and separation steps to purify blended plutonium to the concentration needed for an illicit explosive. If the malefactors are credited with a substantial facility investment, a willingness to accept high-risk accidents, and an expertise from having previously worked with plutonium, it is estimated that at least three days would be required for a blend in the 20 to 30 percent range (Ref. 6). There is, moreover, a substantial probability that more than three days would be required, and that the effort could fail completely.

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The additional time required to separate a blended mixture could be critically important to the recovery operation, should a theft occur. The time could be used to pursue clues on the identity of the individuals involved and on the location of their separation and assembly facility. Many of these clues, e.g., special equipment purchases and radioactive effluents, could be the result of the separation and processing operation itself.

The added problems introduced by a blended mixture--the extra hazards, the skills needed, the greater delay before a weapon could be produced, and the greater risks of process failure, detection, and capture--undoubtedly create a substantial deterrent to any illicit attempt to make a nuclear explosive from blended material.

6.4.5 Summary

The primary purpose of blending plutonium and uranium compounds early in the fuel cycle would be to improve safeguards. It is more difficult to construct nuclear devices with blended material and a larger quantity of material would have to be acquired. The need to extract plutonium oxide from the blend would present an added degree of difficulty, making the endeavor more costly, more time-consuming and more hazardous to the malefactor.

Notwithstanding the fact that additional difficulties would be introduced in either using blended material directly to make an explosive device or in converting blended material into more suitable bomb-quality material, it is still theoretically possible to complete these steps in a relatively short time after acquiring the blended material. If blend separation is required, it is estimated that at least three additional days to locate the stolen materials are available with high assurance that a nuclear explosive has not yet been assembled.

The effectiveness of portal monitors or other radioactive measurement techniques for detecting diversion of plutonium from fixed sites would not be affected appreciably by the use of blends. Moreover, since more blended material would have to be acquired, the frequency of attempted diversion and/or the increased amount of material involved would increase the probability of detection over that for pure PuO_2 .

Although blending would offer safeguards advantages, it would also involve an increase in costs because of the need for additional plant personnel and processing capability. It is estimated, for example, that a 10 percent blend, which is about the lowest level acceptable to the LWR industry,* would increase total MOX industry annualized costs by \$50 million in the year 2000.

*Some fuel elements in some LWR reactors have used concentrations as high as eight to ten percent. It is feasible for the fuel fabricator to further dilute a blend, but it does not appear feasible for the fabricator to concentrate one that is too dilute. Accordingly, a 10 percent blend was considered as the lowest concentration that could meet the requirements of LWR customers.

The first alternative, use of Federal guard forces, was analyzed in detail in the Security Agency Study (Ref. 1) undertaken at the direction of Congress and published by NRC in August 1976. The major conclusion of this study was that guard force effectiveness is essentially independent of whether the force is Federally or privately employed and depends rather on personal qualifications, particularly motivation and training. Appropriate Federal regulations, guidelines, and implementation procedures influencing these factors are equally applicable to Federal and private guard forces. The study pointed out that Federal guard forces might have possible administrative conflicts with the civilian nuclear industry and concluded that there was no compelling reason to enact new legislation to establish such a force.

From the review of the second alternative, use of automatic weapons by guard forces, it was concluded that there is no firm basis for expecting that a significant increase in guard force effectiveness would result from use of such weapons. A preliminary review of various factors (element of surprise, length of battle, number of defenders and attackers, fixed site protection, etc.) indicates that, whereas automatic weapons might benefit the attackers, such weapons might not provide significant benefit to the guard force. Additional study is desirable before definitive conclusions can be reached on the use of automatic weapons. Pending the outcome of such study, recommendations for legislative changes in State gun laws to permit use of automatic weapons by private guards in the MOX industry do not appear to be warranted.

The third alternative considered was to blend plutonium oxide with uranium oxide early in the fuel cycle so that only dilute mixtures of plutonium would be shipped. Blended plutonium compounds (around 10 percent PuO_2 content) would be much more difficult to fabricate directly into an explosive device than would pure PuO_2 , and massive amounts of material would be required.* For a 10 percent blend, a malefactor would probably need to make a chemical separation or concentration of PuO_2 to construct a successful nuclear explosive. This would give the recovery operations additional days, and perhaps weeks, in which to locate stolen blended material before a nuclear device could be assembled. For pure PuO_2 , the comparable high assurance time is only a few hours. It was further concluded that, for blends in the 10 to 20 percent range, the additional amount of raw material (assuming subsequent separation) which would have to be stolen to make an explosive would probably not significantly affect the success or failure of an attack. The additional amount of material required could, however, aid in detecting internal thefts and diversions. Incremental annual costs of blends to the MOX industry in the year 2000 were estimated to be \$30 million for 30 percent and \$50 million for 10 percent blend, in 1975 dollars.

The most significant advantage of the fourth alternative, collocation, would be virtual elimination of pure PuO_2 from the offsite transportation links. Additional advantages include savings in transportation safeguards costs and possible savings in fixed site safeguards costs. If the collocated facility consisted of a single reprocessing plant and a single fabrication plant, possible shutdowns in one plant (due, for example, to process breakdowns or plant maintenance and cleanup) would require plans for intersite transportation of PuO_2 , an amount estimated at 10 percent of the PuO_2 shipments required for dispersed facilities.

*See Table 6.1.