ANRCP-1998-17
October 1998

Amarillo National Resource Center for Plutonium

A Higher Education Consortium of The Texas A&M University System,
Texas Tech University, and The University of Texas System

Process Modeling of Plutonium Conversion and MOX Fabrication for Plutonium Disposition

Kenneth L. Schwartz
Department of Nuclear Engineering
The University of Texas

Edited by

Angela L. Woods
Technical Editor

This report was prepared with the support of the U.S. Department of Energy (DOE) Cooperative Agreement No. DE-FC04-95AL85832. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of DOE. This work was conducted through the Amarillo National Resource Center for Plutonium.

600 South Tyler • Suite 800 • Amarillo, TX 79101
(806) 376-5533 • Fax: (806) 376-5561
http://www.pu.org

ANRCP-1998-17

AMARILLO NATIONAL RESOURCE CENTER FOR PLUTONIUM/
A HIGHER EDUCATION CONSORTIUM

A Report on

Process Modeling of Plutonium Conversion and MOX Fabrication for Plutonium Disposition

Kenneth L. Schwartz
Department of Nuclear Engineering
The University of Texas
Austin, Texas 78712

Submitted for publication to

Amarillo National Resource Center for Plutonium

October 1998

DEDICATION

This work is dedicated to my family for their continuing support. It is also dedicated to my Mom, who taught me that learning can be fun, and that the impact I have on peoples' lives can come in all sizes; always try to make them good ones.

ACKNOWLEDGEMENTS

First and foremost I would like to thank Dr. Sheldon Landsberger who has been a continuing source of drive and strength for many years. He has been my teacher, mentor, the father I never wanted, and a good friend.

I want to thank Sinan Goktepeli for showing me easier ways of accomplishing much of the data analysis.

I would also like to thank Carl Beard for his direction and guidance on this and related works, and Xiaoyun Yang for his help with researching some of the data.

Lastly, I want to thank the ANRCP for their support in funding and education of this and related research.

This thesis was completed on July 20, 1998.

Process Modeling of Plutonium Conversion and MOX Fabrication for Plutonium Disposition

Kenneth Lawrence Schwartz, M.S.E.
The University of Texas at Austin

SUPERVISOR: Sheldon Landsberger

Two processes are currently under consideration for the disposition of 35 MT of surplus plutonium through its conversion into fuel for power production. These processes are the ARIES process, by which plutonium metal is converted into a powdered oxide form, and MOX fuel fabrication, where the oxide powder is combined with uranium oxide powder to form ceramic fuel. This study was undertaken to determine the optimal size for both facilities, whereby the 35 MT of plutonium metal will be converted into fuel and burned for power.

The bounding conditions used were a plutonium concentration of 3-7%, a burnup of 20,000-40,000 MWd/MTHM, a core fraction of 0.1 to 0.4, and the number of reactors ranging from 2-6. Using these boundary conditions, the optimal cost was found with a plutonium concentration of 7%. This resulted in an optimal throughput ranging from 2,000 to 5,000 kg Pu/year. The data showed minimal costs, resulting from throughputs in this range, at 3,840, 2,779, and 3,497 kg Pu/year, which results in a facility lifetime of 9.1, 12.6, and 10.0 years, respectively.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

In an effort to reduce the global stockpile of nuclear explosive devices, over 50 metric tons of weapons-grade plutonium has been declared surplus by the United States. This surplus must now be rendered unattractive for use in nuclear weapons. The goal is that this drive will be concurrent with similar activities in Russia. One method currently under investigation is the conversion of the plutonium metal into mixed-oxide reactor fuel. This fuel would be used in currently operational reactors for power production. The final product would be rendered non-weapons-usable and be compliant with the spent fuel standard.

In order to accomplish this task, two separate plants would be built. The first would convert the plutonium metal into a powdered-oxide form. The second plant would combine the plutonium oxide powder with uranium oxide powder and fabricate mixed-oxide fuel pellets. These pellets would be used to make fuel bundles for power production. At each defined step through the production process, modules, that require defined area and manpower for operation, will be used to process the material(s). Each module can process a certain quantity over a period of time. The number of modules required at each step will depend upon the quantity of material needed in the following module. By varying the properties of the desired mixed-oxide fuel, and the number of reactors that will be used, the number of modules, and therefore the total area and manpower required, can be determined. By examining the results, the optimal desired properties and number of reactors can be determined to keep the manpower and needed facility area to a minimum. This would result in minimizing the cost of the processing facilities. The goal of this thesis is to determine what throughputs would result in the minimum cost of lifetime operation of the two facilities.

2. BACKGROUND

The procedure currently proposed for the conversion, from a metal into an oxide form, is the Advanced Recovery and Integrated Extraction System (ARIES) (LA-UR-97-2909, 8). The plutonium will enter this process in the form of plutonium weapons components, known as pits. A pit is a spherical shell of plutonium, surrounded by a beryllium or stainless-steel cladding, and, depending on the weapon type that it came out of, may have a variety of other attached components. These other components will be removed and sent to other parts of the plant for handling. The remaining pit will be bisected; the plutonium will be removed from the cladding and converted into an oxide. This oxide will undergo gallium removal, then be canned, tagged, decontaminated, and assayed for record (LA-13178). The ARIES facility is intended to put out 35 metric tons of plutonium, in a dioxide powder form.

The second step in the conversion process is the production of MOX fuel rods. This entails combining the plutonium dioxide with depleted or natural uranium dioxide, and using this mixture to fabricate ceramic fuel pellets. A column of pellets is loaded into Zircaloy cladding to form fuel rods. These fuel rods will then be used to form fuel bundles. The fuel bundles will be used as reactor fuel in either boiling water reactors (BWR) or pressurized water reactors (PWR), which could use enrichments ranging from 3 wt% to 7 wt%. The fabrication capacity of the MOX fabrication facility will vary depending upon the final fuel design, the number of reactors employed, the loading pattern, and the cycle length. The nominal facility envisioned by DOE at this time has a fabrication capacity of 100 MT of MOX fuel[1]. The 100 MT facility will combine approximately 96.5 MT of UO_2 with the 3.5 MT of PuO_2 obtained each year from the ARIES process.

Both facilities will be designed to meet federal, state, and local environmental, health, and safety requirements and considerations. Occupational radiological exposures will adhere to federal guidelines, and the plants will be designed around the ALARA principle (As Low As Reasonably Achievable). The current outlook is the start of operations for the ARIES plant and MOX fabrication facility to begin in 2005 and 2006, respectively.

2.1 DESCRIPTION OF THE ARIES PROCESS

ARIES is a modular, low-waste method of disassembling pits and converting the plutonium into a stable, unclassified form. ARIES is made up of a series of interconnected glove-box modules with a non-destructive assay (NDA) module attached. Due to its modular nature, the ARIES line can be adjusted to a variety of throughputs, changes in the process requirements, and new technologies, without having to retrofit the entire line. The ARIES process consists of a number of steps, including pit receiving, pit bisecting, oxide production, primary canning, electrolytic decontamination, secondary canning, and NDA.

2.1.1 Pit Receiving

Upon arrival at the ARIES facility, the explosives, electronics, highly enriched uranium (HEU) and tritium (if applicable) will be removed from the pit and declassified. The plutonium pit will then undergo a non-destructive assay to ascertain the amount and isotopic concentration of plutonium being introduced into the processing system. This assay involves the use of a number of survey instruments, (e.g., calorimeters, spectroscopy systems, mass scales, etc.), and is able to determine the quantity of plutonium present.

[1] 100 MT is the combined weight of plutonium and uranium metal. This number does not include oxygen.

Once the assay is completed, the plutonium is introduced into the glovebox system. This introduction will consist of passing the pit through an airlock system, into the inert lower pressure argon atmosphere of the glovebox.

Each pit contains approximately 4 kg of plutonium. By the time the storage container arrives at the facility, the pit will have been separated from its tritium components. When it arrives, it will be checked for tritium contamination. If the pit contains tritium, it will be sent to the Special Recovery Line (SRL) to have the tritium removed first. If the pit does not contain tritium, it will then be removed from the container and checked for surface contamination. If contaminated, it is cleaned. Each pit will be assayed for accountability of plutonium. During the process, assaying will consist of weighing and cataloging to ensure accountability of the plutonium at each step of the conversion process. The pits are then sent on to the bisector module. The containers are checked for contamination, cleaned, and packed for reuse.

2.1.2 Pit Bisector

The ARIES process requires that all pits introduced into the system be bisected into hemispherical halves. In order to accomplish this task, a device similar to a pipe cutter is used. Following the removal of any external equipment, the pit is placed into the bisector. A blade that rotates with respect to the pit is used to cut into the pit. The pit is bisected into two ~2 kg hemispheres, and all plutonium-bearing components are now ready for plutonium removal. Items that do not contain plutonium can be decontaminated, transferred out of the glovebox, and declassified as necessary. Declassification entails converting the item into a different form and weight in order that the original item is not able to be reproduced. This is accomplished by cutting the item and melting the pieces into pucks for disposal.

2.1.3 Oxide Production

The plutonium-bearing hemisphere is placed into the HYDOX unit. HYDOX is the generic term for the module in which the conversion of plutonium metal to plutonium oxide takes place. The plutonium must be separated from the subassemblies. Hydrogen gas is used to form plutonium hydride, which flakes off and falls to the bottom of the unit, where it is collected in a mesh-frit. Nitrogen gas is passed upward through the plutonium hydride, driving off the hydrogen, and leaving behind plutonium nitride. Once the reaction has gone to completion, oxygen is passed through the plutonium nitride, driving off the nitrogen and forming plutonium oxide. The oxide powder is assayed upon removal from the reactor for accountability. A HYDOX module contains two reactors, each capable of handling a pit hemisphere. The 2 kg of plutonium hemisphere will be loaded into a module and weighed. Once put in the HYDOX reactor, the atmosphere will be evacuated to less than 200 millitorr. The steps of transformation from metal to oxide are shown in Table 1, along with associated times of completion. All HEU remaining is sent to HEU processing, and non-special nuclear materials are sent for declassification.

2.1.4 Gallium Removal

The oxide powder is then passed to another glovebox for gallium oxide (Ga_2O_3) removal. Since the eventual intended use of the plutonium oxide is in the formation of nuclear fuel rods, it is desirable that any gallium that is present be removed. This is due to the effect of gallium on the fuel fabrication process and the potential of a corrosive reaction between gallium and the Zircaloy cladding normally used in nuclear fuel construction. A second reason comes from the fact that in order to create MOX fuel, the plutonium oxide must be made into a

Table 1: HYDOX Flow Chart (LA-UR-97-2208)

Step Procedure	Time Required[2] (min)	Mater. Present at Start/Form of Mater.	Ideal Density of Mater. Present[3] (g/cm^3)
Add Hydrogen	120	Pu / metal	19.86
Purge with Argon and Evacuate	20	PuH_2, PuH_3/ powder	10.40, 9.61
Heat to 250-500 ^oC	60	PuH_2, PuH_3/ powder	10.40, 9.61
Add Nitrogen	240	PuH_2, PuH_3/ powder	10.40, 9.61
Evacuate N_2 and H_2	20	PuN / powder	14.25
Heat to 650 ^oC	60	PuN / powder	14.25
Add Oxygen	120	PuN / powder	14.25
Heat to 850-1000 ^oC	60	PuO_2 / powder	11.46
Cool Down	480	PuO_2 / powder	11.46

ceramic. It was determined that as little as 2000 ppm of gallium in the plutonium will hinder the sintering process during ceramic production (LA-UR-97-4423, 11). Therefore, the gallium must be removed while the plutonium oxide is still in a powdered form. The goal is to get the gallium concentration as low as reasonably achievable. A concentration of less than 100 ppm is desirable in the plutonium dioxide used for MOX fuel, with the lower the better.

To remove the gallium, the plutonium oxide is heated to a temperature at which gallium oxide sublimes into a gaseous form, Ga_2O_3. The gallium oxide is driven off via a negative pressure and condensed for disposal. The current dry removal system being developed is the Thermally Induced Gallium Removal (TIGR) system. In this method, the PuO_2 powder will be raised to 1000-1100 ^oC. Argon, containing 5-6% H_2, will be drawn over the powder. The hydrogen will thermodynamically reduce the Ga_2O_3 to GaO_2. Since the sublimation pressure of GaO_2 is much greater than Ga_2O_3 and PuO_2, the GaO_2 will be driven off selectively from the powder. The gallium will exit the module, along with the argon and H_2O formed from the reduction. The gallium will be recondensed after exit. This process takes approximately half of the time of one cycle of the HYDOX reactor (1 cycle ≈ 20 hours). Therefore, it is currently recommended that there be one gallium removal module per HYDOX module (2 reactors). This will process 5 to 6 kg of PuO_2 powder per cycle. After the gallium removal, the powder should be ball-milled to ensure particle size will meet fuel specifications. The quantity of gallium per pit can vary from <200 ppm, up to approximately 1%, or 10,000 ppm. We will therefore assume a conservative estimate of 1%, which will result in the removal of approximately 40 g of gallium per pit, or about 70 kg of gallium per year. The gaseous gallium collection process is still under study.

A second process that is being reviewed as a backup baseline procedure is the removal of gallium using ion exchange. The first step of this process is to dissolve a quantity of PuO_2 powder by a solution of nitric acid, with a small amount of HF, to

[2] LA-UR-97-2208, Appendix B
[3] Taube, 48

form plutonium nitrate. This feed solution, which contains gallium and americium, is then loaded onto an anion exchange resin. The plutonium will bind with the resin, leaving the gallium and americium in the feed solution. The resin is washed down with nitric acid, and the gallium and americium is carried with it. To remove the plutonium, the plutonium-bearing resin is washed down with a weak solution of nitric acid to disassociate the plutonium nitrate anion. The resultant solution is mixed with oxalic acid, which will precipitate out plutonium oxalate. This oxalate is calcified to water and carbon dioxide, leaving PuO_2. A single process line has the capacity to remove the gallium from .75 metric tons of plutonium per year (LA-UR-97-3769).

The plutonium oxide that remains after the gallium is withdrawn, is removed from the unit and combined with oxide from previous HYDOX processing. This is done to homogenize the gallium content between batches. The plutonium oxide is now ready for packaging, and shipment or storage.

2.1.5 Packaging and Primary Canning

A dual packaging system is used in order to ensure containment integrity. The primary packaging is done while the plutonium is still in the glove box. The plutonium is placed in the primary can, and the container is purged with helium gas. The lid is welded onto the primary container, and when completed, the can is leaked checked by measuring for the presence of helium. If necessary, the welding process can be repeated. Periodically, an empty can will be laser marked, outside of containment, and sent along for tracking purposes.

2.1.6 Electrolytic Decontamination

The primary container is now ready for electrolytic decontamination. The decontamination glovebox is comprised of a contaminated side and a clean side. The cans enter in the contaminated side, are wiped clean, and sent into the electrolytic decontamination chamber. This involves setting up the can as an electrode in a low voltage circuit, and applying an electrolyte fluid to remove any external contamination. The container is rinsed and dried inside that chamber, the door to the clean side is opened, and the can is checked for contamination. If the can is still contaminated, the process is repeated. If the can is clean, the can is removed and sent to the next chamber for secondary canning. In addition to the primary containers, all materials removed from the glovebox will be decontaminated using this method.

All fluids used are recycled, and any contaminants removed from the containers will be filtered from the solution. This, along with the rinse water, will be periodically removed from the chamber. As the waste will be homogeneous, and probably contain sufficient transuranic isotopes, it will be classified as TRU waste, and sent to waste management for disposal.

2.1.7 Secondary Canning

Once the primary containers are removed from the glovebox, they are laser marked to identify the contents, placed into secondary containers, and purged with helium as before. The secondary container lid is then welded on, and the container checked for weld integrity. This can is also laser marked for identification of can contents. The final step that a container undergoes is a non-destructive assay, in order to maintain plutonium accountability. The containers are ready for either storage or shipment; they are ready for inspection and are in an unclassified form appropriate for the application of traditional international safeguards.

2.1.8 Current Industrial Status of the Process

At this time, the ARIES process has not been used as an industrial-scale process. Each component of the process has different levels of experience associated with it. Pit receiving and bisecting are currently in use regularly at Los Alamos National Laboratory and are therefore well-known. The laser marking and canning are also processes that are in industrial use. There are two methods for gallium removal, each with different levels of experience associated. The wet chemical separation process is a demonstrated process and has been used at industrial-scale. The dry process is still in the final developmental stage and has not been tested in production quantities. The hydride-dehydride process, which produces a metal product, is a demonstrated process and has been used on large quantities of plutonium. The hydride-nitride-oxide process has been used on small quantities, but is not a well tested procedure.

2.1.9 Potential Process Variations

In certain parts of the ARIES process, more than one method is being analyzed to accomplish the task required. The baseline procedure is as described above. For the gallium removal step, an aqueous procedure is also being investigated. Since the goal of ARIES is to be a dry process, the thermal removal is favored. For the removal of the plutonium from the cladding, the hydride-nitride-oxide method is favored. The other method under observation is the hydride-oxide method. This method converts the plutonium hydride directly into an oxide by adding oxygen, which will react with the powdered hydride. If the plutonium is to be converted back into a metal for storage purposes, the hydride-dehydride process will

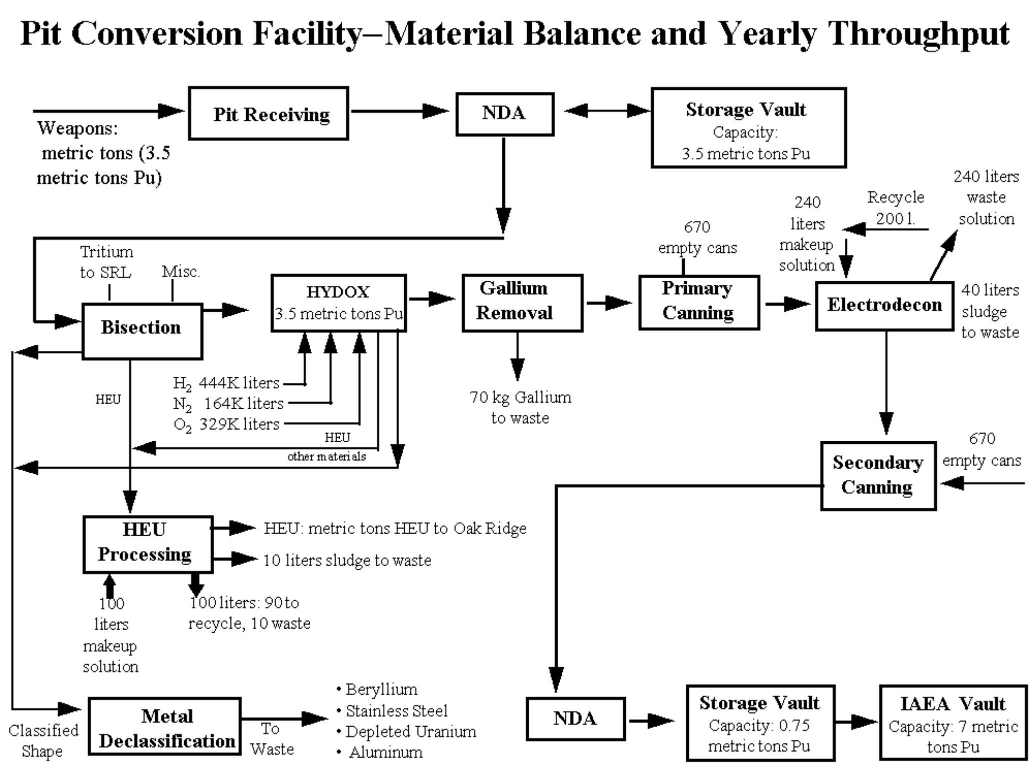

Figure 1: Flow Diagram for the ARIES Pit Conversion Facility (LA-UR-97-2909, 33)

be used. This will heat up the hydride and drive off the hydrogen gas, leaving plutonium metal, which can then be melted into a metal disk, or puck, recast into a nominal mass, and canned using the same procedures. If a metal is to be formed, no gallium removal is to be done as the metal will not be used for MOX fuel directly in the metal form.

2.2. DESCRIPTION OF MOX FUEL FABRICATION

The purpose of the MOX fuel fabrication facility is to combine plutonium dioxide (PuO_2) powder with uranium dioxide (UO_2) powder to form mixed-oxide fuel rods. The fuel rods may then be used to generate power in a variety of power plants.

Upon arrival at the MOX fabrication facility, the PuO_2, UO_2, and other materials for the process are received and stored. The UO_2 is received onsite in a ready-to-use condition. Both powders are weighed and blended together and milled to form a uniform mixture. A further portion of UO_2 is blended to reduce the plutonium concentration. This mixture is blended again to uniformity. A portion of the mixture is removed to add to the next batch.

The mixture is then sent to pellet fabrication. The MOX powder is mixed with lubricant and binding agents, and pressed into pellets. These pellets are loaded into sintering boats, which are then transferred to a sintering furnace and sintered in an argon and 6% hydrogen atmosphere to ensure the oxygen-to-metal ratio. After sintering, the pellets are checked to ensure that they have the proper properties, such as size, density, and homogeneity. Rejected pellets are sent to be recycled. Pellets that are accepted are ground to proper dimensions and inspected. Rejected pellets are sent back to be recycled.

To prepare the fuel rods, the pellets and other components, depending on the type of rod, are loaded into the Zircaloy casing. The end is decontaminated, the casing is backfilled with helium, and the endcap is welded on (the rod arrives with one endcap welded into place). The rod is then inspected for flaws and leak-tested. Accepted rods are stored for their use in fuel bundles. Rejected rods are sent back to be recycled.

To prepare a fuel bundle, the rods are removed from storage and the bundle is compiled. A completed bundle may include depletable neutron absorbers and/or enriched uranium fuel rods depending on the type of reactor the bundle is intended for. The assembled bundle is cleaned and inspected. Accepted bundles are sent to storage for shipping to a reactor site. Rejected bundles are sent back for recycling.

As some of the materials along the process may have been rejected, these materials will be recycled for reuse. If a bundle is rejected, the fuel rods are removed and inspected. If they are acceptable, they will be reused to form a new bundle. The other components of the bundle are inspected, and if not usable, they will be decontaminated and thrown away as scrap. If a fuel rod is rejected, the pellets will be removed and checked. If the pellets are acceptable, they will be used to make another fuel rod. If the rod components are not acceptable, they will be decontaminated and thrown away as scrap. If fuel pellets are found to be unacceptable, but are still uncontaminated, they will be crushed back into a powder. This powder will be heated in a moist environment to convert to UO_2 into U_3O_8, and heated again in an argon-hydrogen atmosphere to revert U_3O_8 back into UO_2. This powder will then be sent to storage to be mixed with fresh powder (LA-UR-97-2067, 69).

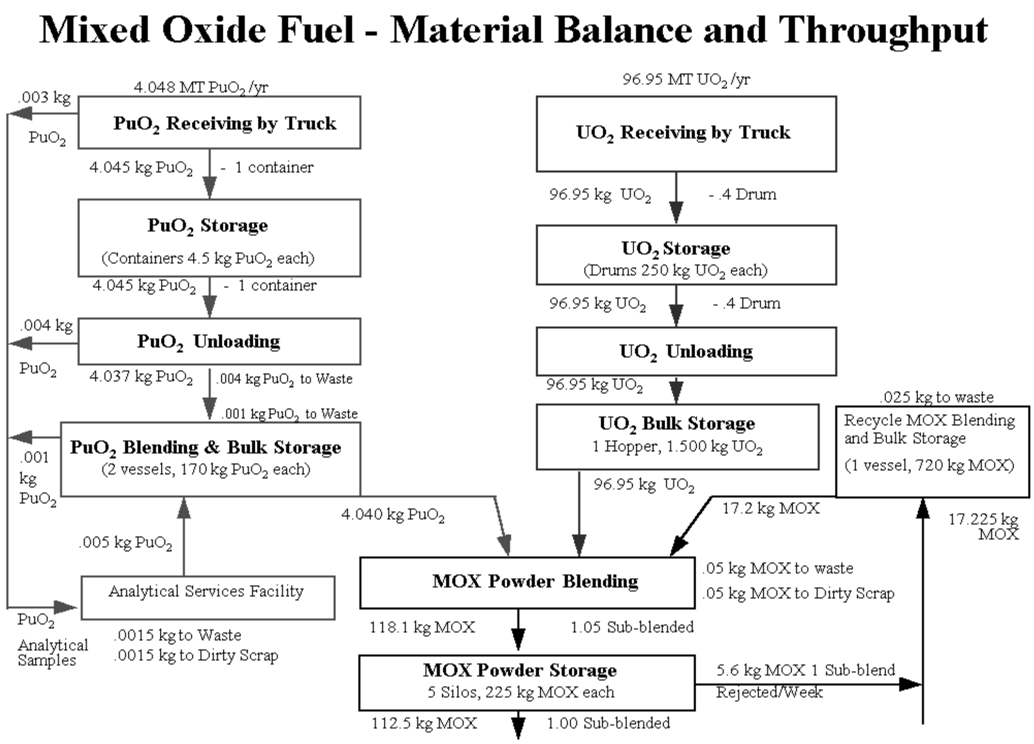

Figure 2a: Flow Diagram for the MOX Fuel Fabrication Facility (LA-UR-97-2067, 141)

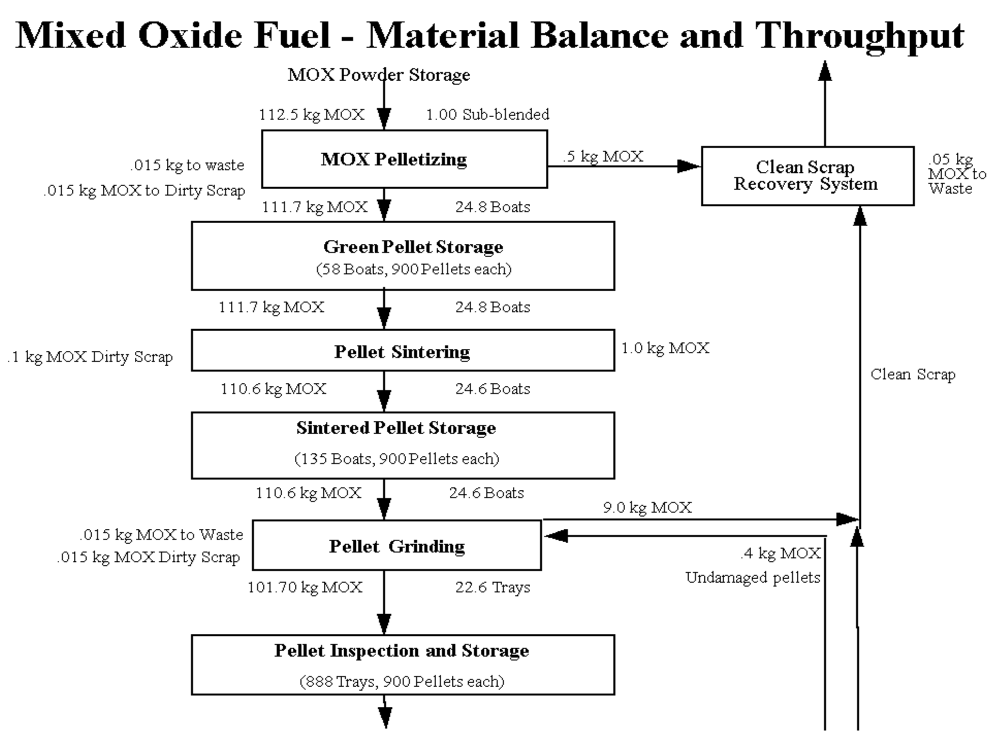

Figure 2b: Flow Diagram for the MOX Fuel Fabrication Facility (LA-UR-97-2067, 141)

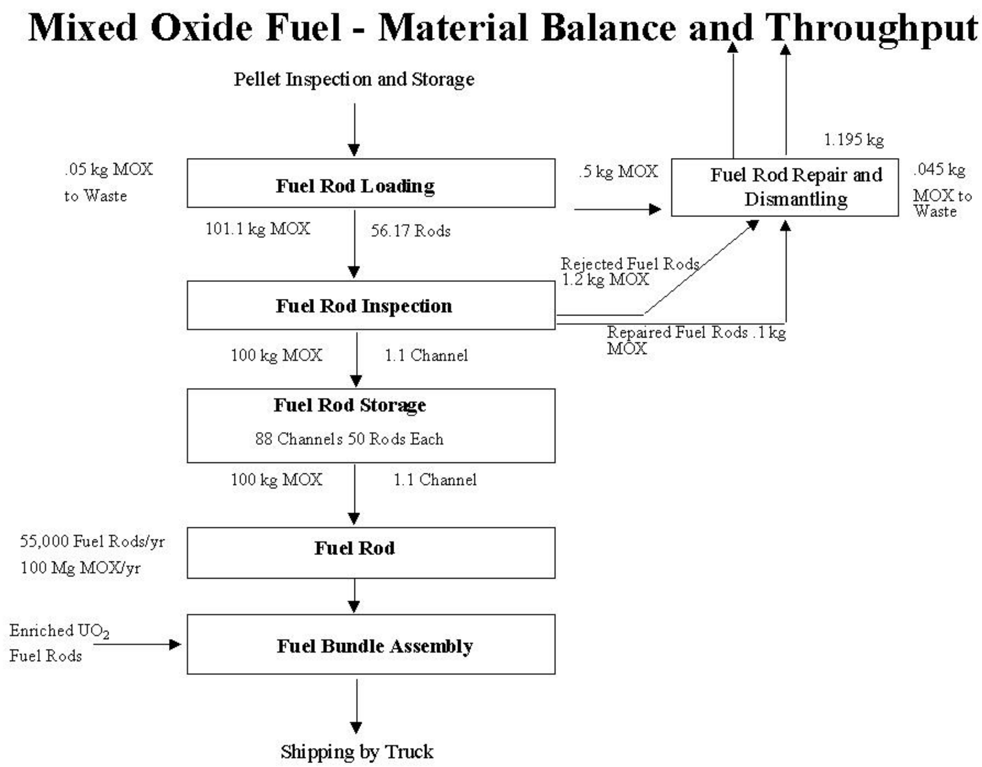

Figure 2c: Flow Diagram for the MOX Fuel Fabrication Facility (LA-UR-97-2067, 141)

In order to fully describe each subprocess in the fuel assembly facility, certain assumptions must be made. It is assumed that the facility will be shut down for scheduled maintenance and repairs for a total of one week every six months. During this time, no MOX fuel will be constructed. This leaves 50 weeks of operational time. At 20 shifts per week, there are 1000 shifts per year. With 8 hours per shift, this yields 8000 hours per year.

2.2.1 Materials Receiving and Storage

In materials receiving and storage, all materials required to convert the plutonium and uranium powders into fuel bundles are received, inspected, sampled, and stored. The materials for the pellet fabrication are PuO_2 from the ARIES facility and UO_2 from natural or depleted uranium. The PuO_2 will arrive in double-canned containers. Each double-can has the capacity of 4.5 kg PuO_2. (Each mass given is the mass of the metal in the powder, i.e., 4.5 kg Pu metal in a powder dioxide form.) If the ARIES and MOX facilities are not at the same site, each shipment will contain 38 cans for a total of 171 kg of PuO_2 per shipment. The UO_2 will arrive in 55 gallon drums, each with a capacity of 250 kg of UO_2. Each shipment will contain 70 drums, for a total of 17,500 kg of UO_2 per shipment. About 5 grams of PuO_2 will be sampled from each can, and sent to be analyzed for accountability. Unused quantities will be returned to the process, and used amounts will be sent to waste handling. All PuO_2 will be sent to a designated storage vault. Uranium dioxide drums will be sent to facility storage.

Other radioactive materials received could potentially include enriched uranium fuel rods used for the final assembly of a fuel bundle. The number of rods and enrichment of the uranium will vary depending on the type of reactor for which the fuel bundles are being used. The facility will also receive

depletable neutron absorbers and neutron absorber rods, fuel bundle and fuel pin hardware, process gases, and other materials required in the process, such as lubricants and binders. All materials received are inspected and analyzed to ensure that they meet required specifications. These materials will be sent to facility storage after leaving receiving. Appropriate measures will be taken to ensure the security of the PuO_2, as well as to comply with criticality requirements.

2.2.2 Feed Material Preparation

The PuO_2 is taken from the vault and entered into a glovebox. The PuO_2 is milled and screened to obtain an optimal particle size distribution. This powder is then mixed with powder from a previous batch that has also been milled and screened, and the new powder is placed into storage. This is done to ensure homogeneity and consistency between the batches to obtain MOX pellets that have uniform properties. When required, a quantity is weighed out and set aside. The UO_2 is removed from storage and two quantities are weighed out. The first is to give the batch a 30 $^{w}/_{o}$ PuO_2. The second will be blended after the primary blending to obtain the final desired weight percent (5 $^{w}/_{o}$ PuO_2) (See Section 2.2.8). If required, a quantity of depletable neutron absorber will also be weighed out. A lubricant, zinc stearate, will be used to aid in the ceramic pellet production, and is also weighed out. All feed materials are then combined, and a portion from a previous batch is added to maintain consistency. A portion of the final blended batch is then removed to combine with the following batch. A larger batch size is preferred to be able to remove a larger portion for consistency. However, batch size will be limited to comply with criticality safety limits.

2.2.3 Fuel Pellet Fabrication

The feed mixture is to be put into a press, and pressed into pellets approximately 1 cm in length. Each pellet contains 5 g of MOX. These pellets are loaded into boats, each with a capacity of 900 pellets. The pellets are sent into a furnace to be sintered. The sintering process will take place in an argon-6% hydrogen atmosphere to maintain metal-oxygen ratio. The temperature in the sintering oven is to be slowly ramped up to ~ 1600 ^{o}C. It remains there for 2 ½ hours, and then is ramped down to ambient temperature (~20 ^{o}C). The entire sintering process takes approximately 24 hours. When complete, the sintered pellets are inspected for flaws resulting during the heating process. They are also to be analyzed to check for consistency in density and homogeneity requirements. Any pellet not meeting specifications will be sent back to materials preparation to be crushed back into a powder, milled, and reblended. The accepted pellets are to be ground to a uniform cylindrical shape and size and stored until needed.

The equipment used in this procedure will generate a large amount of heat, and a cooling tower will be required to lower the temperature of the feed water used to cool the machinery. The additional materials that are required at this step are hydrogen and argon gases, and zinc stearate for use as a lubricant in the pressing process. There will be a small amount of MOX powder resulting from grinding that will be sent to waste handling.

2.2.4 Fuel Rod Fabrication

Fuel rod hardware will be removed from storage, cleaned, and inspected for any flaws. One end of the fuel rod is already sealed by a welded-on cap. Sintered fuel pellets are removed from storage, inspected, and then loaded into the fuel rod, 360 pellets per rod (1.8 kg MOX). This quantity is used for both PWR and BWR fuel rods (LA-UR-97-2067). The rod is back-filled with helium

gas, and the second cap is welded. The rod is leak tested and again inspected for flaws. Accepted rods are cleaned and stored. Defective rods are recycled by removing the fuel pellets, and determining if the rod usable. If not, the rod is decontaminated and sent away as waste. The fuel pellets are again checked, and if usable, they are reloaded into another fuel rod.

2.2.5 Fuel Bundle Assembly

The fuel bundle components are removed from storage, cleaned, and checked for flaws. Flawed components will either be recycled or disposed. MOX, enriched uranium fuel, and guide rods will be removed from storage and inspected. The number of MOX and enriched uranium fuel rods will depend upon the type of reactor for which the bundle is intended. The assembly will then be welded together.

The two primary types of reactor cores being considered are the pressurized water reactor (PWR) and the boiling water reactor (BWR). The PWR fuel bundle consists of a 17x17 grid (289 positions) of which 264 are loaded with fuel rods. The remaining 25 positions are for guide and instrumentation thimbles. The BWR bundle consists of a 9x9 rod assembly. For initial start-up in a BWR, a configuration, based on the GE-11 design, will consist of approximately 36% of the fuel rods consisting of MOX fuel rods, and the remaining will consist of low-enriched uranium fuel. The second design, to be implemented at a later stage, will consist entirely of MOX fuel rods and no enriched-uranium rods. The construction may also include depletable neutron absorbing rods as required. After construction of the bundle, it will be inspected for flaws. If flawed, it will be disassembled and reused. Accepted bundles will be sent to storage for shipment to power plants.

2.2.6 Process Material Recycling

Material that may be recycled during the process include bundle and rod components that were found to be flawed and fuel pellets that were rejected for not meeting specifications, such as density, homogeneity, and dimensional constraints. When a bundle is found to be flawed, usable fuel rods are removed and sent back to storage. Flawed bundle component are decontaminated and sent for scrap. Flawed fuel rods are disassembled, and the fuel pellets are removed. Acceptable fuel pellets are sent back to storage for reuse. Fuel rod components are decontaminated and sent for scrap.

Due to natural imperfections and uncontrollable inconsistencies in the pellet production process, a certain number of the fuel pellets will fail to meet specifications. There is also the possibility that a quantity of unirradiated fuel rods may be shipped to the plant from storage at other DOE sites for disassembly, and flawed MOX pellets will be removed. These pellets and other clean scrap will be crushed and refined as previously described. The wastes generated by this process will be similar to those described in previous processes.

2.2.7 Current Industrial Status of the Process

The fabrication of UO_2 ceramic fuel bundles has been in use for over 40 years. As such, most of the processes in this procedure have many years of industrial practice and use behind them. The combination of PuO_2 and UO_2 powders in the production of fuel rods has been in practice in Belgium and France for over 10 years and is also currently in practice by BNFL in England.

In the production of the feed materials for ceramic production, blending is the common practice to combine various powders to ensure a homogeneous mixture. Milling is the standard method for grinding powders to a

specific particle size distribution. The sintering, grinding, rod construction, and bundle formation are all standard practices to produce nuclear reactor fuel, both in the United States and Europe.

2.2.8 Potential Process Variations

In Europe, there are two methods of producing MOX fuel practiced today. The first is the MIMAS process, used by France's Cogema facilities. The procedure proposed in this report is a slightly more automated version of the process, known as the AMIMAS, or Advanced MIMAS, process. The MIMAS process itself is only slightly different than the second process, used by BNFL known as the Short Binderless Route (SBR). The difference between the two is that during the feed materials preparation, the SBR process mixes the PuO_2 and UO_2 in one step to obtain the final desired composition. The MIMAS and AMIMAS process first combines the powders to obtain approximately a 30 $^{w}/_{o}$ PuO_2, and then adds an additional quantity of UO_2 for a second mixing to get the desired PuO_2 weight percent.

3. METHODOLOGY

In order to minimize the cost of the facilities, and optimize the output, the evaluation is broken into three steps. The first step is to determine the quantity of plutonium that would be required to run the reactors each year. The second step is to determine the fixed variables in the MOX Fuel Fabrication Facility (MOX FFF) to determine how the square-foot area and number of workers change relative to the amount of plutonium required. The third step is to perform the same analysis on the ARIES plant. The evaluation is performed in the reverse-order of the fabrication of the fuel. This is done because the nuclear reactors used to burn MOX fuel are ones that are already in operation. Because of this, it is easy to identify which variables can be changed due to the properties of the nuclear reactors. This minimizes the uncertainty of the results.

In order to calculate the quantity of plutonium required by the nuclear reactors, the variables must be defined. It is easiest to define the governing equation to calculate the quantity of plutonium required per year. Equation 1 is the defining equation, with the definition of the variables given in table 2. The output of this equation will be used as the input for the MOX fuel fabrication calculations. Initially, the values of the required mass of plutonium throughput per year will be calculated using the bounding conditions to determine the minimum and maximum possible values. The input values for the steps that follow will come from varying the mass of plutonium as a function of the plutonium concentration between the two extremes to obtain output values for the number of workers and facility size. The previous equation (1) will then be used again by feeding in the local minimums of the plotted values to find what values for the previous variables would be optimal.

The first process that needs to be evaluated is the MOX fuel fabrication.

$$Pu_{required} = \frac{PowerLevel}{Burnup} * Pu_{conc} * Corefraction * \mathrm{Re}actors * days * (kg / MT) \qquad \textbf{(1)}$$

Table 2: Variable Definitions to Calculate Required Plutonium

Variable	Definition	Default Value or Range
$Pu_{required}$	Amount of plutonium required for power production	Defining Variable (kg of plutonium/yr)
Power Level	Power level of reactors being used	3000 Megawatts (MW)
Burnup	Burnup of reactor fuel	20000-40000 Megawatt-days/Metric tons of heavy metal (MWd/MTHM)
Pu_{conc}	Plutonium concentration of MOX fuel pellets	3-7 (%)
Corefraction	Fraction of reactor core that will contain MOX fuel	10-40 (%)
Reactors	Number of Reactors used to burn MOX fuel	2-6 reactors
Days	Number of days per year	365 days
Kg/metricton	Number of kilograms per metric ton	1000 kg/metric ton

For this, the initial step analyzed was the shipment of the finished MOX fuel bundles, working in the reverse order of the process, to the arrival of the plutonium dioxide (PuO_2) powder at the MOX FFF. An assumption was made that the bundles are shipped to the nuclear reactors as they are needed; therefore calculations will not include the shipping module from the MOX FFF. As the number of shipments to be made per year will be relatively low, the number of workers and square-foot area required by the shipping module will be ignored. The steps in the optimization study of the MOX FFF will closely resemble analyzing the flow modules in the reverse order of Figure 2. A simplified version is given in Figure 3. In order to determine how many fuel bundles the Fuel Bundle Assembly needs to produce per year, the number of kg of plutonium in each bundle needs to be known. To calculate the mass of plutonium per bundle, the number of MOX fuel rods and the mass of plutonium per rod needs to be known. The mass of plutonium per fuel rod was calculated from the number of fuel pellets per rod and the quantity of plutonium per pellet. To define the governing variable in this equation, the type of reactors to be used must be known. The types of reactors have been identified to be Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR). The BWRs used for this study are based upon studies from General Electric (GE-11 design) , and the PWRs, are based upon studies from Westinghouse (Westinghouse ER).

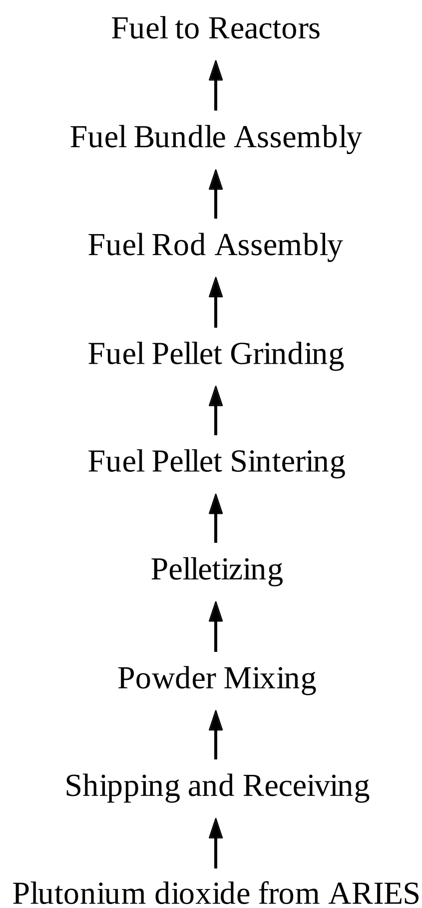

Figure 3: Simplified MOX Reverse Material Flowchart

These two types were selected for this study because they would allow MOX fuel to be fabricated and used in existing power-producing reactors, without requiring new reactors to be built. It was also identified that CANDU heavy-water reactors (HWR) could be used, but these are not included in this study.

The calculation steps are shown in the following equations:

$$BundlesRequired_{year} = \frac{Pu_{required}}{Pu_{bundle}} \quad \textbf{(2)}$$

$$Pu_{bundle} = Rods_{bundle} * Pellets_{rod} * Mass_{pellet} * Pu_{conc} \quad \textbf{(3)}$$

Table 3: Variables to Calculate the Number of Bundles Needed per Year (LA-UR-97-2067, 140)

Variable	Definition	Default quantity or range
Bundles $Required_{year}$	Number of bundles required per year from the MOX FFF	Defining variable
Pu_{bundle}	Mass of plutonium per bundle	Embedded variable (kg)
$Rods_{bundle}$	Number of fuel rods per bundle	BWR – 54 PWR – 264
$Pellets_{rod}$	Number of MOX fuel pellets per fuel rod	360 pellets/rod
$Mass_{pellet}$	Mass of MOX fuel pellet	0.005 kg

The number of bundles per year will vary greatly depending upon what type of reactor for which the bundles are intended. As the assumption is made that there are 360 pellets per rod, regardless of the reactor type (LA-UR-97-2067, 140), the number of rods per bundle is the only variable that is dependant upon the reactor type. The numbers given in Table 2 are determined from the following assumptions given in Section 2.2.5.

A PWR fuel bundle assembly consists of a 17x17 rod array, where 264 of the rod bays are filled with MOX fuel rods. The remaining rod bays will be occupied by guide thimbles and instrumentation thimbles.

A BWR fuel bundle assembly will consist of a 9x9 array, where 54 of the rod positions will be occupied by MOX fuel. Of the remaining positions, 20 will be filled by gadolinium rods, and 2 will be filled by water rods.

To determine the number of workers and the area that is needed to produce the required number of bundles, the rate at which a specific number of workers can produce the bundles is required. The rates for most of the following production steps for the MOX FFF were determined using a flowchart showing 100 kg MOX fuel production during a single 8-hour shift (LA-UR-97-2067). The flowchart shows a production of 56.17 fuel rods per shift, which results in ~ 7 rods/hour. It is planned that the facility will run three 8-hour shifts per day, 20 shifts per week, and 50 weeks per year. This results in an operating time of 8000 hours per year. To calculate the number of bundles produced per year:

$$Bundles_{year} = \frac{7[\frac{rods}{hour}]*8000[\frac{hours}{year}]}{Rods_{bundle}} \quad \textbf{(4)}$$

where $Rods_{bundle}$ is the number of rods per bundle (determined by reactor type). The number of workers per module for bundle construction was assumed to be three, two for

bundle assembly, and one to check for contamination. The area of one module for the bundle assembly is estimated based on a prospective site diagram to be ~3,000 ft^2 (LA-UR-97-2067). To calculate the number of modules required, the number of bundles required per year is divided by the number of bundles that can be produced per year by one module, and rounded to the next integer:

$$MOD = \frac{Bundles\,Required_{year}}{Bundles_{year}} \quad \textbf{(5)}$$

If MOD is not an integer, then MOD = MOD + 1, i.e., if the number of bundles required divided by the number of bundles a module can produce is not a whole number, then the number of modules needed must be rounded up to the next whole number to allow enough production to meet demand. The total number of workers or area needed for bundle production is then the number of workers or area multiplied by the number of modules (MOD). It is assumed that there is no waste of plutonium from bundle production since all components containing plutonium have been checked for flaws in other steps of the process. If a bundle is not constructed properly, then it will be disassembled and reconstructed. Therefore, the quantity of components that are recycled are assumed to be 100%.

Since no plutonium is wasted or added in the bundle production, the input variable for fuel rod assembly is the same as that for fuel bundle assembly. The required number of pins is calculated by multiplying the number of bundles required by the number of pins per bundle (determined by reactor type).

$$Pins_{year} = Bundles\,Required_{year} * Pins_{bundle} \quad \textbf{(6)}$$

Fuel rods are constructed by loading hollow tubes, made from zircaloy, with MOX fuel pellets. During this procedure, some of the fuel pellets may be found to be defective, or some of the rods may be flawed. This would result in some of the MOX either being recycled, or disposed of as waste. The recycled material may return to processing either directly as repaired fuel rods; it may be reintroduced during the pellet grinding stage; or, it may end up being re-blended with fresh MOX powder. Because of waste and recycling, more fuel rods must be produced than will be sent to fuel bundle production. The number of fuel rods to be produced, compared with the number that are sent on, are calculated as:

$$PinsRequired_{year} = Pins_{year} * (1 + Rejected_{pins} + Waste_{pins} - Recycled_{pins}) \quad \textbf{(7)}$$

where $Rejected_{pins}$, $Waste_{pins}$, and $Recycled_{pins}$ are percentages based on $PinsRequired_{year}$ from the flowchart. A list of the modifying percentages used is shown in Table 4.

The last step before the pellets are loaded into the fuel rods is to grind the pellets into the exact size needed. Pellets are cylindrical in shape, with an outer diameter of 0.3088 in. They have dimples at each end to capture fission escape gases. In order to calculate the number of pellets needed from pellet grinding, the first step is to multiply the number of pins required by the number of pellets per pin (360).

$$Pellets_{year} = Pins\,Required_{year} * Pellets / Pin \quad \textbf{(8)}$$

In order to obtain the total pellets needed before grinding, repeat the process described by Equation 7, using applicable percentages. This equation is used in all of the following steps of the MOX FFF, with the exception of shipping and receiving, to determine the input amount needed. Before

pellets are sent to grinding, they have been sintered to form a hard ceramic from a green pressed-powder pellet. The pellets are formed by pressing a mixture of PuO_2, UO_2, and a binder, into a long thin rod, which is cut into pellets. To quantify the amount of Table 4. Percentages and production rates for back-calculating plutonium flow (Calculations based on LA-UR-97-2067 and LA-UR-97-2909) powder required, the number of pellets required is multiplied by the mass of a pellet:

$$KgPlutonium_{year} = PelletsRequired_{year} * massPu / pellet \quad \textbf{(9)}$$

The PuO_2 used in blending the powders is received at the MOX FFF in cans. Each can will contain approximately 4.5 kg of plutonium powder. The number of cans that will be required by the facility per year is determined by dividing the amount of Pu required for blending by the amount of Pu in each can. It is assumed that there will be no plutonium waste, recycled, or rejected from shipping and receiving at the plant.

The plutonium dioxide is shipped in cans from the ARIES facility to the MOX FFF. The total number of cans remains unchanged, and is used for the calculations of the shipping and receiving, secondary

Table 4: Percentages and Production Rates for Back-Calculating Plutonium Flow (Calculations Based on LA-UR-97-2067 and LA-UR-97-2909)

Percentages			
Module	**Waste**	**Rejection**	**Recycling**
MOX			
Fuel Rod Assembly	4.92e-4	1.57e-2	9.81e-4
Pellet Grinding	2.71e-4	7.78e-2	3.62e-3
Sintering	8.95e-4	8.95e-3	0
Pelletizing	2.67e-4	4.44e-3	8.89e-3
Blending	9.9e-4	5.55e-2	1.81e-1
Production Rates			
MOX		**ARIES**	
Module	**Rate/module/year**	**Module**	**Rate/module/year**
Fuel Bundle Assembly	24,000 pins / # of pins per bundle	Shipping and Receiving	912 containers/year
Fuel Rod Assembly	3,200 pins/year	Secondary Canning	1,920 cans/year
Pellet Grinding	460,800 pellets/year	Electro-decontamination	1,280 cans/year
Sintering	3,197,135 pellets/year	Primary Canning	1,920 cans/year
Pelletizing	1,826,934 pellets/year	Gallium Removal	1,536 kg Pu/year
Blending	3,360 kg Pu/year	HYDOX	384 kg Pu/year
Shipping and Receiving	912 containers/year	Pit Bisection	1,540 kg Pu / year
		NDA	2,160 kg Pu / year
		Pit Receiving	As many as possible

canning, electrolytic decontamination, and primary canning steps. To perform the calculations of the gallium removal stage (dry removal), the mass of plutonium is used. This is the same mass that was used to determine the total number of cans ($KgPlutonium_{year}$). For the HYDOX conversion step, waste and recycled material must also be taken into account.

The data used for the previous calculations are given in Table 4. It shows the percentages that are used for waste, recycling, and rejection (where applicable). It also shows the calculated production rates per module. Table 5 gives the workers and area per module used.

Table 5: Workers and Facility Area Required per Module (Calculations based on LA-UR-97-2067 and LA-UR-97-2909)

Module	Workers/module/shift	Land Area per module (square feet)
MOX		
Fuel Bundle Assembly	3	3000
Fuel Rod Assembly	3	3000
Pellet Grinding	2	400
Sintering	2	1000
Pelletizing	2	1000
Blending	2	700
Shipping and Receiving	3	4000
ARIES		
Shipping and Receiving	3	4000
Secondary Canning	2	1000
Electro-decontamination	2	600
Primary Canning	2	600
Gallium Removal	2	500
HYDOX	2	500
Pit Bisection	2	1300
NDA	2	1300
Pit Receiving	2	2000

4. RESULTS

4.1 PRESSURIZED WATER REACTOR (PWR)

Results were obtained first by using the input values for a PWR. A FORTRAN program was used to calculate and tabulate the worker and square-foot land area totals for both facilities. This was done by increasing the amount of plutonium required per year from the minimum amount to the maximum amounts based upon the plutonium concentration in the fuel. This number was varied between 3% and 7% plutonium, increasing by 0.5% each step. The calculated minimums and maximums were used as the second variable, increasing by 5 kg Pu per year for each step. The results were saved in a text file along with the number of years it would take to convert 35 MT into MOX fuel based upon the yearly throughput. The resulting text file was formatted in a spreadsheet to allow analysis of data. The number of workers and land area were multiplied by 8000 (the number of working hours per year) and the number of years to complete conversion. Selected results for the varying plutonium concentration were plotted against each other to show a comparison. The results are shown in Figure 4 and Figure 5. These figures show that the minimum cost plot is at 7% enrichment.

The units of the graphs are either in man-hours lifetime, or square-foot- hours lifetime. The square-foot-hours can be multiplied by the cost of operating 1 square foot of production per hour to find the lifetime cost of the facility.

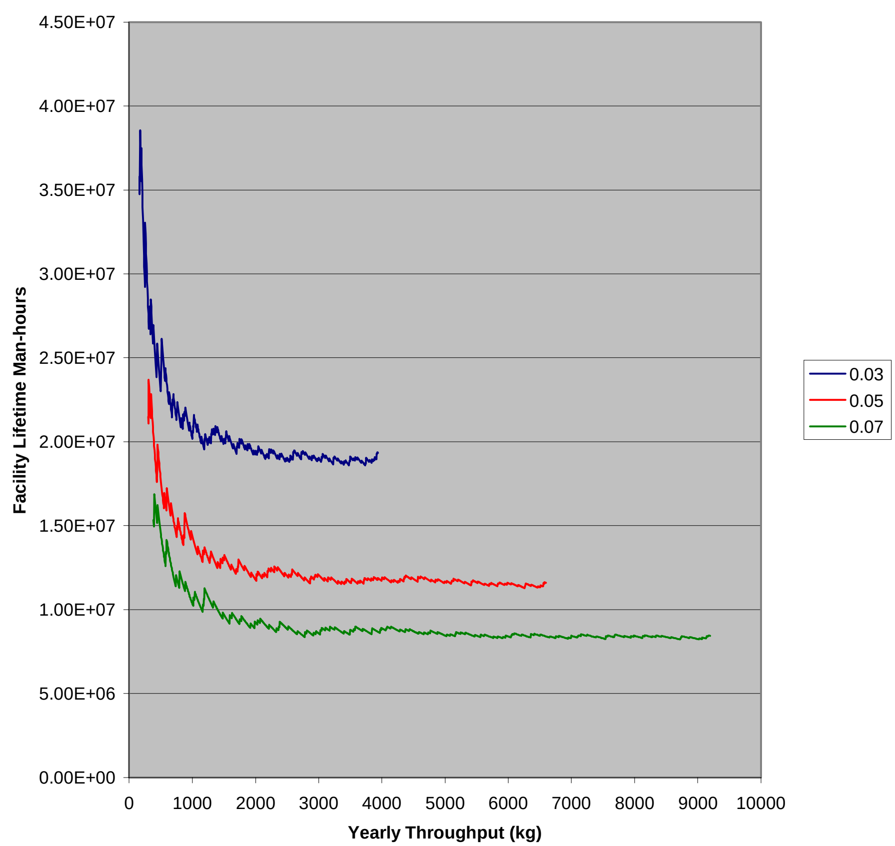

Figure 4: Number of Man-Hours Required Over the Lifetime of the MOX FFF Facility Versus the Yearly Throughput of the Facility to Produce MOX Fuel for a PWR at 3%, 5%, and 7% Pu Concentration

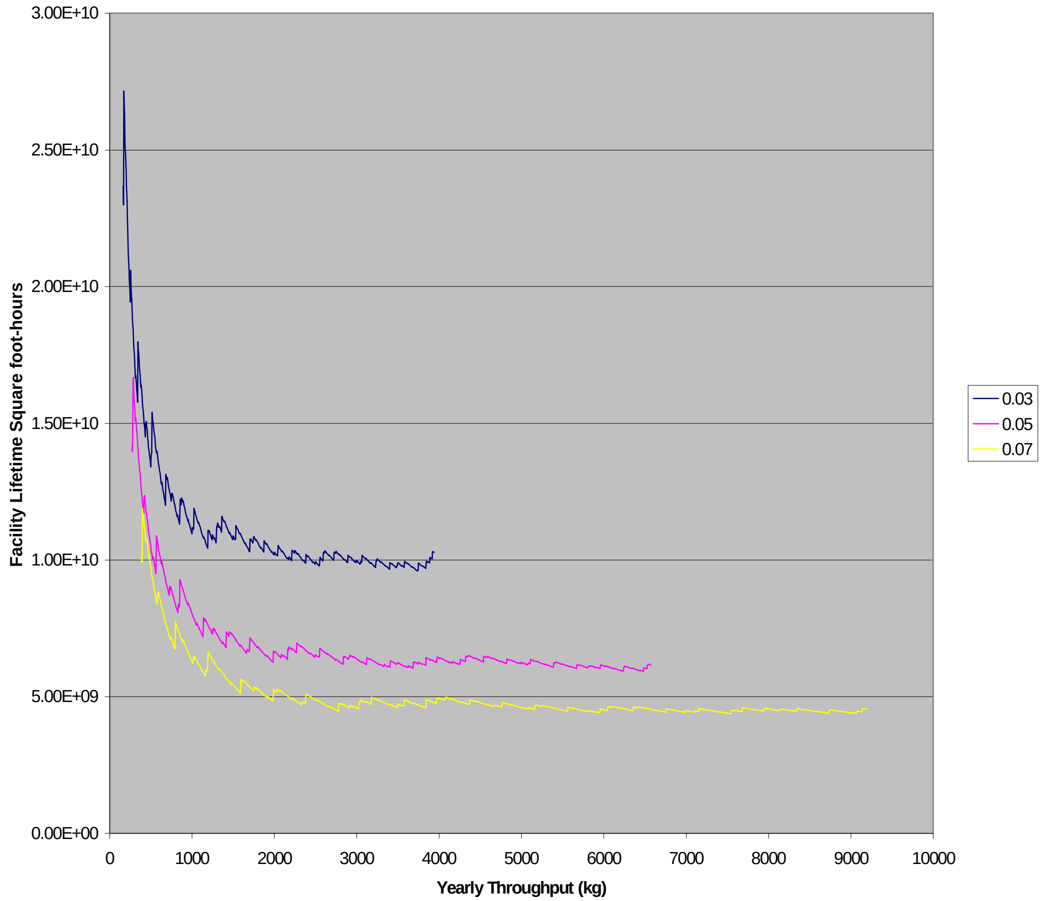

Figure 5: Number of Square-Feet of the Facility Multiplied by the Number of Hours of Operation Required over the Lifetime of the MOX FFF Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a PWR at 3%, 5%, and 7% Pu Concentration

From Figures 4 and 5, it can be observed that less land area and fewer number of workers are required for higher concentrations of plutonium. This is primarily due to the reduced number of pellets that need to be manufactured in the MOX facility. The smaller the number of pellets, the fewer the number of rods and bundles required.

Figure 6 shows the comparison between the number of lifetime man-hours for the ARIES facility for a plutonium concentration of 3% and 5%. This figure demonstrates that the number of worker hours is not dependent upon the plutonium concentration. It is only dependent upon the flow rate of plutonium required per year.

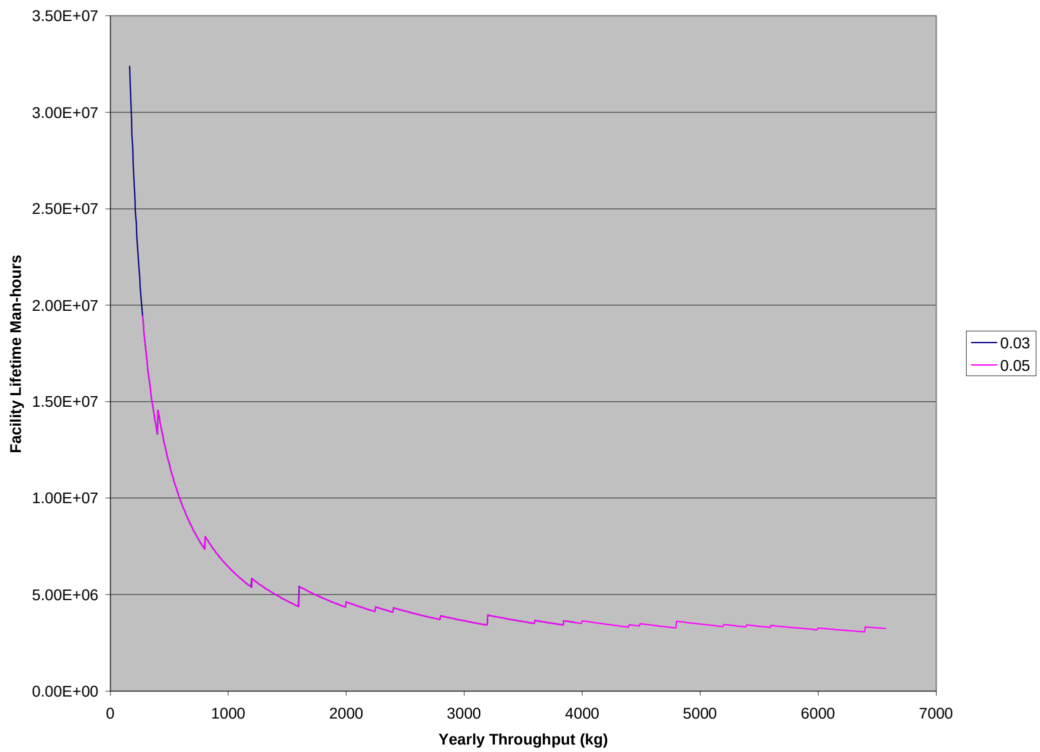

Figure 6: Number of Man-Hours Required over the Lifetime of the ARIES Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a PWR at 3% and 5% Pu Concentration

The next step was to narrow the field of focus of the data for better analysis. This was done by focusing on the goals of the disposition project and this study. The primary goal of DOE for these facilities is to get rid of approximately 35 MT over a relatively short period of time. At the low throughput end of the disposition quantities, the amount of time required for completion increases dramatically. It is also seen on Figures 4 and 5 that below 2,000 kg per year, the number of lifetime man-hours and square-foot hours exponentially increases as the throughput approaches zero. Therefore, the yearly throughput less than 2,000 kg of plutonium throughput per year can be eliminated. In addition, having a large facility that processes large amounts of plutonium in a short period of time would have many extra costs. Among these costs are increased decontamination and decommissioning costs. Therefore, throughputs greater than 5,000 kg of plutonium per year was selected to be eliminated since the time it would take to construct, and later decommission the facilities, would amount to the time to convert 35 MT of plutonium. This leaves a window of 3,000 kg per year. Figure 7 shows the results from Figure 4 for this range.

It is seen on Figure 7 that local minimums occur at 2778, 2913, 3023, 3493, 3838, 4663, 4728, 4583, and 5023 kg per year for the MOX facility. These minimums occur because the throughput has fully utilized one or more of the modules potential throughput. When the yearly throughput is increased by another kilogram of plutonium, an additional module is required to put out that amount.

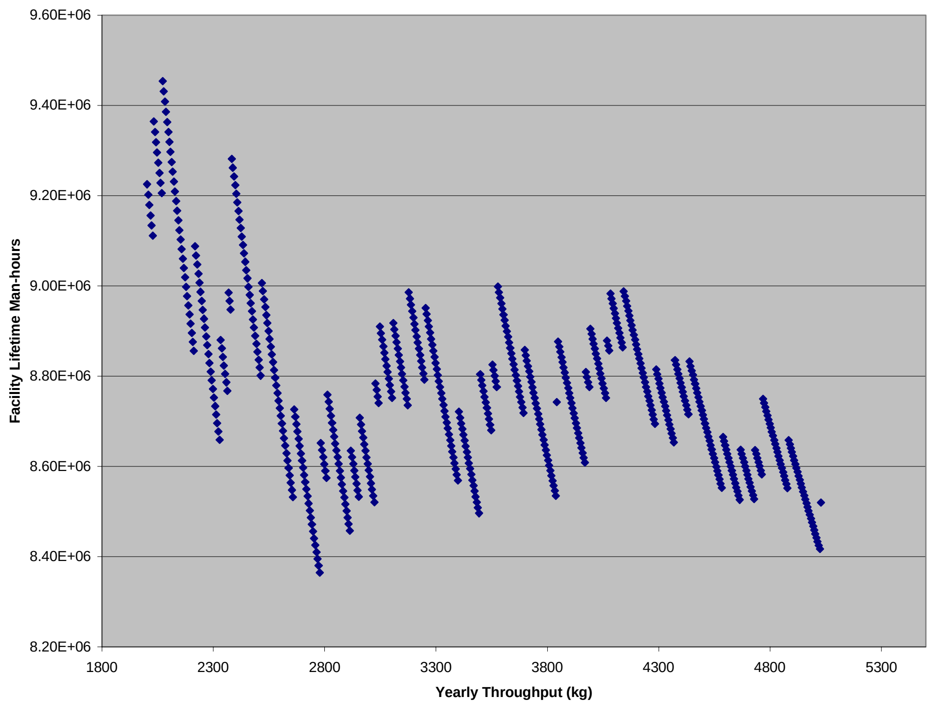

Figure 7: Number of Man-Hours over the Lifetime of the MOX FFF Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a PWR at a 7% Pu Concentration for Throughputs between 1800 and 5300 kg Pu Per Year

By analyzing the graph for workers at the ARIES facility, we can find the minimums and compare them.

The graph for the ARIES facility shows local minimums at 2793, 3193, 3593, 3838, 3993, 4393, 4488, 4793, and 5028 kg plutonium per year. In order to evaluate the optimal facility size for both facilities, the two graphs are plotted together. By combining the worker-hours for the MOX and ARIES facilities, local minimums occur at 2779, 3024, 3177, 3497, 3840, 4368, 4728, and 5023 kg of plutonium per year. The next stage is to analyze the area of the facility using the same technique.

The graph of the combined land areas for both facilities gives matching results for the minimums as the combined worker totals. This is as it should be considering both the number of workers and the area are dependent on the quantity of each module used in both facilities. By comparing the minimum values obtained from each graph for the separate facilities and comparing them to the combined total graph, it can be determined what the optimal values for a facility should be. Table 6 matches the results for easier comparison. All values for the MOX facility are given, while only values that are in close proximity to those numbers are shown for ARIES for simplification. The combined column of Table 6 will be the values that will be focused on when drawing conclusions.

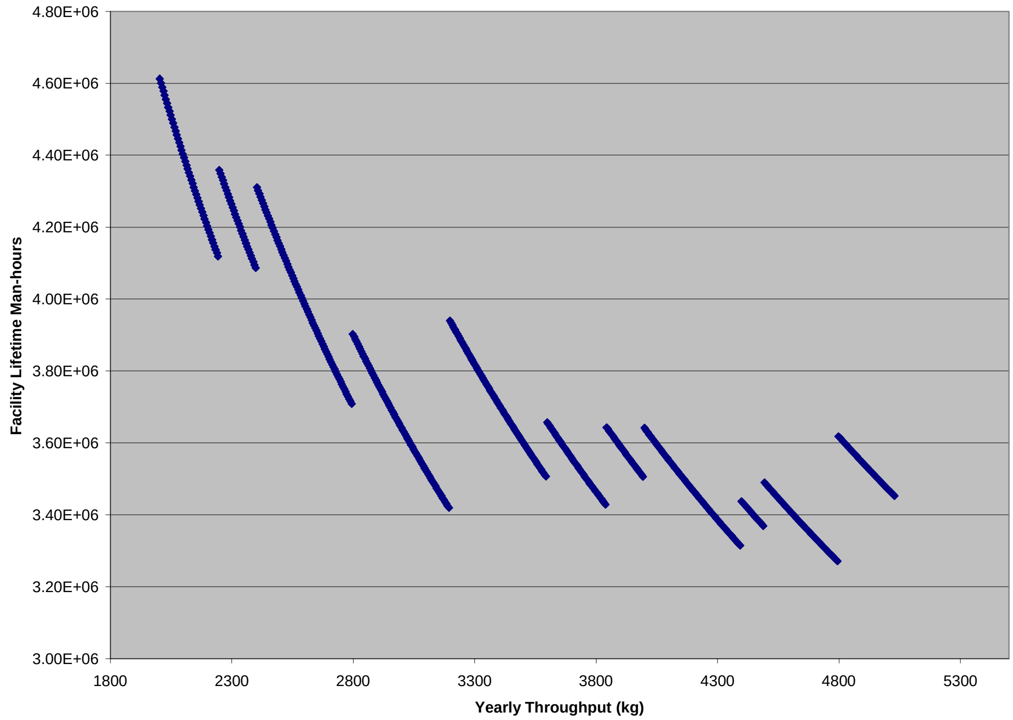

Figure 8: Number of Man-Hours over the Lifetime of the ARIES Facility versus the Yearly Throughput of the Facility to Produce PuO_2 for MOX Fuel Production for a PWR at a 7% Pu Concentration for Throughputs between 1800 and 5300 kg Pu Per Year

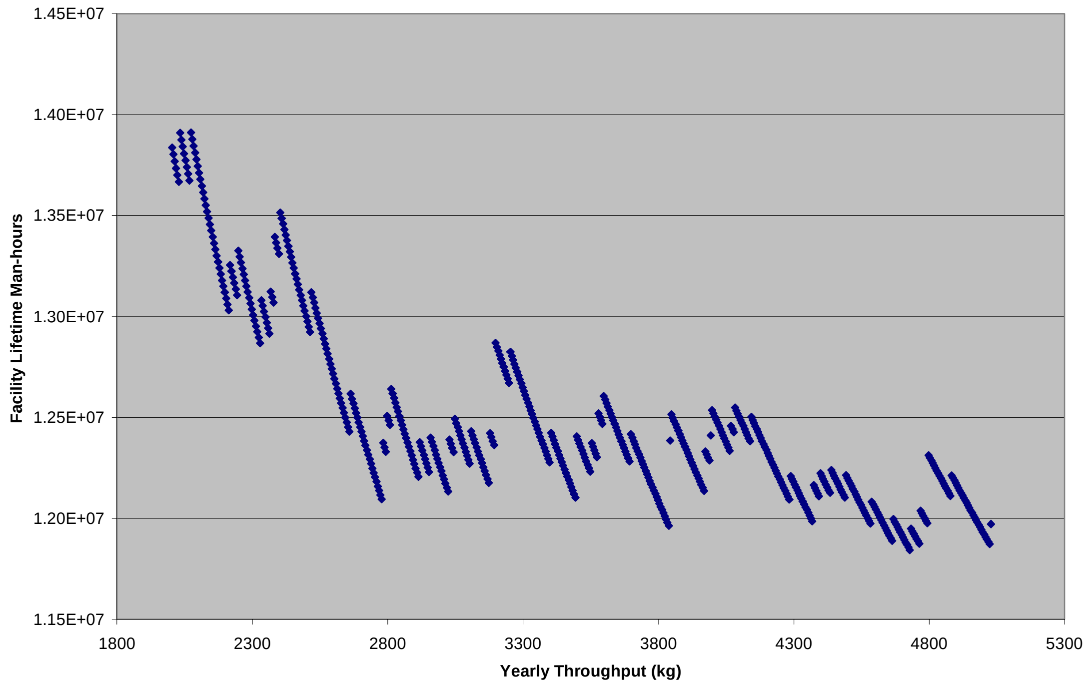

Figure 9: Number of Man-Hours Over the Lifetime of the Combined MOX FFF and the ARIES Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a PWR at a 7% Pu Concentration for Throughputs between 1800 and 5300 kg Pu Per Year

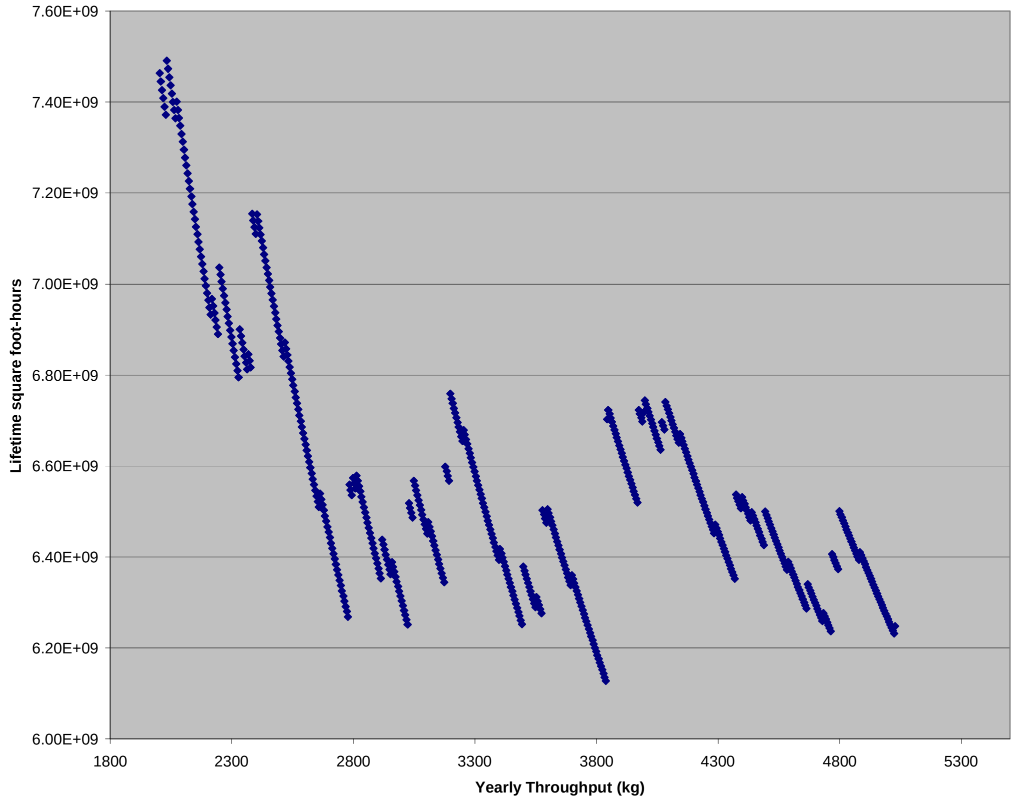

Figure 10: Number of Square-Feet of the Facility Multiplied by the Number of Hours of Operation Required Over the Lifetime of the Combined MOX FFF and ARIES Facility Versus the Yearly Throughput of the Facility to Produce MOX Fuel for a PWR at a 7% Pu Concentration Plotted Between 1800 and 5300 Kg Pu Per Year

Table 6: Comparison of Minimum Values Calculated for each Facility and the Combined Total

MOX (optimal kg Pu/year)	ARIES (optimal kg Pu/year)	Combined (optimal kg Pu/year)
2778	2793	2779
2913		
3023		3024
	3193	3177
3493	3593	3497
3838	3838	3840
4663		
4728	4793	4728
4583		
5023	5028	5023

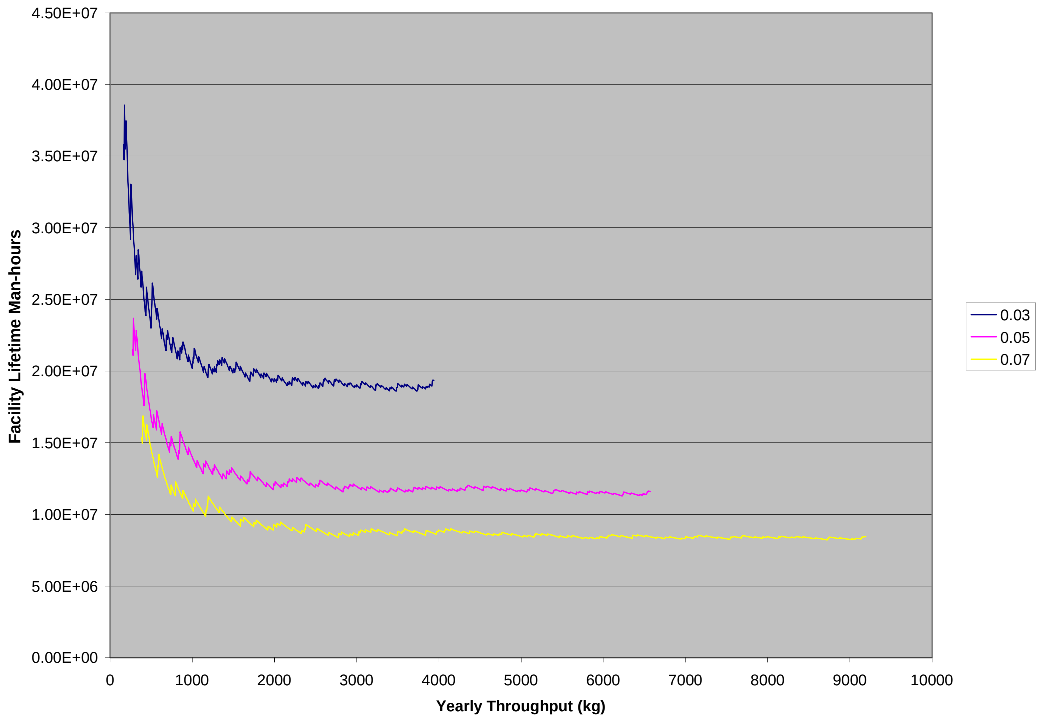

Figure 11: Number of Man-Hours Required over the Lifetime of the MOX FFF Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a BWR at 3%, 5%, and 7% Pu Concentration

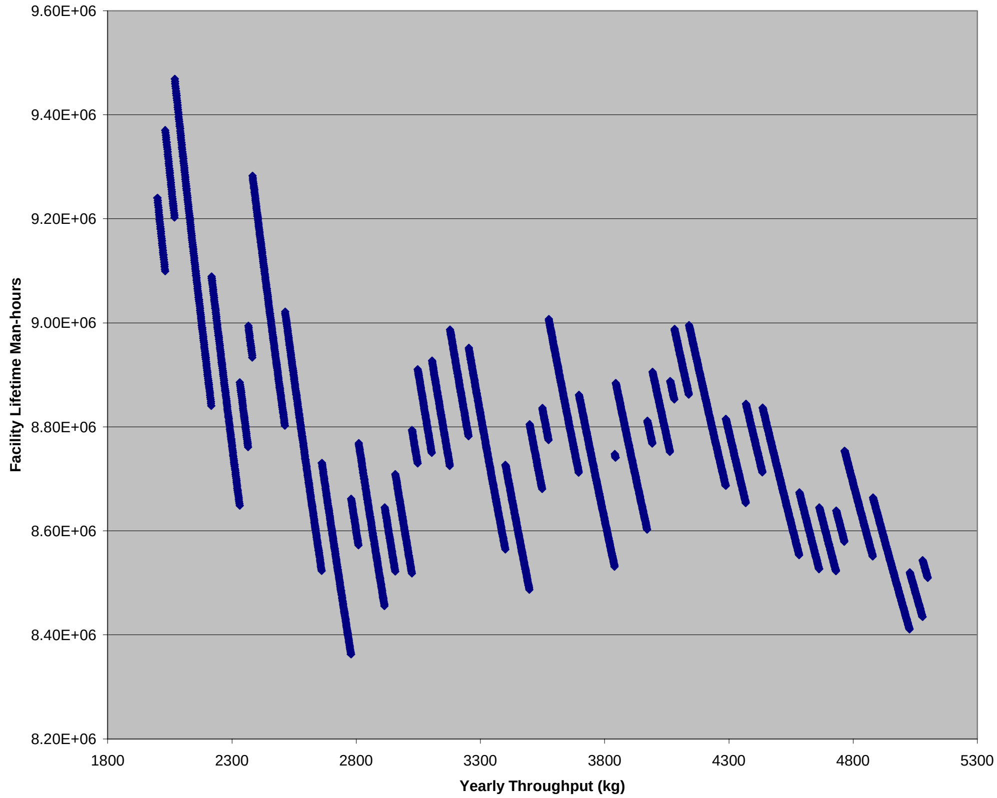

Figure 12: Number of Man-Hours over the Lifetime of the MOX FFF Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a BWR at a 7% Pu Concentration for Throughputs between 1800 and 5300 kg Pu Per Year

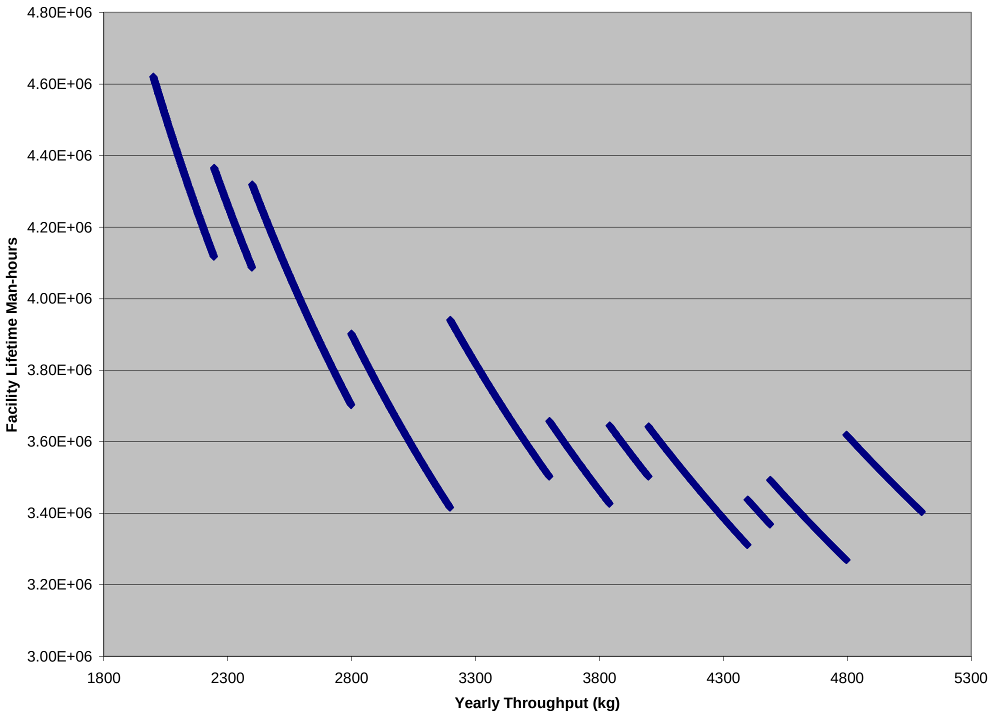

Figure 13: Number of Man-Hours over the Lifetime of the ARIES Facility versus the Yearly Throughput of the Facility to Produce PuO_2 for MOX Fuel for a BWR at a 7% Pu Concentration for Throughputs between 1800 and 5300 kg Pu Per Year

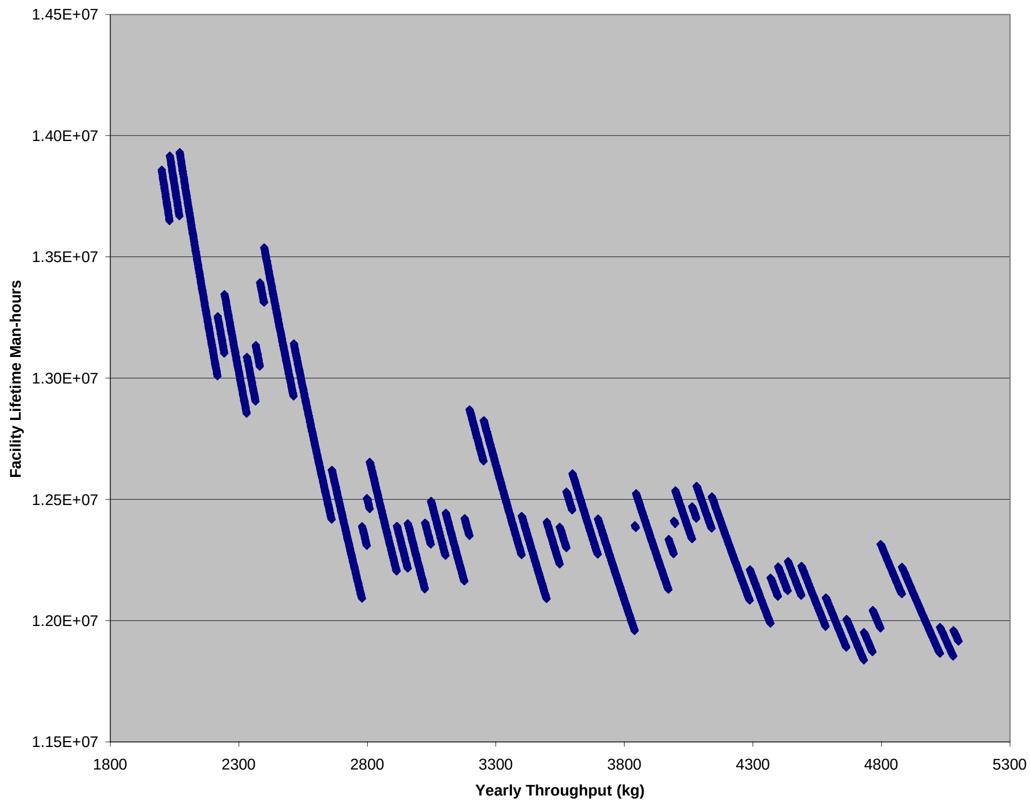

Figure 14: Number of Man-Hours over the Lifetime of the Combined MOX FFF and ARIES Facility versus the Yearly Throughput of the Facility to Produce MOX Fuel for a BWR at a 7% Pu Concentration for Throughputs between 1800 and 5300 kg Pu Per Year

Table 7: Comparison of Minimum Values Calculated for each Facility and the Combined Total for BWR Fuel

MOX	ARIES	Total
2779	2798	2779
2914		
3024	3197	3024
3497	3597	3497
3840	3840	3840
3971	3997	3971
4731	4796	4731
5027		5027

4.2 BOILING WATER REACTORS

The next type of reactor under consideration is the BWR. This reactor is based on the GE-11 BWR design described earlier. There are 54 fuel rods per bundle. The results are graphed and tabulated in the same way as those for a PWR. The results are shown in the following graphs, first with a comparison of the different plutonium concentrations, and then with a focus on the worker-hour minimums for the MOX, ARIES and combined facilities.

Table 8: Optimal Values of Combined Pu throughput for the MOX FFF and ARIES Facility for both Reactor Types

PWR	BWR	Optimal values
2779	2779	2779
3024	3024	3024
3177	3177	3177
3497	3497	3497
3840	3840	3840
4368	4368	4368
4728	4731	4728
5023	5027	5023

4.3 RESULT COMPARISON

In order to find the optimal size of both facilities, the results for the PWR and the BWR must be compared. If the facilities are to be used to construct fuel for a single type of reactor, only optimization specific to that type need consideration. However, since both types of reactors are being considered, and possibly concurrently, an optimization compatible for both fuel types is performed. By comparing the two results, the comparison shows that there is no difference in the throughputs at which the minimum man-hours occur, only in the values of the minimum number of man-hours required for produce BWR fuel versus PWR fuel. These values do not take into account the individual capacity of each facility for each throughput. Taking those into account, 3177 and 4368 kg per year throughputs can be eliminated because there is not an optimal MOX plant size near those throughputs. It can be noted that in some of the cases, the ARIES plant has a higher optimal throughput than the combined minimums. This is acceptable since it acts as the input to the MOX plant, and will act as a buffer for the flow of feed material. It is also accepted since the ARIES facility may be occasionally used to process non-MOX suitable plutonium for other purposes.

Of the six minimums remaining, the choices can be further narrowed by examining the number of workers and area required for those values. As the values for a PWR and BWR differ only by an order of magnitude, only one set need be looked at. Table 9 shows a breakdown of the computed values of workers and land area for the ARIES and MOX FFF to produce MOX fuel for a PWR, as well as the number of year required to process 35 MT of Pu metal. Analyzing the data on Table 9, it is seen that there are no significant discrepancies for the various throughputs. However, as previously

Table 9: Number of Workers and Land Area at Minimums for PWR Fuel

Pu throughput (kg/year)	MOX Workers	MOX Area	ARIES Workers	ARIES Area	Years for completion
2779	83	44,300	37	17,900	12.6
3024	92	49,100	39	18,400	11.6
3497	106	57,300	45	20,700	10.0
3840	117	62,800	47	21,200	9.1
4728	144	78,200	56	27,500	7.4
5023	151	82,000	62	29,800	7.0

described, a larger facility increases operating and future costs. Therefore, throughputs of 4,728 and 5,023 kg plutonium per year facilities were eliminated. By examining the graphs, it is observed that the number of man-hours for a throughput of 3,024 kg of plutonium is greater than those for the three remaining throughputs. It will therefore be eliminated. This leaves 2,779, 3,497, and 3,840 kg of plutonium per year as the optimal facility throughputs.

The final step of analysis is to input the three throughputs and back-calculate the values of the burnup, the number of reactors, and the corefraction that would make these values required values. Figures 15, 16, and 17 show the plots of the corefraction vs. burnup for various number of reactors. Because of the constraints on the number of reactors (2 to 6), the burnup (20,000 to 40,000 MWd/MTHM), and the corefraction (10-40%), some calculated values fell outside of these ranges and are omitted from the graphs.

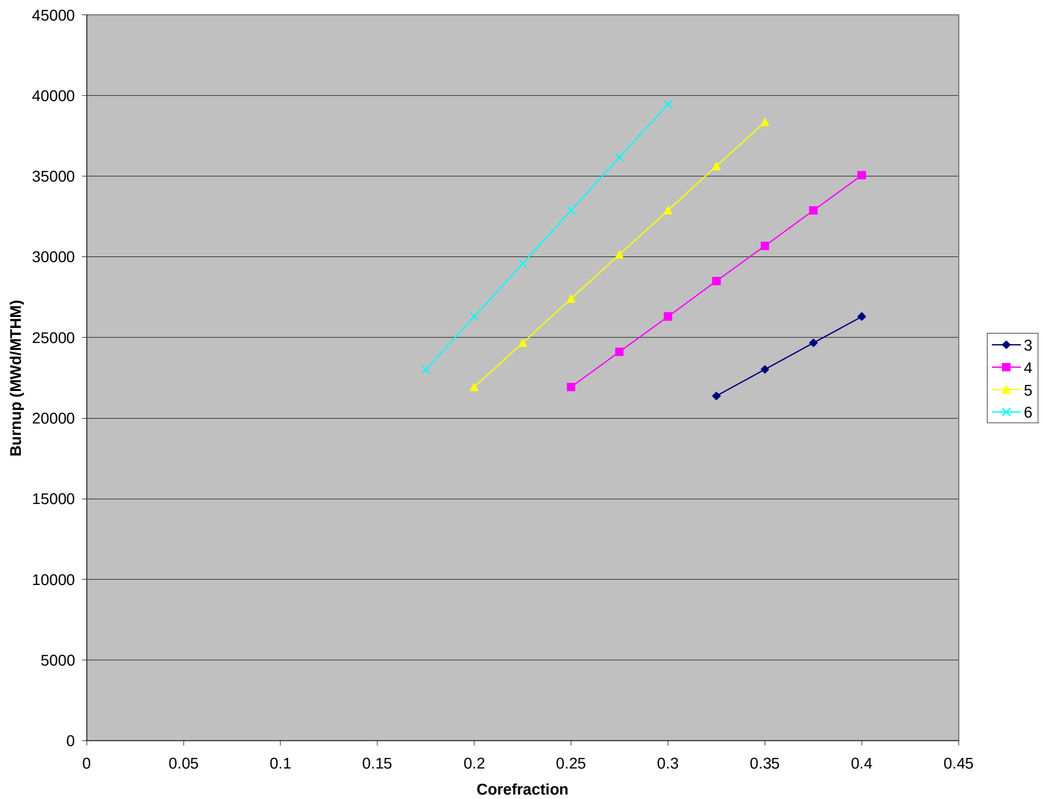

Figure 15: Burnup of the MOX Fuel When Used for Power Production vs. the Corefraction of the Reactor that is MOX Fuel for Various Number of Reactors (3-6) Used to Produce Power from the MOX Fuel

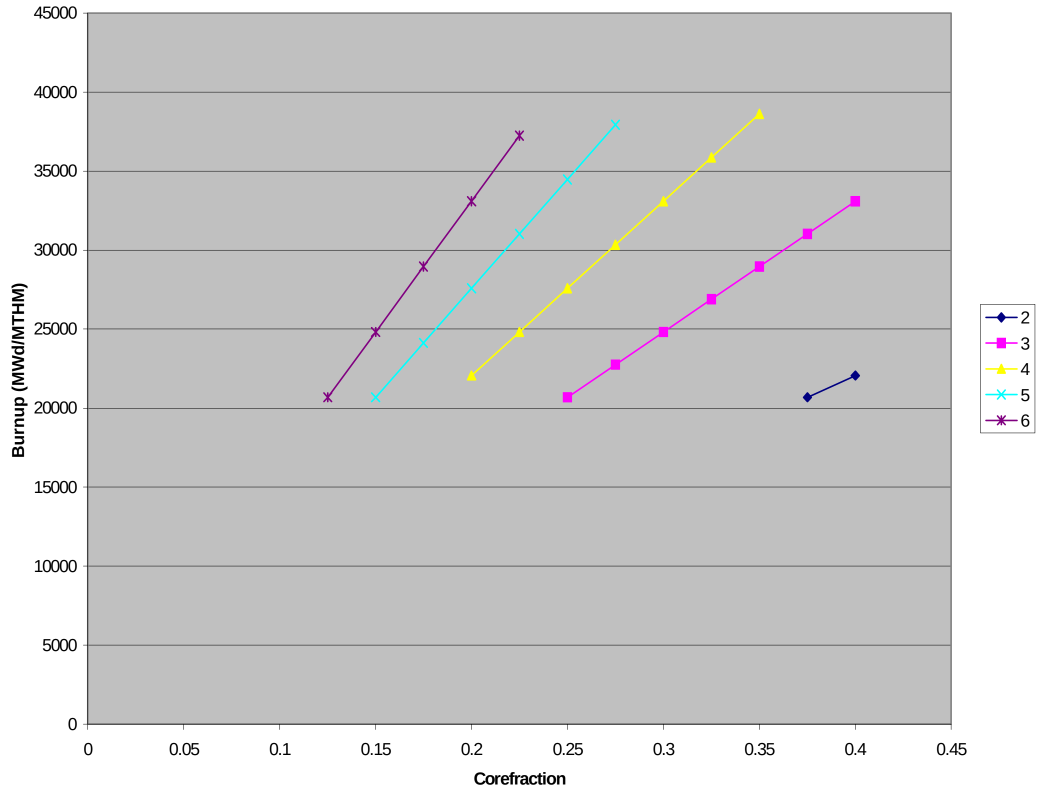

Figure 16: Burnup of the MOX Fuel When Used for Power Production vs. the Corefraction of the Reactor that is MOX Fuel for Various Number of Reactors (2-6) Used to Produce Power from the MOX Fuel for a Throughput of 2779 kg Pu Per Year

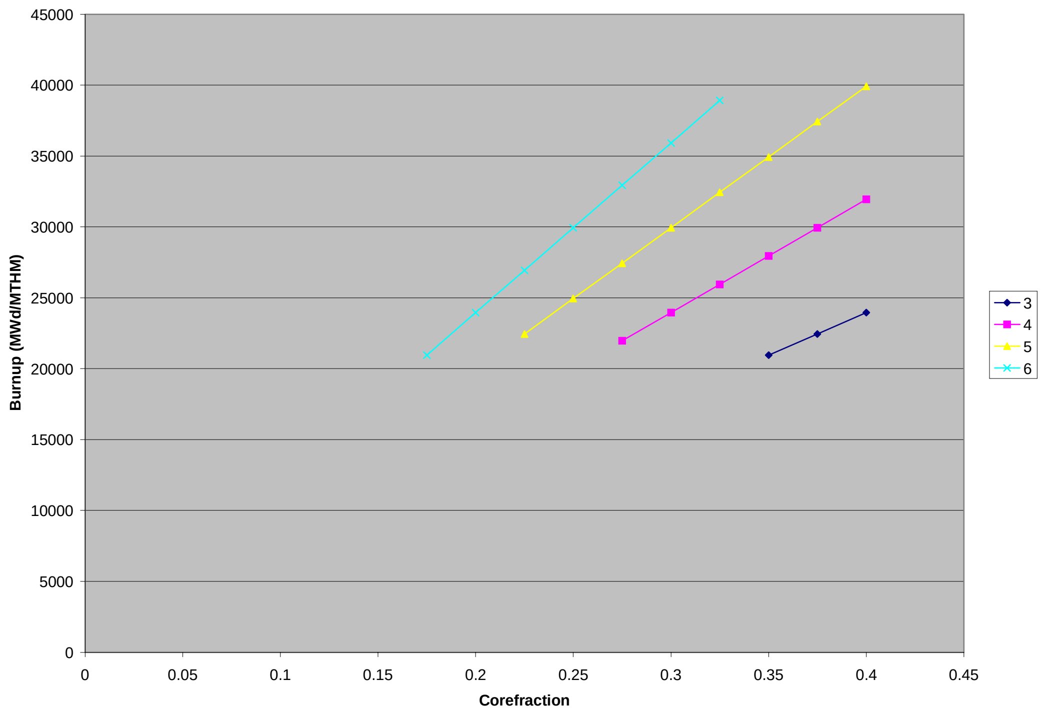

Figure 17: Burnup of the MOX Fuel When Used for Power Production vs. the Corefraction of the Reactor that is MOX Fuel for Various Number of Reactors (3-6) Used to Produce Power from the MOX Fuel for a Throughput of 3840 kg Pu Per Year

5. CONCLUSION

The optimization of the Pu throughput of the pit disassembly and conversion facility, and the mixed-oxide fuel fabrication plant was started by identifying the processing steps between the Pu metal arriving at the ARIES facility to the MOX fuel leaving the MOX FFF. These steps were broken down into modules, and the number of workers and space required for each was estimated from preliminary plant designs. The throughput of each module was calculated and the boundary conditions for required outputs were defined. From this, a FORTRAN program was written to back-calculate the number of man-hours for the lifetime of the plant and area needed for each facility for varying plutonium concentrations. It was determined that the optimal configuration for the defined boundary conditions was at 7% plutonium, the upper bound of the Pu concentration. It was assumed that a throughput of less than 2,000 kg and greater than 5,000 kg Pu was undesirable. From the localized graphs, regional minimums were recognized and defined. These were narrowed down by incompatibility with the optimal throughputs of either the ARIES or the MOX facility. The remaining optimal throughput values, in order of increasing man-hours, were 3,497, 2,779, and 3,840 kg Pu. These translated into facility lifetimes of 9.1, 10.0, and 12.6 years, respectively. If this is compared with DOE's plan of 3.5 MT/year for 10 years, then it matches the third result.

The results show that 2 reactors would be able to handle the power production from the facility at 7% Pu concentration. However, this would require a very low burnup of the fuel, which would result in a low power output from the amount of fuel present. This would be very inefficient.

The minimum costs observed overall are at 7,538 MT/year. However, this facility would be too large to be an efficient conversion process. The time needed to construct, and later decontaminate and decommission, the facility would be greater than the process life of the facility. The quantity of workers and land space required would also be too large to be cost-effective. There is no minimum time required for complete disposition, as the facility could be made large enough to convert the entire quantity of plutonium metal in less than a year. However, the limitations for this facility would be the same as previously described.

Based on the results, it is recommended that the facilities be built for throughputs of 2,779 kg of plutonium per year. Because it is the smallest optimal throughput, the facility sizes will be smaller, requiring less maintenance and decontamination. It will also require fewer workers to be hired. Due to the larger lifetime, the workers that will be hired will be employed for a longer duration, which will benefit the regions in which the plants are built due to a sustained input of money into the local economies. Smaller facilities would also decrease the draw on the regional utilities, such as water and electricity.

REFERENCES

1. DeMuth, S.F., "Preconceptual Design for Separation of Plutonium and Gallium by Ion Exchange," Los Alamos National Laboratory, LA-UR-97-3769, September 30, 1997.

2. DeMuth, S.F., "Ion Exchange Separation of Plutonium from Gallium (1) Resource and Inventory Requirements, (2) Waste, Emissions, and Effluent, and (3) Facility Size, Rev. 1," Los Alamos National Laboratory, LA-UR-97-3902, September 1997.

3. DOE/EIS-0229, "Storage and Disposition of Weapons-Usable Fissile Materials Final Programmatic Environmental Impact Statement," Department of Energy, Office of Fissile Materials Disposition, December 1996.

4. Hower, L.D. Jr., "Mixed-Oxide Fuel Pellet Fabrication and Fuel Rod Assembly for Dresden 1, Batch 7 Reload," Gulf United Nuclear Fuels Corporation, GU-5308, January 1974.

5. LA-UR-97-2208, "Exposure Minimization/Layout Optimization Scope," Los Alamos National Laboratory, July 1997.

6. LA-UR-97-2067, "Initial Response to the Surplus Plutonium Disposition Environmental Impact Statement Data Call for a Mixed Oxide Fuel Fabrication Facility," Los Alamos National Laboratory, June 6, 1997.

7. LA-UR-97-2909, "Pit Disassembly and Conversion Facility Environmental Impact Statement Data Response – Pantex Plant," Los Alamos National Laboratory, July 29, 1997.

8. NUREG-0002, "Final Generic Environmental, Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission, August 1976.

9. Olsen R.E., Goodman, J., "Review of Waste Management for a Large-Scale Mixed Oxide Fuel Fabrication Facility," Westinghouse Electric Corporation, WCAP-9144, September 1977.

10. Sinkule, Barbara, "Waste Estimate Calculations: Wastes of Various Types," Los Alamos National Laboratory, LA-UR-97-1933, 1997.

11. "Study of Plutonium Disposition Using Existing GE Boiling Water Reactors," General Electric Nuclear Energy report NEDO-32351, DOE contract DE-AC03-93SF19681, April 1994.

12. Taube, Mieczyslaw, "Plutonium," Institute of Nuclear Research, Warszawa, Macmillan Company, New York, 1964.

13. Trellue, H.R., Baros, T., "Nuclear Fuels Technologies Fiscal Year 1997 Research and Development Test Results," Los Alamos National Laboratory, LA-UR-97-4423, November 1997.

14. Westinghouse Electrical Corporation, "Environmental Report – Westinghouse Recycle Fuels Plant," July 1973.

APPENDIX A

Example of a FORTRAN Program Written to Calculate Data for Fuel Construction for Use in a PWR

This program calculates the values of workers and area for the MOX and ARIES facility, and the number of years for completion, as the throughput increases, for Pu concentrations varying from 3% to 7%. An excerpt from the beginning of the output file follows showing data for the 3% and the beginning of the 3.5% output.

FORTRAN Program:

```
********************************************************
*** KEN SCHWARTZ                                 ****          ***
                                                 ****
*** THESIS PROGRAM                               ****        ***
                                          ****
*** THIS PROGRAM WILL CALCULATE THE NUMBER       ****
*** OF WORKERS AND AREA OF A PIT DISSASSEMBLY    ****
*** AND CONVERSION FACILITY, MOX FUEL            ****
*** FABRICATION FACILITY, AND THE NUMBER OF      ****
*** YEARS REQUIRED TO CONVERT 35 METRIC TONS     ****
********************************************************
*** VARIABLES                                    ****
*** WORKM = TOTAL WORKERS OF MOX FACILITY        ****
*** AREATOTM = TOTAL AREA OF MOX FACILITY        ****
*** WORKA = TOTAL WORKERS OF ARIES FACILITY      ****
*** AREATOTA = TOTAL AREA OF ARIES FACILITY      ****
*** MASSPU = MASS (KG) PLUTONIUM THROUGHPUT      ****
*** REACTORS TYPE  PWR=  PINS=264                ****
***            BWR=  PINS=54                     ****
********************************************************
      PROGRAM THESIS1
      REAL MASSPU, REQKG, PUMIN, PUMAX, PUCONC
      REAL KGPIN, KGBUN, KGPEL, REQBUN, REQPIN, TEMP
      REAL PRODBUN, REQPEL, REC2, WASTE2, REJ2, REC3
      REAL WASTE3, REJ3, REC4, WASTE4, REJ4, REC5, WASTE5, REJ5
      REAL REC6, WASTE6, REJ6, RECA6, WASTEA6
      REAL RESULT(7,12000), HOURS, PINS, PELLETS
      INTEGER AREATOTM, AREATOTA, WORKA, WORKM, TRIAL, X, Y
      INTEGER MOD, I
      OPEN (UNIT=8, FILE='FORTTH6', STATUS='NEW')
      TRIAL = 0
      PINS=264.
      PELLETS=360.
      HOURS=8000.
```

```
**** RESET COUNTERS ****
      I=1
      X=1
      Y=1
      WORKM=0
      AREATOTM=0
      WORKA=0
      AREATOTA=0
      REC2=(0.1/101.65)
      WASTE2=(0.05/101.65)
      REJ2=(1.6/101.6)
      REC3=(0.4/110.6)
      REJ3=(8.6/110.6)
      WASTE3=(0.03/110.6)
      REC4=0.
      WASTE4=(0.1/111.7)
      REJ4=(1./111.7)
      REC5=(1./112.5)
      WASTE5=(0.03/112.5)
      REJ5=(0.5/112.5)
      REC6=((1.05+17.2)/(96.95+4.04))
      WASTE6=(0.1/(96.95+4.04))
      REJ6=(5.6/(96.95+4.04))
      RECA6=0.3
      WASTEA6=0.3
**** FORMAT OUTPUTS ****
15    FORMAT (1X, I10)
16    FORMAT (1X, E10.4)
      DO 20 PUCONC=0.03, 0.07, 0.005
        WRITE (8,*) PUCONC
        PUMIN=5475*PUCONC
        PUMAX=131400*PUCONC
        DO 10 MASSPU=PUMIN, PUMAX, 5
**** CALCULATE MASS OF PLUTONIUM NEEDED PER YEAR ***
**** CALCULATE MOX FACILITY REQUIREMENTS ****
          KGPEL=.005*PUCONC
          KGPIN=KGPEL*PELLETS
          KGBUN=KGPIN*PINS
*** FUEL BUNDLE ASSEMBLY ****
          REQBUN=MASSPU/KGBUN
          PRODBUN=(3./PINS)*HOURS
          TEMP=REQBUN/PRODBUN
          CALL ROUND(MOD, TEMP)
          WORKM=WORKM+(MOD*3)
          AREATOTM=AREATOTM+(MOD*3000)
*** FUEL ROD ASSEMBLY ****
```

```
      REQPIN=REQBUN*PINS
      REQPIN=REQPIN*(1+REJ2+WASTE2-REC2)
      TEMP=REQPIN/3200.
      CALL ROUND(MOD, TEMP)
      WORKM=WORKM+(MOD*3)
      AREATOTM=AREATOTM+(MOD*3000)
****  PELLET GRINDING  ****
      REQPEL=REQPIN*PELLETS
      REQPEL=REQPEL*(1+REJ3+WASTE3-REC3)
      TEMP=REQPEL/460800.
      CALL ROUND(MOD, TEMP)
      WORKM=WORKM+(MOD*2)
      AREATOTM=AREATOTM+(MOD*400)
****  SINTERING  ****
      REQPEL=REQPEL*(1+REJ4+WASTE4-REC4)
      TEMP=REQPEL/3197135.18
      CALL ROUND(MOD, TEMP)
      WORKM=WORKM+(MOD*2)
      AREATOTM=AREATOTM+(MOD*1000)
****  PELLETIZING  ****
      REQPEL=REQPEL*(1+REJ5+WASTE5-REC5)
      TEMP=REQPEL/1826934.39
      CALL ROUND(MOD, TEMP)
      WORKM=WORKM+(MOD*2)
      AREATOTM=AREATOTM+(MOD*1000)
***  BLENDING  ****
      REQKG=REQPEL*KGPEL
      REQKG=REQKG*(1+REJ6+WASTE6-REC6)
      TEMP=REQKG/3360.
      CALL ROUND(MOD, TEMP)
      WORKM=WORKM+(MOD*2)
      AREATOTM=AREATOTM+(MOD*700)
*** SHIPPING AND RECEIVING  ****
      CONTAIN=REQKG/4.045
      TEMP=CONTAIN/912.
      CALL ROUND(MOD, TEMP)
      WORKM=WORKM+(MOD*3)
      AREATOTM=AREATOTM+(MOD*4000)
*****************************************
**************  ARIES  *******************
*****************************************
****  SHIPPING AND RECEIVING  ****
      CONTAIN=REQKG/4.045
      TEMP=CONTAIN/912.
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*3
```

```
      AREATOTA=AREATOTA+MOD*4000
****  SECONDARY CANNING  ****
      TEMP=CONTAIN/1920.
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*1000
****  ELECTRODECONTAMINATION  ****
      TEMP=CONTAIN/1280.
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*600
****  PRIMARY CANNING  ****
      TEMP=CONTAIN/1920.
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*600
*** GALLIUM REMOVAL  ****
      TEMP=REQKG/1536.
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*500
****  HYDOX  ****
      REQKG=REQKG*(1+WASTEA6-RECA6)
      TEMP=REQKG/384.
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*500
****  BISECTION  ****
      TEMP=REQKG/(384.*4.)
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*1300
****  NDA  ****
      TEMP=REQKG/(539.*4.)
      CALL ROUND(MOD, TEMP)
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*1300
****  PIT RECEIVING  ****
      MOD=1
      WORKA=WORKA+MOD*2
      AREATOTA=AREATOTA+MOD*2000
*****  WRITE DATA TO FORTTH.XLS  ******
      RESULT(1,I)=I
      RESULT(2,I)=MASSPU
      RESULT(3,I)=WORKM
      RESULT(4,I)=AREATOTM
```

```
          RESULT(5,I)=WORKA
          RESULT(6,I)=AREATOTA
          RESULT(7,I)=35000/MASSPU
          WRITE(8,*) (RESULT(J,I), J=1, 7)
          I=I+1
          WORKM=0
          AREATOTM=0
          WORKA=0
          AREATOTA=0
10        CONTINUE
20      CONTINUE
      END
****  ROUND UP (MOD CALCULATOR) ****
      SUBROUTINE ROUND(MD, TMP)
      REAL TMP
      INTEGER MD
      MD=TMP
      IF (MD.LT.TMP) THEN
      MD=MD+1
      ENDIF
      RETURN
      END
```

Output File:

	throughput	MOXW	MOXA	ARIESW	ARIESA	years
0.03						
1	164.25	21	13900	19	11800	213.0898
2	169.25	21	13900	19	11800	206.7947
3	174.25	24	16900	19	11800	200.8608
4	179.25	24	16900	19	11800	195.258
5	184.25	24	16900	19	11800	189.9593
6	189.25	24	16900	19	11800	184.9406
7	194.25	26	17300	19	11800	180.1802
8	199.25	26	17300	19	11800	175.6587
9	204.25	26	17300	19	11800	171.3586
10	209.25	26	17300	19	11800	167.264
11	214.25	26	17300	19	11800	163.3606
12	219.25	26	17300	19	11800	159.6351
13	224.25	26	17300	19	11800	156.0758
14	229.25	26	17300	19	11800	152.6718
15	234.25	26	17300	19	11800	149.413
16	239.25	26	17300	19	11800	146.2905
17	244.25	26	17300	19	11800	143.2958
18	249.25	26	17300	19	11800	140.4213

19	254.25	30	18700	19	11800	137.6598
20	259.25	30	18700	19	11800	135.0048
21	264.25	30	18700	19	11800	132.4503
22	269.25	30	18700	19	11800	129.9907
23	274.25	30	18700	19	11800	127.6208
24	279.25	30	18700	19	11800	125.3357
25	284.25	30	18700	19	11800	123.1311
26	289.25	30	18700	19	11800	121.0026
27	294.25	30	18700	19	11800	118.9465
28	299.25	30	18700	19	11800	116.9591
29	304.25	30	18700	19	11800	115.037
30	309.25	30	18700	19	11800	113.177
31	314.25	30	18700	19	11800	111.3763
32	319.25	32	19100	19	11800	109.632
33	324.25	32	19100	19	11800	107.9414
34	329.25	32	19100	19	11800	106.3022
35	334.25	32	19100	19	11800	104.712
36	339.25	32	19100	19	11800	103.1688
37	344.25	35	22100	19	11800	101.6703
38	349.25	35	22100	19	11800	100.2147
39	354.25	35	22100	19	11800	98.80029
40	359.25	35	22100	19	11800	97.42519
41	364.25	35	22100	19	11800	96.08785
42	369.25	35	22100	19	11800	94.78673
43	374.25	35	22100	19	11800	93.52037
44	379.25	35	22100	19	11800	92.28741
45	384.25	37	22500	19	11800	91.08653
46	389.25	37	22500	19	11800	89.9165
47	394.25	37	22500	19	11800	88.77615
48	399.25	37	22500	19	11800	87.66437
49	404.25	37	22500	21	12300	86.58009
50	409.25	37	22500	21	12300	85.52229
51	414.25	37	22500	21	12300	84.49004
52	419.25	37	22500	21	12300	83.48241
53	424.25	37	22500	21	12300	82.49853
54	429.25	37	22500	21	12300	81.53757
55	434.25	37	22500	21	12300	80.59873
56	439.25	39	23500	21	12300	79.68127
57	444.25	41	23900	21	12300	78.78447
58	449.25	41	23900	21	12300	77.90762
59	454.25	41	23900	21	12300	77.05008
60	459.25	41	23900	21	12300	76.21121
61	464.25	41	23900	21	12300	75.39041
62	469.25	41	23900	21	12300	74.5871
63	474.25	41	23900	21	12300	73.80074
64	479.25	41	23900	21	12300	73.03078

65	484.25	41	23900	21	12300	72.27672
66	489.25	41	23900	21	12300	71.53807
67	494.25	41	23900	21	12300	70.81436
68	499.25	41	23900	21	12300	70.10516
69	504.25	43	24900	21	12300	69.41001
70	509.25	45	25300	21	12300	68.72852
71	514.25	48	28300	21	12300	68.06028
72	519.25	48	28300	21	12300	67.40491
73	524.25	48	28300	21	12300	66.76204
74	529.25	48	28300	21	12300	66.13132
75	534.25	48	28300	21	12300	65.5124
76	539.25	48	28300	21	12300	64.90496
77	544.25	48	28300	21	12300	64.30869
78	549.25	48	28300	21	12300	63.72326
79	554.25	48	28300	21	12300	63.1484
80	559.25	48	28300	21	12300	62.58382
81	564.25	48	28300	21	12300	62.02924
82	569.25	48	28300	21	12300	61.48441
83	574.25	50	28700	21	12300	60.94906
84	579.25	50	28700	21	12300	60.42296
85	584.25	50	28700	21	12300	59.90586
86	589.25	50	28700	21	12300	59.39754
87	594.25	50	28700	21	12300	58.89777
88	599.25	50	28700	21	12300	58.40634
89	604.25	50	28700	21	12300	57.92305
90	609.25	50	28700	21	12300	57.44768
91	614.25	50	28700	21	12300	56.98006
92	619.25	50	28700	21	12300	56.51999
93	624.25	50	28700	21	12300	56.06728
94	629.25	50	28700	21	12300	55.62177
95	634.25	52	29100	21	12300	55.18329
96	639.25	52	29100	21	12300	54.75166
97	644.25	52	29100	21	12300	54.32674
98	649.25	52	29100	21	12300	53.90836
99	654.25	52	29100	21	12300	53.49637
100	659.25	52	29100	21	12300	53.09063
101	664.25	52	29100	21	12300	52.69101
102	669.25	52	29100	21	12300	52.29735
103	674.25	52	29100	21	12300	51.90953
104	679.25	52	29100	21	12300	51.52742
105	684.25	55	32100	21	12300	51.15089
106	689.25	55	32100	21	12300	50.77983
107	694.25	55	32100	21	12300	50.41412
108	699.25	57	32500	21	12300	50.05363
109	704.25	57	32500	21	12300	49.69826
110	709.25	57	32500	21	12300	49.3479

111	714.25	57	32500	21	12300	49.00245
112	719.25	57	32500	21	12300	48.6618
113	724.25	57	32500	21	12300	48.32586
114	729.25	57	32500	21	12300	47.99451
115	734.25	57	32500	21	12300	47.66769
116	739.25	57	32500	21	12300	47.34528
117	744.25	57	32500	21	12300	47.02721
118	749.25	57	32500	21	12300	46.71338
119	754.25	59	33500	21	12300	46.40371
120	759.25	59	33500	21	12300	46.09812
121	764.25	61	33900	21	12300	45.79653
122	769.25	61	33900	21	12300	45.49886
123	774.25	61	33900	21	12300	45.20504
124	779.25	61	33900	21	12300	44.91498
125	784.25	61	33900	21	12300	44.62863
126	789.25	61	33900	21	12300	44.3459
127	794.25	61	33900	21	12300	44.06673
128	799.25	61	33900	21	12300	43.79105
129	804.25	61	33900	23	12800	43.51881
130	809.25	61	33900	23	12800	43.24992
131	814.25	61	33900	23	12800	42.98434
132	819.25	61	33900	23	12800	42.722
133	824.25	63	34300	23	12800	42.46284
134	829.25	63	34300	23	12800	42.20681
135	834.25	63	34300	23	12800	41.95385
136	839.25	63	34300	23	12800	41.7039
137	844.25	63	34300	23	12800	41.45691
138	849.25	63	34300	23	12800	41.21283
139	854.25	66	37300	23	12800	40.97161
140	859.25	66	37300	23	12800	40.7332
141	864.25	66	37300	23	12800	40.49754
142	869.25	66	37300	23	12800	40.2646
143	874.25	68	38300	23	12800	40.03432
144	879.25	68	38300	23	12800	39.80665
145	884.25	68	38300	23	12800	39.58157
146	889.25	70	38700	23	12800	39.35901
147	894.25	70	38700	23	12800	39.13894
148	899.25	70	38700	23	12800	38.92132
149	904.25	70	38700	23	12800	38.70611
150	909.25	70	38700	23	12800	38.49326
151	914.25	70	38700	23	12800	38.28275
152	919.25	70	38700	23	12800	38.07452
153	924.25	70	38700	23	12800	37.86854
154	929.25	70	38700	23	12800	37.66478
155	934.25	70	38700	23	12800	37.46321
156	939.25	70	38700	23	12800	37.26377

157	944.25	70	38700	23	12800	37.06646
158	949.25	70	38700	23	12800	36.87122
159	954.25	72	39100	23	12800	36.67802
160	959.25	72	39100	23	12800	36.48684
161	964.25	72	39100	23	12800	36.29764
162	969.25	72	39100	23	12800	36.11039
163	974.25	72	39100	23	12800	35.92507
164	979.25	72	39100	23	12800	35.74164
165	984.25	72	39100	23	12800	35.56007
166	989.25	72	39100	23	12800	35.38034
167	994.25	72	39100	23	12800	35.20242
168	999.25	72	39100	23	12800	35.02627
169	1004.25	74	40100	23	12800	34.85188
170	1009.25	74	40100	23	12800	34.67922
171	1014.25	76	40500	23	12800	34.50826
172	1019.25	76	40500	23	12800	34.33897
173	1024.25	79	43500	23	12800	34.17134
174	1029.25	79	43500	23	12800	34.00534
175	1034.25	79	43500	23	12800	33.84095
176	1039.25	79	43500	23	12800	33.67813
177	1044.25	79	43500	23	12800	33.51688
178	1049.25	79	43500	23	12800	33.35716
179	1054.25	79	43500	23	12800	33.19896
180	1059.25	79	43500	23	12800	33.04225
181	1064.25	79	43500	23	12800	32.88701
182	1069.25	79	43500	23	12800	32.73322
183	1074.25	79	43500	23	12800	32.58087
184	1079.25	81	43900	23	12800	32.42993
185	1084.25	81	43900	23	12800	32.28038
186	1089.25	81	43900	23	12800	32.1322
187	1094.25	81	43900	23	12800	31.98538
188	1099.25	81	43900	23	12800	31.83989
189	1104.25	81	43900	23	12800	31.69572
190	1109.25	81	43900	23	12800	31.55285
191	1114.25	81	43900	23	12800	31.41126
192	1119.25	81	43900	23	12800	31.27094
193	1124.25	81	43900	23	12800	31.13187
194	1129.25	81	43900	23	12800	30.99402
195	1134.25	81	43900	23	12800	30.8574
196	1139.25	81	43900	23	12800	30.72197
197	1144.25	83	44300	23	12800	30.58772
198	1149.25	83	44300	23	12800	30.45465
199	1154.25	83	44300	23	12800	30.32272
200	1159.25	83	44300	23	12800	30.19193
201	1164.25	83	44300	23	12800	30.06227
202	1169.25	83	44300	23	12800	29.93372

203	1174.25	83	44300	23	12800	29.80626
204	1179.25	83	44300	23	12800	29.67988
205	1184.25	83	44300	23	12800	29.55457
206	1189.25	83	44300	23	12800	29.43031
207	1194.25	86	47300	23	12800	29.3071
208	1199.25	86	47300	25	13300	29.18491
209	1204.25	88	47700	25	13300	29.06373
210	1209.25	88	47700	25	13300	28.94356
211	1214.25	88	47700	25	13300	28.82438
212	1219.25	88	47700	25	13300	28.70617
213	1224.25	88	47700	25	13300	28.58893
214	1229.25	88	47700	25	13300	28.47265
215	1234.25	88	47700	25	13300	28.3573
216	1239.25	88	47700	25	13300	28.24289
217	1244.25	88	47700	25	13300	28.12939
218	1249.25	90	48700	25	13300	28.01681
219	1254.25	90	48700	25	13300	27.90512
220	1259.25	90	48700	25	13300	27.79432
221	1264.25	90	48700	25	13300	27.6844
222	1269.25	92	49100	25	13300	27.57534
223	1274.25	92	49100	25	13300	27.46714
224	1279.25	92	49100	25	13300	27.35978
225	1284.25	92	49100	25	13300	27.25326
226	1289.25	92	49100	25	13300	27.14757
227	1294.25	92	49100	25	13300	27.04269
228	1299.25	95	52100	25	13300	26.93862
229	1304.25	95	52100	25	13300	26.83535
230	1309.25	97	53100	25	13300	26.73286
231	1314.25	97	53100	25	13300	26.63116
232	1319.25	97	53100	25	13300	26.53023
233	1324.25	97	53100	25	13300	26.43006
234	1329.25	97	53100	25	13300	26.33064
235	1334.25	99	53500	25	13300	26.23197
236	1339.25	99	53500	25	13300	26.13403
237	1344.25	99	53500	25	13300	26.03682
238	1349.25	99	53500	25	13300	25.94034
239	1354.25	99	53500	25	13300	25.84456
240	1359.25	99	53500	25	13300	25.74949
241	1364.25	102	56500	25	13300	25.65512
242	1369.25	102	56500	25	13300	25.56144
243	1374.25	102	56500	25	13300	25.46844
244	1379.25	102	56500	25	13300	25.37611
245	1384.25	102	56500	25	13300	25.28445
246	1389.25	102	56500	25	13300	25.19345
247	1394.25	104	56900	25	13300	25.1031
248	1399.25	104	56900	25	13300	25.0134

249	1404.25	104	56900	25	13300	24.92434
250	1409.25	104	56900	25	13300	24.83591
251	1414.25	104	56900	25	13300	24.7481
252	1419.25	104	56900	25	13300	24.66091
253	1424.25	104	56900	25	13300	24.57434
254	1429.25	104	56900	25	13300	24.48837
255	1434.25	104	56900	25	13300	24.403
256	1439.25	104	56900	25	13300	24.31822
257	1444.25	104	56900	25	13300	24.23403
258	1449.25	104	56900	25	13300	24.15042
259	1454.25	104	56900	25	13300	24.06739
260	1459.25	106	57300	25	13300	23.98492
261	1464.25	106	57300	25	13300	23.90302
262	1469.25	106	57300	25	13300	23.82168
263	1474.25	106	57300	25	13300	23.74088
264	1479.25	106	57300	25	13300	23.66064
265	1484.25	106	57300	25	13300	23.58093
266	1489.25	106	57300	25	13300	23.50176
267	1494.25	106	57300	25	13300	23.42312
268	1499.25	108	58300	25	13300	23.34501
269	1504.25	108	58300	25	13300	23.26741
270	1509.25	108	58300	25	13300	23.19033
271	1514.25	108	58300	25	13300	23.11375
272	1519.25	108	58300	25	13300	23.03768
273	1524.25	110	58700	25	13300	22.96211
274	1529.25	110	58700	25	13300	22.88704
275	1534.25	113	61700	25	13300	22.81245
276	1539.25	113	61700	25	13300	22.73835
277	1544.25	113	61700	25	13300	22.66472
278	1549.25	113	61700	25	13300	22.59158
279	1554.25	113	61700	25	13300	22.5189
280	1559.25	113	61700	25	13300	22.44669
281	1564.25	113	61700	25	13300	22.37494
282	1569.25	113	61700	25	13300	22.30365
283	1574.25	113	61700	25	13300	22.23281
284	1579.25	113	61700	25	13300	22.16242
285	1584.25	115	62100	25	13300	22.09247
286	1589.25	115	62100	25	13300	22.02297
287	1594.25	115	62100	25	13300	21.9539
288	1599.25	115	62100	31	15600	21.88526
289	1604.25	115	62100	31	15600	21.81705
290	1609.25	115	62100	31	15600	21.74926
291	1614.25	115	62100	31	15600	21.6819
292	1619.25	115	62100	31	15600	21.61494
293	1624.25	115	62100	31	15600	21.54841
294	1629.25	115	62100	31	15600	21.48228

295	1634.25	115	62100	31	15600	21.41655
296	1639.25	115	62100	31	15600	21.35123
297	1644.25	115	62100	31	15600	21.2863
298	1649.25	117	62500	31	15600	21.22177
299	1654.25	117	62500	31	15600	21.15763
300	1659.25	117	62500	31	15600	21.09387
301	1664.25	117	62500	31	15600	21.03049
302	1669.25	117	62500	31	15600	20.9675
303	1674.25	117	62500	31	15600	20.90488
304	1679.25	117	62500	31	15600	20.84264
305	1684.25	117	62500	31	15600	20.78076
306	1689.25	117	62500	31	15600	20.71925
307	1694.25	117	62500	31	15600	20.65811
308	1699.25	117	62500	31	15600	20.59732
309	1704.25	120	65500	31	15600	20.53689
310	1709.25	120	65500	31	15600	20.47682
311	1714.25	122	65900	31	15600	20.41709
312	1719.25	122	65900	31	15600	20.35771
313	1724.25	122	65900	31	15600	20.29868
314	1729.25	122	65900	31	15600	20.23999
315	1734.25	122	65900	31	15600	20.18163
316	1739.25	122	65900	31	15600	20.12362
317	1744.25	124	66900	31	15600	20.06593
318	1749.25	126	67900	31	15600	20.00858
319	1754.25	126	67900	31	15600	19.95155
320	1759.25	126	67900	31	15600	19.89484
321	1764.25	126	67900	31	15600	19.83846
322	1769.25	126	67900	31	15600	19.78239
323	1774.25	126	67900	31	15600	19.72664
324	1779.25	128	68300	31	15600	19.67121
325	1784.25	128	68300	31	15600	19.61609
326	1789.25	128	68300	31	15600	19.56127
327	1794.25	128	68300	31	15600	19.50676
328	1799.25	128	68300	31	15600	19.45255
329	1804.25	128	68300	31	15600	19.39864
330	1809.25	128	68300	31	15600	19.34503
331	1814.25	128	68300	31	15600	19.29172
332	1819.25	128	68300	31	15600	19.2387
333	1824.25	128	68300	31	15600	19.18597
334	1829.25	128	68300	31	15600	19.13352
335	1834.25	128	68300	31	15600	19.08137
336	1839.25	130	68700	31	15600	19.0295
337	1844.25	130	68700	31	15600	18.9779
338	1849.25	130	68700	31	15600	18.92659
339	1854.25	130	68700	31	15600	18.87556
340	1859.25	130	68700	31	15600	18.82479

341	1864.25	130	68700	31	15600	18.77431
342	1869.25	130	68700	31	15600	18.72409
343	1874.25	133	71700	31	15600	18.67414
344	1879.25	133	71700	31	15600	18.62445
345	1884.25	133	71700	31	15600	18.57503
346	1889.25	133	71700	31	15600	18.52587
347	1894.25	133	71700	31	15600	18.47697
348	1899.25	133	71700	31	15600	18.42833
349	1904.25	135	72100	31	15600	18.37994
350	1909.25	135	72100	31	15600	18.33181
351	1914.25	135	72100	31	15600	18.28392
352	1919.25	135	72100	31	15600	18.23629
353	1924.25	135	72100	31	15600	18.18891
354	1929.25	135	72100	31	15600	18.14177
355	1934.25	135	72100	31	15600	18.09487
356	1939.25	135	72100	31	15600	18.04821
357	1944.25	135	72100	31	15600	18.0018
358	1949.25	135	72100	31	15600	17.95562
359	1954.25	135	72100	31	15600	17.90968
360	1959.25	135	72100	31	15600	17.86398
361	1964.25	135	72100	31	15600	17.81851
362	1969.25	137	72500	31	15600	17.77326
363	1974.25	137	72500	31	15600	17.72825
364	1979.25	137	72500	31	15600	17.68347
365	1984.25	137	72500	31	15600	17.63891
366	1989.25	137	72500	31	15600	17.59457
367	1994.25	137	72500	31	15600	17.55046
368	1999.25	139	73500	33	16100	17.50657
369	2004.25	139	73500	33	16100	17.46289
370	2009.25	139	73500	33	16100	17.41944
371	2014.25	139	73500	33	16100	17.37619
372	2019.25	139	73500	33	16100	17.33317
373	2024.25	139	73500	33	16100	17.29035
374	2029.25	141	73900	33	16100	17.24775
375	2034.25	141	73900	33	16100	17.20536
376	2039.25	141	73900	33	16100	17.16317
377	2044.25	144	76900	33	16100	17.12119
378	2049.25	144	76900	33	16100	17.07942
379	2054.25	144	76900	33	16100	17.03785
380	2059.25	144	76900	33	16100	16.99648
381	2064.25	144	76900	33	16100	16.95531
382	2069.25	144	76900	33	16100	16.91434
383	2074.25	144	76900	33	16100	16.87357
384	2079.25	144	76900	33	16100	16.83299
385	2084.25	144	76900	33	16100	16.79261
386	2089.25	144	76900	33	16100	16.75242

387	2094.25	146	77300	33	16100	16.71243
388	2099.25	146	77300	33	16100	16.67262
389	2104.25	146	77300	33	16100	16.63301
390	2109.25	146	77300	33	16100	16.59358
391	2114.25	146	77300	33	16100	16.55433
392	2119.25	146	77300	33	16100	16.51528
393	2124.25	146	77300	33	16100	16.4764
394	2129.25	146	77300	33	16100	16.43771
395	2134.25	146	77300	33	16100	16.3992
396	2139.25	146	77300	33	16100	16.36087
397	2144.25	146	77300	33	16100	16.32272
398	2149.25	146	77300	33	16100	16.28475
399	2154.25	146	77300	33	16100	16.24695
400	2159.25	148	77700	33	16100	16.20933
401	2164.25	148	77700	33	16100	16.17188
402	2169.25	148	77700	33	16100	16.13461
403	2174.25	148	77700	33	16100	16.09751
404	2179.25	150	78700	33	16100	16.06057
405	2184.25	150	78700	33	16100	16.02381
406	2189.25	150	78700	33	16100	15.98721
407	2194.25	150	78700	33	16100	15.95078
408	2199.25	150	78700	33	16100	15.91452
409	2204.25	150	78700	33	16100	15.87842
410	2209.25	150	78700	33	16100	15.84248
411	2214.25	153	81700	33	16100	15.80671
412	2219.25	155	82100	33	16100	15.77109
413	2224.25	155	82100	33	16100	15.73564
414	2229.25	155	82100	33	16100	15.70035
415	2234.25	155	82100	33	16100	15.66521
416	2239.25	155	82100	33	16100	15.63023
417	2244.25	155	82100	33	16100	15.59541
418	2249.25	157	83100	35	17400	15.56074
419	2254.25	157	83100	35	17400	15.52623
420	2259.25	157	83100	35	17400	15.49187
421	2264.25	157	83100	35	17400	15.45766
422	2269.25	157	83100	35	17400	15.4236
423	2274.25	157	83100	35	17400	15.38969
424	2279.25	157	83100	35	17400	15.35593
425	2284.25	159	83500	35	17400	15.32232
426	2289.25	159	83500	35	17400	15.28885
427	2294.25	159	83500	35	17400	15.25553
428	2299.25	159	83500	35	17400	15.22235
429	2304.25	159	83500	35	17400	15.18932
430	2309.25	159	83500	35	17400	15.15644
431	2314.25	159	83500	35	17400	15.12369
432	2319.25	159	83500	35	17400	15.09109

433	2324.25	159	83500	35	17400	15.05862
434	2329.25	159	83500	35	17400	15.0263
435	2334.25	159	83500	35	17400	14.99411
436	2339.25	159	83500	35	17400	14.96206
437	2344.25	159	83500	35	17400	14.93015
438	2349.25	161	83900	35	17400	14.89837
439	2354.25	161	83900	35	17400	14.86673
440	2359.25	161	83900	35	17400	14.83522
441	2364.25	161	83900	35	17400	14.80385
442	2369.25	161	83900	35	17400	14.77261
443	2374.25	161	83900	35	17400	14.7415
444	2379.25	161	83900	35	17400	14.71052
445	2384.25	164	86900	35	17400	14.67967
446	2389.25	164	86900	35	17400	14.64895
447	2394.25	164	86900	35	17400	14.61836
448	2399.25	164	86900	37	17900	14.58789
449	2404.25	164	86900	37	17900	14.55755
450	2409.25	166	87300	37	17900	14.52734
451	2414.25	166	87300	37	17900	14.49726
452	2419.25	166	87300	37	17900	14.46729
453	2424.25	166	87300	37	17900	14.43746
454	2429.25	166	87300	37	17900	14.40774
455	2434.25	166	87300	37	17900	14.37815
456	2439.25	166	87300	37	17900	14.34867
457	2444.25	166	87300	37	17900	14.31932
458	2449.25	166	87300	37	17900	14.29009
459	2454.25	166	87300	37	17900	14.26098
460	2459.25	166	87300	37	17900	14.23198
461	2464.25	166	87300	37	17900	14.2031
462	2469.25	166	87300	37	17900	14.17434
463	2474.25	168	87700	37	17900	14.1457
464	2479.25	168	87700	37	17900	14.11717
465	2484.25	168	87700	37	17900	14.08876
466	2489.25	168	87700	37	17900	14.06046
467	2494.25	168	87700	37	17900	14.03227
468	2499.25	170	88700	37	17900	14.0042
469	2504.25	170	88700	37	17900	13.97624
470	2509.25	170	88700	37	17900	13.94839
471	2514.25	170	88700	37	17900	13.92065
472	2519.25	170	88700	37	17900	13.89302
473	2524.25	170	88700	37	17900	13.8655
474	2529.25	170	88700	37	17900	13.83809
475	2534.25	170	88700	37	17900	13.81079
476	2539.25	172	89100	37	17900	13.7836
477	2544.25	172	89100	37	17900	13.75651
478	2549.25	172	89100	37	17900	13.72953

479	2554.25	175	92100	37	17900	13.70265
480	2559.25	175	92100	37	17900	13.67588
481	2564.25	175	92100	37	17900	13.64921
482	2569.25	175	92100	37	17900	13.62265
483	2574.25	175	92100	37	17900	13.59619
484	2579.25	175	92100	37	17900	13.56984
485	2584.25	175	92100	37	17900	13.54358
486	2589.25	175	92100	37	17900	13.51743
487	2594.25	178	95100	37	17900	13.49138
488	2599.25	180	95500	37	17900	13.46542
489	2604.25	180	95500	37	17900	13.43957
490	2609.25	180	95500	37	17900	13.41382
491	2614.25	182	96500	37	17900	13.38816
492	2619.25	182	96500	37	17900	13.3626
493	2624.25	182	96500	37	17900	13.33714
494	2629.25	182	96500	37	17900	13.31178
495	2634.25	182	96500	37	17900	13.28651
496	2639.25	182	96500	37	17900	13.26134
497	2644.25	182	96500	37	17900	13.23627
498	2649.25	182	96500	37	17900	13.21129
499	2654.25	182	96500	37	17900	13.1864
500	2659.25	182	96500	37	17900	13.16161
501	2664.25	184	96900	37	17900	13.13691
502	2669.25	184	96900	37	17900	13.1123
503	2674.25	184	96900	37	17900	13.08778
504	2679.25	184	96900	37	17900	13.06336
505	2684.25	184	96900	37	17900	13.03902
506	2689.25	184	96900	37	17900	13.01478
507	2694.25	184	96900	37	17900	12.99063
508	2699.25	184	96900	37	17900	12.96657
509	2704.25	184	96900	37	17900	12.94259
510	2709.25	184	96900	37	17900	12.9187
511	2714.25	184	96900	37	17900	12.89491
512	2719.25	184	96900	37	17900	12.8712
513	2724.25	187	99900	37	17900	12.84757
514	2729.25	189	100300	37	17900	12.82404
515	2734.25	189	100300	37	17900	12.80058
516	2739.25	189	100300	37	17900	12.77722
517	2744.25	189	100300	37	17900	12.75394
518	2749.25	191	101300	37	17900	12.73074
519	2754.25	191	101300	37	17900	12.70763
520	2759.25	191	101300	37	17900	12.68461
521	2764.25	191	101300	37	17900	12.66166
522	2769.25	191	101300	37	17900	12.6388
523	2774.25	191	101300	37	17900	12.61602
524	2779.25	191	101300	37	17900	12.59333

525	2784.25	191	101300	37	17900	12.57071
526	2789.25	193	101700	37	17900	12.54818
527	2794.25	193	101700	37	17900	12.52572
528	2799.25	193	101700	39	18400	12.50335
529	2804.25	193	101700	39	18400	12.48106
530	2809.25	193	101700	39	18400	12.45884
531	2814.25	193	101700	39	18400	12.43671
532	2819.25	193	101700	39	18400	12.41465
533	2824.25	193	101700	39	18400	12.39267
534	2829.25	193	101700	39	18400	12.37077
535	2834.25	193	101700	39	18400	12.34895
536	2839.25	193	101700	39	18400	12.3272
537	2844.25	193	101700	39	18400	12.30553
538	2849.25	193	101700	39	18400	12.28393
539	2854.25	195	102100	39	18400	12.26242
540	2859.25	195	102100	39	18400	12.24097
541	2864.25	195	102100	39	18400	12.2196
542	2869.25	195	102100	39	18400	12.19831
543	2874.25	195	102100	39	18400	12.17709
544	2879.25	195	102100	39	18400	12.15594
545	2884.25	195	102100	39	18400	12.13487
546	2889.25	195	102100	39	18400	12.11387
547	2894.25	198	105100	39	18400	12.09294
548	2899.25	198	105100	39	18400	12.07209
549	2904.25	198	105100	39	18400	12.0513
550	2909.25	198	105100	39	18400	12.03059
551	2914.25	198	105100	39	18400	12.00995
552	2919.25	200	105500	39	18400	11.98938
553	2924.25	200	105500	39	18400	11.96888
554	2929.25	200	105500	39	18400	11.94845
555	2934.25	200	105500	39	18400	11.92809
556	2939.25	200	105500	39	18400	11.9078
557	2944.25	200	105500	39	18400	11.88758
558	2949.25	200	105500	39	18400	11.86742
559	2954.25	200	105500	39	18400	11.84734
560	2959.25	200	105500	39	18400	11.82732
561	2964.25	200	105500	39	18400	11.80737
562	2969.25	200	105500	39	18400	11.78749
563	2974.25	200	105500	39	18400	11.76767
564	2979.25	202	105900	39	18400	11.74792
565	2984.25	202	105900	39	18400	11.72824
566	2989.25	202	105900	39	18400	11.70862
567	2994.25	202	105900	39	18400	11.68907
568	2999.25	204	106900	39	18400	11.66958
569	3004.25	204	106900	39	18400	11.65016
570	3009.25	204	106900	39	18400	11.63081

571	3014.25	204	106900	39	18400	11.61151
572	3019.25	204	106900	39	18400	11.59228
573	3024.25	204	106900	39	18400	11.57312
574	3029.25	204	106900	39	18400	11.55402
575	3034.25	204	106900	39	18400	11.53498
576	3039.25	204	106900	39	18400	11.516
577	3044.25	206	107300	39	18400	11.49708
578	3049.25	208	108300	39	18400	11.47823
579	3054.25	208	108300	39	18400	11.45944
580	3059.25	208	108300	39	18400	11.44071
581	3064.25	211	111300	39	18400	11.42204
582	3069.25	211	111300	39	18400	11.40344
583	3074.25	211	111300	39	18400	11.38489
584	3079.25	211	111300	39	18400	11.3664
585	3084.25	211	111300	39	18400	11.34798
586	3089.25	211	111300	39	18400	11.32961
587	3094.25	211	111300	39	18400	11.3113
588	3099.25	211	111300	39	18400	11.29305
589	3104.25	211	111300	39	18400	11.27487
590	3109.25	213	111700	39	18400	11.25673
591	3114.25	213	111700	39	18400	11.23866
592	3119.25	213	111700	39	18400	11.22065
593	3124.25	213	111700	39	18400	11.20269
594	3129.25	213	111700	39	18400	11.18479
595	3134.25	213	111700	39	18400	11.16695
596	3139.25	213	111700	39	18400	11.14916
597	3144.25	213	111700	39	18400	11.13143
598	3149.25	213	111700	39	18400	11.11376
599	3154.25	213	111700	39	18400	11.09614
600	3159.25	213	111700	39	18400	11.07858
601	3164.25	213	111700	39	18400	11.06107
602	3169.25	215	112100	39	18400	11.04362
603	3174.25	215	112100	39	18400	11.02623
604	3179.25	215	112100	39	18400	11.00889
605	3184.25	215	112100	39	18400	10.9916
606	3189.25	215	112100	39	18400	10.97437
607	3194.25	215	112100	39	18400	10.95719
608	3199.25	215	112100	45	20700	10.94006
609	3204.25	215	112100	45	20700	10.92299
610	3209.25	215	112100	45	20700	10.90598
611	3214.25	215	112100	45	20700	10.88901
612	3219.25	215	112100	45	20700	10.8721
613	3224.25	215	112100	45	20700	10.85524
614	3229.25	215	112100	45	20700	10.83843
615	3234.25	220	115500	45	20700	10.82167
616	3239.25	220	115500	45	20700	10.80497

617	3244.25	220	115500	45	20700	10.78832
618	3249.25	222	116500	45	20700	10.77172
619	3254.25	222	116500	45	20700	10.75517
620	3259.25	222	116500	45	20700	10.73867
621	3264.25	222	116500	45	20700	10.72222
622	3269.25	222	116500	45	20700	10.70582
623	3274.25	222	116500	45	20700	10.68947
624	3279.25	222	116500	45	20700	10.67317
625	3284.25	222	116500	45	20700	10.65692
626	3289.25	222	116500	45	20700	10.64072
627	3294.25	222	116500	45	20700	10.62457
628	3299.25	224	116900	45	20700	10.60847
629	3304.25	224	116900	45	20700	10.59242
630	3309.25	224	116900	45	20700	10.57642
631	3314.25	224	116900	45	20700	10.56046
632	3319.25	224	116900	45	20700	10.54455
633	3324.25	224	116900	45	20700	10.52869
634	3329.25	224	116900	45	20700	10.51288
635	3334.25	224	116900	45	20700	10.49711
636	3339.25	224	116900	45	20700	10.4814
637	3344.25	224	116900	45	20700	10.46572
638	3349.25	224	116900	45	20700	10.4501
639	3354.25	224	116900	45	20700	10.43452
640	3359.25	226	117300	45	20700	10.41899
641	3364.25	226	117300	45	20700	10.40351
642	3369.25	226	117300	45	20700	10.38807
643	3374.25	226	117300	45	20700	10.37267
644	3379.25	226	117300	45	20700	10.35733
645	3384.25	226	117300	45	20700	10.34203
646	3389.25	226	117300	45	20700	10.32677
647	3394.25	226	117300	45	20700	10.31156
648	3399.25	226	117300	45	20700	10.29639
649	3404.25	229	120300	45	20700	10.28127
650	3409.25	229	120300	45	20700	10.26619
651	3414.25	229	120300	45	20700	10.25115
652	3419.25	229	120300	45	20700	10.23616
653	3424.25	231	120700	45	20700	10.22122
654	3429.25	231	120700	45	20700	10.20631
655	3434.25	231	120700	45	20700	10.19145
656	3439.25	231	120700	45	20700	10.17664
657	3444.25	231	120700	45	20700	10.16186
658	3449.25	231	120700	45	20700	10.14713
659	3454.25	231	120700	45	20700	10.13245
660	3459.25	231	120700	45	20700	10.1178
661	3464.25	231	120700	45	20700	10.1032
662	3469.25	231	120700	45	20700	10.08864

663	3474.25	231	120700	45	20700	10.07412
664	3479.25	231	120700	45	20700	10.05964
665	3484.25	233	121700	45	20700	10.0452
666	3489.25	235	122100	45	20700	10.03081
667	3494.25	235	122100	45	20700	10.01646
668	3499.25	239	123800	45	20700	10.00214
669	3504.25	239	123800	45	20700	9.987872
670	3509.25	239	123800	45	20700	9.973641
671	3514.25	239	123800	45	20700	9.959451
672	3519.25	239	123800	45	20700	9.945301
673	3524.25	239	123800	45	20700	9.931191
674	3529.25	239	123800	45	20700	9.917121
675	3534.25	239	123800	45	20700	9.903091
676	3539.25	239	123800	45	20700	9.889101
677	3544.25	239	123800	45	20700	9.87515
678	3549.25	241	124200	45	20700	9.861239
679	3554.25	241	124200	45	20700	9.847365
680	3559.25	241	124200	45	20700	9.833532
681	3564.25	241	124200	45	20700	9.819737
682	3569.25	241	124200	45	20700	9.805982
683	3574.25	241	124200	45	20700	9.792264
684	3579.25	244	127200	45	20700	9.778585
685	3584.25	244	127200	45	20700	9.764944
686	3589.25	244	127200	45	20700	9.751341
687	3594.25	244	127200	45	20700	9.737776
688	3599.25	244	127200	47	21200	9.724248
689	3604.25	244	127200	47	21200	9.710758
690	3609.25	244	127200	47	21200	9.697306
691	3614.25	246	127600	47	21200	9.68389
692	3619.25	246	127600	47	21200	9.670512
693	3624.25	246	127600	47	21200	9.65717
694	3629.25	246	127600	47	21200	9.643866
695	3634.25	246	127600	47	21200	9.630598
696	3639.25	246	127600	47	21200	9.617366
697	3644.25	246	127600	47	21200	9.604171
698	3649.25	246	127600	47	21200	9.591012
699	3654.25	246	127600	47	21200	9.577889
700	3659.25	246	127600	47	21200	9.564801
701	3664.25	246	127600	47	21200	9.55175
702	3669.25	246	127600	47	21200	9.538734
703	3674.25	246	127600	47	21200	9.525754
704	3679.25	248	128000	47	21200	9.512808
705	3684.25	248	128000	47	21200	9.499898
706	3689.25	248	128000	47	21200	9.487023
707	3694.25	248	128000	47	21200	9.474183
708	3699.25	248	128000	47	21200	9.461377

709	3704.25	248	128000	47	21200	9.448607
710	3709.25	248	128000	47	21200	9.43587
711	3714.25	248	128000	47	21200	9.423167
712	3719.25	248	128000	47	21200	9.4105
713	3724.25	248	128000	47	21200	9.397865
714	3729.25	248	128000	47	21200	9.385265
715	3734.25	248	128000	47	21200	9.372699
716	3739.25	250	128400	47	21200	9.360166
717	3744.25	250	128400	47	21200	9.347667
718	3749.25	255	132400	47	21200	9.3352
719	3754.25	255	132400	47	21200	9.322767
720	3759.25	255	132400	47	21200	9.310368
721	3764.25	255	132400	47	21200	9.298001
722	3769.25	255	132400	47	21200	9.285667
723	3774.25	255	132400	47	21200	9.273366
724	3779.25	255	132400	47	21200	9.261097
725	3784.25	255	132400	47	21200	9.24886
726	3789.25	255	132400	47	21200	9.236656
727	3794.25	255	132400	47	21200	9.224484
728	3799.25	255	132400	47	21200	9.212344
729	3804.25	257	132800	47	21200	9.200236
730	3809.25	257	132800	47	21200	9.18816
731	3814.25	257	132800	47	21200	9.176116
732	3819.25	257	132800	47	21200	9.164103
733	3824.25	257	132800	47	21200	9.152122
734	3829.25	257	132800	47	21200	9.140171
735	3834.25	257	132800	47	21200	9.128252
736	3839.25	257	132800	47	21200	9.116364
737	3844.25	260	136800	50	25200	9.104507
738	3849.25	260	136800	50	25200	9.09268
739	3854.25	260	136800	50	25200	9.080885
740	3859.25	260	136800	50	25200	9.06912
741	3864.25	260	136800	50	25200	9.057385
742	3869.25	262	137200	50	25200	9.045681
743	3874.25	262	137200	50	25200	9.034006
744	3879.25	262	137200	50	25200	9.022363
745	3884.25	262	137200	50	25200	9.010749
746	3889.25	265	140200	50	25200	8.999165
747	3894.25	265	140200	50	25200	8.98761
748	3899.25	265	140200	50	25200	8.976085
749	3904.25	265	140200	50	25200	8.96459
750	3909.25	265	140200	50	25200	8.953124
751	3914.25	265	140200	50	25200	8.941688
752	3919.25	270	144200	50	25200	8.93028
753	3924.25	270	144200	50	25200	8.918901
754	3929.25	272	144600	50	25200	8.907553

755	3934.25	272	144600	50	25200	8.896232
756	3939.25	272	144600	50	25200	8.88494
0.035						
757	191.625	21	13900	19	11800	182.6484
758	196.625	21	13900	19	11800	178.0038
759	201.625	24	16900	19	11800	173.5896