American Nuclear Society

Disposition of Surplus Weapons Plutonium Using Mixed Oxide Fuel

Background Information, Position Statement 47

INTRODUCTION

In 1995 the American Nuclear Society (ANS) issued its Position Statement 42, "Protection and Management of Plutonium." The 1995 position statement addressed a broad range of issues associated with worldwide stockpiles of plutonium, both civil and military. The 1995 position statement included an endorsement of the use of reactor irradiation for disposition of surplus U.S. and Russian weapons plutonium. Position Statement 42 remains in effect and reflects the position of ANS on overall plutonium management issues.

This Position Statement 47 background is more narrow in scope. It addresses the use of mixed oxide (MOX) fuel for the purpose of disposing of surplus weapons-grade plutonium in the United States and Russia and makes recommendations that are intended to support the decision by the U.S. Government for the rapid initiation of plutonium disposition using MOX fuel.

BROAD SUPPORT FOR DISPOSING OF SURPLUS WEAPONS-GRADE PLUTONIUM USING MOX FUEL

In 1994 the National Academy of Sciences (NAS) called the presence of surplus weapons-usable plutonium a "clear and present danger to national and international security" (Ref. 1, p. 1). Since the release of that landmark NAS report in 1994, the concept of using MOX fuel to dispose of surplus weapons-usable plutonium has received broad national and international support. Some examples are the following:

- 1995: National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium: Reactor-Related Options*;
- 1995: American Nuclear Society, "Special Report on the Protection and Management of Plutonium";
- 1997: "Final Report of the U.S.-Russian Independent Scientific Commission on Disposition of Excess Weapons Plutonium" (John P. Holdren and Evgeniy P. Velikhov, Cochairs);
- 1998: Center for Strategic and International Studies, "Disposing of Weapons-Grade Plutonium" (John Taylor, Project Chair);

- 2000: Harvard University's Project on Managing the Atom and the Non-Proliferation Project of the Carnegie Endowment for International Peace, "The Next Wave—Urgently Needed New Steps to Control Warheads and Fissile Material" (Matthew Bunn, Author);

- 2001: Secretary of Energy Advisory Board, "A Report Card on the Department of Energy's Nonproliferation Programs with Russia" (Howard Baker and Lloyd Cutler, Cochairs).

The attacks on the United States on September 11, 2001, make it clear that some terrorist groups would stop at nothing to do harm to America. Unfriendly foreign countries continue to make concerted efforts to obtain nuclear weapons. An effective plutonium disposition program will help minimize the danger posed by the existence of substantial quantities of surplus weapons-grade plutonium.

EFFECTIVENESS OF SURPLUS WEAPONS-GRADE PLUTONIUM DISPOSITION USING MOX FUEL

The 1994 NAS report introduced the concept of the "spent fuel standard" for surplus weapons plutonium, defined as follows:

> We believe that the options for long-term disposition of weapons plutonium should seek to meet a "spent fuel standard"—that is, to make this plutonium roughly as inaccessible for weapons use as the much larger and growing quantity of plutonium that exists in spent fuel from commercial reactors. (Ref. 1, p. 12)

Fabricating surplus weapons-grade plutonium into MOX fuel and using that fuel in commercial nuclear power reactors renders the material unattractive for weapons use in a number of ways[a]:

- Irradiation to 40 gigawatt days per tonne (GWd/tonne) heavy metal, the nominal burnup following two 18-month cycles of operation in a pressurized water reactor (PWR), leads to a net reduction of approximately 30% of the initial amount of plutonium.

- Irradiation to 40 GWd/tonne degrades the isotopics of the plutonium. Plutonium-240 is an undesirable isotope for weapons applications; plutonium must be less than 7% ^{240}Pu to meet the definition of weapons grade. Irradiation of MOX fuel in a reactor increases the amount of ^{240}Pu that is present, as illustrated in Table of Isotopic Concentrations (see next page).

  The plutonium in irradiated low-enriched uranium (LEU) fuel and irradiated MOX fuel is classified as reactor grade (i.e., containing more than 20% ^{240}Pu). Reactor-grade plutonium is not as desirable as
  weapons-grade plutonium for use in nuclear weapons, particularly for a rogue state or terrorist group with limited technological capabilities.

TABLE OF ISOTOPIC CONCENTRATIONS

Isotope	Percent in Weapons-Grade MOX Fuel Before Use	Percent in Weapons-Grade MOX Fuel After 40 GWd/tonne Burnup
^{239}Pu	93.5	51
^{240}Pu	6.5	29
^{241}Pu	-	16
^{242}Pu	-	4

- The plutonium in irradiated MOX fuel is encased in a matrix of highly radioactive fission products. While the chemistry for recovering plutonium from spent fuel is well known, the radiation barrier prevents easy access to the material and complicates the steps that would be required to recover it.

- In order to obtain plutonium from spent fuel, it would first be necessary to divert spent fuel assemblies from their storage location. An irradiated MOX fuel assembly is large, massive, and radioactive; typical PWR fuel assemblies are more than 12 feet long, weigh more than 500 kilograms, and produce a very high radiation field following irradiation.[b] Furthermore, spent fuel assemblies are stored in controlled areas (spent-fuel pools or dry storage facilities), and regulations require that they be tracked and monitored.

Theft or diversion of the plutonium in spent nuclear fuel would be difficult and hazardous. Furthermore, even if the plutonium could somehow be stolen and separated from the uranium and the highly radioactive fission products in the ceramic fuel matrix, the isotopics of the resulting plutonium are relatively unattractive for nuclear weapons use.

MATURITY OF MOX FUEL TECHNOLOGY

Plutonium has long been recognized as a potential source of energy. Plutonium isotopes ^{239}Pu and ^{241}Pu are fissionable, similar to uranium isotopes ^{233}U and ^{235}U.

Plutonium is produced as a by-product of nuclear power. A nuclear chain reaction involving LEU fuel produces plutonium through neutron capture in ^{238}U. After a burnup of 40 GWd/tonne, a PWR fuel assembly initially enriched to 4% ^{235}U will be approximately 1% plutonium. At the end of the useful life of such an initially all-uranium fuel assembly, almost half of the power generated in that assembly comes from plutonium fission.

[b]Ten years after shutdown, a PWR fuel assembly with a burnup of 45 000 MWd/tonne heavy metal would produce an unshielded radiation dose rate of more than 2000 rem per hour at a distance of 1 meter from the fuel assembly, according to the report "Impacts on Reactor Systems, Operations, Equipment, and Facilities from the Use of Mixed Oxide (MOX) Fuels" (Ref. 2).

Reactor use of LEU fuel and subsequent reprocessing of the spent fuel to chemically separate the uranium, plutonium, and fission products produced the worldwide stockpiles of plutonium. Weapons-

grade plutonium was produced by reprocessing the fuel after low burnups, prior to buildups of substantial quantities of the ^{240}Pu isotope, which has a high rate of spontaneous fission and is therefore undesirable for weapons applications. Reactor-grade plutonium was and is produced by reprocessing spent fuel after more extensive irradiation in a nuclear reactor.

During much of the second half of the 20th century, there were significant concerns about the availability of sufficient economically recoverable uranium from which LEU fuel for nuclear power reactors could be made. In addition, it was recognized that reprocessing spent reactor fuel, and thereby separating the uranium, plutonium, and highly radioactive fission products, offered potential benefits with respect to management of high-level radioactive waste. As a result, there was considerable worldwide nuclear technology development related to both reprocessing and reuse of the plutonium in nuclear power reactors.

The majority of commercial nuclear power reactors have evolved to a standard fuel type consisting of natural or low-enriched ceramic uranium oxide fuel pellets encased in tubes of zirconium-based alloy. In order to use plutonium as fuel in such reactors, small amounts of plutonium oxide are blended with large amounts of natural or depleted uranium oxide. This blended fuel is known as mixed oxide or MOX fuel. As the MOX fuel fabrication technology developed, it became possible to produce MOX fuel pellets that are very similar to 100% uranium oxide fuel in both physical characteristics and reactor performance.

In the United States, there was substantial development work on MOX fuel technology in the 1960s and 1970s. The work culminated in a series of MOX fuel demonstration programs at five commercial nuclear power reactors: the San Onofre and Ginna PWRs and the Dresden, Quad Cities, and Big Rock Point
BWRs. In each program, lead test assemblies were used for several cycles of operation to study the performance of MOX fuel rods during prototypical conditions. In all of the programs, the MOX fuel performed acceptably and in a similar manner to the co-resident uranium fuel. In the 1970s the U.S. nuclear industry was poised to begin large-scale reprocessing of spent nuclear fuel and associated reuse of the separated plutonium in commercial light water reactors (LWRs). However, fearing the worldwide nonproliferation consequences of separating large quantities of plutonium, the U.S. government made a policy decision against the reprocessing of spent nuclear fuel. At that time the development and deployment of MOX fuel technology in the United States came to a halt.

Other countries, however, continued their development of reprocessing and MOX fuel technologies and deployed those technologies on an industrial scale. In the early 1980s, Germany began using substantial quantities of reprocessed plutonium in the form of MOX fuel in nuclear reactors. Other countries in Europe have followed suit, and as of 2000, MOX fuel has been used in thirty-five nuclear power reactors in France, Germany, Belgium, and Switzerland. Japan also

plans to use MOX fuel in its reactors in the future, although no definite schedule has been established.

Three nuclear fuel fabrication facilities are currently producing MOX fuel. Belgonucleaire operates the P0 MOX fuel fabrication facility at Dessel, Belgium. Cogema operates the Cadarache and Melox MOX fuel fabrication facilities in southern France. A fourth MOX fuel fabrication facility, BNFL's Sellafield manufacturing plant, has been constructed and is starting up, with plutonium commissioning currently underway.

MOX fuel and LEU fuel behave very similarly in reactors. Apart from the fuel pellet material, MOX fuel assemblies and LEU fuel assemblies are essentially identical with respect to mechanical design. Both MOX fuel pellets and LEU fuel pellets consist of sintered ceramic pellets that are predominantly ^{238}U dioxide, and the respective material properties are very similar. The microstructures of the two types of fuel pellets differ somewhat in that LEU fuel is a homogeneous mixture of ^{238}U dioxide and ^{235}U dioxide, while MOX fuel is more heterogeneous, with very small plutonium-rich particles in a matrix of depleted uranium oxide. The nuclear characteristics of MOX and LEU fuel are also different, due to the nuclear cross-section differences between uranium and plutonium. However, the MOX fuel assembly neutronic design can be adjusted to make the MOX fuel nuclear characteristics similar to those of co-resident LEU fuel.

The more significant differences between MOX and LEU fuel are summarized as follows:

- The fission and overall absorption cross sections of ^{239}Pu are substantially higher than those of ^{235}U. Accordingly, for the same power level, MOX fuel has a lower thermal flux. This leads to a reduction in the worth of thermal neutron absorbers in a partial MOX fuel core, most notably soluble boron and control rods. This effect has been successfully addressed by various means, including increasing soluble boron concentration, using enriched soluble boron, adding more control rods to reactors with partial MOX fuel cores, and core design to ensure adequate shutdown margin.

- The flux gradient between LEU fuel assemblies and MOX fuel assemblies requires PWR MOX fuel to incorporate low plutonium concentration zones on the exterior of the fuel assembly. Otherwise, those exterior MOX fuel rods would experience unacceptably high peaking due to thermal neutrons leaking in from the adjacent LEU assemblies with higher neutron flux levels. The intra-assembly zoning for MOX fuel assemblies successfully minimizes the peaking that would otherwise be experienced in partial MOX fuel cores.

- Fission gas release from MOX fuel at elevated burnups (greater than 40 GWd/tonne) is higher than the fission gas release from LEU fuel. This effect has been predominantly tied to the relatively higher power experienced by MOX fuel at high burnups. In Europe the higher fission gas release has been successfully addressed by modifying MOX fuel rod design to provide more plenum space and by establishing specific burnup limits on the MOX fuel assemblies.

- The radionuclide inventory in spent MOX fuel differs somewhat from that of spent LEU fuel. As a result, the decay heat from MOX fuel is slightly lower than that of LEU fuel immediately following shutdown, providing a safety benefit during the time frame of most concern for analyses of postulated transients and accidents. In the longer term, the decay heat from MOX fuel exceeds that of LEU fuel, and that difference must be taken into account for spent-fuel management.

- Spent MOX fuel contains substantially higher quantities of most actinides than does spent LEU fuel. The actinide inventories could affect the off-site doses calculated to result from hypothetical, extremely unlikely core melt accidents with containment failure. In addition, for some geologic repository designs, the actinides can have a substantial impact on the projected doses in very long (hundreds of thousands to millions of years) time frames.

Fundamentally, MOX fuel is very similar to LEU fuel, and MOX fuel has been demonstrated to perform well in commercial nuclear power reactors. Fuel assembly, core, and plant design practices effectively accommodate the differences that do exist between the fuel types.

CHALLENGES

The MOX Fuel Project is a key part of a complex, long-term program to dispose of surplus weapons-grade plutonium in the United States and Russia. In order to succeed, the program will require a substantial investment of government resources, although the estimated costs are small compared to the resources that were invested in producing the weapons-usable material in the first place. The financing for the Russian plutonium disposition program is expected to derive from international sources. The governments of the industrialized nations of the world must recognize the benefit of disposing of substantial quantities of weapons-usable plutonium in Russia and the United States and invest in the plutonium disposition program accordingly.

The September 2000 United States – Russian Federation Plutonium Disposition Agreement calls for each nation to fabricate plutonium into MOX fuel and to use that fuel in existing nuclear reactors. Neither Russia nor the United States has contemporary experience making or using MOX fuel. However, facilities in Europe have been making and using MOX fuel for decades. Information and technology exchange will be essential if U.S. and Russian MOX fuel use is to begin in a timely manner.

Independent safety authorities in the United States and Russia must approve large-scale MOX fuel fabrication and subsequent use in existing nuclear reactors. This oversight must include a proper level of safeguards and physical protection for the weapons-grade plutonium during MOX fuel fabrication, transportation, and use. Fortunately, MOX fuel is a technology that has been proven on an industrial scale in European facilities. To advance the program in the United States, it is essential that the U.S. Nuclear Regulatory Commission fulfill its regulatory responsibilities in a thorough yet timely manner. The nuclear professional community can play an important role in this effort by helping to provide the government and the public with the technical facts that are pertinent to the fabrication and use of MOX fuel.

Compared to the United States, Russia has few existing LWRs available for the use of MOX fuel. In addition, Russia has contemporary experience using the BN-600 sodium-cooled fast reactor to generate power, and this reactor design is very amenable to the use of MOX fuel. Furthermore, Russia is exploring the use of future advanced reactors (including high-temperature gas-cooled reactors and sodium-cooled fast reactors) for power generation and plutonium disposition. Moreover, Canada has expressed interest in supporting a program to dispose of surplus weapons-grade plutonium in existing Canadian CANDU heavy water reactors. Given these facts, coupled with the large and potentially growing quantities of surplus weapons-grade plutonium needing disposition worldwide, it may ultimately be appropriate to expand the plutonium disposition program beyond using MOX fuel in existing reactors. However, it is critical from a nonproliferation perspective to initiate a plutonium disposition program in a timely and cost-effective manner. Use of surplus weapons-grade plutonium as MOX fuel in existing nuclear power reactors offers the best opportunity to accomplish that objective.

References

1. "Management and Disposition of Plutonium," National Academy of Sciences Committee on Arms Control and International Security (1994).

2. "Impacts on Reactor Systems, Operations, Equipment, and Facilities from the Use of Mixed Oxide (MOX) Fuels," ORNL/MD/LTR-140, Oak Ridge National Laboratory (August 1998).

American Nuclear Society

Communications & Outreach Department
555 North Kensington Ave.
La Grange Park, IL 60526-5592

708-352-6611 telephone

outreach@ans.org e-mail
www.ans.org

November 2002