**COMPARATIVE COSTS
OF OXIDE FUEL ELEMENTS
VOLUME 2**

**PROCESS FACILITY DESCRIPTION
AND COST ESTIMATES**

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DECEMBER, 1966

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DEVELOPMENT REPORT**

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VOLUME 2

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FOREWORD

Initially, this report was given limited distribution for review and comments in January, 1967. Results of that review have been incorporated in this report now issued in February, 1968 for standard category distribution.

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

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PROCESS FACILITY DESCRIPTION AND COST ESTIMATES

INTRODUCTION

The purpose of this study is to investigate the feasibility of fabricating plutonium with high photon and neutron dose rates in a glovebox facility, and to determine the comparative costs of fuels fabricated by vibratory compaction and pelleting processes. Most parameters of the study and the detailed fuel cost analyses are presented in Volumes 1 and 3. This volume of the study will describe the building, equipment, shielding requirements, and costs for the conceptual 1 metric ton/day fuel fabrication plants. Six glovebox facilities have been conceptually designed to study the processes and cost of fabricating UO_2 and PuO_2 enriched fuel elements.

It is indicated that some 20,000 to 25,000 kg of plutonium will become available from this country's commercial reactors within the next decade. Large capacity fuel-fabrication plants will be necessary if this material is to be utilized for power-reactor use. Although uranium fuels have been commercially produced in large quantities, all plutonium enriched fuel elements produced to date in this country have been fabricated in pilot scale laboratories. Considerable plutonium fabrication experience and knowledge have been gained by this type of operation,⁽¹⁾ and is applicable to the development of the large-scale production plants that will probably become a reality within the next few years.

A study was made in 1962 by Hanthorn⁽²⁾ on a 1 ton/day fuel plant, but this study did not consider processes requiring radiation shielding. Since several years of additional fabrication experience have been acquired, an up-to-date study of that plant size is presented.

SUMMARY

The feasibility of fabricating 1 ton/day quantities of reactor fuels enriched with UO_2 , and PuO_2 was investigated. Also, fuel manufacturing and construction costs were estimated, and work was performed on the conceptual design of facility and equipment. One-ton per day study plants were conceptually designed for the manufacture of a reference fuel element by pelleting and vibrational compaction processes. Six cases were studied, and the basic assumptions, objectives, and manufacturing cost analyses are reported in Volume 1 of the study report. The plant design assumptions were based on present or projected processes, and on the available, or calculated plutonium dose rate information. From available dose rate information, it seems apparent that fully decontaminated plutonium produced from most power reactors can be fabricated in shielded glovebox facilities. The conceptual plant descriptions, and estimated costs for the buildings, equipment, and shielding are presented in this volume. Even though new processes may be developed or present processes eliminated, the conceptual designs and costs presented here should remain nearly valid for several years. The cost of fuel elements produced by similar processes is comparable for the different enrichments, and deviations from the study costs presented in Volume 1 would occur principally from changes in cladding and fuel prices. Cost variations are presented in Volume 3.

DEFINITION OF TERMS

Only recycled plutonium that is fully decontaminated at the time of separation should be considered for glovebox processing operations. Photon radiation dose rates from fully decontaminated material will be higher than those from nonrecycled material. It has been calculated that plutonium produced from high exposure reactor fuel will also have small amounts of Pu^{236} and Pu^{238} which will contribute, in addition to

the Pu^{240} , a significant number of neutrons to the total dose rate. The isotopic composition of the high dose rate, reference enrichment plutonium is shown in the following table.

ISOTOPIC COMPOSITION OF HIGH DOSE RATE REFERENCE ENRICHMENT
PLUTONIUM

Pu^{236} (ppm)	Pu^{238} (wt%)	Pu^{239} (wt%)	Pu^{240} (wt%)	Pu^{241} (wt%)	Pu^{242} (wt%)
0.047	1.1	62.2	21.2	12.7	3.8

The above isotopic composition will also be referred to in the text as high exposure plutonium. The dose rates have been calculated from the equations presented by Faust.⁽³⁾ They are time dependent for the photon radiation, and an arbitrary material age of 100 days after separation was selected for calculating the shielding requirements. Fuels enriched with decontaminated plutonium having "high" photon and "medium" neutron dose rates have been fabricated in glovebox facilities,⁽¹⁾ but plutonium with high neutron dose rates has not been available for fuel fabrication.

The terms "low exposure," and "high exposure" plutonium are used in the study cases and when used within the proper frame of reference, they are applicable to all plutonium isotopic compositions. There has been no real effort as yet to formulate generally acceptable definitions for the terms; so for the purpose of this report and for interim use within Battelle-Northwest, the following definitions are used.

Low exposure plutonium is defined as material with over 80% Pu^{239} , while Pu^{240} content will generally be less than 12%. This composition, for example, may typically result from the exposure of slightly enriched uranium fuel in light water moderated power reactors to less than 10,000 MWd/ton. The Pu^{238} content will typically be less than 1/2%.

High exposure plutonium is defined as material with less than 80% Pu^{239} , with the Pu^{240} content nominally in the 15 to 25% range, and Pu^{238} in the 1/2 to 5% range. This material would be typically obtained from slightly enriched fuel exposed in most light water moderated power reactors beyond 10,000 MWd/ton. Other isotopes such as Pu^{236} , Pu^{241} , and Pu^{242} also contribute to the total radiation dose. The dose from Pu^{241} increases with time after separation due to the growth of daughter products.

Differences of opinion and misunderstandings can easily occur when the term "remote" is used in reference to fuel fabrication facilities. It is advantageous to automatically perform, or use mechanical aids for all applicable processes in a glovebox fabrication plant in order to economically attain operation efficiency and reduced personnel exposure. Glovebox facilities should not necessarily be described as "remote" just because applicable process operations are done without manual contact. Contact maintenance can be performed on remotized glovebox operations, and can also account for a considerable saving in time and expense over the fully remote maintenance required for hot cell operation.

PART I. DESIGN CRITERIA

ASSUMPTIONS

The assumptions used in this study are for the conceptual design of privately built and operated 1 ton/day fuel plants. The assumptions are believed to be basically applicable to any fuel fabrication plant.

Reference Fuel Element

A fuel element of advanced design generally representative for the industry was chosen. Basically, the reference fuel element was the one designed for a 1,000 MWe PWR reactor.⁽⁴⁾ The more important fuel element design features are summarized in Table 1.

TABLE 1. *Reference Fuel Summary*

Fuel length	132 in.
Tube O. D.	0.402 in.
Tube wall	0.022 in.
Number of tubes per assembly	234
Number of spacer grids	10
Zircaloy tie rods	2
Effective fuel density	9.70 g/cm ³
Goal average burnup	24,000 MWd/MT _U
Enrichment (total fissile)	3.0%
Total weight oxide per assembly	494 kg

Plant Capacity

To compare two processes utilizing three enrichment modes for each, six plants were designed for the reference fuel element. The plants are identified by number (Table 2). The plants were designed to have a capacity of 1 metric ton/day on the basis of a two shift, five-day per week operation, which amounts to one fuel element per shift or 502 fuel elements per year. The two-shift operation allows a maximized plant to be utilized and still provide ample maintenance time necessary for sustained production.

TABLE 2. *Cases Studied*

<u>Plant No.</u>	<u>Production Method</u>	<u>Fuel Composition</u>
1	Vibrational-Compaction	3% enriched UO ₂
2	Vibrational-Compaction	2.50 wt% PuO ₂ (92% fiss)-nat UO ₂
3	Vibrational-Compaction	2.88 wt% PuO ₂ (80% fiss)-nat UO ₂
4	Pellet	3% enriched UO ₂
5	Pellet	2.50 wt% PuO ₂ (92% fiss)-nat UO ₂
6	Pellet	2.88 wt% PuO ₂ (80% fiss)-nat UO ₂

Plant Location

It is assumed that the plant will be located in the midwest; however, a change in location within the United States will make little difference in construction costs.

Building

In this study the use of existing facilities has been discounted. A steel frame building with insulated steel siding is selected because of the versatility and wide acceptance of this design. The building can be readily expanded, and lends itself to interior finishing of only the nuclear processing area. A basement is provided under the process area. The building must be airtight for contamination containment and satisfactory operation of the ventilation system.

Equipment Selection

The equipment is near standard, where possible, for easy repair and replacement. It is sized to the production rates on a practicable basis, but cannot, in most instances, be sized to the exact requirements. Standby equipment is included only where it is necessary for maintaining production. Shielding, gloveboxes, and installation changes are included in the cost of the equipment.

Nuclear Material Containment

Uranium in powder form containing greater than 1% U^{235} , are contained in airtight enclosures. Enriched UO_2 fuel is generally processed in slightly lower quality UO_2 gloveboxes than is plutonium. For operations where the gloveboxes are subjected to severe service, the quality will be identical.

Nuclear Material Control

The process line is designed to allow the material batches and process flow to be maintained in subcritical amounts. Other

than plutonium storage, the amount of plutonium at any step of the operation will not exceed approximately 1 1/2 kg, or one-half the administrative limit. This amount of plutonium will be contained in 48 kg of fuel material, the largest fuel batch. Critical spacing for large batches of rods is required.

Shielding

The shielding will allow the operators to work full time without exceeding the administrative limits of 4 rem/yr. The shielding is to be removable for maintenance access.

Glovebox Atmosphere Supply

It is assumed that fuel processing will be done in dry air in order to maintain acceptable moisture content in the fuel. The plutonium gloveboxes will also be capable of containing inert atmospheres, should they be required. Piping is included in the building costs for dry process air and inert gas. Storage tanks for liquid inert gases are furnished by the gas supplier.

Waste Disposal

Waste material will receive only the minimum treatment necessary for disposal by a commercial contractor.

Utilities

It is assumed that water, electric power, and telephone facilities will exist near any chosen plant location.

Laundry

No provisions are made for in-plant laundry as commercial laundries are available. Basement space will be available if the operator chooses to install laundry equipment.

Fire Protection

Fire detection and protection equipment are included so that it is not necessary to rely on others for fire control.

COSTS

It is assumed from past experience that building equipment and shielding costs will not escalate over the next five years beyond the allowance (1%/yr) and the estimating errors.

SAFETY AND CONTROL REQUIREMENTS

The following safety and control requirements are presented here as examples, and are based on extensive operating experience in the PNL. They are applicable for any assumed design and process criteria.

Analytical Equipment

Analytical results are required on a timely basis to maintain production schedules. In-plant analytical facilities are necessary to provide fast results. Samples are delivered to the analytical facilities by pneumatic tubes in order to prevent costly bagging and packaging operations. The quality of water content analyses is also enhanced by a system such as this in which the test is run immediately after sampling.

Building Ventilation

An adequate ventilation system is required for contamination control and the air is circulated through the building only one time. Approximately 10 air changes per hour will provide good control for a plutonium facility, but equipment to provide 15 air changes per hour is included to insure adequate emergency backup. One-third of the ventilation equipment is supplied with emergency power. High-efficiency filters are used in the ventilation exhaust to provide environmental control of plutonium.

Criticality Control

Provisions in addition to the ones mentioned in the assumptions are required for criticality control. The line is designed to have control stations so that computer control of the process flow⁽⁵⁾ can be used in conjunction with standard criticality control methods. Physical barriers, remotely operated, may be

necessary to achieve the desired control, and locations for such barriers are included in the glovebox line.

PROCESSES

A reactor fuel element design, believed to be representative of the industry needs for the next five years, was selected to serve as a basis for this study. Process flow sheets were established for the manufacture of the reference fuel element by two processes, pelleting and vibratory compaction. It was necessary to write the flow sheets in computer form to study the fuel fabrication costs. These flow sheets are shown in Volume 1. The line numbers on the computerized flow sheets and on the computer runs must, of course, correspond, and the cumulative information on the process steps is very comprehensive. However, it is time consuming to follow a particular process in this manner; therefore, to more easily discuss capital costs, process flow sheets without the computer line numbers will be used. All subsequent references to the processes or equipment will be based on the process flow sheets shown in Figures 1 and 2. A detailed discussion of the processes is given in Part 4, and consolidated unit costs are given in Part 5.

Vibrational Compaction

The vibrational compaction flow sheet (Figure 1) is a composite for Cases 1, 2, and 3. The processes are almost identical to that shown on the flow sheets except that containment and shielding vary with the type of enrichment. Case 1 utilizes uranium enrichment while Cases 2 and 3 use low and high exposure Pu respectively.

Pellet Fuels

The pellet fuel process flow sheet (Figure 2) is a composite for the three enrichments, and represents Cases 4, 5, and 6. The only process difference between the UO_2 (Case 4) enriched fuel, and the PuO_2 (Cases 5 and 6) enriched fuel is in the fuel preparation steps. The UO_2 fuel preparation is shown on the left, with a dotted line used to show the proper processing sequence. In this case, mixing and blending are not required.

FIGURE 1. Vibratory Compacted Fuels; Process Flow Sheet, Cases 1, 2, and 3

FIGURE 2. Pellet Fuels; Process Flow Sheet, Cases 4, 5, and 6

The PuO_2 preparation (shown on the right) is identical for Cases 5 and 6. The weighing, mixing, and blending operations would actually be in the same glovebox even though they appear as separate steps on the flow sheet. The tubing preparation steps and the operations following the final fuel closure are nearly identical for all cases.

GENERAL DISCUSSION OF DESIGN CRITERIA

Production type glovebox facilities for handling large amounts of plutonium fuel materials, similar to the study plants, have never been constructed. Facilities of this type will require heavy duty gloveboxes and production innovations that normally have not been used in the past. However, the general design and operational experience acquired in the past will be applicable for designing the larger plants. A generalized discussion of glovebox facility design criteria is pertinent to this report.

Plutonium is a highly toxic alpha-emitting material, and extreme caution must always be exercised to prevent it from spreading. This can only be accomplished by keeping it confined at all times by the use of gloveboxes, located in facilities, especially designed for handling alpha-emitting materials. All glovebox facilities are similar in principle, but are usually specialized for an intended function. They may be designed specifically for aqueous or chemical processes, non-aqueous or metallurgical processes, or a combination of the two to accomodate integrated process. The outstanding feature of chemical facilities is the use of corrosion resistant materials wherever they come in contact with process chemicals. Metallurgical facilities, which are analogous to the fuel fabrication study plants, usually need materials of only minimum corrosion resistance. Piping, drains, and duct work of ordinary

materials such as aluminum, steel, cast iron, and vitrified clay are satisfactory. Underground exhaust ducts may be constructed on concrete or transite.

Glovebox facilities should be designed to provide adequate services, dependable ventilation systems, contamination control and containment, contaminated waste disposal, and arrangement flexibility. Structures with these features provide the necessary health protection and allow timely and economical process and equipment changes. The requirements for glovebox facilities will vary with purpose, location, and economic limitations, but they must be determined to establish the criteria needed for detail design. There are no precisely established design standards for glovebox facilities, but well recognized requirements for safe facilities have evolved from the vast amount of operational experience. Extensive use is made of nationally recognized construction standards.

Structures

Structures used to house plutonium gloveboxes should be considered as a containment shell for gross contamination incidents, and should be as nearly air-tight as possible. Gloveboxes are considered as the primary plutonium containment enclosure, the surrounding room as the secondary containment, and the structure as the ultimate containment. The compartmentalization shown in the study drawings is conceptual only and would probably be arranged differently in an actual fuel fabrication plant. Compartmentalization has not been universally practiced in plutonium laboratories, but it is desirable for containment control in facilities that handle plutonium in gross quantities. Nonload-bearing walls and systematic ventilation duct arrangement allows almost

unlimited room arrangement. The structure should be maintained at a negative pressure of about 0.1 in. of water to atmospheric pressure, and the glovebox at approximately 1.0 in. of water referenced to the structure pressure. Plutonium processing areas should have smooth, painted interior surfaces, which are easiest to decontaminate, and a minimum number of exposed service ancillaries. Coatings should be at least mildly acid resistant. Floor coverings are subjected to abnormally high usage around gloveboxes, and are the surfaces most likely to become contaminated.

All building functions and equipment not required in the zones of high contamination potential should be located in contamination-free zones. Such items are the ventilation equipment, service headers, electrical bus duct and switch gear, stairways, maintenance shops, store rooms, change rooms, non-nuclear processing areas, and other items of similar nature.

Change rooms are located adjacent to laboratories and provide facilities for storing clean protective clothing, lockers, personal decontamination, showers and toilets.

Services

Many auxiliary services, (i.e., waste disposal, fire department, power, water) are required for the support of a glovebox facility. All or part of these services may be available from other nearby sources, but the number to be provided should be determined before an attempt is made to establish the facility arrangement. The large production reactor sites and the National Laboratories have services readily available, but they must usually be provided for other installations.

Ventilation Systems

The ventilation scheme in a plutonium facility is usually arranged so that the air flows from the least to the highest potentially contaminated zones. Gloveboxes are the highest

potential source of contamination and the surrounding area the next highest. Access corridors should be controlled so they are virtually free from contamination potential. All zones should be negative with respect to the atmosphere, and the gloveboxes should have the greatest negative pressure.

Ventilation supply should have a downward flow of about 10 air changes an hour. A flow path of 12 to 15 ft has proven very effective in confining contamination releases to a localized area.

All air entering the facility should be filtered to remove dust, and all discharged air must be filtered with high-efficiency filters to prevent the release of plutonium contamination to the environs. Ventilation systems should be provided with emergency powered fans to ensure continuous airflow. Should all ventilation fail however, the structure should "breathe" through high efficiency filters to accomodate variations in atmospheric or building pressure. Ventilation systems should be designed to maintain a constant building balance even with changing airflows. Intentional balance upsets in a laboratory should not effect the balance in the adjoining laboratories. Ventilation balance may be controlled with manually operated or automatically modulated dampers, and combination of the two usually provides the most stable balance conditions.

Filters

High efficiency filters are used in glovebox facilities to remove particulate plutonium from the airstreams. The filter flow capacity is rated at a pressure differential of 1 in. of water, with the flow capacity approximately linear to the pressure drop. They are designed 99.95% efficient for removal of 0.3 μ particles, as determined by the DOP

test, (dioctyl phthalate particles). A more graphic example of the filter efficiency is that it will not pass cigarette smoke.

The filters are fabricated from accordion pleated media and installed in a wooden framework to protect the filter and provide a convenient, easily mounted unit. The frames are usually treated with a fire-resistant material. Fire-resistant media that will withstand 100% humid conditions are available. Filters should be installed on metal frames; they should fit in the mounting bolts loosely because swelling or forcing may destroy the filter integrity. To effect a leak-tight seal, gaskets should be compressed to about 70% of the original thickness. Mounting frames must also be straight and free of surface irregularities. Dust-stop filters are often used to protect the high efficiency filter from premature loading, thus greatly extending the filter life.

Pyrophoric dust, oil films, and other combustible materials will cause fire resistant filters to burn readily. Filters may be protected from these materials and from direct flame by wire mesh prefilters. Since filter dimensions may change as improvements are made, glovebox facility designers should obtain the latest manufacturers data before designing filter holders.

Monitoring

Systematic and continual alpha monitoring in glovebox facilities is required. Surface contamination can be easily detected with alpha monitors called "poppies," but air monitoring is much more difficult. It requires special equipment, and is usually provided as an integral part of the facility. Although some portable air samplers are used, a central sampling vacuum system with permanently installed sampler heads is usually employed. Room air is drawn through sample paper at a known rate for the sample period, usually 24 hr. The short

half-life alpha emitters, such as radon and thoron, are allowed to decay, and the sample is counted in an integrating instrument. The maximum permissible concentration (MPC) of Pu^{239} in air is $2 \times 10^{-12} \text{ } \mu\text{Ci}/\text{cm}^3$. Criticality detection and alarm systems are mandatory in all Battelle-Northwest laboratories containing fissionable materials.

Waste Disposal

Most of the contaminated waste generated in metallurgical facilities is dry and can be disposed of by burial. Contaminated liquid wastes are usually of small volume and must be stored in a suitable manner. Cooling water from furnaces, vacuum pumps, etc., with only slight contamination potential, will usually be the largest waste source, (hundreds of thousands of gallons per year) but presents only a negligible problem as it can be safely released to the ground after holdup and monitoring. Closed-loop water recirculating systems are desirable for applications with high contamination potential. Evaporation facilities for reducing the volume of low-level wastes are very desirable.

Gloveboxes

Gloveboxes used in plutonium facilities are basically composed of transparent viewing windows, gasketed to a frame (usually metal), to provide enclosures that are essentially airtight. Port rings are joined to the windows or frames for the attachment of arm-length gauntlet gloves, and provisions are made for material entry and exit. Ventilation openings are covered with high-efficiency filters to provide plutonium containment.

Glovebox Types

The wide variety of operations that have been performed within gloveboxes has been the incentive for many ingenious

designs and innovations. Regardless of the varied uses, however, gloveboxes may be roughly divided into two functional categories. The first and most extensively used functional group is the general purpose type of glovebox. These boxes are often standardized modules that may be used individually or interconnected to form various sized units or glovebox lines. A variety of these units are commercially available, or they may be designed by the user and fabricated by a commercial vendor. The operations to be performed in this group are adapted to the glovebox, usually for the sake of economy.

Operations involving the use of full-scale fuel fabrication equipment, however, are not readily adaptable to general purpose gloveboxes, and form a second functional group. The major problems encountered in this type of operation are operability and maintenance access to the equipment. In specialized designs of this nature, the equipment may be an actual part of the glovebox; this not only provides better working access but allows standard or near standard equipment to be used. The use of manufacturers' standard equipment and specially designed gloveboxes will often be more economical than the adaptation of equipment to a general purpose glovebox. Various ventilation schemes are equally adaptable to any type of glovebox.

Instrument lines and ventilation systems become an integral part of the glovebox, and testing for leak tightness should be done after the glovebox has been completely installed. Gloveboxes are satisfactory for containing inert atmospheres if the maximum leak rate does not exceed $0.25 \text{ ft}^3/\text{hr}$ per 100 ft^3 of hood volume at a static pressure of 4 in. of water.

Materials of Construction

Gloveboxes are relatively expensive, and many materials have been used in an effort to provide low cost enclosures. These have not always been commensurate with the service criteria

however. Acrylic plastic, fiberglass, plywood, aluminum, carbon steel, and stainless steel have all been used.

Acrylic plastic, fiberglass, and painted plywood gloveboxes have at times been unwarrantably used, but they are useful where fire danger does not exist. Flexible plastic such as PVC and polyethelyene supported by a metal framework have also had limited application, especially for supplemental containment or "green house" work. Rigid PVC is useful for corrosion resistance to HF, but is not economical for ordinary glovebox construction.

Aluminum has been used extensively for glovebox construction and has been satisfactory for many applications, especially when the standard recognized design and fabrication practices for aluminum have been employed.

Due to corrosion, the use of carbon steel for gloveboxes is rather impractical. Protection of the carbon steel surfaces with corrosion resistant coatings is not completely satisfactory because the coating integrity is difficult to maintain.

Stainless steel is the material most extensively used for glovebox construction, and it has many advantages over any other single construction material. The ready availability and excellent corrosion resistance of 304L has made this a very popular material for general purposes. Stainless steel glove boxes are still quite expensive, but the relative cost has been diminished by the accumulation of fabrication experience and by the use of local standardized details of construction. Glovebox supports are usually made of carbon steel structural shapes, painted to resist rust and corrosion.

Viewing Windows

The size of glovebox viewing windows should be determined by the functional criteria. Large windows are preferable because

they provide viewing ease, better interior lighting, and less operator fatigue. Windows are gasketed to provide airtight seals and an increase in the gasket area presents a correspondingly greater leak potential. However, good gasket and joint design will provide essentially leak-free window seals even for large windows. (e.g., leak rates less than 0.25cfh per 100 ft³ of box volume are regularly achieved). If gloveboxes are subjected to severe chemical service or if massive gamma shielding is required, the advantages in using small windows would offset the disadvantage of limited viewing.

Even though gloveboxes may be virtually leak-free, they are operated at a negative pressure because, in service they could develop small leaks. With a neutral or positive pressure, plutonium could be released to the surrounding room atmosphere, particularly in the case of a torn rubber glove or plastic bag. A further advantage of negative pressure is that the gloves are conveniently kept inside the box.

It has been well established that linear flow of 100 ft/min through an opening will prevent the escape of plutonium or other particulate material if severe internal turbulence does not exist. This amount of flow is just the effective minimum, and a safer flow value of 150 ft/min is commonly used. This flow rate can be used for airlock door openings and all accidental openings of reasonable size. The largest probable accidental glovebox opening such as in the largest plastic bag ring should be a factor in determining the capacity of a ventilation system. The emergency flow rate should yield a linear flow of 150 ft/min through the opening, plus a reserve capacity of at least 100 ft³/min. Should the largest bag port be the same size as the glove rings (usually an 8 in. diameter), the area of at least two glove rings should be used. Filters

with a capacity of 50 ft³/min, rated for a 1-in. pressure drop, are normally used for glovebox applications. Thus, the number of filters needed for a glovebox application can be determined if the exhaust line static pressure and the emergency flow requirements are known. The exhaust line should be maintained at a static pressure in the range of 4 to 6 in. of water. A central exhaust system with standby equipment will insure continuous glovebox exhausting under normal conditions.

Many materials have been used for glovebox windows, but none have all of the desired qualities. The principal materials that have been used are acrylics, such as Plexiglas; a polymerized polyester resin, called Homalite; and safety glass. The window material is normally selected to meet the functional criteria, but the selection is often a marginal choice.

Glovebox Ventilation

The gloveboxes first used for radioactive materials were relatively unsophisticated and leak rates were quite high. Containment strongly depended on maintaining a pressure below the surrounding atmosphere to insure that all leakage was inward. Gloveboxes were originally used to achieve inert atmospheres with nonradioactive materials, and a slightly positive pressure was used to exclude oxygen. Gloveboxes have been vastly improved and many are virtually leak-free, but plutonium containment boxes are still operated at a negative pressure. This may be accomplished with small individual ventilation fans, or with a central exhaust system serving all boxes in a facility (which is usually more desirable).

The two basic systems for maintaining glove boxes at negative pressures are the dynamic or continuous-flow system, and the static or limited-flow system. The systems are equally adaptable to individual gloveboxes or interconnected glovebox lines.

A static or limited flow ventilation system should be capable of providing either a static atmosphere or a variable controlled flow with a maximum of at least 150 ft³/min. The system will automatically maintain a specific negative pressure when self-sensing supply and exhaust control valves are used. An automatically attained emergency exhaust rate of about 450 ft³/min is desirable for a glovebox ventilation system.

Fire and Explosion Protection

There are several fire detection systems applicable to glovebox use. One very effective system utilizes a small-diameter tube containing a salt-impregnated ceramic core. The salt solution is designed to melt at a predetermined temperature and becomes conductive to complete an alarm circuit. The system is accurate to within 5 °F and is self-restoring. Detection systems may be used as warning systems only, or may be used to activate a fire-control system.

Burning paper, rags, solvents, etc., may be easily extinguished with dry chemical powder, with no danger of pressurizing the glovebox. The extinguishers may be used manually or incorporated into an automatic system. A high-expansion foam system blanketing a glovebox interior has been tried and may prove to be satisfactory for fire control.

Explosions in gloveboxes can be controlled by explosion suppression equipment, but this equipment presently requires detailed, custom-tailored installation, and only a limited number of devices have been installed in gloveboxes.

PART 2. PLANT DESIGN

STRUCTURES

The process structures are nearly identical steel framed buildings with insulated steel siding. The cost is almost as much as concrete and masonry structures, but they were chosen

because the steel construction offers many advantages for a commercial operation. The buildings are very adaptable for rearrangement, expansion, or interior finishing of the nuclear processing areas, which are finished by furring between the steel beams with steel lath and plaster. Finishing is done to provide smooth wall surfaces for decontamination. The autoclave room in each structure is attached to the main structure and is constructed of reinforced concrete. It is located to provide a convenient process flow.

The ventilation exhaust system is located in the basement in such a manner that building expansion will not effect the operation. The basement is also used for storage, auxiliary or ancilliary equipment, and processing operations. A large elevator is provided for equipment and fuel element storage container movement between the basement and first floor.

A maintenance shop is equipped with light equipment only and is used for routine maintenance, while equipment fabrication or noncontaminated machine work will be done in a commercially operated shop.

PLANT LAYOUTS

Studies

Six, 1 ton/day fuel fabrication plant designs were required to study comparative fuel costs and the feasibility of fabricating high exposure plutonium in a glove box facility. Two processes, vibrational compaction and pelleting, and three enrichments-- U^{235} , low exposure PuO_2 , and high exposure PuO_2 --are used. Since this is a comparative study, all factors should be as nearly equal as possible. After a number of plant layout studies were made, it was found possible to optimize a nearly standardized plant applicable for each of the six cases.

Although the plants are conceptual, the design and estimated costs should compare favorably with those done in detail for actual construction.

Administrative Area

The administrative building is attached directly to the process area and is the same for both the vibrational compaction and pelleting facilities. The layout for this area is shown in Figure 3. The building houses the administrative offices, service offices, lunch rooms, change rooms, and heating and ventilation supply equipment. The building is of standardized commercial steel construction of lesser cost than used for the process areas.

The office layouts have been intentionally omitted since they are a matter of personal preference, but the change room arrangements are shown because they are closely associated with the process area. The door to the air locks opens directly into the process area corridor.

Vibrational Compaction

The vibrational compaction process arrangement is shown in Figure 4. The nuclear and non-nuclear processing areas are separated by an access corridor except for the UO_2 storage and final assembly. Since it is impossible to differentiate between plutonium and uranium with an alpha monitoring instrument, and the involved procedure necessary to determine the difference could cause undesirable production delays, the UO_2 storage is separated from the plutonium area for monitoring convenience.

Both the nuclear and non-nuclear material processes are arranged so that only minimum back-tracking is required. The compartmentalization shown on the layout is realistic for this process and is illustrative of the compartmentalization principles that should be used in a plutonium fuels processing plant.

FIRST FLOOR PLAN

SECOND FLOOR PLAN

FRONT ELEVATION

FIGURE 3. Administrative Area

Pellet Process

The pellet processing arrangement (Figure 5) is almost identical to the vibrational compaction layout except for fuel preparation and rod loading. A larger building is required due to the space needed for the sintering furnaces.

PLANT AND EQUIPMENT COST SUMMARIES

Administrative Area Costs

The costs for process heating and ventilating and the change-room space are included under process area costs rather than administrative costs. These areas are located within the office structure, but are required regardless of the office location. Utilities and services are included in the site preparation costs shown in Table 3.

TABLE 3. *Administrative Area Costs*

Office - 1st and 2nd floors	6,860 sq ft @ \$20	\$137,000
Direct Cost		137,000
Field Engineering		4,000
Design - Title I & II		17,000
Contingency		20,000
Site Preparation		<u>5,000</u>
		183,000
Interest During Construction - 10%		<u>13,725</u>
		\$196,700

Process Area Costs

The vibrational compaction process area costs and the pellet process area costs are shown in Table 4 and Table 5, respectively. The pellet facility costs are higher than those of vibrational compaction because of the larger building area,

although site preparation and stack costs are the same. The stack costs may be slightly higher than required, but they were established on the basis of the average assumed meteorological conditions.

TABLE 4. *Vibrational-Compaction Process Area Costs*

First Floor	22,900 sq ft @ \$50	\$1,145,000
Basement	17,270 sq ft @ \$20	345,000
Vent. supply and equip.	3,920 sq ft @ \$30	117,600
Change and lunch	4,900 sq ft @ \$22	107,800
Stack		<u>80,000</u>
	Total Direct Cost	\$1,795,400
Direct Cost		1,795,000
Building Design - Title I & II		190,000
Equipment and Installation Drawings		255,000
Field Engineering		52,000
Contingency		250,000
Site Preparation		<u>75,000</u>
		\$2,617,400
Interest During Construction - 10%		<u>196,300</u>
	Project Cost	\$2,813,700

Capital Cost Summary

The Capital cost summary (Table 6) presents the total Capital costs for the six plants.

TABLE 5. *Process Area Costs, Pellet Line*

First Floor	30,434 sq ft @ \$50	\$1,521,700
Basement	24,804 sq ft @ \$20	496,080
Vent. supply & Equip.	3,920 sq ft @ \$30	117,600
Change & lunch	4,900 sq ft @ \$22	107,800
Stack		<u>80,000</u>
	Total Direct Cost	\$2,323,180
Direct Cost		2,323,180
Building Design - Title I & II		250,000
Equipment and Installation Drawings		340,000
Field Engineering		68,000
Contingency		336,000
Site Preparation		<u>75,000</u>
		\$3,392,180
Interest during construction - 10%		<u>254,413</u>
	Project Cost	<u>\$3,646,600</u>

FIGURE 5. Pellet Fuels

TABLE 6. Capital Cost Summary, One Ton/Day Fuel Fabrication Plants

	Vibrational Compaction			Pelleting and Sintering		
	Enrichment UO ₂ -3%	Enrichment PuO ₂ -LO EX	Enrichment PuO ₂ -HI EX	Enrichment UO ₂ -3%	Enrichment PuO ₂ -LO EX	Enrichment PuO ₂ -HI EX
I. FACILITY						
Building, Utilities & Services	3,010.4	3,010.4	3,010.4	3,843.3	3,843.3	3,843.3
II. EQUIPMENT						
A. Preprocess, Nonnuclear						
Material Receiving & Storage	23.5	23.5	23.5	23.0	23.0	23.0
Rod Preparation	234.5	234.5	234.5	250.0	250.0	250.0
Grid Hardware Preparation	2.5	2.5	2.5	2.5	2.5	2.5
B. Process, Nuclear						
Nuclear Materials, Rec. & Stor.	18.2	98.2	98.2	7.5	99.5	99.5
Fuel Analysis	133.0	155.0	155.0	131.0	153.0	153.0
Fuel Mixing & Blending	27.0	41.0	45.5	0.0	67.0	71.5
Densification	235.0	249.0	250.96	--	--	--
Crushing & Sizing	130.0	149.0	154.0	--	--	--
Vibrational Compaction	68.0	75.0	84.0	--	--	--
Slugging	--	--	--	85.2	96.0	100.0
Granulating	--	--	--	25.5	34.3	35.7
Pelleting	--	--	--	107.8	123.0	128.8
Sintering	--	--	--	491.0	523.0	523.0
Grinding	--	--	--	151.0	199.0	206.0
Pellet Loading	--	--	--	14.1	42.3	48.3
Fuel Rod Closure	115.6	115.6	117.25	115.0	117.6	120.6
Fuel Recycle	18.5	35.0	40.8	41.3	50.9	51.3
Degreasing	16.0	16.0	17.0	16.0	16.0	17.0
Etching	105.0	105.0	115.25	105.0	105.0	115.25
Leak Checking	28.0	28.0	29.5	28.0	28.0	29.5
Autoclaving	205.0	205.0	207.25	205.0	205.0	207.25
Rod Inspection	36.0	38.0	42.5	34.0	34.0	38.5
Rod Rework	15.0	19.0	19.0	15.0	19.0	23.5
Element Assembly	25.0	25.0	30.0	30.0	30.0	35.0
Element Inspection	8.0	8.0	9.5	8.0	8.0	9.5
Quality Audit	15.0	15.0	15.5	15.0	15.0	15.0
Element Rework	4.0	4.0	4.0	7.0	7.0	7.0
Shipping	9.0	9.0	9.0	9.0	9.0	9.0
Decontamination	11.0	31.0	35.26	2.0	21.0	23.0
C. Auxiliary						
Computer	104.0	104.0	104.0	104.0	104.0	104.0
Maintenance	20.0	20.0	20.0	20.0	20.0	20.0
Waste Handling	80.0	80.0	80.0	80.0	80.0	80.0
Subtotal	1,686.80	1,885.30	1,943.97	2,122.90	2,482.10	2,546.70
Total	4,697.20	4,895.70	4,954.37	5,966.20	6,325.40	6,390.00

Dollars in thousands

Includes equipment: hooding, conveyors, shielding, installation

PART 3. DOSE RATES AND SHIELDING REQUIREMENTS

The conditions that exist in a plutonium handling facility lead to two types of radiological control: the control of internal deposition and control of external exposure.

The principal means of internal deposition is by inhalation of plutonium contaminated air and by entry through minor puncture wounds. The maximum permissible concentration of plutonium in air (MPC_A) is $2 \times 10^{-12} \mu\text{C}/\text{cm}^3$. The maximum permissible body burden is (0.04 μC) for Pu^{239} . Under no conditions is there any planned exposure that will result in internal deposition, and therefore all depositions are the result of unplanned occurrences. Virtually no internal deposition problem will exist if the use of reasonable and well known control techniques are employed. Internal deposition will not be considered again in this report because external radiation from high exposure plutonium is the major problem encountered in a glovebox fabrication process.

PERMISSIBLE DOSE RATES

Workers employed 5 days/week, 8 hr/day, work approximately 2,000 hr a year. Although employees in a plutonium fabrication plant do not spend 8 hr in the production area, 8 hr will be used for the purpose of establishing dose rates.

The established occupational exposure limits are 5 rem/yr for the whole body and 75 rem/yr for the extremities (hands, forearms, ankles, and feet). Administrative controls are usually based on 4 rem/yr for the whole body and 60 rem/yr for the extremities. Allowable dose rates in a plutonium fuel plant for a full time employee (2,000 hr/yr) would be 2.5 mrem/hr maximum for the allowable whole-body limit of 5 rem/yr, and 2.0 mrem/hr for the administrative limit of 4 rem/yr.

Several factors contribute to the total radiation dose rate. They are:

- The amount of material present
- The isotopic content
- Time since separation
- The physical or chemical state.

DOSE RATE MEASUREMENTS

Dose rates from high exposure plutonium of the reference composition have been calculated, but they have not been measured because measurable quantities are not yet available. Dose rates associated with the handling of large quantities of other plutonium, including high Pu^{240} material, have previously been calculated and measured, and the calculated and measured dose rates have been in close agreement. The calculated dose rates on the reference high exposure plutonium, as done by Faust, should also have a high degree of reliability. Measured dose rates should be less than the calculated ones since the calculations are on the conservative side.

Measurements on high exposure plutonium, produced under different reactor conditions, (Yankee, Shippingport, etc.) will be made when measureable quantities of the plutonium become available. Shielding values for the various construction and shielding materials and combinations of materials will also be established. Corrections will be made if the results of these measurements show that serious errors have been made in the shielding cost estimates of the study plant. The results will also allow firm detail design to be done for an actual fabrication plant. As stated in the Table in the Introduction p. 3, the high exposure plutonium isotopic composition used for the shielding calculations is:

Pu^{236} (ppm)	Pu^{238} (wt%)	Pu^{239} (wt%)	Pu^{240} (wt%)	Pu^{241} (wt%)	Pu^{242} (wt%)
0.047	1.1	62.2	21.2	12.7	3.8

The information used as a basis for the shielding calculations was compiled by Faust.⁽³⁾

DESIGNING FOR RADIATION CONTROL

Success in operating a high exposure plutonium fuel fabrication plant within the administrative dose rate limits depends very much upon adequate design. Careful design of the structure and equipment will minimize the amount of shielding required, and reduce the operational penalties imposed by the shielding. Although details are not shown for the study plant design, considerable planning was done to provide for the least expensive shielding that will provide adequate personnel protection. The following typical conditions were considered:

- Provide the maximum feasible working distance between, (a) work stations, (b) glovebox lines, (c) operator and source at work stations, (d) glovebox work stations and fuel processing operations not in gloveboxes, and (e) fuel rod processing steps not located in gloveboxes.
- Glovebox designs to accept removable shielding panels.
- Glovebox designs that limit the operational access to the minimum area required for processing efficiency. This allows the use of inexpensive paraffin filled steel shielding panels in most areas, and the more expensive viewing panels for only the work stations.
- Equipment designed to require a minimum of contact operation.
- The use of localized portable shielding for both glovebox and nonglovebox operations.

The dose rates must be determined for the entire operation before the detailed equipment designs are completed and the shielding requirements are established. Although shielding details are not shown in this report, glovebox fabrication feasibility for high exposure plutonium and shielding costs were determined by using the available information.^(1,3)

The dose rate information is derived from this source and is somewhat generalized for this report in order to illustrate the application.*

NEUTRON DOSE RATES

Spontaneous Fission Only

The neutron dose from spontaneous fission at the surface of one rod of $\text{PuO}_2\text{-UO}_2$ material of the stated plutonium isotopic composition is 0.233 rem/hr. Since the surface dose rate varies as mass $1/3$ (mass in grams), then 24 rods (approximately equivalent to twice the blending batch size) will have a dose rate of 0.67 rem/hr and 12 rods (approximately equivalent to two impaction batch sizes) 0.533 rem/hr.

Total Dose Rates (Including α, n Reactions)

The contribution to the total dose rate from PuO_2 (α, n 's) is found by weighting the surface dose rate equation coefficients by the ratio of the α, n yield values to spontaneous fission yields, and by using 0.88 (Pu content of PuO_2) of that ratio. The α, n contribution is 0.08368 x mass to the $1/3$ power.

The dose rate resulting from the α, n reactions will be 0.335 rem/hr and 0.233 rem/hr from the spontaneous fission sources. The total surface dose rate will be 0.568 rem/hr/rod.

**Dose rate calculations for specific conditions will be furnished only if requested, as the authors feel that publishing specific calculations based on the available information, and for a theoretical plant might be subject to misinterpretation.*

Nonsurface Dose Rates

The nonsurface dose rate is simply found by using a division of $\frac{1}{2x}$ where x is the distance in centimeters. Therefore, at a distance of 61 cm, (2 ft.) from the source, the dose rate will be $0.568/2 \times 61$, or 4.65 mrem/hr/rod. This should be considered as the maximum dose rate per rod. These dose rates are for a line source only (fuel rod); other geometric shapes require different considerations.

The basic data cannot be extended in a linear manner for more than one rod; however, we have done so in this study for the sake of convenience. Linear extrapolation will show a higher dose rate than would be actually realized, which should make all shielding allowances highly conservative.

SHIELDING

Gamma

The neutron shielding problem is by far the most significant. Gamma dose rates from high exposure plutonium will be virtually eliminated by the neutron shielding. Where this may not be true, these dose rates are easily attenuated by lead glass and other materials.

Neutron

If we assume that the spontaneous fission and the α, n produced neutrons have about the same energy spectrum as fission neutrons, then the removal cross section should be valid for estimating the shield value. Water has a removal cross section, (Σ_{rem}), of 0.1 cm^{-1} ; acrylic plastic, polyethelyene, paraffin, polycarbonates and other hydrogenous materials are very similar and have been assigned approximately the same value. For a 3/8 in. acrylic glovebox panel, the attenuation is about 9%; for 1 in. it is about 23% and for 4 in.,

about 64%. These maximized values are for total removal, and they are much more significant than is indicated since a portion of the remaining neutrons are thermalized.

Four inches of water closely approximates an infinite thickness for neutron thermalization. Since thermalizing the neutrons reduces the dose rates by a factor of approximately 100, it is estimated that 4 in. of water or similar material would reduce the dose rate from 4.65 mrem/hr to 0.02 mrem/hr. These dose rate approximations help to demonstrate that dose rates can be reduced to acceptable levels by relatively inexpensive materials. Structural materials and processing equipment have been ignored, but they also contribute to the overall dose rate reduction. Boron added to nonviewing paraffin panels will further reduce dose rates by the capture of thermalized neutrons, and gadolinium glass used with hydrogenous viewing panels will serve the same purpose.

Heavy neutron shielding will be required only for locations where large quantities of fuel materials are present (i.e., blending, autoclaving, element storage and assembly) or for the PuO_2 storage and mixing operation. For other operations where material is spaced properly in the production line and the operator-to-source distance is about 61 cm (24 in.), lead glass panels will provide adequate shielding. X-ray type lead glass panels 0.64 cm (0.25 in.) thick are equivalent to approximately 0.16 cm (0.06 in.) of lead, based on 105 keV photon radiation measurement. Panels composed of two thickness, 1.28 cm, (0.5 in.), will provide sufficient shielding for most locations, but panels thicker than 1.28 cm (0.32 cm lead equivalent) are more desirable and less expensive if cast to the required thickness.

Evidence from available information indicates that high exposure plutonium of the calculated compositions formed under the various reactor conditions can be fabricated in a shielded glovebox facility without overexposure of the operating personnel. Exact dose rates and shielding values should be available before actual plants are designed. In any plant design, the amount and type of fuel material will be known for a given location, thus shielding can be applied accordingly. The use of automatic or semi-automatic equipment, mechanical aids such as tongs, simple manipulators, elevators, conveyers, and similar devices will reduce the total amount of shielding required for controlling personnel exposure to an acceptable level.

PART 4. PROCESS AND EQUIPMENT DESCRIPTION

The processes for the vibratory compaction and pellet fabrication have been described in Volume 1, and, therefore, will be described in this volume in a slightly different order. The non-nuclear processes for each fabrication scheme are identical, which allows only one description to cover all three cases of each process. However, where differences occur, the description will be identified by the case number. The cases are:

Vibrational Compaction

Case #1--U²³⁵ enrichment

Case #2--Low exposure PuO₂

Case #3--High exposure PuO₂ enrichment

Pellet Process

Case #4--U²³⁵ enrichment

Case #5--Low exposure PuO₂

Case #6--High exposure PuO₂ enrichment

The process flow diagrams for computer use are shown in Volume 1. Therefore, to easily identify the processes described in this volume, the process flow sheets shown in Figures 1 and 2 (which are derived from the computer flow diagrams) will be used to identify the processes.

It is impractical and also usually undesirable to size production equipment for an exact production rate. It is also difficult to predict an exact production reject rate although the average reject rates can be determined on a statistical basis fairly accurately. For these reasons, the equipment has been sized to process approximately 250 fuel rods (~1000 kg) per shift.

NUCLEAR MATERIAL STORAGE

Uranium

Receiving and Storage

UO₂ (enriched or natural) and U₃O₈ are stored in the nonplutonium portion of the facility for easy contamination identification and control. Since only small quantities of U₃O₈ are required, it is stored in shelving in the uranium storage area.

Enough UO₂ for 21 working days is received and stored once each month. This amounts to 43,200 lb in lot sizes of 1200 lb and contained in 100 lb cans. These cans are transported and stored on pallets holding six cans each. Seventy-two pallets are required for storage and 72 are in transit for a total of 144 pallets. Pallets are 4 ft wide x 6 ft long x 2 ft high; they will hold six cans and provide the spacing required for both transporting and storing large quantities of natural or enriched UO₂. They are designed to provide fixed positions for the cans and to have adequate

strength for stacking. They are sized for transporting in standard commercial trailers; they will pass through standard double doors; and they can be moved by fork lift truck or hoisting hook.

Pallets are expendable and are provided by funds from the ordinary material costs assigned to each element.

Weighing

UO_2 and U_3O_8 are accurately weighed for fuel mixture charges. Weighing is done in a specially designed hood, and an automatic scale that prints out the weight and lot numbers is used.

Plutonium

Plutonium is stored in a shielded airtight glovebox with a storage capacity of 600 kg, (one month's supply) in a critically safe array. The shielding will attenuate 600 kg of high exposure plutonium to a personnel dose rate of less than 1 mrem/hr. The storage arrays hold hermetically sealed cans of plutonium in a fixed position, and a boom mounted electro-mechanical manipulator with three motions is used to remotely handle the plutonium. A manipulator repair station and a plutonium receiving station are included in the glovebox. Shielding is provided by a water wall, lead glass and, concrete.

Nuclear Materials Analysis

An inplant analytical facility is required for process control and is used to provide quality control isotopic and impurity analysis of the nuclear materials received from other suppliers. Density, surface area measurements, and water content determination are also necessary.

Equipment for natural UO_2 analysis is installed in an open-front hood. Equipment for enriched UO_2 and PuO_2 analysis is installed in an airtight glovebox, because alpha control is required for all materials containing plutonium and more than 1% U^{235} . Shielding should not be required; however, a buildup in background dose rate could necessitate some local shielding.

FUEL ELEMENT HARDWARE PROCESSING

Receive Zircaloy Hardware

Zircaloy fuel components are received only once each month. The zircaloy tubing is received in boxes of 200 tubes each, and the boxes are stored on roller arm storage racks with five rows of roller arms on each side, with each arm holding three boxes of tubes. The roller arms allow the boxes to be loaded or unloaded from the racks with a fork lift truck. With each rack holding 6,000 tubes, two racks are required to provide storage for 12,000 tubes. Ten thousand five hundred tubes are required each month; thus the storage racks hold slightly more than the required amount.

Approximately 21,000 end caps required each month are packed in boxes of 500 each. At an assumed reject rate of 5%, forty-four sets of assembly hardware are required each month. Both caps and assembly hardware are stored in shelving.

Inspection

Ultrasonic Tube Inspection

Seven ultrasonic testing units with two stations per unit are required, including one extra unit for standby.

Production rate:

20 min/tube/station = 3 tubes/hr
3 tubes/hr x 12 stations = 36 tubes/hr
500 tubes/day are required
13.9 hr are required to inspect 500 tubes
Standby capacity is 6 tubes/hr.

Tube Straightness Gage

The diameter and straightness gage is a combination gage that measures OD, ID, wall thickness and concentricity simultaneously, while straightness is measured as a separate operation. Two gaging machines, each having two combination gages, are required for a total of four combination gages.

Capacity of each gage = 10 tubes/hr = 6 min/tube
Spare capacity = ~1 gage

Assembly Hardware

Inspection equipment for the assembly hardware is grouped for efficiency, with cleaning inspection being visual. Dimensional inspection of assembly hardware and end caps is by go-no-go gages and weld inspection is by two single scan ultrasonic heads.

Cleaning

A vapor degreaser is used for cleaning the zircaloy tubes, assemblies, and end caps. One section of the degreaser is designed for cleaning 11 ft long tubes, and a second section is for end caps and assemblies. The cleaning unit is sized for the required tube production, while the other cleaning requires only a fraction of the total capacity. Hot clean solvent is available for cleaning use in addition to the solvent vapor.

Tube Capacity:

6 tubes/batch at 10 min/batch = 36 tubes/hr
14 hr/day tube cleaning operation = 1 ton/day fuel plant

End-Cap Capacity

10 min/batch of 500 end caps

One batch required per day for a 1 ton/day fuel plant.

Assembly Hardware Capacity:

30 min/set

Two sets of hardware are required for a 1 ton/day fuel plant.

Hardware Processing

Trim Tubes

The length gage is mounted in the frame of a special tube trimming lathe. The tubes are passed through the length gage; the under length tubes are rejected; and the over length tubes are accumulated for trimming. The tube trimmer is similar to a simplified engine lathe but is especially adapted for trimming tubes to a required length. The trimmer is operated on a required basis.

Weigh Tubes

The weighing station is arranged for easy input and output handling. Fuel rod record cards are started at this operation. A recording scale that automatically prints the weight on the record card is used.

Weld End Cap Number One

A vacuum-welding box is used for welding the first end cap. A flanged tube or pod, containing a rotatable rack that holds 50 tubes, is fastened to the box during the welding operation. Two pods are required for each welding box, and one pod is unloaded and reloaded while the other is attached to the box.

The box is evacuated to a pressure of less than 1 μ and back filled to atmospheric pressure with welding gas. The welding box is used as backup equipment for the final closure end cap welding.

Weld Repair

A standard medium duty engine lathe is used for repairing defective welds on the number 1 end cap.

Production required: 1% of 500 welds/day = 2 1/2 repairs/8 hr day, or a total of 5/16 hr/day. Tubes with defective welds are accumulated and processed in batches of 50 to provide a full welding box load. Although the machine usage seems low, the cost is amortized in approximately 4 months.

Loading Preparation

Contamination prevention masking is necessary for the tube loading and vibrational compaction operation. Molded plastic and fabricated flexible plastic are used to protect the tube. This equipment consists of a work bench with storage for the active inventory of plastic parts.

VIBRATIONAL COMPACTION FUEL PREPARATION AND LOADING

Mixing and Blending

Prew weighed enriched UO_2 and U_3O_8 , Case 1, or preweighed natural UO_2 , U_3O_8 , and PuO_2 , Cases 2 and 3, are mixed in a screw type feeder-mixer; the mixed powder is blended in twin shell blenders for loading into impaction cans. Blender capacity is 72 kg/hr, which equals 504 kg in 7 hr, and blending batch size is 24 kg. Of the two blenders installed, one serves as a spare unit or is used for 12 kg PuO_2 batches.

Load Impaction Cans

Impaction cans hold 12 kg, with each fuel element requiring 42 cans. They are loaded in two stations at one end of the blending glovebox, and loading time is 20 min/can for a total of 36 kg/hr for each station.

Decontaminate Impaction Cans

The outer can surface and weld area are checked after loading for contamination in a small hooded decontamination station. Since contamination is found only occasionally, approximately 10%, or four cans, are decontaminated per shift.

Weld Impaction Cans

The impaction cans are closed with a burn-down weld within small air flow type hoods. Forty-two cans, made of 310 SS, are required for each fuel element.

Heat and Evacuate Impaction Cans

Impaction cans are evacuated and heated (80 min heating time) to approximately 1200 °C. Seven resistance furnaces are required and are hooded for contamination control.

Impaction

The heated cans are impacted by a high energy pneumatic mechanical press to densify the blended fuel material to greater than 98% theoretical. Eight hours are required to heat six cans in each furnace, and a total of 48 shots are made in 8 hr for a total of approximately 500 kg of densified material. The elapsed time between shots is 11 min.

Cool Impaction Cans

The impacted Dynapacked cans are placed in a steel ventilated storage cabinet for cooling where a heat exchanger is required to remove the large amount of heat released from each can. A contamination survey is made before the cans are placed in the cooling cabinet, and the average inventory is approximately six to eight cans stored in fixed positions, or about 100 kg of fuel material.

Grit Blast Impaction Cans

Lubricant applied to the heated cans before impaction turns to a hard scurf after the impacted can has cooled. To prevent fuel contamination, it is removed by sand blasting before the can is opened.

Open Impaction Cans

The cleaned impacted cans are opened with a hydraulic press mounted in a hood or airtight glovebox; each can requiring approximately 10 min to open.

Powder Preparation

After the fuel mixture is densified, it is sized and classified into three fractions for density control of the compacted fuel rod. The classified fuel material is vacuum outgassed at 600 °C to obtain a water content of less than 40 ppm, and the outgassed material is weighed into fuel rod quantities and sealed in watertight containers. Two powder preparation lines are used to process the fuel required for a two shift 1 ton/day fuel plant. The two lines allow emergency maintenance without seriously affecting production rates.

Vibrational Compaction

Although much work remains to be done on fuel rod vibrational compaction technology, the available experience is used with a high degree of confidence in the conceptual design of the compaction facility. Pneumatic compactors with variable amplitude and frequency are used to minimize the capital investment and process space required over that needed for electromagnetic systems. Pneumatic compactors require comparatively little maintenance, and the time required to replace a properly designed unit would be about 15 to 20 min.

Replacement of a defective unit with a spare unit will prevent down time from seriously affecting production, while maintenance on the defective units can be performed in the shop at a convenient time.

Eight loading stations located in a communal glovebox are used, and the compaction units are located in the basement. The fuel rod, loaded in a vertical position, is kept vertical through the final closure welding operation. Prepared tubes brought from the tube preparation area on carts to the loading area are lowered by a dumbwaiter to a conveyer through processing to the welding operation. Conveyer carrier positioners support the tubes, top and bottom, and slots in the floor at the work stations provide access to the upper rod end for processing. Eight compacting units are used, which allows 14 to 16 min to compact each fuel rod.

Rod Open

Approximately 3% of the fuel rods will not compact to specifications, or they will have weld zones that cannot be decontaminated. These rods are recycled to a glovebox for powder removal, and the material from these tubes is recycled through the crush-sieve operation. The area shown on the drawing for this operation includes 16 ft² of glovebox space, which is part of the break out glovebox, and the remaining space is occupied by a device for holding the rods.

Preweld Decontamination

Only a small percent of the rods will have contaminated weld zones since protective devices are used during compaction. These rods are decontaminated in small open face air flow hoods.

Final Closure, End Cap Number Two

Two vacuum welding chambers are used for the final closure. The chambers are identical to the one used for welding

the first end cap, but are installed at an elevation that allows the operator to stand on the floor rather than to work from a platform. Two welding pods are provided for each chamber, and closures can be made in 1 1/2 min each, allowing for pump down-time and 20 min outgassing for each load. The second box will provide standby capacity unless the outgassing time is increased.

PELLET FUEL PREPARATION AND ROD LOADING

Fuel Preparation

The enriched UO_2 , Case 3, is transferred directly from the 100 lb storage cans to the preparation line because it is not necessary to have preweighed fuel charges for this process. Slugging is the first operation required, and cylindrical slugs, 3 x 3 in., weighing approximately 2 kg each, are made from the active powder. Two hundred and fifty slugs are required for each shift, and the production rate is approximately 1 1/2 min each. Although one press will produce the required amount of slugs, two special hydraulic presses are installed, and a conveyor system that can be used selectively for either press permits the standby press to be switched into production within a very short time. The spare press is installed to insure continuous production because die changing or press repairs usually require a considerable amount of time.

The PuO_2 enriched fuel, Cases 4 & 5, is prepared by preweighing sinterable grade PuO_2 and UO_2 and by charging the batches into a screw type feeder-mixer. The mixed material is blended in twin shell or other type mixers in either 12 or 24 kg batches. The blended material is run through a stud mill, such as the Alpine Contraplex, to break up the PuO_2 micro-agglomerates; then the material is transferred on a conveyor system to the slugging operation.

Granulate

The 2 kg slugs are broken into small particles in a granulator similar to the "Alpine Perplex."

Add Lubricant

The pellet preparation is based on a dry process, and a particle lubricant such as zinc boronate or metal stearate must be added to the granules. A twin shell blender is used to mix the lubricant with the fuel material.

Pressing

After the lubricant has been added to the fuel material, it is transferred to the pelleting presses by conveyer. Three 15 ton presses are installed, and the conveyers are arranged to feed any press on a selective basis. Two presses are used for normal production, with the third press as a standby unit. The production rate for each press is 40 pellets/min. The green pellets are transferred by conveyer to an inspection station where they are automatically inspected and loaded into molybdenum lined AlO_2 sintering boats. The boats hold approximately 500 pellets and are transferred by conveyer to the continuous pusher-type feeder furnaces.

Sintering Furnaces

Eight pusher type sintering furnaces are installed; six or seven, depending on the reject rate and the number of pellet per boat, are used on a continuous basis.

Two independent furnaces are joined together with a flanged section to form a complete sintering furnace. The first section is for presintering at low temperature to burn out the lubricant, which prevents a carbonaceous accumulation in the high temperature furnace. The presintering furnaces are 7 ft long and are heated with nichrome elements; the high

temperature section is 21 ft long with a 4 ft long high heat zone. The furnaces are not hooded and repair must be done in a "green house" operation. Space is provided between each furnace so that repair operations may be accomplished without affecting the operation of the adjoining unit. The relatively inexpensive presintering furnace will extend the life of the high temperature furnace, and provides an economical sintering furnace arrangement.

Sintering furnaces must operate on a continuous basis, and pellets, either "green" or sintered, are accumulated on the off-shift in the conveyer system in a critically safe array. If an assumed yield of 88% is used, 72,000 pellets/day would be required. However, yield rates, may vary and sufficient capacity is available to produce the required number of pellets. The sintered pellets are transferred by conveyer to centerless grinders where they are unloaded from the boats; the boats are returned to the loading station via a boat conveyer below the boat charging conveyer.

Grinding

The 1 in. long pellets are automatically ground in centerless grinders at the rate of 20 ft/min. Two grinders are required to produce the required amount of pellets, but three are installed to provide backup capacity. Automatic inspection equipment is located in the grinder gloveboxes.

Cleaning and Drying

The acceptable pellets from the grinding operation are transferred by a conveyer through the cleaning and drying operation.

Rod Loading

The cleaned and dried pellets are transferred to one of three rod loading gloveboxes, with each box having two rod loading stations. The pellets are again automatically inspected, and rod loads of the proper length are assembled in a loading fixture. The rod load length is obtained by using a final pellet of the correct length; therefore, a supply of fractional length pellets must be maintained for this purpose. To reduce the amount required on the glovebox exterior, in-hood shielding is used at the rod loading make up stations. The rods are loaded horizontally into the tubes at the rod loading stations where minor weld zone decontamination is also done. The empty tubes are in a welding pod, and the tube being loaded is withdrawn about 3 ft during the loading operation. After loading, the tube is pushed back into the welding pod which provides radiation shielding of the loaded tubes. The pod is then rolled to the vacuum welding chamber where the final closure is made.

Final Closure

The vacuum welding chambers are similar to those used in the vibrational compaction process except that the pods are attached horizontally to the box. Two chambers are provided, with each having three extra pods (each pod holds 50 tubes). The pods are loaded with empty tubes, rolled to the rod loading operation, and then to the welding operation.

FUEL ROD PROCESSES

After the final closures are made for either the pellet or vibrational compaction process, all subsequent operations are identical and are described in this section. The required shielding is provided for Cases 5 and 6.

Inspect Welds

Closure welds are inspected by a single scan ultrasonic head, two heads mounted on one inspection machine. Welds that are slightly larger than the tube diameter are sized with a special centerless grinder. The production time is approximately 1.9 min/rod.

Degrease

After the welds have been inspected, they are weighed on an automatic balance and cleaned in a special degreaser. The degreaser is horizontal and has a rotating magazine that holds six rods. Rods are loaded on one side and unloaded on the other--an arrangement allowing continuous degreasing. The complete cycle for degreasing six rods is approximately 5.7 min.

Etching

The degreased rods are moved by carts to the etching facility. Two complete etching lines are required; processing is done in a rotating drum type carrier that holds 6 rods. The carrier is moved through the various baths on a track mounted trolley hoist. Approximately 10 min is required for the etching cycle.

Leak Testing

The leak testing unit is composed of a horizontal vacuum chamber and a helium mass spectrometer leak detector. The number of fuel rods to be leak tested at one time should be determined on the basis of operating experience. Up to 250 rods--approximately one fuel element--can be leak checked at one time, but smaller batch sizes are desirable for reducing the radiation dose rates and statistical leak probability.

Autoclaving

The horizontal autoclaves are located in a reinforced concrete structure, adjacent to the process area, and are arranged for convenient process flow. The rods are autoclaved on a 28 hr cycle, 250 at a time. Four autoclaves are provided, two units for rods, one unit for assembly hardware, and the fourth unit for standby. After autoclaving, the rods are inspected; rejected rods are routed to the various rework operations, and acceptable rods are stored until needed for assembly.

Assembly

A rotatable fixture that holds the spacer grids is used for assembling the rods into completed fuel elements. Each element contains 234 rods, and 10 spring clip spacer grids are used. The assembly fixture is shielded for the plutonium enriched fuel material. After the rods are assembled, they are transferred to an inspection table where any misalignment is corrected by using fixtures designed for this purpose. Elements containing damaged rods are sent to an element recovery station where the necessary repairs or element disassembly is done. Completed elements are placed in shipping containers and stored in the basement until a shipment is made. Shipping containers have built-in shielding that attenuates the radiation to an acceptable level.

PART 5 - PROCESS EQUIPMENT COSTS

PRORATION OF THE PROCESS EQUIPMENT COSTS

To study the individual process or functional costs, the equipment costs in this study are prorated. In the computer code, equipment pieces may often carry a cost burden of supporting equipment that seems to be completely out of proportion to the equipment value. Several methods can be used to prorate the equipment costs, but regardless of the method, it is impossible to assign an exact fair value. The assigned costs will be valid for the case being studied however, as long as the sum of the units within a functional process equals the total equipment cost. The inherent errors in the prorated costs of individual equipment pieces are much less significant than the estimating errors contained in a conceptual plant design.

Most equipment has a basic cost, and normally the selling price is not directly proportional to the equipment size or capacity, which is especially true of a glovebox containing process equipment (as several basic costs are involved in the total). For example, the average cost for a heavy duty stainless steel airtight glovebox of the type used at Battelle-Northwest would be approximately \$7,000 for a 128 ft³ box, and approximately \$8,000 for a 160 ft³ box. Yet, installation costs are approximately the same for each glovebox. A blender of a certain capacity may cost \$2,500, and one with double the capacity may be only \$3,000. The \$7,000 glovebox may be large enough to contain a balance and a larger capacity blender; but for reliability, criticality control, or other reasons, two smaller blenders and the larger glovebox may be required. Assuming that the shielding costs are \$2,000 and \$2,500, and the installation cost is approximately \$5,000 for each box, we then have the problem of prorating costs for equipment of equal processing capacity.

Consolidated Costs

<u>Case 1</u>		<u>Case 2</u>	
Glovebox	\$ 7,000	Glovebox	\$ 8,000
Balance	2,000	Balance	2,000
Blender	3,000	Blenders	5,000
Shielding	2,000	Shielding	2,500
Installation	<u>5,000</u>	Installation	<u>5,000</u>
Total	\$19,000		\$22,500

If blending was considered to be the primary function of this operation, the approximate equipment proration needed to establish process costs would be as follows

Prorated Costs (From Computer Runs)

<u>Case 1</u>		<u>Case 2</u>	
Weighing	\$ 6,000	Weighing	\$ 6,000
Blending	<u>13,000</u>	Blending	<u>16,500</u>
	\$19,000		\$22,500

The least expensive acceptable process would be used in a plant design, but both costs are valid in this theoretical example when used for a given cost study. The limited examples above contain the essential fundamentals used to establish the prorated equipment costs that are used in the F.E.F.C. computer runs. A small variation in prorating the costs between the blender and balance would have very little effect since the two equipment pieces carry the total glovebox and installation burden. The prorated costs used in this study would most likely differ from those used in similar studies.

An example of a functional operation from the computer runs, Case 3, (vibrational compacted high exposure $\text{PuO}_2\text{-UO}_2$) is also given in both the prorated and consolidated forms.

Prorated Costs (From Computer Runs)

<u>Job Number</u>		<u>Prorated Equip Cost</u>	<u>Prorated Shielding Costs</u>
15.4	Weigh PuO ₂	\$ 12,000	\$ 2,000
12.8	Mix UO ₂ -PU ₂ -	5,000	
12.9	U ₃ O ₈		
12.9	Blend	16,500	2,000
12.11	Load Impaction Cans	<u>6,000</u>	
		\$ 39,500	

Consolidated Costs

Glovebox	\$ 12,500
Balance	6,000
Feeder-mixer	3,000
Blenders	5,000
Shielding	6,000
Installation	<u>7,000</u>
	\$ 39,500

Only the consolidated costs will be given in this volume, as the prorated costs (by job number) are included in the computer runs, Appendix A, Volume I.

NUCLEAR MATERIALS EQUIPMENT

<u>Plutonium Storage</u>	<u>Consolidated Costs*</u>
Glovebox	\$ 29,000
Water Wall	3,000
Concrete	3,000
Lead Glass	5,000
Manipulator	20,000
Installation	<u>20,000</u>
	\$ 80,000

**See Part 5. for definition of "Consolidated Cost."*

Uranium StorageEnriched or Natural UO₂

Hood	\$9,000
Balance	9,000
Handling Equipment	7,500
Installation	<u>4,000</u>
	\$29,500

(Pallet cost is not included)

U₃O₈

Storage Shelving	\$ 500
Handling Equipment	<u>200</u>
	\$ 700

Analytical EquipmentPuO₂ and Enriched UO₂ Analytical

Glovebox	\$22,000
Equipment	56,000
Installation	<u>15,000</u>
	\$93,000

Natural UO₂ Analytical

Hood	\$ 9,000
Equipment	47,000
Installation	<u>6,000</u>
	\$62,000

NONNUCLEAR PROCESS EQUIPMENTZircaloy ComponentsTubes

Storage Racks	\$ 6,000
Handling Equipment	<u>4,000</u>
	\$10,000

End Caps

Storage Shelving	\$ 1,000
Handling Equipment	<u>2,000</u>
	\$ 3,000

Assembly Hardware

Storage Shelving	\$ 5,000
Handling Equipment	<u>5,000</u>
	\$10,000

Zircaloy InspectionTube Straightness and Diameter Gage

Gage	\$29,000
Installation	<u>4,000</u>
	\$33,000

Ultrasonic Tube Inspection

Gages	\$80,500
Installation	<u>3,500</u>
	\$84,000

Weigh Tubes

Balance	\$ 9,500
Installation	<u>500</u>
	\$10,000

Hardware Inspection

Equipment	\$10,000
Installation	<u>2,000</u>
	\$12,000

Zircaloy ProcessingTrim Tubes

Trimming Lathe with Length Gage	\$ 7,000
Installation	<u>1,500</u>
	\$ 8,500

Cleaning

Equipment	\$27,000
Installation	<u>4,000</u>
	\$31,000

Weld First End Cap

Vacuum Welding Chamber	\$40,000
Installation	<u>10,000</u>
	\$50,000

Weld Repair

Equipment	\$ 6,500
Installation	<u>1,500</u>
	\$ 8,000

Loading Preparation

Equipment	\$ 1,000
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VIBRATORY COMPACTION PROCESS EQUIPMENTMixing and BlendingCase 1

Glove	\$10,500
Feeder-Mixer	2,000
Blender	2,500
Installation	<u>5,000</u>
	\$20,000

Case 2

Glove	\$12,000
Balance	6,000
Feeder Mixer	2,500
Blenders	5,000
Shielding	3,000
Installation	<u>6,500</u>
	\$35,000

Case 3

Glovebox	\$12,500
Balance	6,000
Feeder-Mixer	3,000
Blenders	5,000
Shielding	6,000
Installation	<u>7,000</u>
	\$39,500

Decontaminate Impaction CansCases 1 and 2

Hood	\$ 1,500
Survey Instrument	800
Installation	<u>700</u>
	\$ 3,000

Case 3

Hood	\$ 1,500
Survey Instrument	800
Shielding	160
Installation	<u>700</u>
	\$ 3,160

Weld Impaction CansCase 1

Hoods	\$ 2,000
Equipment	1,000
Power Supplies	1,000
Installation	<u>2,000</u>
	\$ 6,000

Cases 2 and 3

Hoods	\$ 3,600
Equipment	1,000
Power Supplies	1,000
Shielding	300
Installation	<u>2,100</u>
	\$ 8,000

Heat and Evacuate Impaction Cans

Furnace and Hoods	22,000
Power Supply	3,500
Vacuum System	1,500
Installation	<u>9,000</u>
	\$ 36,000

Impaction

Impaction Press	\$100,000
Enclosure	8,000
Tooling	9,000
Installation	<u>28,000</u>
	\$145,000

Cool Impaction Cans

Hood	\$ 3,000
Heat Exchanger	3,000
Survey Instrument	1,000
Installation	<u>3,000</u>
	\$ 10,000

Grit Blast Impaction CansCases 1 and 2

Grit Blaster	\$ 5,000
Installation	<u>1,000</u>
	\$ 6,000

Case 3

Grit Blaster	\$ 5,000
Shielding	500
Installation	<u>1,000</u>
	\$ 6,500

Open Impaction CansCase 1

Hood	\$ 8,000
Press	10,000
Installation	<u>6,000</u>
	\$ 24,000

Case 2

Glovebox	\$ 10,000
Press	12,500
Shielding	2,500
Installation	<u>10,000</u>
	\$ 35,000

Case 3

Glovebox	\$ 10,000
Press	12,500
Shielding	3,800
Installation	<u>10,000</u>
	\$ 36,300

Powder PreparationCase 1

Glovebox	\$ 62,000
Crush-Sieve	10,000
Balance	8,000

Bottle	\$ 1,000
Re-Bottle	1,000
Vacuum Outgas	25,000
Installation	<u>26,000</u>
	\$133,000

Case 2

Glovebox	\$ 70,000
Crush-Sieve	10,000
Balance	8,000
Vacuum Outgas	25,000
Bottle	1,000
Re-Bottle	1,000
Shielding	10,000
Installation	<u>29,000</u>
	\$154,000

Case 3

Glovebox	\$ 70,000
Crush-Sieve	10,000
Balance	8,000
Vacuum Outgas	25,000
Bottle	1,000
Re-Bottle	1,000
Shielding	15,000
Installation	<u>29,000</u>
	\$159,000

Vibratory CompactionCase 1

Glovebox	\$ 17,000
Equipment, Compaction Units	24,000

Equipment, Tube Loading and Misc.	\$ 4,000
Installation	<u>20,000</u>
	\$ 65,000

Case 2

Glovebox	\$ 17,000
Equipment, Compaction Units	24,000
Equipment, Tube Loading and Misc.	4,000
Shielding	5,000
Installation	<u>20,000</u>
	\$ 70,000

Case 3

Glovebox	\$ 17,000
Equipment, Compaction Units	24,000
Equipment, Tube Loading and Misc.	4,000
Shielding	12,000
Installation	<u>22,000</u>
	\$ 79,000

Pre-WeldCase 1

Hoods	\$ 6,400
Survey Instruments	1,600
Installation	<u>1,000</u>
	\$ 9,000

Case 2

Hoods	\$ 6,400
Survey Instruments	1,600
Shielding	800
Installation	<u>1,200</u>
	\$ 10,000

Case 3

Hoods	\$ 6,400
Survey Instruments	1,600
Shielding	2,260
Installation	<u>2,000</u>
	\$ 12,260

Weld End Cap #2Cases 1 and 2

Welding Chambers	\$ 89,000
Installation	<u>20,000</u>
	\$109,000

Case 3

Welding Chambers	\$ 89,000
Shielding	1,650
Installation	<u>20,000</u>
	\$110,650

Rod OpenCase 1

Glovebox	\$ 2,700
Equipment	500
Installation	<u>800</u>
	\$ 4,000

Case 2

Glovebox	\$ 2,700
Equipment	500
Shielding	1,000
Installation	<u>800</u>
	\$ 5,000

Case 3

Glovebox	\$ 2,700
Equipment	500
Shielding	2,100
Installation	<u>1,000</u>
	\$ 6,300

Rework FuelCase 1

Glovebox	\$ 4,500
Crush	1,000
Clean-up	2,500
Storage Racks	500
Installation	<u>3,000</u>
	\$ 11,500

Case 2

Glovebox	\$ 7,000
Crush	1,000
Clean-up	2,500
Balance	6,000
Storage Rods	500
Shielding	2,500
Conveyer	1,500
Installation	<u>6,000</u>
	\$ 27,000

Case 3

Glovebox	\$ 7,000
Crush	1,500
Clean-up	3,500
Storage Racks	500
Balance	6,000
Shielding	5,000
Conveyer	1,500
Installation	<u>6,500</u>
	\$ 31,500

PELLET PROCESS EQUIPMENTPowder Preparation

<u>Case 4</u>	\$ 0
<u>Case 5</u>	67,000
<u>Case 6</u>	71,500

Slug

<u>Case 4</u>	\$ 85,200
<u>Case 5</u>	96,000
<u>Case 6</u>	100,000

Granulate

<u>Case 4</u>	\$ 25,500
<u>Case 5</u>	34,300
<u>Case 6</u>	35,700

Pellet Pressing

<u>Case 4</u>	\$ 90,000
<u>Case 5</u>	103,000
<u>Case 6</u>	108,000

Inspect, Load Pellets

<u>Case 4</u>	\$ 17,800
<u>Case 5</u>	20,000
<u>Case 6</u>	20,800

Sinter Pellets

<u>Case 4</u>	\$491,000
<u>Cases 5 and 6</u>	523,000

Grind and Inspect Pellets

<u>Case 4</u>	\$128,000
<u>Case 5</u>	172,000
<u>Case 6</u>	176,000

Clean and Dry Pellets

<u>Case 4</u>	\$ 23,000
<u>Case 5</u>	27,000
<u>Case 6</u>	30,000

Load Pellets

<u>Case 4</u>	\$ 14,100
<u>Case 5</u>	42,300
<u>Case 6</u>	48,300

Weld End Cap #2

Cases 4 and 5	\$109,000
Case 6	112,000

Empty Pellets-Rework

<u>Case 4</u>	\$ 1,400
<u>Case 5</u>	8,000
<u>Case 6</u>	8,400

FUEL ROD PROCESS EQUIPMENTUltrasonic Weld Test

<u>Cases 1,2,4 and 5</u>	\$ 25,000
<u>Cases 3 and 6</u>	29,000

Weigh

<u>Cases 1,2,4 and 5</u>	\$ 3,000
<u>Cases 3 and 6</u>	3,500

Degrease

<u>Cases 1,2,4 and 5</u>	\$ 16,000
<u>Cases 3 and 6</u>	17,000

Weld Dress

<u>Cases 1 and 4</u>	\$ 4,000
<u>Cases 2,3,5 and 6</u>	6,600

Weld Rework

<u>Cases 1 and 4</u>	\$ 15,000
<u>Cases 2 and 5</u>	19,000
<u>Cases 3 and 6</u>	23,500

Etch

<u>Cases 1,2,4 and 5</u>	\$100,000
<u>Cases 3 and 6</u>	110,000

Leak Test

<u>Cases 1,2,4 and 5</u>	\$ 28,000
<u>Cases 3 and 6</u>	29,500

Inspect

<u>All Cases</u>	\$ 3,000
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Autoclave

<u>Cases 1,2,4 and 5</u>	\$200,000
<u>Cases 3 and 6</u>	202,000

Survey

<u>All Cases</u>	\$ 3,000
------------------	----------

Decontaminate

<u>Cases 1 and 4</u>	\$ 2,000
<u>Cases 2 and 5</u>	21,000
<u>Cases 3 and 6</u>	23,000

Grit Blast

Cases 1,2,4 and 5 \$ 10,000

Cases 3 and 6 10,500

Quality Audit

All Cases \$ 15,000

Survey

All Cases \$ 5,000

Weld Assembly

Cases 1,2,4 and 5 \$ 25,000

Cases 3 and 6 26,500

Inspect Assembly, Rework

Cases 1,2,4 and 5 \$ 12,000

Cases 3 and 6 \$ 13,500

Crate and Store, Misc.

All Cases \$ 12,000

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