U.S. DEPARTMENT OF ENERGY

PNNL-22776

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Opportunities for Process Monitoring Techniques at Delayed Access Facilities

MM Curtis
ET Gitau
SJ Johnson
MJ Schanfein
CM Toomey

September 2013

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

This document was printed on recycled paper.

(8/2010)

PNNL-22776

Opportunities for Process Monitoring Techniques at Delayed Access Facilities

MM Curtis
ET Gitau
SJ Johnson[1]
MJ Schanfein[2]
CM Toomey

September 2013

Pacific Northwest National Laboratory
Richland, Washington 99352

[1]Tucker Creek Consulting, Divide, Montana
[2]Idaho National Laboratory, Idaho Falls, Idaho

Acronyms and Abbreviations

ATPM	advanced thermohydraulic power monitor
C/S	containment and surveillance
IAEA	International Atomic Energy Agency
LEU	low enriched uranium
LWR	light water reactor
MOX	mixed oxide
NNRI	no-notice random inspection
PM	process monitoring
SNRI	short-notice random inspection
SQ	significant quantity

Contents

1.0 Introduction

The International Atomic Energy Agency (IAEA) is tasked with verifying State declarations of nuclear material and activities for their correctness and completeness. This is achieved in part with the implementation of safeguards measures at facilities and IAEA inspections to verify material and activities at these facilities. Except for specific cases where the IAEA maintains a continuous presence at a facility (such as the Japanese Rokkasho Reprocessing Plant), there is always a period of time or delay between the moment a State is notified or aware of an upcoming inspection, and the time the inspector actually enters the material balance area or facility.[1]

Termed by the authors as "delayed access," this period of time between inspection notice and inspector entrance to a facility poses a concern. Any prior knowledge of inspection timing can provide sufficient time for an operator or State to remove, shut down, or disguise undeclared materials and activities or instigate further delay to inspector access to a facility to complete such activities. Sources of further delay, whether legitimate or false, can include: waiting for the arrival of the State inspector or representative; waiting for the arrival of, or lack of, relevant operational personnel; requirement for a whole body counter or safety/security training; contamination in relevant operational area; and uninformed or inadequately trained guards. Delayed access also has the potential to reduce the effectiveness of measures applied as part of the Safeguards Approach for a facility (such as short-notice inspections).

Process monitoring (PM) is defined as an element of a Safeguards Approach that monitors material, processes, and equipment (nuclear and nonnuclear) in all types of nuclear facilities, through independent and/or shared safeguards-relevant operator measurements of process control data (e.g., flow rate, pressure, temperature). PM may be continuous or triggered by an operator or event. Continuous systems collect data independent of operator actions or procedures. In light of maturing process monitoring techniques, this paper considers whether the implementation of process monitoring at selected facilities could be used to increase safeguards effectiveness during a period of delayed access.

The major findings from this project are that PM can be used to maintain, if not increase, the effectiveness of safeguards at these facility types during periods of delayed access. However, the costs associated with PM development, deployment, and maintenance will likely be prohibitive. Further research is necessary to determine whether cost savings in other areas could mitigate the high costs associated with PM implementation.

[1] A brief description of notification periods as defined in INFCIRC/153 (IAEA 1972) can be found in Appendix A.

2.0 Discussion

As discussed in Appendix A, the IAEA agrees with the State as to the schedule of routine inspections, sometimes months in advance of inspector arrival. As part of the Safeguards Approach for a specific facility, the IAEA and State may also agree on the implementation of unannounced or short-notice inspections. The time between the State having knowledge of the inspection and the arrival of the inspectors into the facility may provide an opportunity for a cover-up or falsifications of documents and undeclared operations. The IAEA takes into consideration the impact of these potential delays as it plans inspection activities.

The primary safeguards measures currently available to make sure that no undeclared activities are taking place during any periods of delayed access are containment and surveillance (C/S) and PM. These C/S and PM measures are typically in place as part of a Safeguards Approach for specific facilities and their use for the verification of operator activities during delayed access is an implicit part of inspection activities to meet safeguards requirements.

C/S is used at most facilities[1] and is considered effective at facilities with small material inventories or transfers, indirect use material, or static operations. Application of PM equipment has traditionally centered on facilities that process, or produce, a significant quantity (SQ) of direct use material within timeliness goals for detection.[2] These facility types include enrichment facilities, mixed oxide (MOX) fuel fabrication facilities, research reactors over 25 MWt,[3] commercial light water reactors (LWRs),[4] and reprocessing facilities.

In an attempt to define what effectiveness gains may be found from wider use of PM, the authors considered three facility types: low enriched uranium (LEU) fuel fabrication facilities, large post-irradiation examination facilities, and research reactors below 25 MWt. These facility types represent a cross-section of facilities where the IAEA employs other measures, instead of PM, to verify the absence of undeclared activities during delayed access.

The authors suggest that there are ways in which PM can be used to maintain, if not increase, the effectiveness of safeguards at these facility types, including the effectiveness of measures used to verify activities during delayed access. PM at LEU fuel fabrication facilities could possibly be implemented at the sintering furnace by monitoring neutron and gamma emissions of pellets entering and exiting the furnace, along with a surveillance camera to make sure that other radioactive sources are not being used.

---

[1] The IAEA does not currently deploy C/S measures at mines and concentration plants (i.e., mills).

[2] Considered here are facilities beholden to traditional timeliness goals for detection as well as those which may have a modified timeliness goal. Longer timeliness goals may be found in States with an Additional Protocol in force and States where the IAEA has concluded and maintained a conclusion of the absence of undeclared nuclear material and activities (IAEA 2002).

[3] The IAEA has determined that research reactors must have a minimum power of 25 MWt to generate a flux capable of producing at least 1 SQ of plutonium or uranium-233 in a year.

[4] Material movements at LWRs are fairly static and the material is restricted to easily identifiable items, so C/S is relied upon to verify the absence of undeclared activities. While the amount of plutonium in spent fuel is of concern, it remains trapped within fuel and can only be removed at a facility equipped to perform reprocessing. Fuel movements occur during core reload, spent fuel cask loading, and fresh fuel unloading. As these movements are infrequent and scheduled, an inspector is typically present or the IAEA may choose to install additional equipment (likely C/S measures) to confidently verify fuel movements.

Neutron and gamma monitors can also be used to monitor movements of material within post-irradiation examination facilities. Currently, research reactors over 25 MWt are typically monitored using standardized equipment like the advanced thermohydraulic power monitor (ATPM). Monitoring of research reactors designed without a cooling loop for application of the ATPM could possibly be achieved using antineutrino detectors. However that technology has not matured sufficiently for implementation, and its viability for application at low-power facilities has not been proven. The full discussion regarding the examination of potential PM applications at these facilities is presented in Appendix B.

The selected inspection regime and scheduling frequency will dictate, in part, the type of PM that can be used to verify activities during delayed access. A Safeguards Approach that calls only for routinely scheduled inspections could possibly incorporate continuous PM (preferably with remote transmission) in order to detect undeclared activities and to add assurance to the verification of the declared inventory and inventory changes. A Safeguards Approach that incorporates either short-notice random inspections (SNRI) or no-notice random inspections (NNRI) could use continuous PM, or it may be agreed with the State to implement PM systems that are activated by the operator at the time of the announcement of a pending IAEA inspection. The systems having time-stamping capabilities will record a verifiable start time. The implementation of SNRI/NNRI normally relies upon the operator posting declarations of inventory, inventory change, and operational information into an electronic mailbox on an agreed frequency. This information is verified during the SNRI/NNRI.

3.0 Conclusions

While PM can be used to maintain, and potentially increase, IAEA confidence in conclusions regarding undeclared activities during delayed access, the wider deployment of such systems must consider the balance of efficiency improvements versus the cost required to gain that increase. Preliminary research suggests that for the facility types considered in Appendix B, the costs associated with development, deployment, and maintenance of PM equipment would likely discourage their use over measures currently deployed (such as C/S). It should be noted that as these facility types become more complex over time, reevaluation of the effectiveness of current measures may warrant and justify the implementation of PM measures. Process monitoring measures should certainly be considered during the design and building of new facilities.

To better quantify this balance between the effectiveness and efficiency of safeguards measures, there is merit in developing a State model that can be used to explore these competing approaches. While the model might initially support examination of efficiency constraints on the effectiveness of safeguards measures (or vice versa) to support development of State-level analysis, such a model could also be

- shared with the IAEA for comparison to current methods of evaluating effectiveness and efficiency
- adapted to evaluate effectiveness of timeliness goals (for specific facilities and entire States) under various material production or process scenarios
- used to investigate how a State might pursue construction of certain facilities and request/deny specific IAEA measures and approaches to avoid or limit intrusive inspections, potentially revealing deficiencies in the process used to establish State-level safeguards
- made available to domestic safeguards professionals for education and training purposes.

4.0 References

IAEA – International Atomic Energy Agency. 1972. *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons.* INFCIRC/153 (Corrected), International Atomic Energy Agency, Vienna, Austria. Available at http://www.iaea.org/Publications/Documents/Infcircs/Others/infcirc153.pdf.

IAEA – International Atomic Energy Agency. 1997. *Model Protocol Additional to the Agreement(s) Between States and the International Atomic Energy Agency for that Application of Safeguards*. INFCIRC/540 (corrected), International Atomic Energy Agency, Vienna, Austria. Available at http://www.iaea.org/Publications/Documents/Infcircs/1997/infcirc540c.pdf.

IAEA – International Atomic Energy Agency. 2002. IAEA Safeguards Glossary 2001 Edition. International Nuclear Verification Series No. 3, International Atomic Energy Agency, Vienna, Austria. Available at http://www-pub.iaea.org/MTCD/publications/PDF/nvs-3-cd/Start.pdf.

Appendix A

Notice of Inspections and Design Information Verification Visits

Appendix A

Notice of Inspections and Design Information Verification Visits

The safeguards activities that the International Atomic Energy Agency (IAEA) may carry out in a State have different notification periods associated with each. For States with a Comprehensive Safeguards Agreement (CSA), INFCIRC/153, Paragraph 83 states that at least a 24-hour notification must be provided by the IAEA to a State for ad hoc and routine inspections (IAEA 1972). For a design information verification visit, at least a one-week notification must be provided. For special inspections, the IAEA must provide the State with a notification as soon as possible. Also, under INFCIRC/153, Paragraph 84 provides that the IAEA may carry out no-notice, or unannounced, random inspections in a State (IAEA 1972). This type of random inspection is commonly used to verify inventory changes within facilities, such as uranium enrichment or fuel fabrication facilities. It is also used to reduce the inspection effort in certain States.

Routine inspections are normally scheduled well in advance as part of cooperation between the IAEA and the State. Therefore, the State and operators are aware of the inspections. However, if agreed, the IAEA may use a certain number of short-notice random inspections (SNRIs) and/or no-notice random inspections (NNRIs) in addition to, or in lieu of, scheduled routine inspections. The implementation of random inspections increases both safeguards effectiveness and efficiency. The timing of SNRI/NNRIs are not revealed in advance by the IAEA, although the number of SNRIs or NNRIs and the notification periods for such random inspections are agreed to with the State and may vary from facility to facility.

A.1 References

IAEA – International Atomic Energy Agency. 1972. *The Structure and Content of Agreements Between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons.* INFCIRC/153 (Corrected), International Atomic Energy Agency, Vienna, Austria. Available at http://www.iaea.org/Publications/Documents/Infcircs/Others/infcirc153.pdf.

Appendix B

Application of Process Monitoring at Specific Facility Types

Appendix B

Application of Process Monitoring at Specific Facility Types

Three facility types—low-enriched uranium (LEU) fuel fabrication facilities, large post-irradiation examination facilities, and research reactors below 25 MWt—are described. For each facility type, the authors discuss concerns with safeguarding these types of facilities, and evaluate the potential contribution of process monitoring equipment in addressing these concerns during delayed inspector access.

B.1 LEU Fuel Fabrication Facilities

Commercial LEU fuel fabrication facilities can vary in capacity and type of process, but all result in the production of fuel for use in a nuclear reactor. The processing steps for a notional fuel fabrication facility are shown in Figure B.1. Fuel begins as UF_6 gas in large cylinders. The cylinders are heated in autoclaves and then fed into the plant. The gas is converted to UO_2 powder using either a dry or wet process. The dry process introduces the UF_6 gas to steam to create solid uranyl fluoride. The mixture is then reacted with hydrogen gas that bonds with fluorine, leaving UO_2 as the product. In the wet process, the UF_6 is mixed with water to form a uranyl fluoride slush or slurry. Ammonium is added to the mixture and then the resulting mixture is dried and reduced to UO_2.

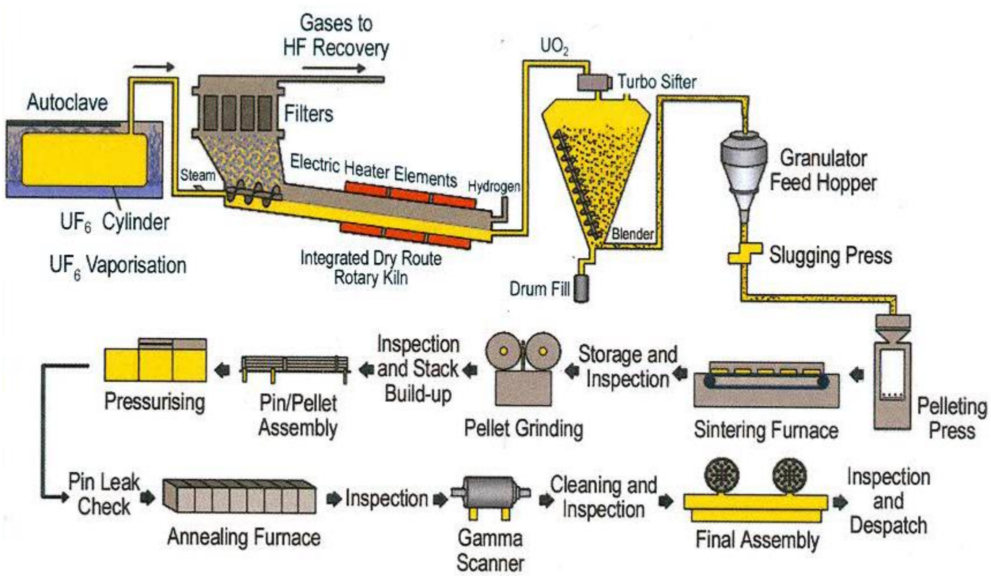

Figure B.1. Process Layout for a Notional Uranium Fuel Fabrication Facility

Once the UO_2 has been produced and blended to the required enrichment needed, the plant feeds the material into dies and presses them into pellets.[1] Once green pellets have been pressed, these green pellets are loaded into open face trays called "boats" and fed into a furnace to be sintered.[2]

After the pellets have been sintered, they are ground to their final dimensions to ensure uniformity and adherence to technical requirements. The ground pellets are ready to be loaded into the cladding material, typically a zirconium alloy tube. The sealed tubes, called fuel pins, are then arranged and secured into a lattice structure to form the final fuel assembly.

B.1.1 Safeguards Concerns

It is assumed that the current International Atomic Energy Agency (IAEA) Safeguards Approach for this facility addresses the following material diversion and borrowing scenarios for LEU fuel fabrication facilities:

- diversion of LEU from the feed, process, or product
- diversion of uranium from the fuel fabrication plant receipts or shipments
- nuclear material borrowing (i.e., borrowing purified uranium feed to support falsified product inventories at the conversion plant or borrowing finished nuclear fuel assemblies to support falsified fuel inventories at research and power reactors).

In addition to these diversion scenarios, it is assumed that a State has the capability to exercise the following facility misuse scenarios, in concert with delayed access, to prevent the IAEA from detecting any illicit activities:

- undeclared use of fuel fabrication plant capacity and/or process lines to produce undeclared uranium
- production of specially design target fuel optimized for the production of plutonium-239 or uranium-233.

In the case of misuse by means of the introduction of undeclared feed to a facility, it is assumed that the undeclared feed material would be the same range of enrichment of material used during routine operations at the facility, negating the use of environmental sampling as a means of detection.

B.1.2 Contribution of Process Monitoring During Delayed Access

Any delay in inspector access by an operator or State can be used to process undeclared material or obscure the processing of such material at a fuel fabrication facility. While such misuse could use any portion of the facility capabilities, the authors consider the ability to apply process monitoring (PM) to the

[1] Some facilities directly receive UO_2, avoiding these front-end processes and start with pellet pressing.
[2] A typical fuel fabrication facility will have multiple process lines to optimize production of various fuel types. For example, the Ulba Metallurgical Plant in Kazakhstan has two process lines to manufacture pellets for RBMK (Reaktor Bolshoy Moshchnosti Kanalniy, or high-power channel-type reactor) and VVER (Vodo-Vodyanoi Energetichesky Reactor, or water-water power reactor) fuel assemblies, each with a capacity of 1000 MTU/year. In 2014, a third line dedicated to production of pellets for Western-style fuel assemblies is expected to start operations with a capacity of 400 MTU/year (World Nuclear News 2011).

sintering furnace, a key piece of equipment found in fuel fabrication facilities, to detect undeclared production of UO_2 fuel pellets. Some facilities directly receive UO_2, avoiding these front-end processes and start with pellet pressing.

The sintering furnace uses a continuous belt feeding mechanism to transport the boats through the furnace. The residency time in the furnace and its temperature of operation are all controlled to make sure the pellets reach their required density and porosity and are close to the required geometry. Without the knowledge of actual pellet throughput through the sintering furnace, the IAEA cannot be sure of detecting the misuse identified here.

Therefore, a single solution would have to be applied to each sintering furnace. To acquire the necessary information on sintering furnace throughput, the authors propose the use of a dedicated unattended and remote monitoring system that uses both optical and radiation sensors to provide a robust authenticated signature of the presence of and the count of boats with the expected nuclear material. While the specific details for calibration and data review/conclusions would require further analysis and testing, it is proposed that a Next Generation Surveillance System (NGSS) camera and a combined gamma/neutron sensor be placed at the input side of the sintering furnace so that these sensors can see each boat just prior to entry into the furnace. This is not considered a challenging environment or challenging task for such a system, and it would likely be capable of operating continuously and upon operator activation. In this case, continuous PM would be required to detect misuse.

By knowing the number of boats, the average mass, and average enrichment, a comparison can easily be made between the operator's declared throughput and the final product inventory including scrap/waste. If a mailbox system is in place, this can also be used with data remotely transmitted back to the IAEA for a periodic reconciliation between the IAEA's monitoring system and the operator's mailbox declaration.

B.2 Post-irradiation Examination Facilities

Post-irradiation Examination (PIE) facilities are often co-located with other facilities like research reactors or research laboratories. These facilities can be used for fuel research, isotope processing, and examination and testing of fuel bundles, pins, and assemblies that has been previously irradiated. While PIE hot cell sizes vary depending upon the application of the facility, the authors consider a generic PIE constructed to examine and process irradiated light water reactor fuel. Figure B.2 depicts the layout for such a facility.

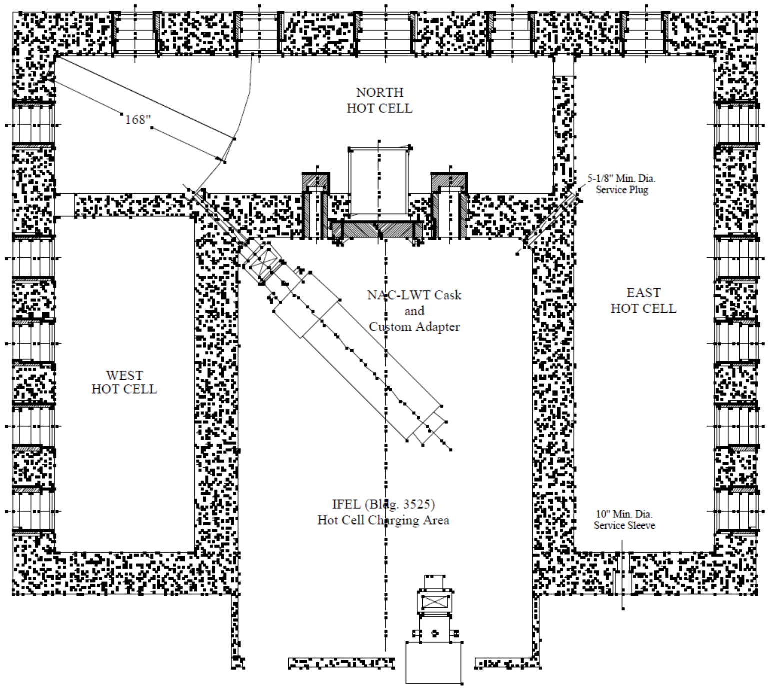

Figure B.2. Layout of Irradiated Fuels Examination Facility at Oak Ridge National Laboratory (Oak Ridge National Laboratory 2013)

This PIE facility contains three separate work areas located around a central staging area for charging the cells. Separated by 3 feet of high-density concrete, each cell has 4-5 oil-filled leaded glass windows that allow viewing of the material being worked by a pair of remote manipulators situated at each window. The PIE facility has two levels, the first housing the hot cells and the second housing the decontamination area, storage area, and necessary supporting infrastructure such as ventilation ducts and control valves. Hatches connect the decontamination area and hot equipment storage area above the hot cells.

Each cell contains specific remotely operated equipment for the disassembly, cutting, imaging, packaging, and dissolution of materials for both non-destructive and destructive testing (Figure B.3). Heavy objects can be moved using a 3-ton crane in each cell. Material can be transferred between cells or removed using a shielded air-lock system. A PIE facility with these capabilities can not only support the development of fuels for use in a reactor, but can also be used in the research and development required for the advancement of a reprocessing capability.

Figure B.3. NAC-LWT Cask Mated to the East Hot Cell of IFEL for Unloading of Full-length Fuel Rods (left) and a Remote Capsule Disassembly System Located in the IFEL West Hot Cell (right) (Shaw 2010)

B.2.1 Safeguards Concerns

While many operations may occur within any PIE facility, of primary safeguards concerns are the capability to

- receive, ship, and handle spent fuel in transfer casks
- disassemble spent fuel and transfer of selected rod(s) to an examination hot-cell
- slice/cut fuel rods into specimens
- carry out physical testing and non-destructive assay on specimen
- dissolve specimens for destructive assay.

Two basic safeguards considerations at PIE facilities that could result in diversion of material and facility misuse are: 1) the undeclared removal of fuel rods from a fuel assembly, and 2) the replacement of the rod with an irradiated dummy rod and the dissolution of fuel specimen and undeclared separation of plutonium. When considering detection of these events, current Safeguards Approaches face some challenges:

- Spent fuel transfers from a reactor to a reprocessing plant or away from reactor storage can take up to two weeks, giving sufficient time for a detour to a PIE facility.
- Spent fuel transfer casks which are full, are normally not sealed in order to reduce the inspection effort.
- There is little or no continuity of knowledge maintained on facility operations or transfers during the time between inspections.
- Separators can be introduced to the hot cell and removed prior to scheduled inspections.
- Examination hot cells can have a large variety of installed equipment and utilities, which can be removed, introduced, or modified between inspections.

- One hot cell may contain hundreds of specimens, making item counting and identification difficult. Furthermore, this makes measurements for gross defects extremely difficult.

B.2.2 Contribution of Process Monitoring During Delayed Access

The addition of PM, combined with C/S, to the Safeguards Approach for a PIE facility would provide higher assurance that there are no undeclared receipts and shipments and that there is no misuse of the hot cell. Two possible technical additions to the Safeguards Approach would be:

- Neutron and gamma monitors, with surveillance, installed on the cask receipt and shipment portal would assure that there are no undeclared receipts and shipments.
- Neutron and gamma monitors, with surveillance, installed on the transfer route to the examination hot cell would provide indications of excessive movement of material into and out of the cell, and an unusual amount of movement just prior to an inspection.

B.3 Research Reactors Below 25 MWt[1]

Research reactors come in a variety of designs and configurations that are meant to support applications such as training, experimentation, and isotope production. The most common type of research reactor less than 25 MWt would be the pool-type, dominated by the water moderated Russian design (known as IRT), the Training, Research, Isotope Production General Atomic (TRIGA), and Materials Test Reactor (MTR) variants. Other types of research reactors include heavy-water-moderated and graphite-moderated varieties. Pool-type designs consist of largely the same elements–a cluster of fuel assemblies in a large pool of water, control rods, experiment facilities, and a graphite or beryllium reflector. These cores can also be mounted onto a mobile bridge capable of traversing the pool to allow for additional flux environments for experiments.

The primary differences between these designs lie with the fuel design and the operating characteristics associated with each. TRIGA reactors use a uranium zirconium hydride (U-ZrH) metal fuel contained in Zircaloy clad rods typically arranged in a square array to form a fuel assembly. MTR and IRT reactors use thin aluminum plates with a fuel alloy containing uranium and aluminum. In MTR fuel, up to 18 of these slightly curved plates are uniformly spaced in an aluminum housing to form a fuel assembly. In IRT fuel these thin plates are arranged in increasing larger squares to form the assembly (Figure B.4).

When first constructed, many reactors were fueled using highly enriched uranium (HEU). However, efforts over the past decade have worked to convert these facilities to operate using LEU.

[1] The IAEA already deploys process monitoring equipment at large research reactors of 25 MWt or more.

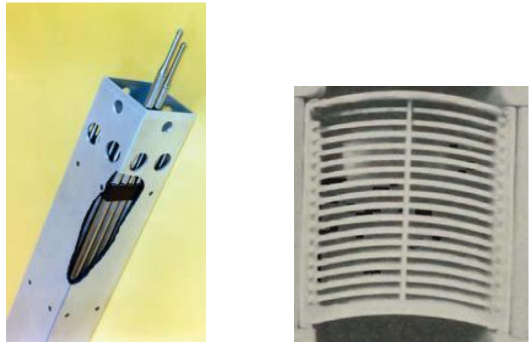

Figure B.4. TRIGA Fuel Assembly (left) and MTR Fuel Assembly Viewed from the Top (right)

B.3.1 Safeguards Concerns

There are two primary safeguards concerns with research reactors–the diversion of HEU fuel and the undeclared production of plutonium. Some HEU-fueled research reactors will remain so for the near future as efforts are made to remove spent or excess HEU fuel from storage areas and convert these facilities to LEU, enriched to just under 20 percent uranium-235 by weight. The high enrichment of research reactor fuel makes it a potential target of greater value to a proliferator. Remaining HEU elements or LEU elements could be diverted and substituted with dummy elements. With respect to misuse, research reactor design lends itself to the introduction of targets, such as natural or depleted uranium and thorium, for the production of weapons-grade plutonium and uranium-233, respectively. In the case of undeclared activities at these facilities, the IAEA has determined that "no safeguards measures need to be directed towards the detection of undeclared production at smaller[1] research reactors until the provisions necessary for the larger reactors are fully implemented (IAEA 2003)." While the IAEA may still draw a conclusion regarding the absence of undeclared activities at a facility and within the State, the lack of specialized measures at the small facilities to detect misuse increases the difficulty of verification.

B.3.2 Contribution of Process Monitoring During Delayed Access

The IAEA requires that additional C/S measures be implemented to verify that no undeclared production is taking place for facilities that fall at or above 25 MWt. The most common of these measures is the advanced thermohydraulic power monitor (ATPM), shown in Figure B.5. This unit is connected to the forced cooling system (i.e., primary loop) of a research reactor and monitors energy output by tracking coolant temperature and flow. The ATPM ultimately allows the IAEA to address misuse scenarios—such as short cycling the facility to produce a higher grade of plutonium—by detecting any deviation from normal cooling operations at the facility. This overcomes any challenge presented by the reconfigurability of research reactors by not relying upon a radiation signature, something that varies as reactor configuration changes.

There are more recent increased concerns in the undeclared production of even small amounts of plutonium in lower power research reactors that may be used to develop reprocessing technologies.

[1] The threshold between "smaller" and "larger" research reactors was placed at 25 MWt, the power found necessary to generate a flux capable of producing at least 1 SQ of plutonium or U-233 per year (Pan et al. 2012).

However, many of the smaller reactors are not designed with a forced cooling system. Lower power reactors are often capable of relying upon natural convection to remove heat from the reactor core. TRIGA designer General Atomics has determined that their fuel elements can safely operate up to 2 MWt, relying upon only natural convection to cool the reactor core (IAEA 2004). Furthermore, smaller facilities may not operate in long cycles like some larger facilities. Smaller facilities may only be used for training or education purposes, meaning shorter, infrequent operations may be the normal operating schedule. This would make short cycling difficult to discern from normal operations at the facility.

Figure B.5. Advanced Thermohydraulic Power Monitor(IAEA 2011)

For lower-power research reactors, without forced cooling loops, an adaption of the ATPM system may be possible. These would need to be placed under surveillance or sealed within a tamper-indicating enclosure to ensure no undeclared access has occurred. In the future, low-power facilities could possibly be monitored using antineutrino detectors. These systems are being explored for international safeguards because research has shown they can be used to monitor power levels and fissile content of the core at a distance. Currently, the technology is not mature enough for deployment at commercial reactors, and additional work would have to be performed to confirm its viability for low power facilities.

More difficult to detect at low power facilities would be the introduction of targets into, or around, the reactor core to produce plutonium or uranium-233. These reactors typically have multiple irradiation facilities within the core and around its periphery. Access to large irradiation facilities is often below grade, out of view from surveillance measures in the reactor hall or building. Use of any type of radiation monitor to monitor material movements would be ineffective as these areas are often exposed to high radiation fields as part of irradiations. However, access hatches to these irradiation channels could be outfitted with a monitor that records when access has occurred.

B.4 References

Gramond M, P Jaunet, and E Damge. 2013. *Involvement of plant operator in the safeguarding of the shipment of fabricated MOX FA : operator experience*. IAEA-CN-184/318, International Atomic Energy Agency, Vienna, Austria. Accessed August 28, 2013 at http://www.iaea.org/safeguards/Symposium/2010/Documents/PapersRepository/318.pdf.

IAEA – International Atomic Energy Agency. 2003. "Policy Paper 6: Undeclared Plutonium or Uranium 233 Production in Research and Power Reactors." *Safeguards Manual SMR 2.6*, International Atomic Energy Agency, Vienna, Austria.

IAEA – International Atomic Energy Agency. 2004. "2.1 TRIGA Reactors with Natural Convection Cooling." *Training Material on TRIGA Research Reactors*, International Atomic Energy Agency, Nuclear Installation Safety Division, Vienna Austria.

IAEA – International Atomic Energy Agency. 2011. *Safeguards Techniques and Equipment: 2011 Edition.* International Nuclear Verification Series No. 1 (Rev. 2), International Atomic Energy Agency, Vienna, Austria.

Oak Ridge National Laboratory. 2013. "Irradiated Fuels Examination Laboratory [Building 3525]." Accessed August 28, 2013 at http://web.ornl.gov/sci/physical_sciences_directorate/mst/NMST/images/IFEL/Appendix%20A.pdf.

Pan, P, B Boyer, and C Murphy. 2012. *Safeguards by Design (SBD): Safeguards Guidance for Research Reactors and Critical Assemblies.* LA-UR-12-26349, Los Alamos National Laboratory, Albuquerque, New Mexico. Available (as *Guidance for Research Reactors and Critical Assemblies* NGSI-SBD-003) at http://nnsa.energy.gov/sites/default/files/nnsa/01-13-inlinefiles/2013-01-28%20SBD%20-%20Guidance%20for%20Research%20Reactors%20and%20Critical%20Assemblies.pdf.

Shaw J. 2010. *Directory of Nuclear Science and Technology Capabilities at Oak Ridge National Laboratory*. ORNL 2010-G01338/mhr, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Available at http://atrnsuf.inl.gov/Capabilities/PostIrradiationExamination/tabid/101/Default.aspx.

World Nuclear News. 2011. "Record year for Kazakh uranium." February 1, 2011. Accessed August 28, 2013 at http://www.world-nuclear-news.org/C-Record_year_for_Kazakh_uranium-0102117.html.

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

U.S. DEPARTMENT OF
ENERGY

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)
www.pnnl.gov