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Advanced Safeguards Approaches for New Reprocessing Facilities

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June 2007

Pacific Northwest
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Advanced Safeguards Approaches for New Reprocessing Facilities

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Final Report

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Prepared for the U.S. Department of Energy
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Contents

Executive Summary

U.S. efforts to promote the international expansion of nuclear energy through the Global Nuclear Energy Partnership (GNEP) and other Advanced Nuclear Fuel Cycle programs will result in a dramatic expansion of nuclear fuel cycle facilities in the United States. Demonstration Facilities, such as the Advanced Fuel Cycle Facility (AFCF), the Advanced Burner Reactor (ABR), and the Consolidated Fuel Treatment Center (CFTC) will use advanced nuclear and chemical process technologies that must incorporate increased proliferation resistance to enhance nuclear safeguards.

The ASA-100 Project, "Advanced Safeguards Approaches for New Nuclear Fuel Cycle Facilities," commissioned by the NA-243 Office of NNSA, has been tasked with reviewing and developing advanced safeguards approaches for these demonstration facilities. Because one goal of GNEP and other Advanced Nuclear Fuel Cycles is developing and sharing proliferation-resistant nuclear technology and services with partner nations, the safeguards approaches considered are consistent with international safeguards as currently implemented by the International Atomic Energy Agency (IAEA). This first report reviews possible safeguards approaches for the new fuel reprocessing processes to be deployed at the AFCF and CFTC facilities. Similar analyses addressing the ABR and the transuranic (TRU) fuel fabrication lines at AFCF will be presented in subsequent reports.

Lessons learned from applying nuclear material safeguards to nuclear fuel reprocessing plants over the last 40 years lay the groundwork for safeguarding future facilities. In particular, safeguards approaches applied to reprocessing plants at West Valley (New York/USA), Hanford (Washington/USA), AGNS-Barnwell (South Carolina/USA), Tokaimura (Japan), and Rokkashomura (Japan) provide the keystone to safeguarding AFCF and CFTC. In addition, the safeguards experience and challenges encountered in the pyro-metallurgical reprocessing process at EBR-II at Idaho Falls (Idaho/USA) and the pyro-electrochemical ACP facility at the Korean Atomic Energy Research Institute (KAERI) Site (Daejeon/Republic of Korea) provided data and fundamental principles for safeguarding the pyro-metallurgical reprocessing line planned for AFCF.

The foundation for developing a nuclear material safeguards approach for aqueous reprocessing starts with the well-established plutonium/uranium reduction extraction (PUREX) process developed in the 1950's. However, the Advanced Nuclear Fuel Cycles envision new fuel reprocessing methods making use of more complex aqueous and pyro-chemical and metallurgical processes that are intended to provide proliferation resistance. CFTC is a conceptual very large scale reprocessing plant, with an annual capacity of 3,000 metric tonnes heavy metal (MTHM) - nearly four times current large scale commercial reprocessing plants. This report identifies the technical challenges inherent in safeguarding these new processes and facilities. The scientists, engineers, and safeguards specialists who constitute the ASA-100 Project Team identified needs that, if addressed, would ensure that the new reprocessing processes and facilities could be adequately safeguarded.

These needs are:

- Develop a method to accurately measure the plutonium (Pu) and actinide content in spent LWR fuel and metallic fast-reactor fuel for the random verification of the spent fuel receipts, and to provide an analytical basis for estimating shipper/receiver differences in a timely manner. It is expected that this method should be capable of detecting "partial-defects" in accordance with current IAEA criteria, i.e. approximately. +/- 5% total Pu.

- Develop on-line assay techniques to measure the plutonium, uranium and actinide content of aqueous process solutions to a level of +/- 1%, or better. Absence of these techniques makes it impossible to remotely monitor reprocessing plants, since the concentration of the nuclear material in the main process streams and inventory vessels is of fundamental safeguards importance.

- Develop a more effective automated and integrated data collect and review system for analyzing process and on-line assay data and surveillance imagery to support verification of the nuclear material transfers, inventory, and operational status of the facility.

- Establish an active dialogue with the IAEA to negotiate a more flexible interpretation of the IAEA Department of Safeguards SGTS Policy #20, concerning the joint use of equipment for safeguards purposes. The current interpretation is very restrictive and limits the ability of the IAEA to use a broad range of existing plant instruments because of the supposed need to derive independent safeguards conclusions from these instruments. It is proposed that this strict interpretation should be applied only to those instruments of primary safeguards importance – and not to the extensive array of plant instruments, which could still provide complementary data of safeguards relevance regarding operation of the facility.

- Make greater use of automated, unattended/remote monitoring systems for collecting safeguards data, while cooperating with the facility owner/operator and national authorities to ensure protection of proprietary information.

- Cooperate with the facility owner/operator and national authorities to try to design-in safeguards requirements and equipment in the earliest stages of the conceptual design of the facility.

- Improve the inspection regime by making more effective use of randomized short-notice inspections, applying a "statistical process control" approach to verification of the reprocessing facilities rather than a scheduled systematic verification of all major transfers of plutonium-bearing materials. For this kind of approach to be effective the facility operator would need to declare the major activities involving nuclear material in advance. It would also be more efficient to apply this approach on a site, rather than facility, level.

- Improve the accuracy of the methods for the assay of nuclear materials by destructive assay (DA) and non-destructive assay (NDA) and the measurement of the volume and mass of process solutions. These improvements are especially needed for safeguarding the very-large-scale reprocessing plant at CFTC and for the experimental pyro-reprocessing process at AFCF.

If these needs are addressed, DOE would be able to present a viable international safeguards approach for the new reprocessing facilities. It would also further the goals of DOE by advancing safeguards technology and “building-in” proliferation resistance into these new reprocessing facilities.

1. Background

As the United States works to promote the global expansion of nuclear power through its Global Nuclear Energy Partnership (GNEP) and other Advanced Nuclear Fuel Cycle programs, the nuclear fuel cycle in the United States is expected to expand substantially. New facilities will be constructed employing advanced nuclear and chemical process technologies. In addition, it is envisioned that these new Demonstration Facilities will be designed to be inherently easier to safeguard and more proliferation-resistant. Two of the main objectives of GNEP and Advanced Nuclear Fuel Cycles are the recycle of nuclear fuel using new proliferation resistant technologies to recover more energy and reduce waste, and to reduce proliferation risks through the use of these new technologies.[1] The facilities that will demonstrate a new and proliferation-resistant nuclear fuel-cycle include the Advanced Fuel Cycle Facility (AFCF), the Advanced Burner Reactor (ABR), and the Consolidated Fuel Treatment Center (CFTC, formerly called ESD).[2]

The ASA-100 Project, "Advanced Safeguards Approaches for New Nuclear Fuel Cycle Facilities," commissioned by the NA-243 Office of NNSA, has been tasked with reviewing and developing advanced safeguards approaches for the Demonstration Facilities. The United States has consistently demonstrated its support for international safeguards, as evidenced by the US government having over 280 nuclear facilities listed on the Eligible Facility List (EFL) under its Voluntary Offer (Safeguards) Agreement with the IAEA. It is likely that the GNEP or other Advanced Fuel Cycle Demonstration Facilities would be placed on this list as well. Furthermore, the development and sharing of proliferation-resistant nuclear technology and services is a GNEP and Advanced Nuclear Fuel Cycle cornerstone. Therefore, the conceptual safeguards approaches developed in this study are consistent with international safeguards and practices.

Because reprocessing has in the past resulted in separated streams of purified plutonium-bearing materials that could potentially be diverted and misused, the ASA-100 Project Team has focused in this study on safeguarding reprocessing processes and facilities as the first priority for analysis. The specific processes analyzed are the aqueous and pyrometallurgical processes that will be used at the experimental scale AFCF, and the aqueous process that will be used at the very large scale CFTC.

Safeguards applied to former and current reprocessing plants are of significant interest to this study and lessons learned from previous safeguards experiences strongly influenced the conclusions reached.[3] The safeguards approaches used at the following aqueous reprocessing facilities were referred to in the course of this study.

- West Valley, New York (USA)
- PUREX Reprocessing Plant, Hanford, Washington State (USA)
- Allied General Nuclear Services (AGNS), Barnwell, South Carolina (USA)
- Tokai Reprocessing Plant, Tokaimura, Ibaraki Prefecture (Japan)
- Rokkashomura Reprocessing Plant, Rokkashomura, Aomori Prefecture (Japan)

And since a pyroprocess line will be installed at AFCF to reprocess the metallic fuel from the ABR, safeguards approaches for a pyroprocess were also considered. To develop a safeguards approach for the pyroprocess, the team researched and reviewed safeguards approaches for the processes used at the:

- Integrated Fuel Cycle Facility (IFC) at EBR-II, Idaho Falls, Idaho (USA)[4]
- Advanced Spent Fuel Conditioning Process (ACP), Korean Atomic Energy Research Institute (KAERI), Daejeon, (Republic of Korea)[5]

As preparation and background, the team also examined the significant international safeguards projects and references including:

- TASTEX – The Tokai Advanced Safeguards Technology Exercise,[6]
- LASCAR – The Large Scale Reprocessing Plant Safeguards Forum,[7] and
- Others - as noted in the reference.[8]

In addition, several team members worked as project engineers on the IAEA Department of Safeguards Japan Nuclear Fuel Ltd. (JNFL) Project for developing the safeguards approach and concomitant equipment to safeguard the Rokkashomura Reprocessing Plant (RRP) in Japan. As the most recently commissioned commercial reprocessing plant under international (IAEA) safeguards, RRP was a logical point of reference for developing a new safeguards approach for new reprocessing facilities. However, the use of RRP as a baseline reference did not limit the scope of safeguards concepts considered for the Demonstration Facilities. On the contrary, a full spectrum of prospective safeguards measures were considered and compared against those currently used at RRP.

The safeguards objective addressed by the approaches presented in this report is consistent with the goals of the IAEA; specifically, the timely detection of the diversion of one significant quantity (SQ) of nuclear material.[9] The over-arching objective, then, is the detection of the diversion of 8 kilograms of plutonium within one month of diversion. It should be understood from this study that safeguards measures also apply to uranium (although to a lesser extent) and may also be applied to alternative nuclear materials (ANM) in the future, such as neptunium and americium.

Traditionally, safeguards have depended primarily on nuclear material accountancy (*e.g.* accountability), supplemented with containment and surveillance. It is well recognized that safeguards objectives cannot be met by nuclear material accountancy alone – certainly not with the measurement uncertainties inherent in the nuclear material flow of a large-scale reprocessing plant. To address this weakness, the conceptual approaches considered in this report introduce other safeguards measures in addition to accountancy that, in combination, will allow the inspecting authority to meet the safeguards objective.

2. Description of Reprocessing Facilities and Processes

2. a. Reference Facility – Rokkasho Reprocessing Plant (RRP)

The Rokkasho Reprocessing Plant (RRP) is the newest large-scale commercial nuclear fuel reprocessing plant in the world and is operated by the commercial utility and nuclear industry consortium, Japan Nuclear Fuel Ltd. (JNFL). Located in the northernmost part of the Japanese island of Honshu in Aomori Prefecture, RRP occupies a very large nuclear site adjacent to the Rokkasho Enrichment Plant (REP). The design reprocessing capacity is 800 MTHM (metric tonnes heavy metal) per year.[*] It took over 10 years to construct and at one point was the largest industrial project in Japan, valued at approximately 20 billion USD.[10] The French Concern Cogema (now Areva) provided the reprocessing technology and turnkey support during plant commissioning and startup.

RRP began hot operation officially in October 2006, after a lengthy period of cold commissioning with chemical reagents and natural uranium solution. The facility was subject to Design Information Verification (DIV) activities by the IAEA Department of Safeguards since ground-breaking circa 1996, and is now subject to routine inspection activities (addressed in detail in Section 4 of this report).

The chemical process used at RRP is the plutonium/uranium reduction extraction (PUREX) process, the most commonly used process for civilian nuclear fuel reprocessing since the 1950's.[11,12] It is an aqueous-based solvent extraction process, involving the dissolution of the nuclear fuel "meat" in hot nitric acid and separation of the uranium and plutonium metal by solvent extraction, first from the fission products, and later from each other to produce a stream of purified uranyl-nitrate and plutonium nitrate. RRP remixes the plutonium nitrate solution with uranyl nitrate and co-denitrates these solutions to form a mixed plutonium-uranium oxide (MOX) product powder. The MOX product is containerized for storage in secured storage pits at the facility for use at a later date. When construction of the JMOX Fuel Fabrication Plant at Rokkashomura is completed and the facility has started up, it will use this MOX powder to manufacture MOX LWR fuel assemblies.[13]

A simplified diagram of the PUREX process at RRP is shown in Figure 2. It should be noted that RRP is licensed to reprocess light water reactor (LWR) assemblies, but not MOX assemblies from the Fast Reactors, Monju and Joyo, or the Advanced Test Reactor, (ATR)-Fugen. At RRP, the maximum burn-up of the spent fuel is 40,000 MWd/tonne and the fuel is stored at least one year to minimize the release of gaseous fission products during reprocessing. [14]

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[*] MTHM is nominally the combined mass of uranium, plutonium, and actinides in the fuel, expressed in metric tonnes.

Figure 1: Rokkashomura Reprocessing Plant (RRP) Complex

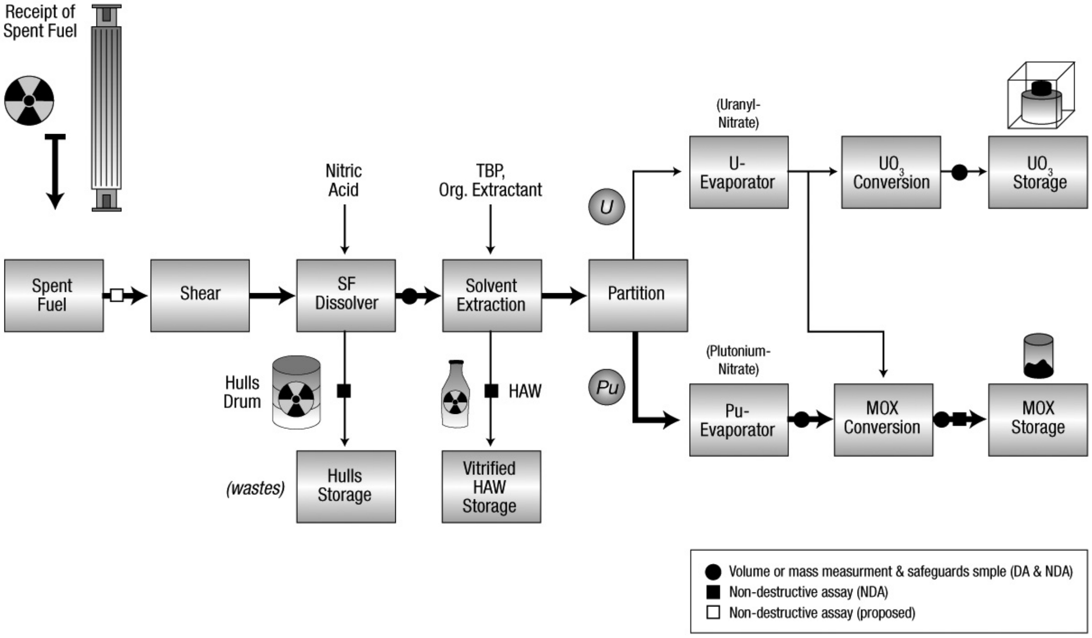


Figure 2: Simplified Process Flow Schematic of PUREX Process at RRP

The spent fuel pond at RRP can store 3,000 tonnes of LWR spent fuel, which is nearly four years of storage capacity. There is additional dry fuel storage in spent fuel cask facilities on-site with more dry storage currently under construction in Aomori prefecture. The process begins when spent fuel is transferred to the mechanical process cell, where the fuel is sheared into small segments and fed into a continuous rotary dissolver, of proprietary Areva (formerly Cogema) design. The fuel meat in the pieces is dissolved in hot nitric acid, with the uranium, plutonium and fission products going into solution. The dissolved fuel solution is clarified in a centrifuge and transferred to an input accountancy (accountability) vessel, where the volume of solution is determined and samples are taken to determine the concentration of nuclear material. The dissolver solution is then fed to the first extraction (co-decontamination) cycle where the solution is fed countercurrent against an organic solvent of 30% tributyl-phosphate (TBP). Repeated extraction into the organic stream and solution "stripping" from the organic stream in solvent-extraction cycles results in partitioned streams of uranyl-nitrate and plutonium nitrate solution. The respective solutions are concentrated in up-flow evaporators and the volume of the concentrated purified plutonium nitrate solution is measured and a sample is taken from the output accountancy vessel, to determine the final output of plutonium from the process. Uranyl and plutonium nitrate solution is then remixed, denitrated and calcined into a mixed plutonium-uranium oxide (MOX) product, nominally 50% plutonium. However, the majority of the purified uranyl-nitrate is not consumed in producing the MOX powder product, so it is denitrated and calcined to UO3 and stored in a UO3 Storage Vault. The MOX powder product is analyzed by destructive and non-destructive assay and stored in the MOX product storage vault.

While the above describes the main separations process, RRP also has several ancillary process units that support the main process. These units concentrate and vitrify high activity liquid waste (HALW), concentrate medium and low-level waste, and scrub and filter the process off-gases so that they can meet discharge limits to permit release from the 100 m tall plant stack. From a safeguards perspective, it is important to monitor and verify the output from many of these ancillary units.

RRP is significant as a point of reference because it is the most modern large scale reprocessing facility under international safeguards. The lessons learned in safeguarding this facility will be relevant to applying international safeguards to the reprocessing processes envisioned for AFCF and CFTC. However, it should also be noted that while the safeguards approach employed by the IAEA at RRP is a point of reference and useful for learning, the aqueous reprocessing processes being considered for use at the demonstration facilities, UREX+ (and more recently COEX), deviate considerably from the PUREX process.

As these processes are addressed, the differences will be highlighted, and the safeguards significance of those differences underscored. It should also be noted from the outset that the pyroprocess proposed for AFCF is not an aqueous solvent-extraction process. It is a high-temperature process that may use float-zone refining or electro-chemical techniques to separate uranium and plutonium and actinides from the fission products in either molten metal or molten salts, or both. Nonetheless, this alternate process will also reprocess spent fuel and produce a plutonium-bearing product. Therefore, it can still be compared and discussed in the general context of applying international safeguards to nuclear fuel reprocessing processes.

The international safeguards approach developed and implemented at RRP is discussed in Section 4.

2. b. Advanced Fuel Cycle Facility (AFCF) – Aqueous Line

The Advanced Fuel Cycle Facility (AFCF) is a conceptual research facility to develop and test new nuclear fuel reprocessing and fuel fabrication flowsheets and technology.[15] The aqueous line of the facility will demonstrate and test aqueous separations processes that will recover uranium, plutonium, and actinides from spent fuel, which will then be fed to the fuel fabrication line to be made into advanced transuranic (TRU) fuel. A process flow schematic of the main aqueous separations process is shown in Figure 3. The most prominent feature of the conceptual AFCF aqueous separations line is that it is essentially a hot reprocessing pilot-plant, sized at 25 MTHM per year. Compared to the Japanese medium-scale Tokai Reprocessing Plant (210 MTHM capacity) and the large-scale commercial reprocessing plant at Rokkashomura (800 MTHM capacity), this is relatively small. However, since the main purpose of AFCF is to demonstrate reprocessing and fuel fabrication flowsheets and safeguards technology, the throughput is appropriate.

Although the aqueous separations line at AFCF is still being designed, the basic design features are as described herein. The capacity of the aqueous separations process will be between 10 to 25 MTHM per year. This will provide the nuclear material to fabricate 10 lead test assemblies (LTAs) to support development of the advanced burner reactor (ABR). Spent fuel will be received at AFCF and stored in a single spent fuel storage pond for feeding either the aqueous separations or pyroprocessing line. The spent fuel pond will be of typical construction and will have a capacity for storing 40 tonnes of light-water reactor (LWR) and 1 tonne of fast reactor (FR) fuel. Spent fuel will be conveyed to a single mechanical process cell that will have a fuel shear. The fuel shear will cut off the end nozzles and shear the fuel into small pieces to be fed to either the aqueous dissolver in the aqueous separations line or the TRU electro-refiner in the pyroprocessing line. It is also possible that pins may be withdrawn from spent fuel assemblies prior to shearing.

The reprocessing process is a variant of the PUREX solvent extraction process, referred to as UREX+, shown in Figure-3. A variety of conceptual UREX+ flowsheets are also being considered, which will be described later in more detail. The extraction process will use centrifugal contactors instead of traditional mixer-settlers or pulse-columns. The size of the contactors will dictate the daily throughput capabilities and operating requirements. The facility is being designed for around-the-clock operation, 240 days a year. At 25 MTHM/year and a typical plutonium concentration of 1% in the LWR spent fuel, the facility would be able to produce 250 kg plutonium per year or about 1 kg plutonium per day.

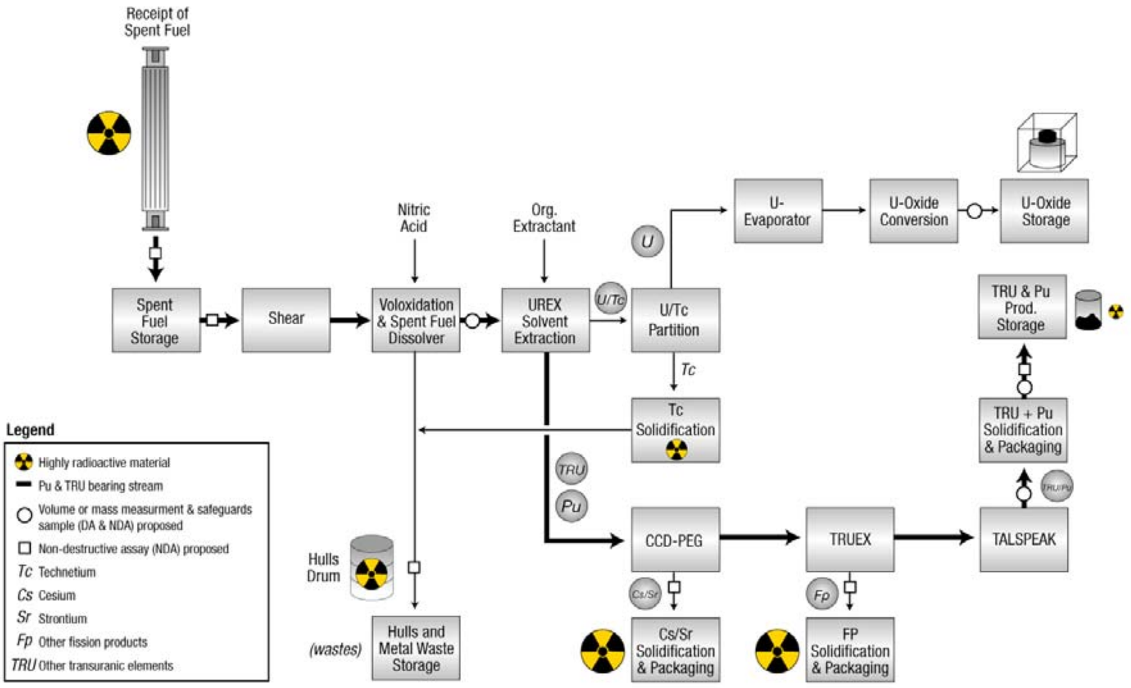


Figure 3: Simplified Process Flow Schematic of UREX+ Process

The aqueous processing line will likely include a voloxidation stream prior to dissolution. During voloxidation, the sheared fuel pieces are heated in an oxygen-rich atmosphere, which changes the crystalline structure of the spent fuel to facilitate removal of the fuel from the cladding. This is a relatively new processing step in fuel reprocessing and should result in a reduction in the nuclear material that is carried away with the hulls, which has been as high as 0.1% of throughput in the past. The aqueous process line includes equipment to support and measure residual fuel in the hulls for disposal. There continues to be discussion of the physical processes to handle hulls and other residual hardware from the fuel assemblies, with the possibility of recycling the metals. It is not clear yet if hulls will be handled after dry mechanical removal of fuel or after dissolution. In any case, there will be some sort of hulls rinse with subsequent handling of the rinse solutions.

AFCF will employ a batch dissolver to dissolve the spent fuel in hot nitric acid. After the uranium and other heavy metals in the spent fuel have dissolved, the spent fuel dissolver solution will be clarified to remove un-dissolved solids. The spent fuel dissolution step will produce clarified dissolver solution, which will be fed to an input accountancy (accountability) vessel to determine the concentration of nuclear material. This step will also produce rinsed hulls and waste rinse solutions containing “fines”, which will be concentrated and routed to the high level waste (HLW) stream. Once-through spent fuel produces a minimum of un-dissolved fines, but fuel made from reprocessed nuclear material tends to be more refractory and harder to dissolve – this will pose both a process challenge and a challenge for measuring and monitoring the nuclear material in the solid waste streams. It is expected that the aqueous process will recycle chemicals and condensates to the greatest extent possible. Therefore, the nuclear material mass balance will have to consider these recycle streams and the nuclear material they might contain.

While the designers of AFCF are currently leaning towards the UREX+1a process, it is also important to remember that AFCF is intended to develop and test reprocessing flowsheets and safeguards methodology, so the facility could ultimately test a variety of solvent extraction processes.[16] The varying chemical composition of process streams may pose analytical challenges, but the safeguards approach is expected to remain largely the same. The UREX+ processes differ from the PUREX process in that they do not completely separate plutonium, thereby “designing-in” proliferation resistance. The suite of UREX+ processes being considered all produce a plutonium-bearing stream, a stream of uranium, a technetium stream, a stream of cesium and strontium, and one or more streams containing all other fission products. The difference between the process variants is how they separate the transuranic (TRU) elements and lanthanides.
These processes are summarized below and in Table-1.

- UREX+1 – All actinides, including Pu (but not U), are recovered as a combined product including the lanthanides.
- UREX+1a – All actinides, including Pu (but not U), are recovered as a combined product, with an additional step (e.g., TALSPEAK) to separate the actinides from the lanthanides.
- UREX+1b – This is the same as +1a but U is also present in the actinide combined product mix by introducing U to the strip feed of the actinide/lanthanide separation step.
- UREX+2 – Plutonium and Np are recovered as a combined product while the remaining actinides (Am, Cm) plus the lanthanides are a separate “product” to be handled.
- UREX+2a – This is the same as +2 but U is also present in the Pu/Np combined product mix.
- UREX+3 – This is essentially the same as +2 but the lanthanides as a waste are separated from the Am/Cm “product” which is available for subsequent re-combinations or as a material for target fabrication for reactor-based disposal.
- UREX+3a – This is the same as +3 but U is also present in the Pu/Np combined product mix.
- UREX+4 – In this variant, Pu and Np are again delivered as a combined product, but Am and Cm are separate products.

Table 1
Comparison of the "UREX+" Processes by Product and Flow-streams

Process	Prod. # 1	Prod. # 2	Prod. #3	Prod. #4	Prod. #5	Prod. #6	Prod. #7
UREX+1	U	Tc	Cs/Sr	TRU + Ln	FP		
UREX+1A	U	Tc	Cs/Sr	TRU	All FP		
UREX+1B	U	Tc	Cs/Sr	U + TRU	All FP		
UREX+2	U	Tc	Cs/Sr	Pu + Np	Am + Cm + Ln	FP	
UREX+2A	U	Tc	Cs/Sr	U + Pu + Np	Am + Cm + Ln	FP	
UREX+3	U	Tc	Cs/Sr	Pu + Np	Am + Cm	All FP	
UREX+3A	U	Tc	Cs/Sr	U + Pu + Np	Am + Cm	All FP	
UREX+4	U	Tc	Cs/Sr	Pu + Np	Am	Cm	All FP

Notes: (1) In all cases, iodine is removed as an off-gas from the dissolution process.
(2) Processes are designed for the generation of no liquid high-level wastes.

U: uranium (removed in order to reduce the mass and volume of high-level waste)
Tc: technetium (long-lived fission product, prime contributor to long-term dose at Yucca Mtn.)
Cs/Sr: cesium and strontium (primary short-term heat generators; repository impact
TRU: transuranic elements (Pu: Plutonium, Np: neptunium, Am: americium, Cm: curium)
Ln: lanthanide (rare earth) fission products
FP: fission products other than cesium, strontium, technetium, iodine, and the lanthanides
All FP: fission products plus lanthanides

The PUREX processes typically use nitric acid and an organic solvent containing tributyl-phosphate (TBP) extractant in the solvent extraction process. The UREX+ processes could use several different feed chemicals and solvent extraction reagents. Therefore, there may need to be several different treatment and recovery systems to separate and recycle the different chemicals.

In all the UREX process variants the product streams from the solvent extraction system will be in solution form. It should be possible to sample and analyze these using established destructive analysis (DA) and non-destructive assay (NDA) methods, with sufficient accuracy to meet the safeguards goals at the relatively low throughput of the AFCF aqueous line.[17,18]

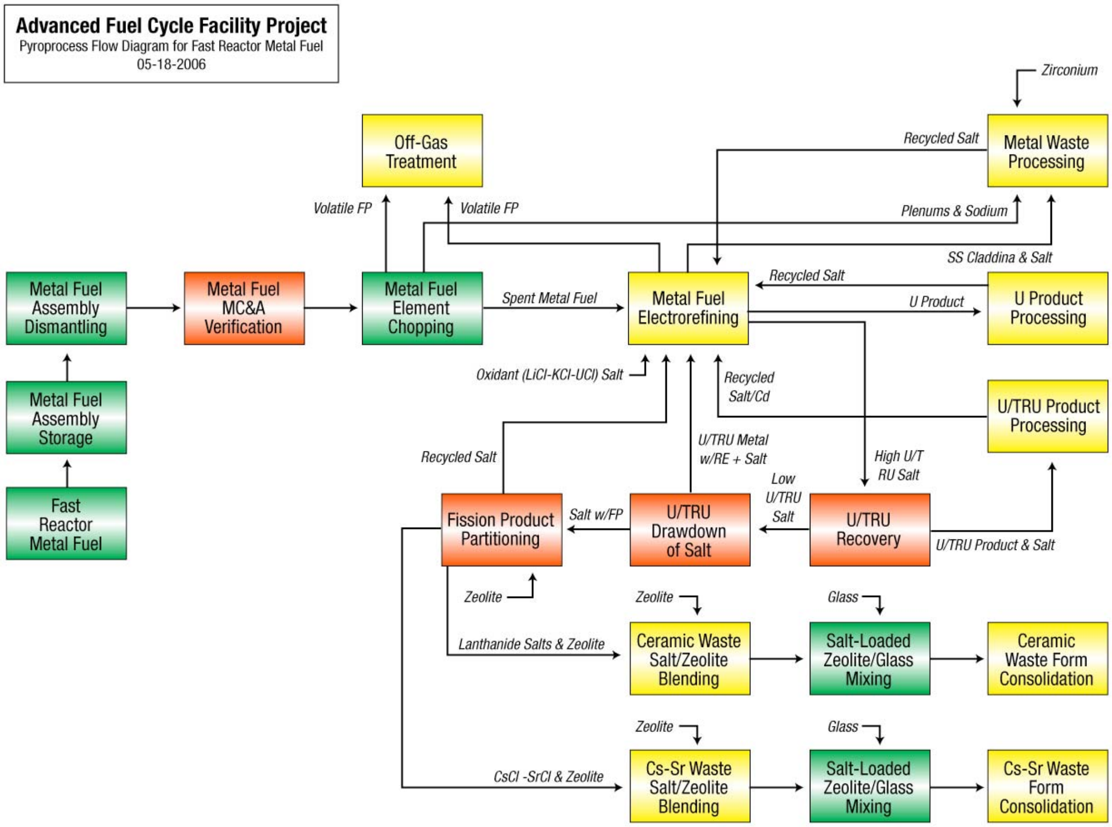
Products from the solvent extraction process will be in aqueous solution. Conversion of these solutions to a dry oxide powder is required prior to packaging, transport and fuel fabrication. However, these conversion processes have not yet been defined. The options range from precipitation and calcination to a variety of “direct de-nitration” processes. In any case they will result in an oxide product to be measured, handled, and packaged for transport to the fabrication part of the facility. The material accountancy system will need to especially monitor and verify the plutonium-bearing streams. Similar, but lesser, safeguards measures will be applied to the uranium streams as well. Safeguards measures may also need to be applied to the streams containing neptunium and potentially americium, if these are determined by DOE and the IAEA to be “safeguardable materials”. It is expected that the product materials will be sampled and analyzed by DA and NDA techniques. However, the prospective DA and NDA techniques will need to be developed to be more accurate and to determine the plutonium, uranium and actinide content in products of varying composition.

The waste handling, conversion, and packaging processes are not well defined at this stage. However, it is believed that the assay techniques would be comparable to the NDA techniques used at RRP to assay the hulls, vitrified high-level waste, and medium to low-level waste.

The design and construction of AFCF will need to be flexible and adaptable to accommodate the research and testing requirements specified by the GNEP or other advanced nuclear fuel cycle programs. Therefore, the facility design will accommodate changes as required to support the reprocessing experiments. It will also have extensive remote maintenance capabilities: remotely operated cranes and master-slave or servo-robotic manipulators and glove-boxes. The previous U.S. reprocessing facilities at Savannah River and Hanford were reconfigurable, but not to the extent expected at AFCF. Also, it should be noted that these were never subject to international safeguards. The flexibility of the facility configuration will be an additional challenge in safeguarding AFCF, especially when verifying the facility design information.

2.c. Advanced Fuel Cycle Facility – Pyroprocessing Line

The AFCF Pyroprocessing line is still in the early stages of design, but a simplified schematic of the conceptual process is shown in Figure-4.[19] Note in this figure that plutonium follows the spent fuel and TRU streams, and thus, these streams are especially important in terms of safeguards.



Note: **Green boxes – Process Modules that are developed**
Yellow boxes – Process Modules that are being developed
Red boxes – Process Modules that need extensive development

Figure 4: Simplified Process Flow Diagram of the Pyroprocess at AFCF

ANL had previously designed a conceptual pyroprocessing facility that would recycle metallic fuel from a sodium-cooled fast reactor.[20] Although the throughput would be reduced for AFCF (~1 MTHM/yr, rather than ~12 MTHM/yr for a full-scale facility), the concept of an integrated facility for spent fuel receiving, reprocessing, and fresh fuel fabrication is still consistent with the AFCF mission. The original design was modified slightly and used by the Gen IV Proliferation Resistance and Physical Protection (PR&PP) working group to study methodologies for evaluating the safeguards and proliferation resistance of a typical pyroprocessing facility.[21] The current conceptual layout of the pyroprocess and fuel fabrication part of AFCF is shown in Figure-5.[22]

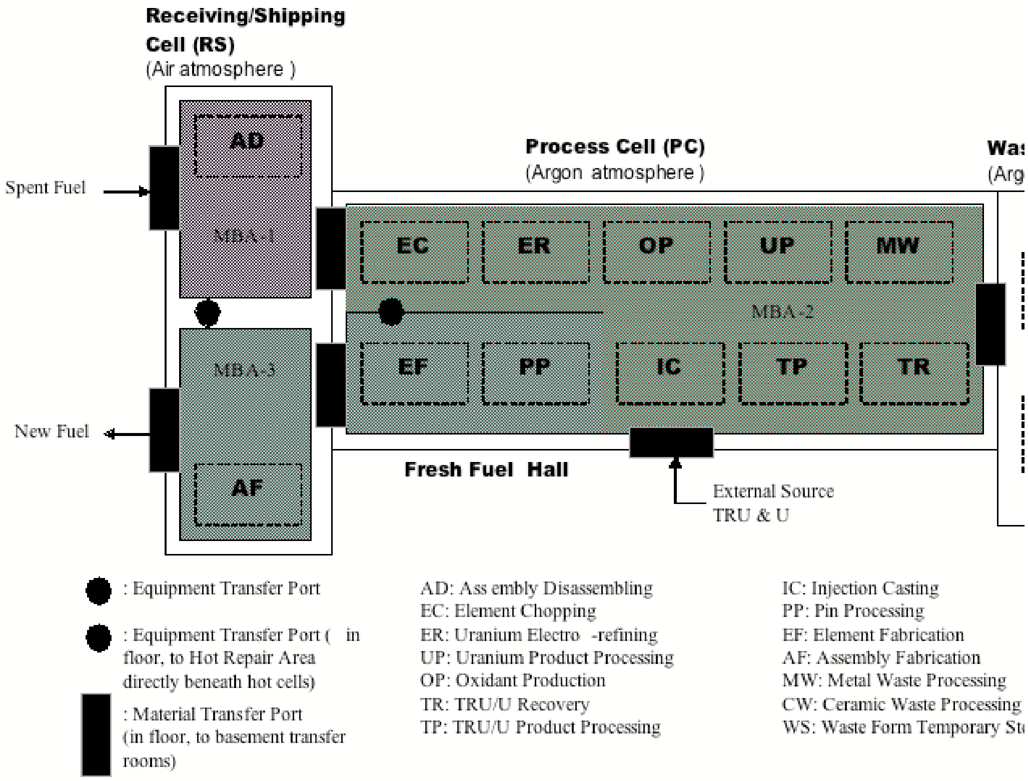


Figure 5: A Conceptual Layout of the AFCF Pyroprocessing Line

Pyroprocessing separates uranium, transuranic (TRU) elements, and fission products, using electrochemical and pyro-metallurgical methods.[23] Pyroprocessing has been studied primarily for reprocessing metallic fuel from fast reactors. In fact, pyroprocessing had been used as early as the mid 1960s at the reprocessing line adjacent to the Experimental Breeder Reactor No. 2 (EBR-II) at Idaho National Laboratory (INL).[24] The process normally has two distinguishing attributes: it operates at high temperature to perform the metallurgical or electrochemical separation, and the plutonium and TRU-bearing materials transferred between the process steps are typically in the form of ingots or solid batches at room temperature. Historically, the process has been deployed in a suite of hot-cells because of the highly radioactive and radiotoxic nuclear materials. The processing steps have been performed batch-wise, using master-slave manipulators. Although the operation of the process is more difficult when done by remote handling, the hot cells add physical protection against material theft and help define a more definitive safeguards envelope.

The typical pyroprocess shown in Figure 4 has five main process steps:

1. Fast-reactor spent fuel assemblies are disassembled and the constituent fuel pins are sheared or mechanically chopped into small pieces that will fit in the electro-refiner (or molten-salt dissolver).

2. The spent fuel pin pieces are charged to the electro-refiner to separate the uranium and actinide elements from the fission products. This step produces a uranium product that contains plutonium and other TRU elements in impure form. This step also generates un-dissolved pieces of fuel cladding (hulls), which will be discharged as waste to hulls drums.
3. The uranium product is further processed to remove residual salt and produce the purified uranium metal product. The TRU-bearing salt from this step is transferred back to the electro-refiner, where a U/TRU product is recovered as a metal. This is further processed to produce the purified U/TRU metal product.
4. The U product, U/TRU metal product, and other fuel make-up materials are recombined in the desired composition and cast to form metal fuel pins.[*] These fuel pins are fabricated and assembled into fuel assemblies and stored.
5. The metallic and salt wastes are converted and conditioned to stable waste forms.

A more detailed description of the pyroprocess is found in the references noted. [25, 26] Even though the description of the process in those references was for a larger pyroprocessing line, the process steps at AFCF are expected to be very similar.

Possible safeguards approaches for the AFCF pyroprocessing line will be described in Section 5.

2.d. Consolidated Fuel Treatment Center – Aqueous Line

The Consolidated Fuel Treatment Center (CFTC) will be a very large scale commercial reprocessing plant. While the concept of the CFTC has evolved from preliminary efforts in the GNEP plan to design an "Engineering Scale Facility" (ESF), it has now evolved, and continues to evolve, as a commercial enterprise rather than as a DOE facility. The primary design requirement is that the plant will reprocess 3,000 MTHM/year, approximately the annual spent fuel discharged from the current base of operating nuclear power stations in the US. By comparison, the THORP facility in the United Kingdom has a capacity of about 800 MTHM/year, the French reprocessing plants at La Hague (UP-2 and 3) each have a capacity of about 700 MTHM/year, and the recently completed Japanese plant (RRP) has a capacity of 800 MTHM/year. Thus, when CFTC is constructed its throughput will be 3-4 times that of existing facilities. This is the most prominent feature of CFTF, along with the fact that the nuclear material flows and efforts to safeguard that material will increase with the size of the plant.

A goal of the Advanced Nuclear Fuel Cycles is to "not produce a stream of purified separated plutonium," which will be achieved by the UREX+ processes since the plutonium stream will be tainted with other actinides. Preliminary designs have been drafted within the DOE laboratory complex with Washington Group International (WGI)

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[*] The fuel fabrication line may also include a ceramic fuel fabrication line and process. However, the metal fuel fabrication line is cited simply to show the completion of the process to final fuel assembly. Safeguarding the fuel fabrication lines will be addressed in a subsequent report.

as the architect/engineer. However, DOE has only issued a call for “expression of interest” (EOI) from the public sector in the last twelve months. Any subsequent actions, such as “request for proposal,” (RFP), would follow. Therefore, only generalities can be noted regarding the conceptual design of CFTC.

1. The throughput of this facility far exceeds that of any previous commercial reprocessing plant. Mechanical processing and dissolution at the front of the facility tend to be limited in possible size and throughput. It is very likely this facility will consist of several parallel solvent extraction lines with multiple shared fuel shears and spent fuel dissolvers.
2. It is not clear if a single solvent extraction line could be scaled up to handle this throughput. There are a number of concerns, not the least of which involves potential nuclear criticality that may limit the throughput through the solvent extraction equipment with the fissile material concentrations envisioned. This imposes another design constraint, which may dictate the design of parallel processing lines.
3. As noted in the discussion on the aqueous process at AFCF, the waste and product forms have not yet been selected.

However, the baseline for the Engineering Alternatives Study (the current stage of the CFTC design effort) does define key features: [27, 28]

1. The process is likely to be the UREX+1a. This will result in separate LEU, TRU (including Pu), and fission product waste streams. (The aqueous separations process will be similar to that to be developed at AFCF. See the aforementioned description of the aqueous line at AFCF for a description of the chemical process).
2. The baseline assumes both wet and dry storage areas for spent fuel awaiting dissolution.
3. Both storage areas feed into the same head-end process.
4. The TRU product will be mixed with some of the LEU product (both in oxide form) to produce the input material for fuel fabrication.
5. Voloxidation will be used to improve dissolution of the spent fuel oxide, reduce un-dissolved solids (fines) and reduce the release of tritium gas.
6. Cladding hulls will be rinsed and then compacted into metal waste forms.
7. Some cladding hulls may be alloyed with technetium to produce a metal waste form.
8. Pu and TRU measurements of wastes will be necessary for accountancy purposes and to sort and characterize waste.
9. A greater level of remote manipulation and hot cell operation will be required than is currently standard for similar facilities.

The lessons learned from applying international safeguards to other large scale reprocessing plants, such as RRP, are relevant. The most important of those lessons is that traditional nuclear material accountancy based on accountancy vessel volume measurement and grab-sample taking and analysis by DA or NDA will not be sufficient to meet the over-arching safeguards objective. Additional safeguards measures, such as "near real-time accounting" (NRTA), "process monitoring", and others will be necessary to meet this challenge, as will be discussed in Section 5.

Current domestic regulations for such a facility do not yet exist. When the NRC safeguards requirements were revised to meet modern requirements in the early 1980s, the US had abandoned plans for reprocessing. The revised requirements applied only to facilities that existed at the time, facilities that were designed for processing highly enriched uranium on a relatively small scale. However, these requirements offer insight into the requirements that will evolve for a reprocessing plant such as the CFTC and they will parallel requirements that have evolved internationally for the RRP in Japan.

As the regulations evolve, they will first be driven by domestic safeguards concerns, an important fact, because it will be the operator's responsibility to support the safeguards system. Oversight ensuring that plans are followed will be provided by a domestic authority, likely the NRC. The operator will have a wide variety of information available from his plant control system, and this would normally be the basis for information potentially provided to the IAEA, if the facility, or parts thereof, are selected for inspection. It then becomes the responsibility of the IAEA to verify the declaration from the operator and, by implication, the state. Declarations and verification activities authorized by the state and operator must recognize export control and proprietary design constraints. So there will be dual challenges: to develop an effective safeguards system, and to negotiate an effective verification methodology.

The proposed safeguards approach for CFTC is presented in more detail in Section 5.

3. The Current International Safeguards Approach for the Reference Facility[*]

The safeguards approach for RRP was developed in the context of an INFCIRC/153-type comprehensive safeguards agreement concluded between Japan and the IAEA. The international safeguards approach applied to RRP is based predominantly on the same safeguards criteria and foundation as the approach applied to the Japan's reprocessing plant at Tokaimura (TRP).[29] This should be remembered when the application of international safeguards may be in a weapons state under a Voluntary Offer-type safeguards agreement with the IAEA, such as the United States. Nonetheless, the reprocessing processes being considered for new fuel cycle facilities in the United States could ultimately be shared with Japan, and conceivably with other nations, where the application of international safeguards per comprehensive safeguards agreements would be required.

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[*] For a detailed comparison of the proposed safeguards measures with the current safeguards criteria and between facilities see Appendix-A, "A Comparison of Known and Proposed Safeguards Measures for Selected Reprocessing Facilities."

The safeguards objective for RRP is the timely detection of the diversion of 1 significant quantity (SQ) of nuclear material.[30] The over-arching safeguards objective then is the detection of the diversion of 8 kg of plutonium within one month of diversion. Safeguards also apply to uranium, but to a lesser extent. Additionally, "flow-sheet verification" is used to confirm that neptunium is not separated.

The safeguards approach for RRP is based on the traditional approach applied to all reprocessing plants in accordance with the IAEA safeguards agreement, which includes:[31]

- Defined Material Balance Areas (MBA) for nuclear material accounting
- Defined Key Measurement Points (KMPs) for measuring the flow and inventory of nuclear material
- Defined Strategic Points for containment and surveillance (C/S) and other verification measures
- Nuclear Material Accountancy, supported by review of operating records and state reports
- Annual Physical Inventory Verification (PIV) – typically a "shutdown cleanout" inventory taking
- Verification of domestic and international transfers of nuclear material
- Statistical evaluation of the nuclear material balance to determine "Material Unaccounted for" (MUF)
- Routine, (monthly) interim inventory verifications (IIVs) for the timely detection of possible diversion of nuclear material
- Verification of facility design information
- Verification of the operator's measurement system

However, it was realized that traditional safeguards measures alone would not meet the safeguards objective at RRP, so a "strengthened safeguards" approach was implemented with the following additional measures:[32]

- Additional continuity of knowledge (CofK) over the plutonium-bearing material, using the Solution Monitoring System (SMS) and the Plutonium Inventory Measuring System (PIMS),
- Short Interval Verification, taking samples every ten days to provide additional assurance for the monthly interim inventory verification (IIV), and
- Frequent evaluation of the nuclear material balance, using near real-time accounting (NRTA).

The successful implementation of safeguards at RRP also necessitated the following:

- A very large automated Solution Monitoring System (SMS) to monitor the volume and nuclear material solution transfers from 92 vessels, verifying nuclear material inventory, inventory change, or other transfers,
- A very large automated and authenticated system throughout the plant for collecting samples for DA and NDA,[33]

- An On-Site radiochemical Laboratory (OSL), jointly operated by inspector-analysts from the IAEA and the Japanese Nuclear Material Control Center (NMCC), which analyzes samples for plutonium and uranium content by destructive and non-destructive assay (DA and NDA),
- An extensive computerized inspector data collection and analysis system (I3S) that collects data from over 50 measurement and monitoring systems and approximately 70 surveillance camera systems, producing about 2 GB of data per day,[34]
- Early and detailed declaration of Facility Design Information (DI) by the national authorities (JSGO),
- Extensive verification of the design information (DIV) by the IAEA, over a 10 year period from ground-breaking in 1996 through vessel calibration and hot-startup in 2006,
- Very close communication between the IAEA, the facility operator (JNFL), the national nuclear inspectorate (JSGO), and the technical support organization (NMCC),
- An elaborate neutron detector network (PIMS system) in the MOX Co-denitration Process Area to provide real-time inventory of Pu-bearing materials and process glove box "hold-up,"[35]
- An extensive array of Cm-244 based non-destructive assay systems to monitor all major high, medium and low-level waste streams.

Despite the significant achievement of the strengthened safeguards approach, the following issues and problems occurred, which should be considered as lessons to be learned for safeguarding future reprocessing facilities:[36]

1. There are a very large number of safeguards samples and it is still difficult to obtain sample results in a timely manner – even with the On-Site Laboratory.
2. The solution monitoring systems (SMS) does function, but the automated data analysis feature was not fully implemented. This means that the inspector must still evaluate and process a great deal of safeguards data manually.
3. The Integrated Spent Fuel Verification System (ISVS) does not work optimally to verify the spent fuel by NDA.
4. Because the RRP project was such a large and complex project taking place over ten years, it has been very difficult to maintain and keep organized all of the facility design information that will be relevant for performing future DIV activities.
5. The use of curium-based NDA systems to monitor the waste packages and streams at RRP are based on the assumption that the ratio of plutonium to curium is relatively constant from the head-end to the tail-end of the process. This assumption is open to question.
6. The IAEA Safeguards Department revised its policy on the joint-use of safeguards equipment.[37] One key point in this new policy is that all data used to verify the operator's declarations will not be shared with the operator or the State until the declaration has been received by the IAEA. This means that in some cases the operator cannot use their own instruments in a timely manner.

7. Authentication of equipment supplied by the operator or the State proved to be expensive and required compromises in the level of authentication attained. This also refers to the costly retroactive installation of tamper-indicating conduit.
8. The use of a data collection system that included components supplied and maintained by both parties required a new data acquisition, authentication, and encryption architecture to be developed by the IAEA. While this architecture appears to be effective, the design of the shared data collection system severely impacts the IAEA's ability to interact with the monitoring equipment over the network. Many operations that could have been done remotely require a visit to the equipment.
9. The safeguards approach at RRP requires a "continuous inspection" regime, with inspectors on site at all times. This resulted in increased inspection costs for the IAEA.

Despite these deficiencies, it should be recognized that the application of international safeguards at RRP is in the "learning" phase, and that many of the safeguards systems are prototypes. It is expected that these systems and the safeguards verification activities will be improved over time, as they had been at the Tokai Reprocessing Plant, which has operated in Japan since 1978. Nonetheless, mention is made of these issues so that the relevant "lessons learned" can be applied to the safeguards approaches that are being considered and presented in this report for new reprocessing processes.

4. Safeguards Approach Options – Aqueous Lines [*]

Safeguards approach options, particularly as applied to the new aqueous reprocessing processes, are dictated largely by throughput. In the case of the low-throughput aqueous separations line at AFCF, the safeguards objectives can probably be met by conventional nuclear material accountancy and established safeguards measures. Even with the evolving facility design and anticipated variations in waste and product materials, safeguards measures currently available will likely meet the challenges. However, ACFC is also intended to be a test bed to develop safeguards measures suitable for CFTC. So, the measures employed to safeguard the aqueous line at AFCF may be more complex than would normally be required.

However, the large throughput and ill defined product and waste forms at CFTC present significant challenges. CFTC will have to rely on innovative additional measures to meet domestic and international safeguards requirements. Further, international safeguards goals include both quantity and timeliness goals. In developing safeguards for reprocessing in Japan, Belgium and Germany, the IAEA adopted the application of "near real-time accountancy" (NRTA), evaluated on a 30-day basis during plant operation. This measure allowed the one month timeliness goal for plutonium to be met. But when it came to develop the approach for the RRP, it did not appear that the quantity goal could

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[*] For a comparison of the detailed safeguards measures discussed relative to the reference facility (RRP), please see Appendix-A.

be detected in the 30-day window. As a result, the safeguards approach for RRP was modified to apply NRTA every seven to ten days, augmented with automated solution monitoring and other measures, to reduce the uncertainty in the nuclear “material unaccounted for” (MUF).

Another point to remember when comparing the aqueous reprocessing lines at AFCF and CFTC is that the AFCF will be a completely remotely maintained and flexible experimental facility. CFTC by contrast will be a fixed-design, high throughput commercial facility. So, the safeguards approach for the AFCF will need to consider maintenance and redesign capabilities that may not be a significant concern for the CFTC. How this will evolve for AFCF is still not clear - specifically, whether additional surveillance, measurement requirements, or administrative controls will be required. When it comes to developing and demonstrating techniques for larger facilities within the AFCF, the ability to “scale-up” will also need to be considered. Instrument performance and measurement capabilities are totally different in a small facility compared to a very large one.

5. Safeguards Approach Options - Pyroprocessing Lines

There are no pyro-processing facilities other than laboratories currently under international safeguards. However, the U.S. AEC and later DOE, the Japan Nuclear Fuel Cycle Institute (JNC), Toshiba, and the Korean Atomic Energy Research Institute (KAERI) have looked at pyro-metallurgical and pyro-electrochemical processes to condition or reprocess spent fuel. These concepts and the associated safeguards and proliferation analyses are documented in detail in the references noted. [38 39, 40, 41, 42]

5.a Elements of a Safeguards Approach for Pyroprocessing

Fundamentally, the safeguards approach applied to a small pyroprocessing facility will meet the safeguards objectives of an approach applied to a small aqueous reprocessing facility. The details regarding prospective safeguards measures are shown in Appendix A for the pyroprocessing line at AFCF. As in an aqueous reprocessing plant, the nuclear material in the spent fuel will be verified to the extent possible and the fuel will be stored in a spent fuel pond until it has cooled to allow the decay of gaseous fission products within the fuel. The fuel to be reprocessed by the pyro-line may be either metallic or oxide. The safeguards essentially follow the plutonium, although accounting of the uranium must also be done but to a lesser extent. Also, there will likely be a higher fraction of other actinides in the fast reactor fuel, so accounting for neptunium, americium and curium may be relevant.

Safeguards will focus on the spent fuel input, the plutonium and TRU-bearing materials in the process, and the plutonium and TRU-bearing output streams. There are some important aspects related to safeguarding this prospective process:

- There is not a lot of international experience with the pyroprocessing processes beyond laboratory or pilot-scale – that is part of the mission for AFCF.

- High temperature salt and metal solutions are highly corrosive; such an environment will be a very challenging for safeguards equipment and instruments.
- The small throughput of the AFCF pyroprocessing line (1 MTHM/yr) should allow the safeguards approach to be optimized as the pyroprocessing technology is developed.
- Assay of the nuclear materials in metal or salt solutions by DA or NDA will be very challenging, partly because there is not the same level of experience analyzing these materials as with the solutions from a PUREX-type reprocessing plant.

There are basically four prospective safeguards approaches for a pyroprocessing facility:[43]

Option 1: Neutron balance – Cm accounting, involves a total neutron measurement on each pin entering the system, on the electro-refiner (molten-salt dissolver), on the waste streams and U product, and neutron/video monitoring of the material transfer pathways. NDA or DA is conducted on the U/TRU product to determine Pu/Cm ratio, and process monitoring is used on the electro-refiner.[44] This concept maintains CofK for the Pu/Cm mixture, but does not measure plutonium directly, except perhaps retroactively from the U/TRU measurement at the end. In essence, the bulk of the neutrons measured are attributed to Cm-244, which can be measured by NDA. If the ratio of Pu to Cm-244 is assumed to be fixed, then one can deduce the amount of plutonium present. This method assumes that the Cm is never separated from the Pu, and that the U/TRU material is homogeneous. One drawback of this option is that the approximately 30 kg hold-up of plutonium in the process would not be directly verifiable. However, if the neutron balance is applied between the shear and product line, the holdup becomes a constant that cancels on both sides of the balance as a function of time. Because the holdup is not accessible and can only be inferred, the facility design should minimize it to enhance proliferation resistance and safeguards.

Option 2: Electro-refiner Assay, involves essentially closing the material balance on the electro-refiner each day, and does so through a complex set of assays on the Pu content of all U cathodes removed from the electro-refiner, all metal waste streams, the electro-refiner salt prior to daily removal (must be homogeneous), recharge salt returning to the electro-refiner, and the recovered salts from the metal waste and U product processing units. A weight of the electro-refiner salt removed daily is also needed. The contents of the electro-refiner are assumed to be well mixed and homogeneous. The above information, along with DA sampling of the U/TRU product, allows the plutonium balance to be closed. This approach represents a major batch or multi-batch tracking effort. It relies on elaborate analyses that would certainly impact operations and cause delays between processing steps. It also assumes a constant Pu/Cm ratio, which could require process monitoring to confirm that this is the case.

Option 3: Homogenized Input, involves adding a homogenization step (e.g., oxidation/reduction and melting) after the element chopping step to produce a homogeneous molten salt solution for DA sample taking, to obtain Pu composition and

Pu/Cm ratio for Pu accountability and downstream analysis steps. A Pu/Cm ratio (using total neutron data) can then be used until DA on the U/TRU product (assuming homogeneity) for Pu content can be obtained. Process monitoring could be used to ensure that the Pu/Cm ratio remains constant and integrated video & neutron monitoring would be used to monitor nuclear material entry and removal paths. This option is the most disruptive and would require that the current conceptual design of the pyroprocess at AFCF be modified. But it would provide for the most accurate nuclear material accountancy for plutonium and the other actinides.

Option 4: Assay of Pu in Spent Fuel via Pu/Cm ratio and DA, involves detailed total neutron axial profile measurements of each pin entering the process stream, and DA on a select number of rod pieces to determine the Pu/Cm ratio on a pin by pin basis. Total neutron measurements can then be used on the electro-refiner and waste streams. NDA or DA of U/TRU product would be used to confirm the Pu/Cm ratio and provide Pu assay for transfer to the next MBA. This ratio would also be used with electro-refiner neutron data to obtain the Pu inventory in the electro-refiner. Again, process monitoring and integrated video & neutron monitoring of material paths would be required. This is a modification of Option 1 to determine the plutonium content through detailed neutron profile assay and DA sampling of incoming pins. This technique would be the most straightforward option if there is a good measurement system for obtaining Pu content in the spent fuel. Without such a capability, the initial Pu assay must rely to some extent on calculations of the distribution of the Pu/Cm ratio within the pin. This could raise a question regarding validity of the verification. DA sampling of the spent fuel would have to be performed to prove that the assumptions are valid.

Each of the safeguards approach options as noted above has advantages and disadvantages, but in concept it appears feasible to use traditional nuclear material accountancy and other safeguards measures to safeguard at least a small pyroprocessing facility. The determining factor will most likely be whether the DA and NDA analytical techniques and tools can be improved to the level of accuracy required. The AFCF pyroprocessing line can ultimately help determine which of the aforementioned assumptions hold valid. In fact, apart from developing the pyroprocessing technology, the benefits of using the pyroprocessing line at AFCF to test and develop different safeguards measures should not be understated.

5.b. Acquisition Path Analysis Studies

An evaluation of alternate safeguards approaches for the conceptual facility design has been performed, for the options noted above.[45] The fourth option is a variation of the first, while the second option requires extensive and elaborate batch tracking and an analysis scheme that might not be feasible without impacting operations. It was therefore decided to evaluate option #3 and 4, as the most promising, as summarized above.

In evaluating the safeguards and proliferation resistance of these options, a conceptual MBA structure was developed, as follows:[*]

MBA 1: RS – Spent Fuel Receiving Cell
MBA 2: PC - Process Cell
MBA 3: Fresh Fuel Production hall
MBA 4: U/TRU Product Store [Formerly Pu store]
MBA 5: WC – Waste Cell
MBA 6: AF – Fresh Fuel Fabrication and Storage

Note that the fresh fuel production hall, U/TRU (Pu) product store, and fresh fuel storage area are not exclusively part of the AFCF pyroprocessing line, but are part of the TRU-Fuel Fabrication Line that will be studied in a subsequent report. Nonetheless, the safeguards approach must also address the nuclear material transfers between these functionally linked areas and the pyroprocessing line. This study focused on the Process Cell, since that is where the spent fuel is reprocessed. This area presents the greatest safeguards challenge in the pyroprocess.

5.c. Conclusions from the Referenced Study

Ultimately the accuracy of the plutonium input accountancy measurement dictates the ability to detect an 8 kg diversion using traditional nuclear material accountancy or the use of “additional measures” to supplement the safeguards. Near Real-Time Accounting (NRTA) can fill the gaps and detect anomalous activities on a batch-by-batch basis. However, this added effectiveness is achieved at the cost of considerable complexity.

The Pu/Cm method did provide some accountancy data, but relied on homogeneity of the ER, electrolysis TRU separations unit and U/TRU product. The “spoofing” of the neutron count via the addition of a neutron source (such as Cf-252) was identified as potential method for fooling the neutron assay equipment. However, the subsequent presence of Cf-252 in the product would be a “smoking gun.” The possible use of other neutron sources, absorbers, and shielding to conceal the possible diversion of plutonium and other actinides would need to be considered. The timeliest detection systems tended to be integrated video/neutron monitoring and process monitoring (including UCl_3 and Cl_2 monitoring). If these can be analyzed in real time, they provide significant early detection. Both are essential to maintaining confidence in the stability and usefulness of the Pu/Cm ratio that allows total neutron counting to be used in some areas. Process monitoring for directly measuring low UCl_3 concentration in the salt and for low-threshold detection of Cl_2 gas production would detect several diversion scenarios. Extensive DA of salt samples also helps to detect the addition of a neutron emitter (such as Cf-252) to spoof the Pu/Cm ratio. However, homogenization of the electrorefiner and other containers must be assured. In addition, DA is time-consuming and expensive.

In terms of misuse of the facility to produce Pu of sufficient purity to be handled in a glove box, the electrolysis unit creates the greatest challenge for safeguards. The ability

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[*] See Figure-5 for the conceptual layout of the indicated pyroprocessing areas.

to detect Pu in low concentration in a U/TRU ingot will be important. Addition of a non-Cm neutron source to increase the neutron counts is also more difficult to detect here. As an additional safeguards measure, it may be desirable to monitor the salt containers – before and after use.

5.d PR&PP ESFR Safeguards Risk Analysis Study

The PR&PP working group study of proliferation resistance of a preliminary safeguards approach for an example pyroprocessing facility examines a subset (called a "slice") of the example pyro facility and tests a variety of proliferation resistance tools (Structured Logic-Tree method and Markov Model analysis) against the assumed facility.[22] They caution that the study is aimed at examining the tools, rather than a comprehensive analysis of the safeguards approach for the facility; however, it can be instructive to look at the general observations and conclusions from that study.

The study selected "Option 1" (described above) from the example safeguards approach, with a somewhat simplified 3-MBA structure. In addition to the measures described above for "Option 1" (total neutrons Cm tracking, with static Pu/Cm ratio, process monitoring, and integrated video/neutron monitoring), the safeguards approach includes mass tracking, particularly of the inputs to and outputs from the receiving and process cells. Accurate masses are needed for the spent fuel, assembly hardware and waste, full pins, pin hardware from receiving, fresh fuel pens in final assembly area, external TRU and external U input to the process cell, salt and clad sent to metal waste, salt sent to ceramic waste, and reject waste & pin assembly hardware. Destructive analysis (DA) is used extensively. DA is used on the ER content to validate burnup calculations, the Pu content of the salt/clad sent to waste, and the homogeneity of the salt. DA of the pins is used to verify the Cm/Pu ratio. DA of the spent salt fro TRU extraction is used to validate the Pu content of the salt sent to ceramic waste processing, and the homogeneity of the salt.

The proposed safeguards approach for MBA-1 (receiving of spent fuel) is to verify the operator's declaration by item counting, NDA verification (gross attribute) of a random sample of elements using a safeguards neutron monitor, and mass tracking. Irradiated fuel assemblies are verified prior to transfer into MBA-1, and continuity of knowledge is maintained through seals, surveillance, and inspection activities. The operator declaration will be based on modeling of the SF taking into account burnup. This can be verified by validating the burnup calculation through the DA samples, and then comparing the declared Pu content with the Pu content obtained from neutron measurement of the Cm content combined with the validated modeling of the Cm/Pu ratio. Unfortunately, this extensive modeling may be difficult to perform if the SF comes from less-well characterized reactors, and would need to be independently validated by the IAEA for use in Agency safeguards (the IAEA does not currently accept reactor modeling as a valid independent input accountability tool).

The inspection regime will be complemented by optical surveillance and neutron monitoring (total neutrons) applied to all ports that provide access to the AD side of the

RS cell. This includes the loading port(s), the transfer port(s) to the PC, and the equipment hatch to the shielded repair area. The neutron monitor on the transfer port to the PC may be the same instrument used to measure the total neutron rate from each element. The neutron monitor on the RS loading port is qualitative, being used to detect the transfer of nuclear material but not provide a non-destructive assay.

The proposed safeguards approach for MBA-2 (bulk processing areas) would be much as described earlier, including use of integrated vide/neutron monitoring, seals on less-frequently used hatches, total neutron monitoring (for Cm), process monitoring checked by DA to improve confidence in lack of Pu/Cm partitioning, and burnup calculations with DA validation to obtain input assay Pu values (perhaps only good to 10%). In addition, administrative controls over the hot cell crane(s) (required for lifting heavy objects) and weighing of objects at critical process points, provides some additional measures of safeguards confidence.

In all safeguards approaches extensive use of validated process monitoring is required to verify that the facility operates as declared and to provide confidence in the stability of the Pu/Cm ratio. Where possible, authenticated signals from the operator's process monitoring equipment is used, but where required, independent IAEA monitoring equipment may be installed. Such monitoring includes cell voltage, current and species concentration, as well as salt level & density in the ER and detection of Cl_2 gas. Process monitoring could include monitoring electrochemical cell voltage, current, ion concentration, as well as salt level and density in the Electro-refiner. In particular, the cell voltage in the electro-refiner provides an indication of the quality of the product being collected at the cathode. Under normal operation, the cell voltage should remain within a specified range, below an upper limit. Exceeding this limit can signal the production of a cathode deposit with a TRU/U ratio higher than design specifications. Besides being routinely monitored for process control, the cell voltage data can be used for safeguards objectives using a dual-use sensor. If using a dual-use voltage sensor for both safeguards and process control is unacceptable in terms of safeguards requirements, an additional, separate voltage sensor will need to be instrumented. The cell voltage can be computed by measuring the voltage difference between two probes connected to the anode and cathode electrodes, respectively. This is a proven, robust technique to monitor cell voltage that is used routinely during electro-refiner operation.

The cell current in the electro-refiner provides an indication of the rate that material is being electro-transported to the cathode. Sensing a nonzero value for the current between the anode and the cathode, along with an adequate value for cell voltage, signals that the electro-refiner is being operated and that a cathode deposit is being produced. However, monitoring cell current alone does not directly quantify the total mass of material collected during a given electro-refiner run. To this end, the cell current is integrated with respect to time to compute the ampere-hours passed during each electro-refiner run. This ampere-hours value is proportional to the amount of material (primarily uranium) electro-transported across the electrolytic cell and deposited at the respective cathode during the given electro-refiner run. In steady state operation and assuming fixed anode mass loading, the ampere-hours value of any electro-refiner run should be within a narrow range, indicating constant mass loading per cathode produced. The case of a low ampere-hour value associated with an electro-refiner run may signal an incomplete processing of a given spent fuel batch, which could imply subsequent unauthorized material diversion or processing scenarios. These integrated cell currents can also be used as a consistency check against material inventories that may be computed from measurements taken at subsequent process steps. Besides being routinely collected for process control, the cell current can also be monitored for safeguards objectives using a dual-use sensor. The control of this current is performed by the electro-refiner's power supply, which maintains it near a specified set point, regardless of process variations that may occur in the electrochemical cell. This technique for measuring and controlling the cell current is a proven, robust approach that is used routinely during electro-refiner operation. Its applicability for safeguards purposes should be explored.

The actual concentrations of important species (particularly U and Pu) in the electrolytic salt also provide an indication on the quality of the cathode material that may be produced not only by electro-refining but also by electrolysis (if this salt is transferred out for further processing). In general, these concentration measurements provide the salt chemistry information of potential utility for safeguards. Under normal operation, the Pu/U ratio should remain within a specified range, below an upper limit. Exceeding this limit can signal the production of a cathode deposit with a TRU/U ratio higher than declared. Similarly, production of unauthorized material with a high TRU/U ratio can be facilitated if a salt material with high TRU/U ratio is used.

To determine concentrations of these ionic species online (i.e., U and Pu) in the eutectic salt, a technique based on voltammetry is being investigated. Voltammetric methods have long been used as a qualitative and quantitative means to analyze constituents in electrolytic solutions. Based on reduction-oxidation chemistry and half-cell potentials, ionic species can be detected by scanning a voltage range bounding the half-cell potential of the species of interest and recording the current output. The species concentration, which is proportional to the intensity of this current output, can thus be estimated. This approach has not been tested yet in a commercial-scale electro-refiner, but is in the early stage of development.

Two additional process variables can be monitored for safeguards purposes, i.e., salt level and density. Given these two measurements and information on salt chemistry (from DA analysis or using the above online method for detecting and quantifying U and Pu concentrations), a total inventory of these species can be estimated for the electro-refiner. These values can then be used to compute, confirm, or calibrate U and Pu inventories derived from other methods. While no technical difficulty is anticipated in instrumenting these measurement capabilities, no online estimation of actual salt level or density is currently available for either safeguards or process control. The problems identified earlier with possible density gradients in the salt also apply here.

Cell voltage current will be monitored in the TRU Extraction. Species concentration salt density will be determined from relevant measurements in the ER.

6. Safeguards Approach Challenges

6.a Challenges Posed by Aqueous Reprocessing

The throughput of AFCF (25 MTHM) is an order of magnitude smaller than the Japanese facilities that have been effectively safeguarded in the past. Even with the non-conventional forms of TRU product and possible waste forms, application of traditional measurements safeguards measures should be sufficient to meet the international safeguards objective. The relatively small quantities of material in process equipment at the time of the interim inventory verification (IIV) should allow application of traditional safeguards measures. However, assay of the TRU product material in the oxide form and waste materials could be challenging – especially if the plutonium and uranium are mixed with other actinides, or if the waste forms are not well characterized.

The CFTC, on the other hand, presents a significant challenge, because of the very large throughput (3,000 MTHM per year) – nearly four times that of a large scale reprocessing plant. As with the AFCF, there is a need for development in the area of "verification" measurements for the TRU-oxide product. The sheer size of the throughput at CFTC means traditional nuclear material accountancy with NRTA would not be able to achieve the detection sensitivity to meet the international safeguard objective. For the CFTC, the challenge is to develop additional measures beyond those developed for the Rokkasho Reprocessing Plant. Improvements in measurement of the In-Process Inventory for the IIV will be important. However, innovative approaches in the area of process monitoring and other safeguards measures will also be required. As the safeguards approach for RRP evolved, containment and surveillance (C/S) measures were increasingly applied. However, the extensive use of surveillance also requires an attendant development in efficient data collection and automated review systems.

Another challenge is the use of the facility operator's instruments to supplement the information derived from dedicated safeguards instruments, such as has been proposed with Process Monitoring, especially the potential monitoring of cold chemical streams. Despite the apparent and obvious benefits of such a proposal, the IAEA has developed a very strict policy regarding the joint-use of equipment for safeguards purposes.[46] This policy has imposed burdens on the facility operator as a consequence. Since the trend appears to be greater use of facility-wide data for safeguards purposes, NNSA should consider an early dialogue with the IAEA to seek a more flexible interpretation of this policy. In the past, the IAEA has insisted on the ability to derive independent safeguards conclusions. In the context of using the operator's instruments to supplement safeguards knowledge, it may be that the higher level of independence and authentication is reserved for primary safeguards instruments. It could be argued that other, supplemental (operator's) instruments would not need this same level of independence and authentication, and therefore the burdens that might be imposed on the facility designer and operator would be less.

6.b Challenges Posed by Pyroprocessing

From the discussion in Section-5, the following are the main challenges in safeguarding a pyro-reprocessing facility:

- The design of such facilities and the characteristics of major process components are not well defined at this stage. So, the safeguards approach is only conceptual at this stage.
- Characteristic metallic process solutions and processed materials are not available for assay at this time. Until DA and NDA measurements can be made on materials of similar composition, volume, and configuration, the accuracy of such assay techniques cannot be determined.
- The most vulnerable element in the pyroprocessing process, from the standpoint of diversion, is the TRU electro-refiner.
- Extensive integrated video surveillance/neutron monitoring may be required. This will generate huge data streams that must be analyzed efficiently by an automated review system.
- Extensive process monitoring may be required, and such monitoring will need to be verifiable and authenticated.
- Accurate methods for assaying the Pu content of spent fuel and TRU mixtures would greatly improve the ability of nuclear material accountancy and potentially NRTA to detect diversions. Timeliness and cost considerations, as well as the uncertainty in homogeneity of critical materials, favor the development of more accurate NDA measurement methods, if the error of these methods can be reduced from 5-10% to less than 1.0 %.
- Extensive DA analysis may be required to verify the stability of the Pu/Cm ratio and homogeneity of various materials. Safeguards can be substantially improved if the speed of such analysis can be increased, and cost decreased.
- The distinct “combined batch” nature of the electro-refiner will lead to accountancy problems. As the uranium from each batch is separated out, the TRU content will build up in the electro-refiner until the concentration is high enough to allow the TRU-product to be removed. This makes it impossible to assign specific TRU amounts to original receipts and input batches of spent nuclear fuel, except by using average or nominal values.

6.c. Challenges Posed by Spent Fuel Verification

While the above discussions focused on the verification of the nuclear materials in the process stream, there remains the need to verify spent fuel at the front end of the process. Under the current safeguards criteria, there is a need to randomly verify spent fuel receipts at the reprocessing plant. In the past this was done with the qualitative Improved Cerenkov Viewing Device (ICVD) to confirm that the selected spent fuel assembly had the gross radiation attribute of spent fuel.[47] However, this method does not permit the detection of partial defects in the assembly, i.e. removed or missing fuel pins, approximately +/- 5% total Pu or better. This level of verification is required to ensure adequate verification of the spent fuel receipts, as well as to provide an effective basis for comparing the Shipper/Receiver difference. The challenges in performing this verification will be discussed in the next section, but there is a definite need to verify the spent LWR fuel receipts to detect partial defects. This same need exists for verifying the receipts of metallic fast reactor fuel, but since the amount of spent LWR fuel so far exceeds the latter, the primary concern is verifying the receipts of spent LWR fuel.

7. Safeguards Technology Needs and Gaps

The following summarizes the most apparent technology gaps and identifies needs for safeguarding the processes discussed:

- Develop a method to accurately measure the plutonium (Pu) and actinide content in spent LWR fuel and metallic fast-reactor fuel for the random verification of the spent fuel receipts. It is expected that this method should be capable of detecting "partial-defects" in accordance with current IAEA criteria, i.e. approximately. +/- 5% total Pu. It may be possible to accurately measure spent fuel directly by NDA. Improved neutron detectors that can function in intense gamma backgrounds, active interrogation facilitated by compact and reliable accelerators, tomography techniques, and rapidly growing compact computing capabilities may allow previously impractical techniques to become feasible. A recent study identified seven techniques that merit further investigation to determine how well they can quantify the fissile content in spent fuel and mixed actinide compositions: (1) delayed neutron counting (with various interrogating sources, including min-accelerators), (2) differential die-away, (3) lead slowing-down-time spectroscopy, (4) neutron resonance absorption, (5) passive multiplicity counting, (6) passive neutron albedo reactivity (PNAR), and (7) x-ray fluorescence.[48]

- Develop on-line assay techniques to measure the plutonium, uranium and actinide content of aqueous process solutions to a level of +/- 1%, or better. Absence of these techniques makes it impossible to remotely monitor reprocessing plants, since the concentration of the nuclear material in the main process streams and inventory vessels is of fundamental safeguards importance.

- Develop a more effective automated and integrated data collect and review system for analyzing process and on-line assay data and surveillance imagery to support verification of the nuclear material transfers, inventory, and operational status of the facility. An advanced automated inspector review and data integration system is needed to review the huge amounts of surveillance and NDA data that could be made available to the inspectors. The camera data from RRP is already overwhelming the capability of inspectors to review it in an accurate, timely, and comprehensive way. However, in facilities such as the pyroprocessing line at AFCF, integrated video and neutron monitoring systems could be used to monitor access hatches and removal routes thereby strengthening the safeguards approach.

- Establish an active dialogue with the IAEA to negotiate a more flexible interpretation of the IAEA Department of Safeguards SGTS Policy #20, concerning the joint use of equipment for safeguards purposes. The current interpretation is very restrictive and limits the ability of the IAEA to use a broad range of existing plant instruments because of the supposed need to derive independent safeguards conclusions from these instruments. It is proposed that this strict interpretation should be applied only to those instruments of primary safeguards importance – and not to the extensive array of plant instruments, which could still provide complementary data of safeguards relevance regarding operation of the facility.

- Process and facility monitoring integrated into the plant design could reap benefits in improved efficiency and by enabling a better and more accurate material accountancy (reduced uncertainty). The improvements in process monitoring can be combined with better and more innovative statistical evaluations. Methods that take advantage of oxidation/reduction properties of various elements throughout the process coupled with strategically placed gamma ray spectrometry have been proposed.[49] The question is whether protracted diversion scenarios that remove material slowly over time will produce a measurable effect and if the gamma count rates will be too high to use available NDA techniques. A safeguards envelope incorporating process and facility modeling of seemingly disparate sensors could be used combined with using anomaly detection algorithms to detect a protracted diversion. Such a system may also be helpful to plant operators to monitor processes and sensors for quality assurance and quality control. Facility monitoring incorporating designed-in containment and surveillance would compliment the process monitoring and provide extra measures beyond accountancy to cover material diversion paths. The use of explicit model-based diagnostic approaches, which take real facility data to model all aspects of a process including nominal operation, calibration, hold-up, known processes, and upsets, would create a complementary tool to analyze the process and facility monitoring data, enabling better detection of diversion scenarios beyond using the basic tool of material accountancy.[50] Novel methods for process flow monitoring are being considered, such as ultra low-field nuclear magnetic resonance, which, if it works, will give DA-type accuracy in an NDA technique. The technique is only just now being considered for safeguards.[51]

- There is uncertainty as to how best to measure bulk Pu content in the mixed-actinide UREX+ product in sealed containers which will be used for shipments to pyroprocessing and fuel fabrication facilities. Because there is no accountability tank in pyroprocessing facilities (analogous to those used in PUREX facilities), we need to develop a novel way to obtain an accurate measurement of the fissile material content in the heterogeneous SF that comes from the fast neutron reactor (reactor power calculations are not sufficiently accurate, and the material may be too heterogeneous to use chemical assay methods). There should also be work done to better characterize LWR spent fuel. Recently, methods are being considered for measurements of mixed actinide product using the Pu/Cm ratios.[52] One method that has the potential to improve temporal neutrons by several orders of magnitude is fast neutron counting with liquid scintillators.

- Accountability of the higher actinides in TRU-fuels, the "alternate nuclear materials" (Np, Am, and Cm) needs to be addressed. This will entail developing NDA in the presence of Pu or U and robust and inexpensive DA techniques for detection of Np, Am, and Cm. This will all be new technology dealing with the challenge of detecting alternate nuclear materials in the various flow streams inherent in the GNEP reprocessing systems. As mentioned above, there are seven techniques that merit further investigation for improving the NDA accuracy of mixed actinide measurements for measurement of spent fuel. Novel passive NDA methods, such as the micro-calorimeter and superconducting ultra-high resolution gamma ray spectrometer offer interesting alternatives for low energy gamma ray spectrometry.[53, 54, 55] In addition, the same report identified five techniques to improve the speed and reduce costs for DA. One suggestion is an on-line Hybrid K-Edge Densitometer to determine the uranium, plutonium, and actinide content of principle process solutions. One research issue for this technique is that high energy gamma rays can ionize high Z materials, creating characteristic fluorescence. This can complicate detailed analysis of the x-ray region in materials (enhance or degrade the signal). Standard gamma-ray methods will benefit from improvements in electromechanically cooled germanium detectors and Compton suppression. In the novel category, new materials science and device fabrication is underway to create new materials with good resolution at room temperature. New scintillators and semiconductor detectors for gamma and neutron counting are being developed by the national laboratories, universities and industry by the National Scintillator Consortium and the Virtual Center for Semiconductors.

- Enhanced tools for performing Design Information Verification will be necessary throughout the lifecycle of the facilities. The 3-Dimensional Laser Range Finder Detector (3DLRF) was developed by JRC/Ispra and used extensively at RRP to verify the construction and installation of the main process cells, vessels, and piping of safeguards significance. However, these tools may need other features such as gamma detection to permit the inspectors to verify the configuration of cells and vessels that will no longer be accessible due to high radiation.[56]

- Equipment that will be offered to the IAEA for safeguards use needs to meet the IAEA’s authentication requirements. These requirements have become more stringent in the recent past; so many equipment designers are not familiar with designing to these new standards. Also, future safeguards equipment should be designed to be more easily inspected for authentication purposes. The IAEA’s equipment authentication procedures sometimes result in the expensive replacement of equipment.

- The ability to remotely ascertain the state of health (SoH) of safeguards equipment and to perform remote maintenance on the equipment could greatly reduce the cost of operating the equipment while enhancing its reliability. Unfortunately, doing this without compromising the security of the equipment is extremely difficult and requires additional development.

8. Novel Safeguards Approaches – Possibilities

In principle, the 25 MTHM/yr capacity of the aqueous reprocessing line at AFCF does not appear to present a challenge for the application of an international safeguards approach. The greater safeguards challenge may be coping with the flexible nature of the facility, and the idea of potentially applying international safeguards and/or methods in a sophisticated reprocessing pilot-scale facility in a nuclear weapons state, like the United States. On top of this will be the challenge of perhaps performing design information verification and other inspection activities over the construction and operating life of the facility in a situation where the facility may be made available on the Eligible Facility List (EFL), and selected for verification one year, but perhaps not the following years. The IAEA could also perhaps select only one MBA for inspection, such as the spent fuel pond or the aqueous or pyroprocessing line, to test new procedures, methods, and equipment. The reader should bear in mind that the spent fuel ponds and plutonium product storage vaults at the British Thermal Oxide Reprocessing Plant (THORP) and the their counterparts at the French UP-3 Reprocessing Plant are safeguarded by the IAEA – in two nuclear weapons states. So, such a precedent does exist. The fact remains that it should be straight forward to apply an international safeguards approach to a small aqueous reprocessing line such as at AFCF.

On the other hand, the application of international safeguards to a 3,000 MTHM/yr aqueous reprocessing plant, such as the conceptual CFTC, seems like an incredible challenge. This is especially so, in light of the international safeguards experience at the 210 MTHM/yr plant at Tokaimura and the recently commissioned 800 MTHM/yr plant at Rokkashomura, Japan. Such a facility is moving outside of the bounds of traditional safeguards. This challenge cannot be understated. However, for such a facility it would be appropriate to think of very novel safeguards measures and methods, such as the following:

Process Monitoring

Process monitoring originated back in the early 1980’s. As a topic, it has become a part of the mix of proposed safeguards measures, but it has not generally been pursued to the extent often discussed. In current applications, process monitoring (often referred to as solution monitoring) has been limited to the evaluation of inter-tank transfers and to provide “additional assurances” that declared nuclear material is not being diverted and that the facility is not being misused. Process monitoring as discussed in the 70’ and 80’s made it into the NRC regulations for facilities handling “materials of high strategic value”. Process monitoring in this application was intended to include a variety of options to look at parts of the process and evaluate those “unit processes” for very small losses of nuclear material in a timely manner. It was envisioned that such evaluations based on “process monitoring” would evolve beyond traditional material balance evaluations to include monitoring and evaluating the variations in process operating conditions and parameters and/or performing mass balance evaluations on other related streams or even non-nuclear (cold) chemicals. The international safeguards community, especially facility operators and national authorities, have not always accepted the proposed methodology, because the technique is more intrusive and allows the inspecting authorities to peer more closely at the actual chemical process – which could be proprietary, or which would most likely be sensitive from the standpoint of nuclear proliferation. Nonetheless, it is probably time to reconsider such a holistic safeguards approach, if only to demonstrate the concept at the R&D level.

Enhanced Physical Barrier Containment

The idea in this case is that there are certain situations, such as hot-cells and reprocessing canyons, where the construction of the facility severally restricts the movement of material and personnel access to the material. Currently, the IAEA safeguards criteria does not really consider the physical barrier as affecting the safeguarding of the material. As a consequence, the verification requirements remain the same, if the material contains plutonium, regardless of whether the material is fairly inaccessible in a reprocessing canyon, or directly accessible in a product-handling glove box. However, provided that the physical barrier dramatically reduces access to the nuclear material, the nuclear material verification requirements could be potentially reduced, if one could verify those things that would indicate that the material has not been moved. In the case above, the Solution Monitoring System was the additional measure. It is also possible that the monitoring of transfer pumps, or use of neutron-triggered surveillance to monitor access hatches and ports, could be an additional safeguards measure that might permit the lessening of other more onerous requirements – such as frequent sample taking and material verification. Of course, each case would have to be considered to determine if the measure is actually as, or more effective, but the idea is to define a more "safeguardable" perimeter within which the traditional safeguards criteria could perhaps be relaxed.

Randomized Verification Approach

The IAEA Safeguards Criteria defines the frequency of verification, and required level of detection probability, for the verification of plutonium and uranium, based on the type of nuclear facility, whether the material is "direct use", "non-direct use", irradiated, the type of inventory, or inventory change, etc.[57] However, if the safeguards approach uses highly complementary safeguards measures, and if the facility operator can provide declarations of activities in advance, it is conceivable that the inspectors could randomly select activities, rather than verify all activities. An example might be the random verification of plutonium nitrate transfers from the Output accountancy vessel. We see this as being the safeguards equivalent of applying the principles of "Statistical Process Control", rather than sampling and testing 100% of all items (or transfers) of interest. For this measure to be effective, the state would have to have acceptable "non-proliferation" credentials, the facility operator would have to have a history of being cooperative, the operator would have to be able to declare activities in advance, and the additional measures would have to be capable of recording the activities that were not verified by the inspector. Such a methodology could perhaps be tested on the aqueous line at AFCF, since it is more like a traditional small-scale reprocessing line.

Supplementing Inspection Effort with Regional Inspectorates

To more efficiently use IAEA inspection resources there are cases where the IAEA has taken verification credit for safeguards verification activities performed by multi-national regional inspection agencies, such as Euratom and ABACC.[58] Of course, this has depended on the type of inspection activity, and the IAEA has always insisted on the right to independently verify the activity. Another evolution of this idea could involve multi-national (regional) verification at a site level, for especially sensitive facilities, such as reprocessing and enrichment plants. There is already discussion of "International Fuel Cycle Centers" being subjected to international safeguards.[59] However, what exactly this means and what it would entail is still being discussed. But along the same idea, a regional inspection agency could also inspect the "international" or "regional" fuel cycle facility, provided that they do this in support of the IAEA, and that the IAEA still has the right to perform independent verifications.

In summary, some novel safeguards concepts have been presented that go well beyond traditional safeguards measures and approaches. It is recommended that they be discussed in an international forum, and in the most promising cases, that they be tested at the Advanced Nuclear Fuel Cycle Demonstration Facilities to determine if they do improve the effectiveness and efficiency of safeguards.

9. Conclusions and Recommendations

This study concluded that an effective safeguards approach for the aqueous separations (UREX) line of AFCF could be based on traditional safeguards measures, as have been applied to the Rokkashomura Reprocessing Plant (RRP). It should be easier to safeguard the aqueous line at AFCF than RRP, because of the relatively low throughput of 25 MTHM per year, despite the flexible nature of this experimental facility. However, safeguarding the 3,000 MTHM per year CFTC will be significantly more challenging, since it will have nearly four times the capacity of existing large-scale commercial reprocessing plants. To safeguard a plant of such size, the team recommends that the facility be designed with four reprocessing lines of nearly 800 MTHM per year – more akin to the existing commercial reprocessing plants. This would help the facility meet current international safeguards goals using existing safeguards measures. Safeguarding the 1 MTHM per year pyro-reprocessing line at AFCF is facilitated by the low throughput of the experimental facility. However there is little international experience safeguarding such a process, so the safeguards approach and measures will have to be optimized as the process technology is developed.

To implement effective safeguards approaches for the reprocessing lines at AFCF and CFTC, the team identified the following over-arching needs:

- Develop a method to accurately measure the plutonium (Pu) and actinide content in spent LWR fuel and metallic fast-reactor fuel for the random verification of the spent fuel receipts, and to provide an analytical basis for estimating shipper/receiver differences in a timely manner. It is expected that this method should be capable of detecting “partial-defects” in accordance with current IAEA criteria, i.e. approximately. +/- 5% total Pu.

- Develop on-line assay techniques to measure the plutonium, uranium and actinide content of aqueous process solutions to a level of +/- 1%, or better. Absence of these techniques makes it impossible to remotely monitor reprocessing plants, since the concentration of the nuclear material in the main process streams and inventory vessels is of fundamental safeguards importance.

- Develop a more effective automated and integrated data collect and review system for analyzing process and on-line assay data and surveillance imagery to support verification of the nuclear material transfers, inventory, and operational status of the facility.

- Establish an active dialogue with the IAEA to negotiate a more flexible interpretation of the IAEA Department of Safeguards SGTS Policy #20, concerning the joint use of equipment for safeguards purposes. The current interpretation is very restrictive and limits the ability of the IAEA to use a broad range of existing plant instruments because of the supposed need to derive independent safeguards conclusions from these instruments. It is proposed that this strict interpretation should be applied only to those instruments of primary safeguards importance – and not to the extensive array of plant instruments, which could still provide complementary data of safeguards relevance regarding operation of the facility.

- Make greater use of automated, unattended/remote monitoring systems for collecting safeguards data, while cooperating with the facility owner/operator and national authorities to ensure protection of proprietary information.

- Cooperate with the facility owner/operator and national authorities to try to "design-in" safeguards requirements and equipment in the earliest stages of the conceptual design of the facility.

- Improve the inspection regime by making more effective use of randomized short-notice inspections, applying a "statistical process control" approach to verification of the reprocessing facilities rather than a scheduled systematic verification of all major transfers of plutonium-bearing materials. For this kind of approach to be effective the facility operator would need to declare the major activities involving nuclear material in advance. It would also be more efficient to apply this approach on a site, rather than facility, level.

If these needs are addressed, DOE would be able to present a viable international safeguards approach for the new reprocessing facilities. It would also further the goals of DOE by advancing safeguards technology and "building-in" proliferation resistance into these new reprocessing facilities.

Appendix-A: A Comparison of Known and Proposed Safeguards Measures for Selected Reprocessing Facilities[1]

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]**	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]**	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]**
A) Spent Fuel - Verification of Receipts	*LWR SF*	*LWR SF*	*Fast Reactor SF (metallic)*	*LWR SF*
Annual Capacity --	800 tonnes/yr	25 tonnes/yr	1 tonne /yr	3,000 tonnes/yr
A) Spent Fuel - Verification of Receipts **IAEA SG Criteria[6]:** -100% Item count & -Random-medium verification of gross (SF radiation) attribute[7] [8],&	**Current:** -Item verification, Surveillance, Item count, ID check, direction of fuel movement verification	Item verification, Surveillance, Item count, ID check, direction of fuel movement verification	Item verification, Surveillance, Item count, ID check, direction of fuel movement verification.	Item verification, Surveillance, Item count, ID check, direction of fuel movement verification

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[1] Regarding the Color Code: Green highlights safeguards measures directly relevant to RRP. Yellow highlights measures similar to those at RRP, and Red highlights measures that require additional development, or information that is not well defined.

[2] Process Flow Diagram – "(Safeguards) Inspection Activities of Rokkasho Reprocessing Plant (RRP)", ca. 2002, Japan Nuclear Fuel Ltd. (JNFL).

[3] Advanced Fuel Cycle Facility (AFCF) Block Flow Diagrams (30% Conceptual Design Stage), circa Jan. 2007, Washington Group International.

[4] Ibid 2

[5] CFTC Design Reference: The Statement of Work for the Engineering Alternative Studies, SOW-4008, U.S. DOE GNEP Program, 2006.

[6] IAEA Safeguards Criteria, Vienna, Austria, 2004 Edition

[7] Detection probability as defined in the IAEA SG Criteria – random high is typically 90%, random-medium is 50%, and random-low is 20%.

[8] The spent fuel radiation attribute is currently verified by the Improved Cerenkov Viewing Device (ICVD) and the variants, DCVD and ACVD.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]**	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]**	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]**
-Verification of ID number (UWCC) to confirm identity of randomly selected assembly for verification.[9] -IAEA SG Criteria continues to push for more quantitative verification of SF [10] -Receipt of SF to be monitored under dual containment and surveillance (C/S) (to detect removal of spent fuel and confirmation of removal of empty SF cask from pond).	Inspector performed burn-up code calculations and comparison to operator's declaration of nuclear material content in spent fuel, based on declaration from reactor (shipper) to support a preliminary estimate of the shipper/receiver difference.	**Potential**: Inspector performed burn-up code calculations and comparison to operator's declaration of nuclear material content in spent fuel, based on declaration from reactor (shipper) to support a preliminary estimate of the shipper/receiver difference. Gross defect measurement - verification of assemblies Partial defect[11] measurement - verification of assemblies[12]	**Potential:** Inspector performed burn-up code calculations and comparison to operator's declaration of nuclear material content in spent fuel, based on declaration from reactor (shipper). Preliminary estimate of the shipper/ receiver difference.[13] Verification by NDA (total neutron counting) for gross and partial defects. Weighing of fuel segments and mass and neutron balance used to monitor distribution of nuclear material (Pu, U, and actinides throughout the process.)	**Potential:** -Inspector performed burn-up code calculations and comparison to operator's declaration of nuclear material content in spent fuel, based on declaration from reactor (shipper). Preliminary estimate of the shipper/ receiver difference. Gross defect measurement - verification of assemblies Partial defect measurement - verification of assemblies,
1) Spent Fuel Storage - Inventory Verification:	*LWR SF*	*LWR SF*	*Fast RX SF*	*LWR SF*

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[9] In addition to those activities stated, a burn-up evaluation is performed by the inspectors (based on the reactor SF declaration) to compare with the nuclear material content declared by the shipper.

[10] Equipment considered for this purpose includes the IAEA's IRAT, FDET, SFAT, and SMOPY, etc.

[11] The equipment noted under the note above is being considered for the verification of partial defects, with the target of being able to detect one missing fuel pin, although this technique has not been refined.

[12] Note that the NDA verification of spent fuel is very challenging due to the presence of fission products producing high-gamma radiation, as well as the variable actinide (TRU) composition. The current level of measurement accuracy is estimated at +/- 10 to 20% for Pu and U. This is an area requiring further development.

[13] Burn-up codes for metallic or TRU fuels need to be developed and/or validated, (especially to accurately determine Pu, Cm and Actinide content in general).

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
Spent Fuel Storage	3,000 tonnes	40 tonnes	1 tonne	9,000 tonnes
a) Monthly (IIV) **IAEA SG Criteria –** Successful review of dual C/S to confirm that undeclared SF removal did not occur[14]	Reviewing surveillance media (automated technical review and SG review by automated change-scene detection)	Reviewing surveillance media (automated technical review and SG review by automated change-scene detection) More/better automation in review?[15]	More information needed regarding storage of spent fuel from fast reactor (Dry storage pits, spent fuel pond, etc. However, quantity is relatively small, so Dual C/S measures should be possible.	Reviewing surveillance media (automated technical review and SG review by automated change-scene detection) More/better automation in review?

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[14] The current timeliness for the detection of spent fuel is three months – so a review of surveillance media could in principle be performed quarterly. However, it is currently more convenient and more effective to perform the review monthly integrated with the routine monthly inspection activities.

[15] Digital surveillance systems have been used very effectively to maintain the "Continuity of Knowledge" over the spent fuel in the spent fuel pond and to monitor the transfer of SF to the transfer canals.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
1) Spent Fuel Storage - Inventory Verification: b) Annual (PIV) IAEA SG Criteria – -Successful Review of Dual C/S to confirm that undeclared SF removal did not occur. -Comparison of Operating Records and State Reports over the Material Balance Period for consistency – i.e. confirmation of cumulative receipts of SF and transfers to the Mechanical Transfer Cell. -Determination of cumulative Shipper/Receiver Difference (SRD) for the entire year, based on data from the Input Accountancy Vessel, as correlated to individual fuel batches, and where possible, SF assemblies.	Reviewing surveillance media (automated technical review and SG review by automated change-scene detection). If Surveillance review is not conclusive for Dual C/S then item count, random ID check and verification of SF for radiation attributes.	Surveillance review, item count, random ID check Authentication of operator movement Gross defect measurement - verification of assemblies, (Cerenkov?) Partial defect measurement - verification of ssemblies,	Item verification, Surveillance, Item count, ID check. Successful Review of C/S Potential improvement in review methods to reduce inspector time Random Verification by NDA (total neutron counting) for gross and partial defects.	Surveillance review, item count, random ID check Authentication of operator movement by crane movements, and other control measurements. Gross defect measurement - verification of assemblies, (Cerenkov?) Partial defect measurement - verification of assemblies,
B) Process Flow and Transfer Verification – From Spent Fuel Storage to the Process (Design Flowrate)	800 tonnes/yr – (8 tonnes Pu/yr)	25 tonnes/yr (LWR) (250 kg Pu/yr)	1 tonne /yr Fast RX Fuel (200 kg Pu/yr Max.)	3,000 tonnes/yr (30 tonnes Pu/yr, apx.)

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
B.1) Transfer to the Mechanical Process (Shearing) Cell **IAEA SG Criteria:** - Continuity of Knowledge (CoK) shall be maintained over SF transferred from the SF pond to the Mechanical Process Cell. -The SF shall be item counted, and where possible, verified by ID check.	Verification of transfer into mechanical cell (COK) by surveillance using combinations of gross radiation sensors and cameras (**Note –** At RRP, some of the equipment is the plant operators' & some are dedicated IAEA instruments and cameras. **-Important IAEA SG Policy Issue regarding equipment shared jointly with the Plant Operator or National Inspectorate).**[16]	Verification of transfer into mechanical cell, surveillance (SGs dedicated-OR authenticate operators data?) Individual pin partial defect verification[17]	Successful Review of C/S covering transfers of fuel to mechanical process cell. 100% Verification by NDA (total neutron counting) for gross and partial defects. Weighing of fuel segments and mass and neutron balance used to monitor distribution of nuclear material (Pu, U, and actinides throughout the process.) Integrated optical surveillance and neutron monitoring of all MBA transfer paths and the transfer of chopped pins from the fuel shear to the metal electro-refiner (molten dissolver).[18]	Verification of transfer into mechanical cell, surveillance (SGs dedicated-OR authenticate operators data?) Individual pin partial defect verification

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[16] Note the recently issued, IAEA Safeguards Department Policy (#20) – Regarding the Joint Use of Safeguards Equipment between the IAEA and an External Party, IAEA, Vienna, Austria, April 20, 2006 – this policy notes that each proposal for joint use of safeguards instruments must be approved by the IAEA DDG of Safeguards on a case by case basis – i.e. precedent is not a guarantee that this will be allowed for future cases. It will depend on the facility and the State where the facility would be located.

[17] There is the potential to verify the nuclear material content of the spent fuel by NDA, by measuring single pins. This could be done on a 100% basis, or randomly. (The SG Criteria does not currently require this, but this could be very helpful for establishing the nuclide content of the SF fuel, especially for the Pyro-process.)

[18] The subject instrument to integrate and evaluate the optical surveillance, neutron detector signals, and vessel weight or load-cell data has not yet been developed. It is envisioned to be analogous to a "Solution Monitoring System", but for metallic or electrochemical solutions.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]**	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]**	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]**
			Potential?: Individual pin partial defect verification[19]	
B.2) Transfer to Voloxidation[20] **IAEA SG Criteria** Do not specifically address this process unit, but it is understood that the CoK must be maintained for the fuel that is sheared or voloxidized and transferred to the spent fuel dissolver.	(Not Relevant at RRP)	A voloxidation unit may be used. It might be a batch operation This represents a process step between shearing and dissolution that has not been addressed in international safeguards before	(Not Relevant to Pyro)	A voloxidation unit will likely be used. This could be a continuous process unit. This represents a process step between shearing and dissolution that has not been addressed in international safeguards before.
B.3) SF Dissolution & Input Accountancy **IAEA SG Criteria:** -Each transfer of dissolver solution to the process will be verified by volume or weight measurement, & -Each batch shall be sampled and analyzed for Pu (and randomly for U) content (with	Verification of Input Accountancy Tank, volume and density measurement, Verification of Pu (and U) content by DA sample taking and analysis. Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results.	Input Accountancy Tank, volume and density measurement. Verification of Pu (and U) content by DA sample taking and analysis. On-site laboratory for timely analysis of samples. Can an on-site laboratory be justified based on throughput and will	-100% Verification by NDA (total neutron counting) for gross and partial defects.[27] Weighing of fuel segments and mass and neutron balance used to monitor distribution of nuclear material (Pu, U, and actinides throughout the process.) -Integrated optical surveil-	Input Accountancy Tank, volume and density measurement. Verification of Pu (and U) content by DA sample taking and analysis. Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results.

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[19] There is the potential to verify the nuclear material content of the spent fuel by NDA, by measuring single pins. This could be done on a 100% basis, or randomly. (The SG Criteria does not currently require this, but this could be very helpful for establishing the nuclide content of the SF fuel, especially for the Pyro-process.)

[20] This is a process to oxidize fuel prior to dissolution to improve the dissolution rate. It will probably incorporate a physical separation of powder from hulls

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]**	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]**	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]**
the ability to detect bias defects).[21] [22] -Suitable C/S shall be maintained to detect all such transfers.[23] -(As part of the Material Balance Evaluation): - Batches will be correlated and evaluated at this point to compare with the declared nuclear material content in spent fuel in order to calculate the Shipper/Receiver Difference (SRD),[24] &	Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the Input Accountancy Tank.	it be allowed in the security design for AFCF Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the Input Accountancy Tank. Continuous online Pu measurement[25]	lance and neutron monitoring of all MBA transfer paths and the transfer of chopped pins from the fuel shear to the metal electro-refiner (molten dissolver). -Use of Operator's process monitoring data to supplement safeguards instruments (to confirm operator's declaration of operation).	Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the Input Continuous online Pu measurement.

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[21] Historically dissolver batches have contained more than 1 Significant Quantity of Pu (8kg). Therefore, it was required to verify each dissolver batch by destructive analysis for Pu content (DA).

[22] Where samples are taken for safeguards, adequate C/S measures must be in place to ensure that the sample is collected from the vessel of interest and that this sample is not manipulated prior to treatment or analysis by the IAEA. (Ensuring the integrity of safeguards samples can be addressed using human surveillance, short-term video surveillance, specially designed sample vials with tamper indicators, etc.)

[23] An independent process solution monitoring system (SMS) typically meets this requirement.

[24] Note that the SF dissolver at RRP is a rotary dissolver operating in continuous mode. Not enough operating experience has been gained to demonstrate how easy or effective it will be to determine the SRD for discrete fuel batches, let alone individual assemblies. Consequently, the Operator may be advised to try to process campaigns of like fuel assemblies to more effectively monitor the "batch-smeared" (average) SRD for a group of similar fuel.

[25] Continuous on-line assay is attractive in order to expedite the determination of Pu-content. This would also allow for a timelier estimate of the MUF and MUF-D statistics. However, this technique has not yet been developed to the level of accuracy required (relative to the International Target Value for PUREX Dissolver solution – apx. +/- 0.5%)

[26] The small throughput of the facility might allow meeting of safeguards objectives through randomized verification of inputs rather than requiring 100% verification

[27] Note that the NDA verification of spent fuel is very challenging due to the presence of fission products producing high-gamma radiation, as well as the variable actinide (TRU) composition. The current level of measurement accuracy is estimated at +/- 10 to 20% for Pu and U. This is an area requiring further development.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
-As a input to establish the Material Unaccounted For (MUF) and operator-inspector difference (MUF-D) statistic.		Automated (real-time) evaluation of Solution Monitoring System and comparison with predictive (process) model. Randomized selection and verification of input batch transfers[26].		Automated (real-time) evaluation of Solution Monitoring System and comparison with predictive (process) model.
2) Main Process Area Inventory Verification:				
2.1) Main Process Area Inventory Verification: a) Monthly (IIV): [28]				
Maximum Estimated Inventory at IIV (Pu kg))	500 kg Pu	10-20 kg Pu?	TBD	500 kg Pu/line & multiple lines

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[28] The verification frequency is reduced to quarterly, if the amount Pu-bearing material is less than 8kg.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
IAEA SG Criteria: - Random-medium verification of Pu-bearing solutions, by volume or weight verification and DA sampling to determine Pu-content. - Random sample plan is based on operator's declaration, regarding which process vessels contain measurable quantities of Pu. - The IAEA will use measures to confirm that the operator's declaration of Pu-bearing vessels is consistent. -The Operators records (general ledger) will be compared with State Reports (nuclear material receipts, shipments, etc.) with the ability to detect discrepancies. -The MUF and MUF-D statistic will be calculated to detect if they are within allowed statistical limits.	**Current**: For vessels that may contain significant Pu inventory at the time of "inventory taking": Volume and density measurement, and verification of Pu (and U) content by DA sample taking and analysis. Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistics are within limits.	For vessels that may contain significant Pu inventory at the time of "inventory taking": Volume and density measurement, and verification of Pu (and U) content by DA sample taking and analysis. Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistics are within limits.	Vessels that may contain significant Pu inventory at the time of "inventory taking": volume or weight measurement, and verification of Pu (and U) content by DA sample taking and analysis.[29] NDA techniques have also been proposed for determining the Pu and actinide content of the pyro-process inventory vessels.[30] Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the inventory vessels. Use of Near Real Time Accountancy (NRTA), applied to the entire process	For vessels that may contain significant Pu inventory at the time of "inventory taking": Volume and density measurement, and verification of Pu (and U) content by DA sample taking and analysis. Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistic is within limits.

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[29] See verification frequency note, above.

[30] The current level of accuracy to determine the content of Pu in such solutions by NDA is on the order of +/- 20%. This will need to be enhanced considerably to approach the international target values for the DA of aqueous solutions for Pu (apx. +/- 0.5%).

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
	Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the inventory vessels.	Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the inventory vessels. Greater use of the Operator's instruments used for process control and nuclear safety to supplement safeguards instruments to confirm plant operation is as declared.[31] Dynamic process modeling based on process parameters (temp, press, flow, valve positions, on-line NDA), with unit process and area evaluation methodology. Use of a randomized running inventory evaluation, rather than the traditional monthly work stoppage and inventory taking. Low Throughput may limit the need and/or the ability to do effective improvements to NRTA and the additional measures discussed above	Low Throughput may limit the need and/or the ability to do effective improvements or even to apply NRTA	Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the inventory vessels. Greater use of the Operator's instruments used for process control and nuclear safety to supplement safeguards instruments to confirm plant operation is as declared.[32] Use of on-line monitors to determine the Pu content in key inventory vessels. Dynamic process modeling based on process parameters (temp, press, flow, valve positions, on-line NDA), with unit process and area evaluation methodology. Use of a randomized running inventory evaluation, rather than the traditional monthly work stoppage and inventory taking.[33]

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[31] See note-18, regarding the IAEA Policy regarding Joint-Use Equipment. Although it could be argued that this is not relevant to the use of the Operator's instruments, where this is only to supplement the IAEA's main safeguards instruments (i.e. they would not be used to draw primary safeguards conclusions).

[32] See note-18, regarding the IAEA Policy regarding Joint-Use Equipment. Although it could be argued that this is not relevant to the use of the Operator's instruments, where this is only to supplement the IAEA's main safeguards instruments (i.e. they would not be used to draw primary safeguards conclusions).

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
2b) Main Process Area Inventory Verification: Annual (PIV):				
Maximum Estimated Inventory at PIV (Pu kg))	>5 kg Pu	>>1Kg	TBD	TBD (<5kg)
IAEA SG Criteria: - Random-high verification of Pu-bearing solutions, by volume or weight verification and DA sampling to determine Pu-content. -Random-medium verification of U-bearing solutions and materials by volume or weight verification and DA sampling. - Random sample plan is based on operator's declaration, regarding which process vessels contain measurable quantities of Pu and U. - The IAEA will use measures to confirm that the operator's declaration of Pu and U-	**Current:** The activities as performed at the monthly IIV are similarly performed at the time of the PIV – except the process is carefully and sequentially shut down and cleaned out. Those few vessels containing solution are verified are stratified on the basis of content of detection, and the solutions and process materials are randomly verified. Verification of uranium inventory is also randomly made.[34]	The activities as performed at the monthly IIV are similarly performed at the time of the PIV – except the process is carefully and sequentially shut down and cleaned out. Those few vessels containing solution are verified are stratified on the basis of content of detection, and the solutions and process materials are randomly verified. Monitoring and verification of shutdown and cleanout procedures.[35]	The activities as performed at the monthly IIV are similarly performed at the time of the PIV – except that the vessels containing solution are verified at a higher probability of detection, and the solutions and process materials are randomly verified for uranium content as well.[37] -Depending on the composition of the fuel, DA verification of particular actinides may also be required – Am and Np.	The activities as performed at the monthly IIV are similarly performed at the time of the PIV – except the process is carefully and sequentially shut down and cleaned out. Those few vessels containing solution are verified are stratified on the basis of content of detection, and the solutions and process materials are randomly verified. Verification of uranium

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[33] The running inventory taking is more attractive for a large through-put plant, to minimize work stoppage, but detection limits become more critical for such a facility.
[34] Verification activities are substantially reduced, if the process vessels contain little inventory.
[35] It may be possible to monitor the progress and cleanout status of the process, by using the Operator's process instruments – to supplement safeguards instruments.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]**	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]**	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]**
bearing vessels is consistent, i.e. to confirm that empty vessels are in fact empty, or below measurable limits. -The Operators records (general ledger) are compared with State Reports (nuclear material receipts, shipments, etc.) to detect discrepancies. -The MUF and MUF-D statistic is calculated to detect if they are within allowed statistical limits. - Material Balance Evaluations are performed over the entire Material Balance Period (i.e. typically one year) to check for consistency with the cumulative monthly running material balance.		Randomized, rolling inventory of main process vessels or units for annual PIV.[36]		inventory is also randomly made Monitoring and verification of shutdown and cleanout procedures. Randomized, rolling inventory of main process vessels or units for annual PIV.[38]

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[36] It may be possible to perform annual physical verification of selected vessels and process units in a rolling dynamic mode to minimize work stoppage, before or after the scheduled PIV, provided that CoK over the inventoried vessels or process area is maintained.

[37] To minimize verification activities, it is expected that the process vessels be cleaned out to the greatest extent possible. However, this state of "emptiness" will have to be verified by the IAEA.

[38] It may be possible to perform annual physical verification of selected vessels and process units in a rolling dynamic mode to minimize work stoppage, before or after the scheduled PIV, provided that CoK over the inventoried vessels or process area is maintained.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
C.1) Process Flow and Transfer Verification – From Pu solution Output Accountancy Vessel				
(Nominal Amount of Pu-bearing Material Transferred per year (Kg Pu))	8,000 kg Pu	250 kg Pu Depends on MBA structure if a solution output is produced	TBD (200 kg Pu annually??)	Apx. 30,000 kg Pu annually
IAEA SG Criteria: -Each transfer of Pu-bearing solution to the Output Accountancy Vessel will be verified by volume or weight measurement,[39] & -Each batch shall be sampled and analyzed for Pu content (with the ability to detect bias defects). -Suitable C/S shall be maintained to detect all such transfers.[40] -(As part of the Material Balance Evaluation): An evaluation of cumulative transfers to and from the Output Accountancy vessel shall	**-Current:** Output Accountancy Tank, volume and density measurement, and verification of Pu content by DA sample taking and analysis. -Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. -Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from	Output Accountancy Tank, volume and density measurement, and verification of Pu (and U) content by DA sample taking and analysis. -Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. -Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from	-Output Accountancy Tank (U/TRU Product Processing), volume or weight measurement, and verification of Pu (and U and Actinide) content by DA sample taking and analysis. [41] -Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. -Use of NDA to determine Pu, U, and Actinide Content may also be an option. -Use of On-line Process monitors may also be an option.	Output Accountancy Tank, volume and density measurement, and verification of Pu content by DA sample taking and analysis. -Use of an On-Site Laboratory to facilitate rapid sample analysis and turnaround of results. -Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and

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[39] Historically, output batches have been greater than 8kg Pu. Consequently, it was required that every Output Batch be verified. However, if the size of the Pu batch is below 8Kg, then in principle a random sampling approach could be applied (based on a random-high detection probability).

[40] An independent process solution monitoring system (SMS) typically meets this requirement.

[41] There is a need to ensure that the molten solution contents of the U/TRU/Product Vessel are well mixed to ensure that the DA sample is representative. This is a generic problem with all of the vessels in the Pyro reprocessing line, where DA samples need be taken. This is also an area requiring further development.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line**[3]	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line**[4]	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)**[5]
be performed to establish the Material Unaccounted For (MUF) and operator-inspector difference (MUF-D) statistic.	the Output Accountancy Tank. -Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistics are within limits.	the Output Accountancy Tank. Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistics are within limits.	-Use of a Solution Measurement System and Evaluation Software to analyze each transfer of process solution to and from the U/TRU Product Processing Vessel. -Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistic is within limits. Low Throughput may limit the need and/or the ability to do effective improvements to NRTA	from the Output Accountancy Tank. -Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistics are within limits. Use of NDA to determine Pu, U, and Actinide Content may also be an option. -Use of On-line Process monitors may also be an option. - Use of Near Real Time Accountancy (NRTA), applied to the entire process and neighboring Material Balance Areas (MBAs) to determine that the MUF and MUF-D statistic is within limits.
C.2) Process Flow for Monthly (IIV)Inventory				

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]**	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]**	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]**
Verification – From oxide Conversion to (Product) Storage				
(Nominal Amount of Pu-bearing Material Transferred per year (Kg Pu)	8,000 kg Pu	250 kg Pu	TBD (200 kg Pu annually??)	Apx. 30,000 kg Pu annually
IAEA SG Criteria: -The CoK shall be maintained for Pu-bearing materials being moved (from Output Accountancy) through MOX Conversion to storage. -To count towards the monthly IIV and annual PIV verification, Pu-bearing materials must be verified with a high detection probability for gross, partial, and bias defects. -ID of verified MOX canisters must be checked and confirmed. -Operators Records and State Reports must be compared during monthly IIV. -NRTA and Material Balance Evaluation must be performed on Pu-bearing materials in Conversion, as well as	**Current:** Use of NRTA in MOX Conversion area. -Key vessels in MOX Conversion Area monitored by Solution Monitoring System. -NDA Verification of MOX in gloveboxes and MOX Canister Transfer Cart.[42] -Collection of samples for DA to satisfy requirement to detect bias defects in MOX and product material. -Direction of MOX canister and cart movement monitored and verified.	-Use of NRTA in TRU Conversion area. Key vessels in TRU product Conversion Area monitored by Solution Monitoring System NDA Verification of TRU product Container -Collection of samples for DA to satisfy requirement to detect bias defects in MOX and product material. TRU product canisters are sealed after verification.[43] -Direction of TRU product canister and cart movement	-Metal Product ingots are stored under inventory values as measured and verified during transfer from the U/TRU/Product casting. -Use of NRTA in Pyro processing area. -Key equipment in the pyro process to be monitored by a Process Monitoring System. NDA Verification of pyro process area and Canister Transfer Cart. Collection of samples for DA to satisfy requirement to detect bias defects in product material.	-Use of NRTA in TRU Conversion area. Key vessels in TRU Conversion Area monitored by Solution Monitoring System. NDA Verification of TRU in gloveboxes NDA verification of TRU Canister Transfer Cart. – Collection of samples for DA to satisfy requirement to detect bias defects in TRU product material. TRU canisters may be sealed after verification.

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[42] This is a very elaborate NDA system consisting of a series of coincident-neutron detectors and gamma sensors distributed in a network throughout the MOX Conversion Glove-box area, and a dedicated canister verification system.

[43] It is not clear if containers can be sealed or if it is necessary

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
transferred to MOX Storage. MUF and MUF-D statistic to be calculated and compared to limits.	-Use of Dual C/S (surveillance) over MOX storage area to confirm that MOX canister movements are as declared.	monitored and verified. -Use of Dual C/S (surveillance) over storage area to confirm that product canister movements are as declared.	Canisters may be sealed after verification or will be under C/S from measurement to storage -Direction of canister and cart movement monitored and verified. Use of Dual C/S (surveillance) over storage area to confirm that canister movements are as declared.	-Direction of TRU canister and cart movement monitored and verified. -Use of Dual C/S (surveillance) over TRU storage area to confirm that TRU canister movements are as declared.
C.3) Verification of MOX or Pu-Bearing TRU Product Shipments	MOX cans to JMOX (quantities and frequency TBD)	TRU oxides to fuel fabrication area (on site)	TRU castings to fuel fabrication (on site)	(TRU oxides to fuel fabrication (on or off site TBD)
IAEA SG Criteria: -Transfers of Pu-bearing materials shall be item counted, identified and verified with a random-high probability for gross, partial and bias defects. -If the stored material has been under dual C/S, then a successful review of the C/S shall be adequate. -All transfers will be made under C/S (inspector	**Current:** -Use of previous NDA verification of stored MOX canister (if stored under successful dual C/S). -Direction of MOX canister and cart movement monitored and verified. -Use of Dual C/S (surveillance) over MOX storage area to confirm that MOX canister movements are as declared.	Use of previous NDA verification of stored TRU canister (if stored under successful dual C/S). -Direction of TRU canister and cart movement monitored and verified. -Use of Dual C/S (surveillance) over TRU storage area to confirm that TRU canister movements are as declared.	-Use of previous DA or NDA verification of stored canister (if stored under successful dual C/S). -Direction of canister and cart movement monitored and verified. -Use of Dual C/S (surveillance) over storage area to confirm that canister movements are	-Use of previous NDA verification of stored TRU canister (if stored under successful dual C/S). -Direction of TRU canister and cart movement monitored and verified. -Use of Dual C/S (surveillance) over TRU

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
presence, or sealed containers).			as declared.	storage area to confirm that MOX canister movements are as declared.
3) Product Storage, Inventory Verification: **(See C.2 Above)**				
(Storage Capacity - Pu kg)	30,000 kg Pu	500 kg Pu	10 Yr. Capacity (2,000 kg Pu?)	TBD (if 10 yr. capacity) Approx. 60,000 kg Pu
a) Monthly (IIV):	Dual C/S on material flow into the storage via cameras and directional radiation detectors	Dual C/S on material flow into the storage via cameras and directional radiation detectors	Dual C/S on material flow into the storage via cameras and directional radiation detectors	Dual C/S on material flow into the storage via cameras and directional radiation detectors
b) Annually (PIV):	Dual C/S on material flow into the storage via cameras and directional radiation detectors	Dual C/S on material flow into the storage via cameras and directional radiation detectors	Dual C/S on material flow into the storage via cameras and directional radiation detectors	Dual C/S on material flow into the storage via cameras and directional radiation detectors
D) Process Flow Verification, to Waste Streams				
1) Hulls (Estimate in total Pu (kg per year) Discharged to Waste)	0.1% THM Throughput (80 Kg Pu/yr Total)	0.1% THM Throughput (.25 Kg Pu/yr Total)[44]	Need to verify (5% losses = 15 kg Pu)	0.1% THM Throughput (240 Kg Pu Total)

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[44] Note that verification requirements are dramatically reduced for such a small quantity of Pu – the random verification of one or two hulls drums per year should suffice.

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
IAEA SG Criteria: -Hulls drums will be item counted, randomly ID checked and verified at a random-medium level for gross defects (hulls radiation attribute).[45] -Comparison of Operators Records with State Reports for consistency, regarding declared transfers and Pu and U content of hulls drums. -Cumulative hulls transfers are to be included in Material Balance Evaluation to evaluate MUF and MUF-D, and to compare to allowed limits.	Current: Use of operator video surveillance and ID check the hulls drum serial number. Gross neutron detectors to verify movement of hull drums from loading, to measurement, to transfer to waste Operator uses active Coincident neutron detection (NDA) system to assay the drum for Pu and U content for reporting IAEA uses passive gross neutron and Pu/ Cm-242 ratio.)[46] Quantitative hulls data is considered in NRTA calculations.	Use of video surveillance to item count and ID check the hulls drum serial number. Handling methods to be considered for monitoring of transfers of hulls Use of active coincident neutron detection (NDA) system to assay the drum for Pu and U Verification method for hulls to TBD Cumulative hulls data is considered in NRTA calculations.	Hulls handling, packaging and transfer methods TBD for monitoring transfer and measurement -Use of Coincident neutron detection (NDA) system to assay hulls package for Pu and U content -Cumulative hulls data is considered in NRTA calculations.	t: Use of video surveillance to item count and ID check the hulls drum serial number. Handling methods to be considered for monitoring of transfers of hulls Use of active coincident neutron detection (NDA) system to assay the drum for Pu and U Verification method for hulls to TBD Cumulative hulls data is considered in NRTA calculations. .
b) MAW:	RRP is structured so that all MAW streams are routed to MBA-3, Waste processing.	Procedures depend on MBA structure. Depending on the MBA structure, there may not	Waste forms, MBA structure and quantities are TBD. All will probably be solid waste and	Waste forms, MBA structure and quantities are TBD. Forms. Final

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[45] The current requirement is for verification of the Hulls drums for radiation attributes. However, considering the possibility of Pu-bearing material being routed through this waste route, improved NDA techniques are recommended to more accurately verify these transfers.

[46] The operator relinquished three neutron tubes in their hull monitor for direct use by the IAEA for passive measurement

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
	These transfers affect the material balance for the processing area, MBA-2. All transfers are covered by: ∞ Solution monitoring for volume measurement verification and transfer monitoring ∞ Random independent samples to on-site lab for verification of concentration	be any MAW transfers that influence the material.	NDA measurements must be developed.	disposal form will be solid wastes and NDA measurements will be requited. Depending on the processes and MBA structure, liquid wastes stream may require verification by traditional volume measurements and random sample and analyses.
c) HAW (solution):	RRP is structured so that the HAW streams are routed to MBA-3, Waste processing. These transfers affect the material balance for the processing area, MBA-2. All transfers are covered by: ∞ Solution monitoring for volume measurement verification and transfer monitoring Random independent samples to on-site lab for verification of concentration	Final waste forms and measurement requirement with respect to MBA structure TBD	Final waste forms TBD	Final waste forms and measurement requirement with respect to MBA structure TBD
	🟩	Final waste forms TBD	Final waste forms TBD	Final waste forms TBD

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
d) HAW (solid):	Vitrified glass	Form TBD	Form TBD	Form TBD
	Solution monitoring of flow to melter for continuity of knowledge Verification of glass formation in disposal container verified	Requires COK on flows from HAW measurement to final form preparation	Requires COK on flows from HAW measurement to final form preparation	Requires COK on flows from HAW measurement to final form preparation
e) HAW (solid):	Process trash and laboratory solid waste	TBD	TBD	TBD
	Segregation and measurement by NDA	TBD	TBD	TBD
E) Shipments: Verification of Pu-bearing Product Shipment		(600 kg HM in storage)		
(Typical Product Shipment - kg Pu per shipment and per year).	Does not ship product at this time (16,000kg/yr 50% MOX when JMOX is up)	40 kg HM/LTA 10 LTA/yr 400 kg HM/yr	As noted under C.3 Product shipments are expected to be internal to the metallic fuel fabrication line at AFCF.	TBD

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line[3]	Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line[4]	(Consolidated Fuel Test Center (CFTC) Aqueous Line)[5]
	MOX product transfers to JMOX will be monitored by passive directional transfer monitors, Fuel will be fabricated in JMOX, which is under design.	Dual C/S on material flow into the Fuel Fab area via cameras and directional radiation detectors **Current**: Item verification, Surveillance, Item count, ID check, fuel movement verification with Gross and Partial Defect measures with UNARM - (as at Dessel in Belgium - MOX fab plant) Sealing of assemblies prior to shipment with Dual system to maintain CoK		Dual C/S on material flow into the Fuel Fab area via cameras and directional radiation detectors **Current**: Item verification, Surveillance, Item count, ID check, fuel movement verification with Gross and Partial Defect measures with UNARM - (as at Dessel in Belgium - MOX fab plant) Sealing of assemblies prior to shipment with Dual system fo maintain CoK
X) Other Verification Activities:				
a) Design Information Verification	DIV during construction. Design of facility to enable better DIV at all times. Use of laser range finder and other techniques to check that facility has not been changed without notification.	DIV during construction. Design of facility to enable better DIV at all times. Use of laser range finder and other techniques to check that facility has not been changed without notification.	DIV during construction. Design of facility to enable better DIV at all times. Use of laser range finder and other techniques to check that facility has not been changed without notification.	DIV during construction. Design of facility to enable better DIV at all times. Use of laser range finder and other techniques to check that facility has not been changed without notification.
b) Other Strategic Points	Random checks for operation as declared	TBD	TBD	TBD
Z) Inventory and Annual				

	IAEA Ref. Facility - Rokkashomura Reprocessing Plant[2]	**Advanced Fuel Cycle Facility (AFCF) - Aqueous Repro. Line**[3]	**Advanced Fuel Cycle Facility (AFCF) Pyro-Reprocessing Line**[4]	**(Consolidated Fuel Test Center (CFTC) Aqueous Line)**[5]
Verifications will also include verification of Uranium, but to a lesser extent).				

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