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PLUTONIUM MANAGEMENT AT ROCKY FLATS

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ABSTRACT

Some major technical considerations in plutonium materials management are discussed. This report is based upon practices developed and evaluated during nearly fifteen years of experience in large-scale plutonium chemical, metallurgical, and fabrication operations at the USAEC's Rocky Flats Plant. Particular emphasis is placed upon the problem of containment and on means of coping with loss of containment situations. Recent work on handling and measurement of plutonium shipments is summarized. Effective methods for plutonium handling and control during processing are described. Current problems in plutonium materials management are identified.

INTRODUCTION

From recent nuclear power growth predictions[1,2], it can be anticipated that plutonium may be the largest single source of electrical energy in the world by the end of this century. If this prediction is to become a reality, it will be of continuing importance to appraise and improve plutonium material management practices.

This report covers some of the technical considerations that are important in any operation requiring the handling, measurement, shipping, or fabrication of plutonium materials. It describes methods of safe and economical plutonium material management, and defines problems to which better solutions must be achieved if plutonium material management is to be further improved. Most of the information in this report is based upon experience obtained at the USAEC's Rocky Flats Plant.

Rocky Flats Plant Operations

The Rocky Flats Plant has been operated for the AEC by The Dow Chemical Company for nearly fifteen years. It is a production plant within the Albuquerque Operations weapons complex of the AEC. It is located 25 miles from Denver, Colorado.

The Rocky Flats Plant is one of the world's largest and most diversified facilities engaged in chemical, metallurgical, and fabrication operations with plutonium. At Rocky Flats, plutonium has been produced and fabricated in virtually every known way and form from laboratory scale on up. Rocky Flats has over 200,000 sq. ft. of plutonium working space. Within this perspective of experience gained in extended manufacturing and research operations with plutonium, the special problems in plutonium work will be discussed.

Properties of Plutonium

A reasonable place to begin is with the unique properties of the material plutonium. Because of its radio-toxicological properties, the maximum permissible body burden for deposition in bone is 0.6 micrograms. It is radioactive, displaying alpha, gamma, X-ray, beta, and neutron radiations. It is an extraordinary metal without equal in the diversity of its properties. The metal has six solid allotropes, one of which has a negative coefficient of expansion. The room temperature stable allotrope (alpha phase) has the unusual monoclinic structure. When unalloyed, it is as brittle as glass; when stabilized in its delta phase, the metal is as soft and ductile as lead. It is pyrophoric, corrodes in air, and is chemically reactive. Plutonium oxide is relatively hygroscopic. It can be extremely refractory and difficult to dissolve. In aqueous solution, plutonium exhibits the most complex chemistry of any element. It can exist simultaneously in four different oxidation states and in several different hydrolytic species. Plutonium has the unique nuclear property of including fissile (Pu-239 and Pu-241) and fertile (Pu-240) isotopes in major abundance. Dr. Seaborg has been quoted[2] as saying: "We chose Pu as the chemical symbol rather than Pl for the reason you would suppose".

Handling of Plutonium

The radioactive property of plutonium imposes the requirement that plutonium materials be handled in enclosures. Most plutonium work is performed inside glovebox enclosures. Consequently, our discussion of plutonium handling can be considered in terms of 1) the glovebox enclosures and accessory tools needed to ensure containment, 2) tools and procedures required to cope with loss of containment situations, 3) measurement of plutonium removed from gloveboxes, and 4) containers for enclosing plutonium during shipment or transfer.

GLOVEBOX ENCLOSURES

In its simplest form, the glovebox enclosure is a device for containing plutonium. To do this adequately, it ordinarily must be maintained at a negative pressure with respect to the surrounding atmosphere. Consequently, joints in the box must be tightly sealed and a ventilation system provided to maintain a negative pressure.

Ventilation Systems - The ventilation system must include filters to collect plutonium from the exhaust air stream prior to release to the outside atmosphere. If a controlled atmosphere is required in the glovebox, the ventilation system may include provision for recirculation after removal of water and/or oxygen. The cost of the glovebox facility is dependent upon the ventilation requirements. If the enclosure must be evacuated prior to purging with inert gas, adequate structural reinforcement must be provided. To demonstrate compliance with AEC safety regulations, an adequate exhaust stack sampling system must be incorporated to monitor discharge of radioactive materials.

Windows - Visual access into the glovebox enclosure is ordinarily provided by windows. These windows may be made of safety glass or of transparent plastics. A Plexiglas formulation (SE-3) provides excellent mechanical, optical, and chemical resistance characteristics over a long period of time and, in addition, is fire resistant. The importance of fire-resistant windows was realized after a glovebox fire at Rocky Flats in 1957[3]. This fire apparently began by spontaneous ignition of some plutonium metal foundry residues ("skulls" from the tops of castings). Sufficient heat was generated to ignite the methylmethacrylate window panels. As a result of the loss of containment, plutonium contamination spread into the room. A far more serious (and costly) situation resulted, however, when the box filters burned out and the partially-combusted fumes from the acrylic window material ignited in the exhaust filter plenum. The resulting explosions pressurized the building exhaust system forcing contamination into every room in the building. The resulting decontamination cost was many times greater than it would have been if the filter plenum explosion had not occurred. This incident emphasized the need for nonflammable glovebox filters and windows, and for rapid fire control procedures. Fire detection and control systems for the filter banks are also required to minimize catastrophic release of radioactivity[4].

Gloves - It is necessary to have access to the glovebox enclosure for hand manipulations. This is provided through gloves. The expense in time and materials for glove replacement can be a significant portion of the total operating expense. This can be reduced significantly through careful selection and specification of gloves. In the past year, a cost reduction of over $56,000 has been realized at Rocky Flats through use of Hypalon-coated gloves in boxes containing corrosive acids. Because of the relatively long life of these gloves, costs of purchasing and installing new gloves and of disposing of old gloves are minimized.

Leaded gloves (0.1 or 0.36 mm lead equivalent) are used in gloveboxes where additional radiation shielding is required. Multi-film construction of the heavy-weight gloves (0.36 mm lead equivalent) increases operating efficiency through greater hand manipulative action. As a result of the shorter time required for hand operations, radiation exposure problems are less apt to occur.

For gloveboxes in which it is necessary to minimize either diffusion of toxic gases out of the box or air and water vapor into the box, low permeability butyl gloves are used.

Shielding - If large amounts of plutonium are to be handled in a glovebox enclosure, it may be necessary to provide shielding so that the operator's gamma and neutron radiation exposure will not exceed the maximum permissible radiation tolerance. Gamma shielding can be provided through the utilization of leaded gloves mentioned above and through the installation of leaded glass overlays on the glovebox windows. A 1/4-inch leaded glass panel, protected on both sides with laminates of Plexiglas about 1/16-inch thick, exhibits acceptable optical properties and is resistant to chemical vapors and to thermal cycling.

The gamma radiation shielding requirement is governed by the abundance of the isotope Pu-241 and its decay products, Am-241 and U-237. Neutron shielding may be required if the plutonium contains a high percentage of the isotope Pu-240, which has a relatively high rate of decay by spontaneous fission (as well as by alpha emission). In addition, neutron shielding may be required for operations with plutonium in compounds with light elements. Neutron emission in the latter case is proportional to the cross-section of the light element for the alpha-neutron nuclear reaction. Relative neutron emission rates of plutonium and some of its compounds have been compiled by Birchall[5]. The neutron emission rate in neutrons per gram per second from plutonium due to spontaneous fission is approximately ten times the weight percent of Pu-240.

Present methods for neutron dosimetry[6] require that film calibration be done with sources of the same energy as exists in the process area. Knowledge of the neutron energy spectrum is, therefore, necessary. A typical range for a plutonium scrap recovery plant is 0.1-1 Mev. To limit exposure of personnel to neutrons, continuous hydrofluorination equipment at Rocky Flats, containing about 10-15 kg of plutonium tetrafluoride (up to 7% Pu-240), is operated from behind a 4-inch thick Plexiglas shield.

Research-size batches of plutonium, containing up to 16% Pu-240 and 3% Pu-241, have been processed[7] at Rocky Flats through operations of conversion of nitrate solution to metal, fabrication of metal, and scrap recovery. While these operations were successfully performed with direct material handling, the personnel radiation exposures were approaching maximum permissible limits. Specially-shielded or remote handling facilities may be required if plutonium compounds containing more than 1% Pu-241 are to be handled continuously in production-size batches.

At Rocky Flats it has been observed[8] that as much as half of the background neutron and gamma radiation in the scrap recovery plant is due to residual plutonium dispersed throughout the glovebox lines. Shielding concentrated around process equipment in the glovebox lines is, therefore, relatively ineffective in reducing background radiation.

Monitoring Methods - The major chronic source of loss of containment of the glovebox enclosure is through failure of the gloves. Failure is usually manifested by the occurrence of "pinholes". To minimize contamination, means must be provided for early detection of the failure. The most successful system devised for this purpose is that which makes use of individual hand monitors[9] mounted on the gloveboxes. The dry atmosphere in Rocky Flats plutonium buildings permits use of air proportional detectors which have either rechargeable batteries or charged capacitor power supplies. With these monitors available, the operators are required to check their hands every time they remove them from the gloves. These instruments, along with self-monitoring equipment located at the exits from plutonium-handling areas, assure early detection of glove failure. The "Combo" air proportional counting instrument[10] at Rocky Flats provides a rapid and simple means of self-monitoring hands and shoe covers. The ultimate control of airborne radioactivity is based upon measurements from a complete air-sampling system[11,12].

Nuclear Safety Controls - Handling of plutonium inside glovebox enclosures requires certain safeguards aimed at preventing the accumulation of a critical mass of a fissile material. This is done through administrative control covered in a "Criticality Procedure Manual"[13]. Controls are indicated by signs posted on each glovebox enclosure. These signs indicate the maximum amount of plutonium permitted in the box at any time. In addition to administrative control, other controls are used whenever practical. These may include the construction of racks so that there is a minimum distance separating containers of plutonium.

Within the glovebox enclosures, there may be processing equipment which contains residual amounts of plutonium. The ingenuity of the nuclear safety engineer and the process engineer can frequently be combined to design equipment which is inherently safe[14]. This design can take the form of annular cylinders or of cylinders with a maximum diameter of approximately five inches. Storage tanks for process solutions are frequently built using this concept.

Alternatively, chemical reactors, storage tanks, and dissolution equipment may utilize nuclear poisons[15] to maintain safe criticality control. Borosilicate Raschig rings have been used as poisons at Rocky Flats for over five years[16,17]. If properly tempered, these rings can be relied upon to withstand repeated shock[18]. A recent standard for their use has been issued by the American Nuclear Society[19]. Other poisons can be either of the fixed insoluble type, such as boron steel, or they may be of the soluble type, such as cadmium. Selective boron leaching from boron steel has been observed[20] in some corrosive solutions. Soluble poisons are not usually relied on for primary criticality control because of the possibility of segregation due to precipitation or adsorption.

CATASTROPHIC LOSS OF CONTAINMENT

In any operation which depends upon containment within a confined space, the possibility exists of loss of containment due to catastrophic explosion. Glovebox enclosures for plutonium present special hazards in this respect because of the pyrophoric properties of plutonium metal, the self-heating of plutonium in bulk quantities, and the chemical reactivity of plutonium metal and of some of its compounds.

Explosions from Combustion - It is obvious that one can minimize the possibility of explosion by prohibiting the use of flammable solvents, like acetone and alcohols, in glovebox enclosures in which an air atmosphere is used. In addition, restrictions should be placed on the use of solvents that, while not ordinarily considered explosive, may be reactive under certain conditions. For example, explosions have occurred[21] in gloveboxes where formulations of trichloroethane were being used as coolants during plutonium machining operations. Presumably the explosions resulted from the reaction of the trichloroethane and oxygen in the air. The source of ignition in these cases would have been burning chips of plutonium metal produced in the machining operation.

Other Explosive Reactions - In addition, several incidents[22,23] have been reported in which hot plutonium metal has reacted violently with carbon tetrachloride. Recent experiments[24,25] have shown the reaction between carbon tetrachloride and burning plutonium metal to be much more vigorous than between burning plutonium and 1,1,1-trichloroethane, perchloroethylene, chloroform, methanol, or water.

The common operation of purification and concentration of plutonium through anion exchange has been a possible source of three explosions[26,27,28] over the past few years. A similar incident has occurred in neptunium processing[29]. Ignition of dry nitrate-form anion exchange resins at temperatures above 100°C has been reported[30]. In one of the incidents reported[27], the explosion was attributed to contact of the resin with nitric acid (above 10N). The precise causes of the other incidents have not been determined.

Consequences of Loss of Containment - The loss of containment obviously has serious consequences. In economic terms, the most serious consequence is ordinarily the cost of decontaminating the area affected by the explosion. In some cases[3,26,31], this has run over $300,000. A second effect of loss of containment is that of personnel contamination through ingestion, inhalation, open wounds, or skin surface activity. Plutonium contamination cases at Rocky Flats from 1961 through 1965 are summarized in Table 1.

Diagnosis of Plutonium Retention in Humans - One of the most useful tools available for diagnostic purposes when open wounds are incurred during plutonium handling operations is the wound counter developed at Rocky Flats in 1957[32]. In this device, the 17-kilovolt X-rays from plutonium near the surface of the skin are measured. This instrument can be used to estimate plutonium contamination in wounds. The information can then be used as a guide to the attending physician in the decontamination or excision treatment.

Table 1

Plutonium Contamination Cases at Rocky Flats

Type of Case	Ave. No. of Cases per Year	Approx. % of Total People in Pu Area
Surface Skin Contamination	400	40
Contaminated Wounds	100	10
Contaminated Wounds Requiring Surgery	15	1.5
Detectable Activity Retained in Wounds	7	0.7

A second valuable diagnostic tool is the body counter[33]. Through methods developed recently at Rocky Flats, it is possible to estimate plutonium in the human body by measurement of the 60-kilovolt gamma radiation from the Pu-241 decay product, Am-241. While this method is an invaluable tool in providing early estimates of the amount of plutonium in the human body, there are some limitations in its use for an extended period of time after the exposure. These limitations are imposed by uncertainties in the mechanisms and the rates for translocation of plutonium and of americium within the human body. The method depends on having a known ratio of americium to plutonium in the body.

Therapy for Plutonium Retention in Humans - Therapy ordinarily used[34] in the event of plutonium exposure includes administering organic complexing agents for removal of plutonium from the bloodstream. The complexing agent DTPA (diethylenetriaminepentaacetic acid) has been widely used for this purpose. In some cases, it has been very effective. Its effectiveness depends[35] upon the form and manner in which the plutonium is introduced (soluble or insoluble) into the body. Recent studies[36] indicate that other complexing agents, such as TTHA (triethylenetetraaminehexaacetic acid), are more effective than DTPA in removing plutonium from animal organisms. Human studies have not yet been reported.

Psychological Effects - No systematic effort to study the psychological effects of working with plutonium has been reported. Fear (or anxiety) and somatic reactions to working with plutonium have been observed[37]. A better understanding of these psychological effects could aid in developing new approaches to design of plutonium work areas and to management of men working with plutonium. Similarly, understanding of the psychological reactions of persons carrying body burdens of plutonium could assist in devising more effective therapy.

Safety Performance - In view of the hazards involved in working with plutonium, it is reassuring to note that the best safety record achieved to date in an AEC plant is that of the Rocky Flats Plant whose major activity involves plutonium handling. This record of 24,295,542 man-hours without a disabling injury is also the fourth longest reported to date for all industry in the United States. Of the fourteen disabling injuries incurred since the start of the Rocky Flats operations in 1952, only four were due to plutonium contamination.

MEASUREMENT OF PLUTONIUM REMOVED FROM GLOVEBOXES

In-Line Analysis - Measurement of plutonium in process lines can be done using in-line colorimeters[38] or using instruments which detect the plutonium radiation. If no other significant amounts of alpha radioactive material are present, in-line alpha counters[39] can be used for this purpose. If moderate amounts of Am-241 are present, a simultaneous measurement[40] of alpha and gamma activity can be used to give the plutonium content of the process stream. Where relatively large amounts of Am-241 are present (as a decay product of Pu-241), the measurement problem is much more difficult. Adequate procedures have not yet been worked out.

Measurement of Transfers and Shipments - Bulk plutonium transferred from one operation to another can be measured either chemically or calorimetrically. In the case of shipments of plutonium oxide or metal in quantities of a kilogram or more, a convenient nondestructive measurement is achieved by measuring the thermal output from the container in a calorimeter[42]. A 1% difference between thermal and radiometric values for Pu-239 half-life remains to be resolved[43]. Solutions of plutonium cannot be measured in this way because of other reactions resulting from radiolysis of the solution. Chemical analysis of samples is used to give a measure of plutonium in solution shipments. While procedures have been worked out for this purpose, there have been instances in which analytical bias is reported[44] between laboratories.

Changes During Shipment - The major material changes occurring in a plutonium shipment are: 1) decrease of metal weight due to oxidation, 2) decrease of solution weight and increase of plutonium concentration due to evaporation, 3) decrease of oxide weight and increase of plutonium concentration due to moisture desorption from oxide (moisture adsorption could cause a weight increase and a plutonium concentration decrease), and 4) "heels" left in container after transfer of bulk material. Typical measured magnitudes of these changes are shown in Table 2.

The largest changes in Table 2 are those associated with concentration changes due to solution evaporation and adsorption or desorption of moisture from oxide. These changes also show the greatest variability. It is clear that accurate measurement of plutonium concentration in solution and in oxide is a critical factor in minimizing shipper-receiver differences.

Measurement Precision - In Table 3, the measurement precisions reported for plutonium metal, nitrate, and oxide are compared. The bulk measurement (weight or volume) uncertainty for these three forms of shipment is not significant. The nitrate measurement seems to be limited by the analytical determination of plutonium in solution. The oxide measurement is limited by sampling. Control of moisture in the atmosphere in which the oxide is handled may decrease the sampling error. If either of these variables were improved, the uncertainties of nitrate or oxide shipment could be close to that of the metal shipment. These uncertainties can be decreased by multiple measurement. To achieve the precisions for shipper-receiver difference shown in Table 2,

Table 2

Typical Material Changes During Plutonium Shipments

	Form of Shipment					
	Metal	Nitrate[44]		Oxide[45,46]		
Shipper	-	Hanford	RF	RF	Hanford	UK-AEA
Receiver	RF	RF	Hanford	Hanford	RF	CEA
No. of Containers	100	7	6	6	6	39
% Wt. Change	-0.06	-0.53	-0.31	-0.15	-0.01	+0.11[a]
% Pu Conc. Change	0	+0.79	+0.31[b]	+0.28	+0.15	-0.17[a]
% "heel" [c]	+0.06	+0.20	+0.18	+0.02	0	--
% Shipper-Receiver Diff. [(Receiver-Shipper)x100 / Receiver Value]	0	+0.45	+0.18[b]	+0.15	+0.14	-0.21[d]
Variability of Changes (% Pu)						
Std. Dev. of Wt. Change	±0.11	±0.08	±0.07	±0.04	±0.07	±0.46[a]
Std. Dev. of Conc. Change	0	±0.21	±0.12[b]	±0.20	±0.29	±0.30[a]
Std. Dev. of "heel" Change	±0.07	±0.07	±0.03	±0.01	±0.01	-
Std. Dev. of Shipper-Receiver Diff.	±0.11	±0.22	±0.11[b]	±0.16	±0.29	-

a. Change measured in 15 g PuO_2 samples shipped in separate containers.
b. Rocky Flats analyses used for all calculations.
c. "Heel" is material remaining in container after transfer.
+0.06% means 0.06% of plutonium shipped remains in container after bulk transfer.
d. Difference reported for 44.9 kg shipment (39 batches).

Table 3

Typical Measurement Precision for Plutonium Shipping Forms

Measurement Operation	Std. Dev. (% Pu)		
	Metal	Nitrate[44]	Oxide[45]
Weight or Volume	<0.01	<0.01	<0.01
Sampling	not measured	<0.07	0.20
Pu Concentration	0.05	0.20	0.06

duplicate analyses were run on four shipper and four receiver nitrate samples. For the oxides, duplicate analyses of three samples were used.

Measurement Accuracy - The major factors that have been known to cause measurement bias in recent studies are:

1. Bias in Plutonium Determination in Nitrate Solution. Average differences of nearly 1% in plutonium concentration were obtained for twelve interplant shipments[44] between Hanford and Rocky Flats. The difference was virtually eliminated when all samples were analyzed by the same laboratory. The reason for this difference and for other reported discrepancies between laboratories in plutonium nitrate analysis is not known. Nitrate solution can contain plutonium in four valences and in hydrolyzed and polymerized species. Changes can occur from chemical and radiolytic reaction mechanisms. An interlaboratory comparison program is currently being sponsored by the USAEC to evaluate methods for determination of plutonium in nitrate solution.

2. Moisture Exchange Between Plutonium Oxide and the Atmosphere. In the recent Rocky Flats study[45] and in the U.K.-France oxide shipment[46], the major cause of measurement bias was the adsorption or desorption of water[47] from oxide samples. The magnitude of this bias was 0.14% in the Rocky Flats-Hanford interplant studies. The bias can be eliminated by using the calorimetric measurement method which does not require either sampling or exposure of oxide to the atmosphere between shipper and receiver measurements. Presumably, the bias could also be eliminated by standardization of shipper and receiver glovebox humidity. The moisture problem is greater with plutonium oxide that contains more than 1% moisture or 4% other volatile impurities. Proper preparation of oxide yields a sufficiently stable material.

For maximum accuracy, other factors that can cause bias must also be carefully controlled. These include proper bulk measurement calibration, representative sampling, complete transfer of material, and analytical standardization.

SHIPPING PLUTONIUM

Approved Containers for Plutonium - Materials removed from the glovebox for transport to another location may be shipped in a variety of containers. The containers must be designed so as to satisfy Nuclear Safety and Industrial Safety requirements. If transportation is to be by a common carrier, the containers must meet the ICC, Coast Guard, FAA, or IATA requirements. In addition, they must meet USAEC Division of Material Licensing requirements. Several containers have been designed for plutonium shipment which have met these requirements. The birdcage design was first adopted[48] for plutonium metal shipment. Two sizes (3-liter and 10-liter) of nitrate solution shipping packages have been designed[49] to meet proposed AEC Fissile Class I and II requirements. Packages have also been designed and tested[50] for plutonium oxide in accordance with Fissile Class I and II requirements.

Economics of Shipment - Table 4 summarizes the major cost components for shipping different forms and different amounts of plutonium. Plutonium metal is the most economical shipping form now known. However, there would be a serious economic penalty in converting nitrate to metal solely for shipping convenience. The USAEC has published a cost of $1.50 per gram ($1500 per kilogram) for converting nitrate solution to metal. The same argument applies to the conversion of nitrate to oxide for shipping convenience. This conversion would cost over $100 per kilogram. If the shipper can produce an oxide that is directly usable by the receiver, the oxide form of shipment becomes most economical.

The development of larger shipping containers for plutonium nitrate could give the nitrate form an economic advantage. The nitrate would also have an advantage in situations where the processor and/or the receiver do not desire to convert a nitrate solution to oxide, or where the oxide needed for processing purposes was not compatible with that required for safe shipment and accurate measurement.

The unit cost of shipping plutonium is within a factor of two of $100 per kilogram. This is the same range as the anticipated cost of fabricating plutonium into fuel elements for fast reactors (20% plutonium - 80% uranium). At the USAEC price for plutonium of $10,000 per kilogram (for Pu-239 and Pu-241), the shipping cost is about 1% of the plutonium value. Shipping can be a significant factor in the economics of using plutonium, and even small reductions in unit shipping cost can be important in commerce.

Present Status of Plutonium Shipping - Plutonium can be shipped as metal, nitrate, or oxide with measurement uncertainties less than 0.1-0.2% if proper procedures are used. The most critical procedures are those related to analytical determination[44] of plutonium (in nitrate solution) and exposure of plutonium oxide and metal to atmospheric moisture[45,46,47]. Instability can be caused by hexavalent plutonium in nitrate solutions and by incomplete calcination of plutonium oxide.

Recommendations for Improved Plutonium Shipping - Three main areas of investigation have been recommended[51] for improvement of the safety, measurement precision, and cost of plutonium shipping.

1. The safe shipping of large quantities of plutonium nitrate solution requires a better understanding of the radiation chemistry in the solution. The mechanism of radiolysis in plutonium nitrate solutions is not well understood. The radiolysis

Table 4

Estimated Plutonium Shipping Costs[51]
(Class I, 2000 Miles, Rail)

	Nitrate Solution[47]		Oxide[48]	Metal
Kg Pu/Package	2	50[a]	6	6
Container Cost ÷ 25[b]	$30/kg Pu	$ 5/kg Pu	$ 1/kg Pu	$ 1/kg Pu
Filling	44	5	20	20
Analysis	23	5	40	15
Transport	66	20	6	6
Receiving	37	5	19	23
Total $/kg Pu	$200/kg Pu	$40/kg Pu[a]	$86/kg Pu	$65/kg Pu

a. Estimated cost for a 200-300 liter shipping container - not yet designed.

b. Container life of 25 shipments assumed.

mechanism is closely related to the gas production phenomena which presents a possible means of loss of containment.

2. The determination of plutonium in nitrate solutions is not as precise as that of plutonium in solid materials. If the advantages of shipping plutonium as a nitrate solution are to be fully realized, a better understanding, and an improvement in the precision, of the methods for determining plutonium in nitrate must be achieved.

3. Because of the strong dependence of unit shipping costs on the amount of plutonium in the container from which a sample must be taken, one of the most obvious directions for reduction of unit costs is to develop larger solution containers. The larger shipping container for plutonium nitrate solution presents engineering problems in structural integrity and containment. To surmount the nuclear safety hazards involved, it is necessary to utilize criticality poisons or to go to geometrically-safe containers.

SUMMARY

Some of the new or unique tools used at Rocky Flats as aids to safe and economical plutonium materials management are:

1. Improved leaded gloves
2. Hand alpha self-monitors
3. Hand and foot "Combo" self-monitors
4. Criticality "safe" geometry equipment
5. Borosilicate Raschig ring neutron poisons
6. Wound counter
7. Body counter for plutonium measurement
8. In-line alpha-gamma counter for Pu-Am solutions
9. Bulk waste gamma-neutron counter
10. Calorimetric method for bulk plutonium measurement
11. Shipping containers

Some of the problem areas in which solutions would improve safety and economy of plutonium materials management are:

1. Decreased explosion hazard for solvents in gloveboxes.
2. Decreased explosion hazard for plutonium anion exchange resin.
3. More accurate measurement of plutonium retention in body over extended time periods.
4. Improved therapy for plutonium removal from body.
5. Knowledge of biochemical equilibrium of plutonium in body.
6. Understanding of psychological effects of plutonium work and of body retention of plutonium.

7. In-line measurement of plutonium in waste streams containing americium.
8. Resolution of Pu-239 half-life discrepancy and of uncertainties in gamma radiation assignments for more accurate measurement of plutonium in waste streams.
9. Larger plutonium nitrate solution shipping containers.
10. Better understanding of radiolytic and chemical reactions in plutonium nitrate solutions that may cause polymerization and precipitation or other instability affecting measurement accuracy.

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