Plutonium Transportation – Risks and Benefits

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INTRODUCTION

In June of 2000, James Lake, President of the American Nuclear Society, addressed the Latin American Symposium with the following introduction:

> "Plentiful, affordable electrical energy is a critically important commodity to Nations wishing to grow their economy. There is a well known correlation between several standard of living indices (from Gross Domestic Product to life expectancy) and electricity use that suggests that energy, and more specifically electricity, is the fuel of economic growth. However, more than one third of the world's population (more than two billion people) live a subsistence lifestyle today without access to any electricity. Further, another two billion people in the world exist on less than 100 watts of electricity per capita. By comparison, the large economies of Japan and France use more than 800 watts of electricity per capita, and the United States uses nearly 1500 watts of electricity per capita.

These words still motivate us. In this message to the Latin American Symposium, we address an important nuclear fuel – plutonium. Specifically, we address plutonium transportation while touching upon other issues surrounding the widespread use of plutonium as a fuel for providing electrical energy.

Plutonium is a radioactive, silvery, metallic transuranic element, produced artificially by neutron bombardment of uranium, having 15 isotopes with masses ranging from 232 to 246 and half-lives from 20 minutes to 76 million years. It is normally produced in a nuclear reactor as a by-product of nuclear power production. The principal radiation from plutonium is the alpha particle. Alpha particles are totally stopped by a single sheet of paper or even an inch of air. These alpha particles cannot penetrate the outer layer of human skin; therefore, plutonium outside the body is relatively harmless. The primary hazard is from inhalation. Plutonium can extend nuclear fuel resources for a very long time. Plutonium can be used to produce power, just as uranium-235 is used, but first it must be transported to the facility where it is extracted from spent fuel and incorporated into fresh fuel.

We begin by reviewing the first "transport" of plutonium that took place in 1941. It was much more "ad hoc" and primitive compared with today's standards. We will then review experience with transport of plutonium and plutonium bearing materials in the United States, and experience with maritime transport of Mixed Oxide (MOX) fuel. Finally, we address the topics of plutonium toxicity, terrorism, and proliferation, as no discussion of plutonium would be complete without them.

PLUTONIUM TRANSPORTATION – THE FIRST INSTANCE

The first known "transport" of plutonium (Seaborg, 2001) occurred in March 1941 in Berkeley, California. Emilio Segre and Glenn Seaborg had irradiated 1.2 kg of uranium in the cyclotron to produce a microgram (0.25 microgram) of element 93 which was laced throughout with fission products from neutron bombardment.

The precautions taken at that time to transport the new material were primitive by today's standards. The irradiated sample went into a lead bucket and was carried on a long pole. Segre and Seaborg wore lead gloves and goggles to carry the bucket from the cyclotron across the street and up two flights of stairs in the Chemistry building where the target was dissolved to remove uranium from element 93, element 94 and fission products.

A centrifuge was used to separate fission products from elements 93 and 94. The solution was placed in a centrifuge tube in a lead beaker and the beaker was placed in a wooden box with long poles as handles and carried to the Crocker Laboratory that had a large centrifuge. This was done repeatedly (6 cycles of re-precipitation and centrifugations in 3 days) between the Chemistry building and Crocker Laboratory using the wooden box-long pole transportation container. The centrifuge separated out the lighter fission products from the heavier plutonium.

Using a platinum dish (the size of a dime), Seaborg evaporated off the liquid and covered the sample with a thin layer of Duco cement and glued the dish to a cardboard backing, and labeled it Sample A. The decay of element 93 in Sample A was complete after 3 weeks. On March 28, 1941, kicks (fissions) were measured when Sample A (in paraffin) was placed in the path of the cyclotron's neutrons, thus proving that fission can occur in element 94.

Glenn Seaborg lived a long and productive life. He died at an age of 89, some 50 years after the discovery and early transportation of plutonium.

PLUTONIUM TRANSPORTATION – A U. S. PERSPECTIVE

In 1977, the U. S. Nuclear Regulatory Commission (USNRC) published NUREG-0170 (1977), the first comprehensive risk assessment of radioactive materials transportation. Although NUREG-0170 included all radioactive materials, its genesis was the plan to transport plutonium by air and the need to assess the risks posed by such transportation. Today, in the U. S. only very small amounts of any radioactive material are transported by air, and plutonium is not usually transported in this way because of the containment requirements. However, NUREG-0170 paved the way for a continuing intensive examination of the risks of radioactive materials transportation, and for a series of stringent regulations governing such transportation.

The most radioactive isotope of plutonium is plutonium-238, with an 87-year half-life, a by-product of the production of fissile plutonium-239. Although it is the most radioactive plutonium isotope, its specific activity (radioactivity per gram) is about 1/3 of the radioactivity of the fission products strontium-90 and cesium-137, and about 15% of the specific activity of tritium. Plutonium-239, half-life 24,600 years, has less than 1% of the specific radioactivity of plutonium-238. We are careful about transporting plutonium-239 because plutonium-239 is a fissile isotope. However, sustaining nuclear fission requires a critical mass of fissile material. Packaging for transportation is first of all designed so that a critical mass cannot form, to preclude an accidental criticality.

The USNRC regulations (10 CFR Part 71) for transportation packaging of fissile material like plutonium-239 and uranium-235 require multiple safeguards to prevent criticality. The amount of fissile material that can be transported in one land shipment (which is usually just one container) is strictly limited. Maritime shipments carry a number of containers that are placed so as to prevent an accidental criticalityFurther prevention of criticality is ensured by guaranteeing that material will be dispersed – pushed apart – in an accident, so that a critical mass cannot form. Moreover, the container is designed so that if water, a potential neutron moderator, enters it, criticality still would not occur.

Currently, plutonium is transported in double containment, in accordance with USNRC regulations (10 CFR 71.73). The regulation requires that each containment layer has a maximum allowed leak rate of one one-millionth of the plutonium content. Thus, the net amount of plutonium that could leak out is one trillionth of the contents. For most plutonium shipments, this would amount to a few nanograms of plutonium that would be allowed to leak from the container. In fact, shipments of plutonium have taken place without detectable leaks. The Waste Isolation Pilot Plant (WIPP) in southern New Mexico has received several hundred highway shipments of plutonium-contaminated debris and pyrolytic salts of plutonium without incident.

Maritime transportation of mixed plutonium / uranium oxide (MOX) is no more hazardous than maritime transportation of any fresh (unirradiated) nuclear fuel, and we have been transporting nuclear fuel around the world for decades. Moreover, maritime transport is in some ways inherently safer than land transport. Maritime ship accident rates are about 2.8 x10^{-7} per kilometer (Saricks and Tompkins, 1999), or about the same as the railcar accident rate in the United States. For example, in 400 maritime trips between Hampton Roads, Virginia to St. Petersburg, Russia (about 9,000 km), there could be one accident (2.8 x10^{-7} x 0.9 x10^{4} x 0.4 x 10^{3} 1.0). About 10% of these accidents happen more than 60 miles offshore. Most ship accidents take place in coastal waters and ports, not on the open seas, so that minimizing port calls actually minimizes accident likelihood. As with rail, 99% (DOE, 1999) of these accidents would not involve damage to the cargo.

The only people exposed to ionizing radiation during maritime travel are the ship's crew, and if they are more than 3 meters from the cargo, the radiation they are exposed to can't even be measured. For most of the trip, the crew is more than 10 meters from the cargo. Average radiation dose to a ship's crewmember from intact MOX fuel containers is about 0.3% of the average dose to a truck driver transporting the same material.

The USNRC and the nuclear engineering community understand the inherent risks in fissile and radioactive material transportation, and thus have paid careful attention to the design and construction of shipping containers. Radioactive materials are more carefully and safely packaged for transportation than any other hazardous material. Plutonium shipping containers are designed to withstand both the rigors of normal transportation and transportation accidents and are referred to as Type B packaging. Nuclear fuel containing plutonium is packaged much more sturdily than unirradiated uranium-235 nuclear fuel.

Type B packaging is required withstand, without any damage (10 CFR Part 71 Sub E).

- a 30-foot drop onto an unyielding target, the equivalent of a 2,000-foot drop from an aircraft,
- a puncture test in which the cask is dropped onto a projecting spike,
- various drops on the edge, corner, and end of the cask,
- a half-hour-long fully engulfing fire with fire temperature 800 deg C. (1480 deg. F.), and
- eight hours of full immersion in water.

Sandia National Laboratories has subjected Type B casks to both these tests and more rigorous tests. The tests are performed on full-sized, instrumented, prototype casks, and examples of all cask designs are tested. (Full-size casks are used because half-scale or 3/4-scale casks cost as much as a full-size cask and the test cost is independent of cask size (Sprung et al, 2000)). Casks have emerged essentially unscathed from a propane gas tank explosion, a fire aboard ship (the SS Lykes), a train hitting the cask broadside at 80 mph, and a rocket sled crash into a concrete barrier. Recent studies at Sandia indicate that the forces generated in these tests encompass all forces in actual observed accidents (Sorenson, 2002). This is true for both mechanical forces (impact) and thermal forces (heat). Analysis of accidents involving ocean-going freighters indicate that the cask would remain intact if a ship is in a collision, and that the hull of the ship would suffer any damage that would occur.

To date, 90 Type B casks have been involved in highway and rail accidents in the United States (out of about 3,000 shipments) (Weiner, 2000). In no case was the cask damaged, and in no case was any leaking of radioactive material observed. The double containers of steel and concrete that enclose materials containing plutonium are massive, and the body of the container is virtually impossible to damage accidentally. Any damage would occur around the seals at the ends of the casks.

Eighty-seven of these events involved casks on trucks, and three involved rail casks. Sixteen of the events were “accidents” where an accident is an event in which there is a death or an injury, or a vehicle involved in the accident cannot move under its own power. The remaining 74 events were “incidents” where an incident is any event other than normal, routine, "incident-free" transportation, and can include "fender benders," flat tires, cask weeping, and unauthorized stops. Two of the 90 events happened after 1990.

Although plutonium is not very radioactive, some ionizing radiation may be given off by the shipment. The maximum dose rate of external radiation allowed by the USNRC is 10 millirem per hour at 2 meters from the side of the vehicle, or 14 millirem per hour at 1 meter from the side. This is the maximum allowed, independent of the transporting vehicle, so it applies to plutonium as well as to any other radioactive material being transported. It is also the dose rate used in transportation risk assessment, because it is bounding. This external radiation, which would be about half gamma rays and half neutrons, would deliver a dose of about 5 millirem to a person standing about 30 meters from the truck for 12 hours, or someone standing about 6 meters from the truck for an hour. A passing vehicle carrying a cask would deliver a dose of about 0.001 millirem to a person at the side of the road.

Plutonium is usually transported as a metal or as an oxide. Plutonium oxide is a chemically un-reactive ceramic material. Plutonium metal, though its chemical properties are similar to those of other heavy metals like lead, is relatively insoluble, and dissolves to any extent only in acid or strong carbonate solution. Because plutonium-239 and plutonium-240 are not very radioactive, cleaning up a release of these substances would not be expected to cause much radiological damage. Plutonium is, of course, a strategic material, and any amount transported (or released) must be very carefully accounted for. Only a few laboratories in the United States are licensed and equipped to handle plutonium, and in these laboratories a great deal of attention is paid to containment and accountability of plutonium. The United States stopped plutonium production for weapons use in 1989, more than 12 years ago. The plutonium stockpile that exists is under careful stewardship.

If there were a plutonium release into the ocean, it would have very little effect on the aquatic ecosystem, either in terms of chemical effect or radiological effect. Seawater is a complex solution containing a majority of the naturally occurring elements.

Uranium, which is radioactive, is one of the elements naturally present in seawater. In the marine environment most of the background radiation dose rate to phytoplankton, zooplankton, and pelagic fish arises from ingested radioactive material, alpha-emitting isotopes. Polonium-210 (Po-210), a daughter product of uranium, is the primary contributor, with potassium-40 (K-40) contributing most of the remainder. The exposure of these organisms (marine invertebrates and fish) appears to make the oceans the highest known natural radiation domain in our biosphere. In general, aquatic organisms tend to be more resistant to adverse radiation effects than terrestrial mammals. (DOE 1999)

Radionuclides have been discharged deliberately into the oceans, as a result of human activity, since 1944. However, in 1981 it was estimated that the total anthropogenic input of radionuclides, essentially from waste disposal and nuclear weapons testing, approached only 0.7% of the natural radioactivity in the world's oceans. (DOE 1999)

A cask or container drop at a port loading and unloading facility, though unlikely, is more likely to happen than an accident at sea. However, the double containment ensures that the containment would not be breached, and the regulation of fissile material content ensures that casks are designed to preclude criticality under any accident conditions.

PLUTONIUM TRANSPORTATION – MARITIME MOX SHIPMENTS

British Nuclear Fuels plc (BNFL) of the UK, Compagnie Générale des Matières Nucléaires (COGEMA) of France, and the Overseas Reprocessing Committee (ORC, 2001), a consortium of ten Japanese electric utilities, have regularly transported shipments of spent fuel from Japan to Europe for reprocessing and returned conditioned waste and recycled fuel back again in more than 160 round-trip voyages over more than 30 years. The safety record is second to none. These ships have transported more than 8,000 tonnes of nuclear material, and have traveled more than four-and-a-half million miles, without a single occurrence involving the release of radioactivity.

The shipments comply fully with the rigorous international regulations set by two bodies of the United Nations (International Atomic Energy Agency (IAEA), and the International Maritime Organization (IMO)) and in many cases goes beyond what is called for by law. In fact, their standards are so demanding that experts have asserted that these ships are among the safest and best managed on the world's oceans today. These regulations include:

- INF Code – The Code for the Safe Carriage of Irradiated Nuclear Fuel, Plutonium, and High-Level Radioactive Wastes in Flasks on Board Ships (IMO)
- IMDG Code – International Maritime Dangerous Goods Code (IMO)
- SOLAS – International Convention for the Safety of Life at Sea (IMO)
- MARPOL – The International Convention for the Prevention of Pollution from Ships (IMO)
- ISM Code – International Safety Management Code (IMO)
- Safety Series 6 – Regulations for the Safe Transport of Radioactive Material (IAEA)
- Safety Series 87 – Emergency Response Planning and Preparedness for Transport Accidents Involving Radioactive Material (IAEA)
- Convention on the Physical Protection of Nuclear Material (IAEA)
- INFCIRC/225/Rev. 3 – The Physical Protection of Nuclear Material (IAEA)

- United Nations Convention on the Law of the Sea (UNCLOS)

The conclusion from the joint working group of three United Nations bodies, the IAEA, the IMO and the United Nations Environment Program, declared in April of 1993 that “All the information demonstrates very low levels of radiological consequences from the maritime transport of radioactive material . . . It was the unanimous conclusion of the Member States that there was no information or data . . . that would cast doubt on the adequacy of the IAEA Regulations.”

MOX Fuel

At the end of a fuel load cycle, the spent, or used, nuclear fuel can then either be placed in a repository or recycled. By separating the waste from the usable uranium and plutonium, over 94% of the nuclear fuel can be recycled. To manufacture MOX fuel, uranium and plutonium powders are blended to include 3 to 10 % plutonium, depending upon the type of reactor where the fuel is to be used. The powder is then mixed with a lubricant and pressed into cylindrical pellets approximately one centimeter in length.

Next, the pellets are hardened by sintering or baking them, and ground to meet exacting specifications. The hardened pellets are loaded into zirconium alloy tubes, which are sealed and welded. These fuel rods are fabricated together into fuel assembly frameworks, which are then placed into specially designed steel casks for transport to the nuclear power station.

With its inherent stability, portability and high energy content, several countries are looking to use MOX fuel to help meet their growing energy demands. One pellet, weighing about six grams, generates the energy equivalent of one tonne (1,000 kg) of coal. The energy contained in just three pellets of MOX fuel is enough to provide all a U. S family’s electricity needs for an entire year. Each fuel assembly produces enough electricity to supply 30,000 families for one year. One ship can carry around 20 MOX fuel transportation casks, which are equivalent in energy content to a fleet of 25 large oil tankers of 200,000 tons each.

Using MOX fuel significantly reduces the need to mine and deplete global reserves of uranium ore, allowing reserves of uranium to last much longer. This also reduces the need to use dwindling supplies of fossil fuels, which are particularly critical to progress in the developing world. Today, fossil fuels provide around 90 % of the world's primary energy. Reserves of oil and gas are finite and are neither recyclable nor renewable. MOX fuel is a technological resource that is renewable and abundant.

Recycling spent fuel into MOX reduces the radioactivity of nuclear waste to eventually be disposed of, compared with the direct placement of spent fuel in a repository. The waste also does not require as long a sequestration time as spent nuclear fuel, because it consists mostly of shorter half-life fission products. The radioactive waste from MOX fuel production can be stabilized or vitrified, facilitating both transport and disposal. Recycling plutonium is a clean, moral and responsible way of managing our environment for future generations.

Converting military plutonium into MOX fuel supports nonproliferation of nuclear weapons. The U.S. National Academy of Sciences and the U.S. Department of Energy (DOE) have stated that MOX fuel is a viable option for disposing of weapons plutonium. Surplus military plutonium from decommissioned warheads in the USA and Russia is expected to be used to manufacture MOX fuel, which in turn will generate electricity. Exchanging megatons of weapons for megawatts of electricity is today’s equivalent to the biblical “swords into plowshares.”

The safety and stability of MOX fuel have been proven through 35 years of secure transport and use in many commercial nuclear power plants around the world. The U. S. has many years of experience with MOX irradiation in EBR-II (experimental assemblies) and in FFTF (driver assemblies), as does France with MOX fuel in Phoenix and Super-Phoenix. Nuclear energy based on advanced MOX fuel technology contributes to the electrical power generating capabilities of Japan as well as France, Germany, Belgium and Switzerland. It is being used today in around 30 European reactors, together with enriched uranium fuel. Around 70 reactors worldwide are expected to be using MOX fuel by 2010.

Maritime Shipments of MOX fuel

MOX shipments represent a small fraction of the total volume of designated hazardous shipments on the high seas. Every year there are thousands of shipments of liquid petroleum gas, explosives, corrosive chemical oil and other hazardous cargos, which are regarded by experts as more hazardous than MOX fuel shipments. Oil tankers account for around half of the world's bulk (unpackaged) shipments. Fewer than 10 % of oil tankers have double hulls.

To ensure the safety of all shipments of nuclear material -- whether it's MOX fuel, used nuclear fuel or vitrified waste -- a "safety in depth" system is applied. This program, based upon years of research and experience, takes a careful look at all components of the transport process, identifies its most critical points, and applies the most effective methods to prevent mishaps of any kind.

All the nuclear materials that are shipped by sea are in a highly stable form that is inherently safe and resistant to the effects of outside elements. The MOX fuel pellets are a hard, ceramic, stone-like material that is so stable it can survive the rigors of a nuclear power plant -- where temperatures can reach over 1,800 degrees Celsius - without significant degradation. MOX fuel pellets are so durable that if you placed one in water, it would take thousands and thousands of years to dissolve. The effect has been compared to that of dropping a marble into a glass of water -- nothing happens.

This characteristic of MOX fuel may be contrasted to that of other hazardous cargo, such as oil or chemicals, which immediately disperse into the water or air in an accident. Indeed, many such cargoes, like oil, are stored directly in ship holds and not placed in protective transport containers of any sort.

Specialized transport casks for MOX are built to standards set by international experts representing the 127-member countries of the IAEA. The philosophy underlying these stringent international standards is that transport safety is ensured by the secure packaging. Other factors such as the mode of transport -- in this case the purpose-built ship provide additional protection.

The transport casks are massive steel structures, such as the TN 12/2, which is made from 0.3 meters thick forged steel and weighs around 100 tonnes. The reusable casks contain around five tonnes of the solid MOX fuel inside, so the vast majority of the weight is the protective casing of the cask itself. The casks measure approximately 6 meters long and 2.5 meters in diameter.

The security and reliability of these casks have been carefully tested. Collision, fire and submersion performance have all been demonstrated by a series of dramatic tests, meeting all IAEA requirements. These tests include:

- Punishing Drop tests. In one, the lid seal must remain intact after the cask is dropped one meter onto a reinforced concrete and steel spike. In another test, the cask is dropped nine meters onto an unyielding surface -- a surface more inflexible than any found in nature -- to simulate real impacts from far greater heights. These tests are performed at angles, which ensure the maximum impact on the cask.

- Fire testing. The cask is subjected to fire testing, requiring it to withstand an all-engulfing fire -- far more destructive than real fires -- of 800 degrees Celsius for 30 minutes.
- Pressure tests. The cask is also given an immersion test where it must withstand the pressure of at least 15 meters of water. In fact, the casks are able to survive in several thousands of meters of water.
- After these tests have been performed in sequence, the cask design must maintain its integrity to be approved for use.

International experts rate the ships used to transport MOX fuel to be among the world's safest. The fleet is certified to INF3 -- the highest safety category of the International Maritime Organization (IMO) for nuclear voyages. The ships have been designed and built specifically to carry these nuclear materials. And they employ a range of safety features far in excess of those found on conventional cargo vessels:

- Ship within a ship. The ships are constructed with double hulls, effectively making them a "ship within a ship." This construction is designed to withstand a severe collision with a much larger vessel without penetrating the inner hull. This includes a double bottom structure and a wing tank space that has been structurally stiffened to further protect the cargo in the event of grounding or impact.
- Enhanced buoyancy. The ships have enhanced buoyancy enabling them to remain afloat even in extreme circumstances.
- Dual systems. Each ship has two sets of navigation, communications, cargo monitoring, electrical and cooling systems, so there is always a back up in the event of failure or damage. The navigation system includes automatic radar plotting and collision avoidance equipment. This "doubling up" extends to the ship’s propulsion system; each propeller and engine has its own back up. In practice, if one engine stops, the other remains engaged so that the ship can continue its voyage.
- Firefighting equipment. Every part of the ships is covered by a fire detection system. And every vessel has sophisticated firefighting equipment on board. In the highly unlikely event of fire, a ship's hold, engine room or any other on-board space, may be flooded with fire-suppressant gases. Individual holds can even be deliberately flooded -- and if all the holds were flooded in this way, the ship would still remain afloat.
- Satellite navigation and tracking. The ships carry the most modern satellite navigation, weather routing and tracking equipment, enabling them to automatically transmit their position back to the homeport. While at sea, each ship's crew maintains permanent communication with a report center that is operated 24-hours a day.
- An experienced crew. Each ship sails with a fully trained and highly experienced crew that is approximately twice as large as those found on chemical tankers of a similar size. All navigation and engineering officers hold certificates of qualification for the responsibilities of their next higher ranked officer. So the Chief Officer of the ship is qualified to take over the Captain's duties if that need were to arise.

Although emergencies at sea are unlikely, the shipping company is prepared. An extensive array of emergency response arrangements have been put in place in the event a ship encounters difficulty. These arrangements include having a fully trained and equipped emergency team of marine and nuclear experts on standby 24-hours a day. This team of experts can operate independently and is not reliant on the assistance of any country along a ship's route. Several emergency training exercises are held each year.

It would not be necessary for the ship to head toward the nearest port in the event of difficulty. Each ship carries sufficient amounts of fuel to complete a journey. As a result, every shipment can be a continuous voyage with no stops at any ports. If maintenance is needed during a voyage, a wide range of spare parts is on hand. And under pre-arranged agreements, the world's most experienced and technologically advanced salvage teams are also on stand- by, available 24 hours a day throughout the world.

As an additional safeguard, every ship is equipped with an advanced sonar location system. The sonar can operate in depths of over 6,000 meters and relay back to the surface the depth and angle of the vessel, whether the hatch covers are in place, and the precise radiation level in each hold. The battery-powered sonar has the capability to continue working for more than seven years.

Environmental Analysis

In addition to detailed assessments performed by the IAEA and a number of other agencies, the U.S. government's Sandia National Laboratories have independently analyzed a range of scenarios at sea. They have found no plausible way for the cargo carried on the vessels becoming exposed to the environment.

However, an environmental impact assessment was undertaken by discounting the sealing capacity of a cask on the seabed at a depth of 200 meters. The result of the assessment is an impact on local residents thousands of times smaller than the exposure levels a person receives from a single medical x-ray examination -- or one millionth of natural background radiation levels. The analysis shows that the impact on the environment is even smaller in deeper water.

For more than three decades nuclear materials have been safely and routinely transported across the globe. The methods designed and equipment employed have been verified as safe by the top international regulatory bodies that govern this secure maritime transport and have been tested by time. The result is that after millions of transport miles the delivery of nuclear materials has become a standard practice.

PLUTONIUM AND PROLIFERATION – A PROBLEM OF PROTECTION

There are two paths to producing material for nuclear weapons: plutonium production and uranium-235 production using isotope separation technology. Plutonium production can be accomplished in commercial power reactors, specially designed plutonium production reactors, or research reactors.

The operation of nuclear power reactors fueled with uranium to generate electricity creates a mixture of plutonium isotopes known as "reactor-grade plutonium." Reactor-grade plutonium has a less predictable yield and is more difficult to design and construct. In addition, a plant for generating nuclear electricity is by necessity large and highly complex. It would be very difficult to keep the construction or operation of such a power reactor secret. Reactor-grade plutonium has a relatively high proportion (~20 to 30%) of the isotope plutonium-240 which produces spontaneous neutrons that can pre-detonate a bomb before it can be completely assembled and reduce the predictability of a bomb's effectiveness.

A much better bomb fuel is "weapons-grade plutonium," produced by plutonium production reactors – reactors operated purposely to make weapons grade plutonium. Weapons-grade plutonium has much less plutonium-240. It would be somewhat cheaper and faster to construct a plutonium production reactor than a power reactor; and the plutonium it produces would make more reliable bombs with less effort and expense.

However, obtaining plutonium from reactors is not the only way to get material for nuclear weapons. The other principal method is to mine natural uranium and develop an isotope separation capability to enrich natural uranium in the isotope uranium-235. Many nations now have facilities for isotope separation, and others would have little difficulty in acquiring it. The uranium-235 could be fabricated into bombs much easier than making a plutonium bomb even with weapons-grade plutonium.

But that is not the impression the public has received. The public and political leaders generally have the impression that nuclear power plants are precursors to making weapons of mass destruction. They rarely differentiate between a power reactor for producing electricity and other ways to make bomb material.

Stopping reprocessing of commercial nuclear power reactor fuel is not an effective way of preventing weapons proliferation. Stopping reprocessing and the use of plutonium in power reactors to produce electricity will not prevent nations from developing nuclear weapons. The ANS (ANS 2001) believes that nuclear science and technology can be applied for peaceful purposes in a manner that fully supports and is compatible with achieving desired nonproliferation goals.

Reprocessing provides an important source of fuel for future energy needs. A reprocessing plant should be subject to very close scrutiny and strict accountability control by IAEA inspectors to ensure that its reactor-grade plutonium is not diverted for use in weapons. The IAEA has teams of inspectors trained and equipped to detect diversion of plutonium. In nations subject to safeguards programs, the IAEA has ready access to all nuclear power plants, reprocessing plants, and other facilities involved in handling plutonium.

Finally, we must continue to explore and develop technologies that further enhance the proliferation resistance of nuclear power systems, and ensure that the safeguarded nuclear fuel cycle will remain an unattractive route for acquiring plutonium.

PLUTONIUM AND TERRORISM – A PROBLEM OF PERCEPTION

Because of recent world events, terrorism is on our minds. An issue linking nuclear power with nuclear weapons is the possibility that terrorists might steal plutonium to use for making a nuclear weapon.

In the November 5, 2001, issue of Newsweek magazine, the destruction of nuclear facilities is listed as one of the top ten hazards – but only nuclear facilities are presumed to be hit by the jet plane although a jet plane hitting a skyscraper or packed stadium would have greater consequences. However, the media is getting smarter with more balanced coverage. There is less sensationalism from anti-nuclear groups in the legitimate media and more widespread recognition of hazards from non-nuclear materials.

News stories are changing. People are starting to recognize that nuclear facilities and materials are well protected. The nuclear industry has not neglected protection of its facilities and materials. These facilities have

- Armed protection
- Background checks

- Robust containers
- Emergency plans in place
- Fitness for duty programs
- Strict restriction on personnel access, and
- Radiation protection

We cannot avoid risk in our lives and we cannot disband our institutions and infrastructure. But we can develop rational defenses and focus on stamping out terrorism.

We do not stop the mail because anthrax spores have been sent through the postal system. We don't stop eating because people have died of food poisoning. We don't stop generating nuclear electricity because of fear of dissemination of radioactive material. Dispersal of radioactive material would be easily detected and can be avoided. It would be disruptive and costly but not necessarily life threatening.

We must balance this risk against the prospects for abundant energy to sustain economic development all over the world. Reliable energy supplies that do not depend upon a sometimes-unfriendly nation, are essential to fuel industry and provide medical care. An informed and educated public is key to putting risks in perspective.

The obstacles faced by terrorists in obtaining, fabricating and using a nuclear bomb are formidable. (NUREG 0414) Plutonium is protected, tracked and monitored. The only significant transport of plutonium in connection with nuclear power is of ton-size fuel assemblies in which the plutonium is intimately mixed with large quantities of uranium from which it would have to be chemically separated before use in bombs. If terrorists do manage to steal some plutonium from nuclear power operations and evade the intensive police searches that are certain to follow their theft, their next problem is to fabricate it into a bomb.

The fabrication requires a wide degree of expertise and experience in technical areas. It requires people capable of carrying out complex physics and engineering computations, handling hazardous materials, arranging electronically for a hundred or so triggers to fire simultaneously within much less than a millionth of a second, accurately shaping explosive charges, attaching them precisely and connecting the triggers to them, and so on. Terrorists would surely face severe difficulty in obtaining the needed expertise.

PLUTONIUM TOXICITY – A PROBLEM OF PRESENTATION

Ralph Nader has stated that a pound of plutonium could kill 8 billion people. (Nader, 1975) He should be sued for slander. Let's look at the results of some science.

The principal radiation from plutonium is the alpha particle. Alpha particles are totally stopped by a single sheet of paper or even an inch of air. These alpha particles cannot penetrate the outer layer of human skin; therefore, plutonium outside the body is considered harmless. Even ingestion of plutonium is of relatively low risk to humans. The greatest risk is from in inhaling plutonium particles.

A more rational result has been provided by Sutcliffe et al (1995). These scientists assume that one kilogram of plutonium is available to a terrorist group for dispersal in the atmosphere of a city with the population density of Munich. Considering the concentration of respirable particles, the rates of breathing by humans, and the rate of particle fallout, Sutcliffe estimates 960 latent cancer fatalities per kilogram (or 436 LCF's per pound of plutonium). The authors go on to suggest that even this estimate is pessimistic to the point of not being credible. Effects such as evacuation, use of protective breathing equipment or a light breeze to carry the contamination beyond the city would reduce the number of fatalities even further.

Bernard Cohen (1990) in his book "The Nuclear Energy Option: An Alternative for the 90s," argues that a pound of plutonium dispersed in a large city would cause an average of 19 latent cancer fatalities due to inhaling from the dust cloud during the first hour or so, with seven additional LCF's due to resuspension during the first year, and perhaps one more LCF over the remaining tens of thousands of years it remains in the top layers of soil. Cohen gives an ultimate total of 27 eventual fatalities per pound of plutonium dispersed.

None of the above discussion should be taken to mean that dispersal of plutonium in the atmosphere would not be a serious problem, but these findings leave plutonium far from the "most toxic substance known to man." The normal meaning of "toxic" is related to poisons with a fairly fast, often fatal, effect. Biological agents, like botulism toxin and anthrax spores, are many hundreds or thousands of times more toxic and very small amounts will cause almost immediate death. Plutonium toxicity is similar to that of nerve gas in that the effects of low-level exposures to plutonium may not be detected for many years if at all. (Rothchild, 1964) But given the choice of being in a room with equal quantities of plutonium dust and nerve gas, the latter would be much more dangerous.

It has often been suggested that plutonium dispersion might be used as an instrument for terrorism. But this is hardly realistic because none of the fatalities would occur for at least 10 years, and most would be delayed 20 to 40 years. It could not be used for blackmail because if the dispersal is recognized, protective action is easily taken -- breathing through handkerchiefs, going indoors, and decontaminating affected areas. There are certainly other alternatives for terrorists with more immediate toxic effects that should be given priority for protective measures.

The most significant effects of plutonium toxicity by far are those due to nuclear bombs exploded in the atmosphere. Only about 20% of the plutonium in a bomb is consumed, while the rest is vaporized and floats around in the Earth's atmosphere as a fine dust. Over 10,000 pounds of plutonium have been released in that fashion by bomb tests to date, (WASH-1359, 1974)). Hence, if it were true that a pound of plutonium could kill billions of people, the world's population should have already been killed many times.

Given these facts, why are such tight regulations are imposed on plutonium releases if they involve so little danger. Cohen's (1990) answer is that government regulators are driven much less by actual dangers than by public concern. They do pay attention to technological practicalities, and it turns out to be not difficult to achieve very low releases of respirable plutonium.

The difficulty with this approach to regulation is that the public interprets very elaborate safety measures as indicators of great potential danger. This increases public concern and perpetuates what has become a vicious cycle involving all aspects of radiation protection--the more we protect, the greater the public concern; and the greater the public concern, the more we must protect.

No other element has had its behavior so carefully studied, with innumerable animal and plant experiments, copious chemical research, careful observation of exposed humans, environmental monitoring of fallout from bomb tests, and so on. Lack of information can therefore hardly be an issue. We can only conclude that the campaign to frighten the public about plutonium toxicity is a misguided issue. There is nothing in the scientific literature to support the claims about the extraordinary dangers of plutonium. There is nothing scientifically special about plutonium that would make it more toxic than many other radioactive elements. Considering the fact that plutonium toxicity is a strictly scientific question, this is a most reprehensible situation.

SUMMARY

In summary, plutonium is one of many nuclear materials transported throughout the United States and all over the world. It is a fact that after fifty years of careful handling by humans in the nuclear industry and the weapons program of many nations, there are no known fatalities due to plutonium exposure. It is not nearly as radioactive as spent, or irradiated, nuclear fuel, which contains very radioactive fission products. Plutonium-239 is not, in fact, very radioactive at all. Plutonium is packaged and transported very carefully, in strong, double containment casks. Its transportation is significantly less hazardous than transportation of gasoline, ammonia, chlorine, or any of a hundred other substances that travel our roads, rails, and waterways every day. The transportation of plutonium is all the more safe because both U. S. regulatory agencies and IAEA recognize the risks and require the design of transportation containers and protocols to minimize those risks. If all hazardous materials were transported with the same care used in transporting plutonium, the world would be a much safer place.

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