ORNL/SPR-2019/1329

Model MC&A Plan for Pebble Bed Reactors

Donald Kovacic
Phillip Gibbs
Logan Scott

March 2020

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

ORNL/SPR-2019/1329

Nuclear Nonproliferation Division

NRCHQ2514D0004-NRCHQ2517T0001
NON-LIGHT WATER REACTOR POLICY AND TECHNICAL GUIDANCE SUPPORT

LETTER REPORT FOR TECHNICAL DIRECTION #5 TASK 2.6
MODEL MC&A PLAN FOR PEBBLE BED REACTORS

Donald Kovacic
Philip Gibbs
Logan Scott

March 2020

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

TABLE OF CONTENTS

ACRONYMS

AEC	US Atomic Energy Commission
ANSI	American National Standards Institute
CFR	US Code of Federal Regulations
DOE	US Department of Energy
EI	ending inventory
FKG	formula kilogram
FKMP	Flow Key Measurement Point
FNMCP	Fundamental Nuclear Material Control Plan
FRAM	fixed energy, response function analysis with multiple efficiencies
IAEA	International Atomic Energy Agency
ICA	Item Control Area
ID	inventory difference
IKMP	Inventory Key Measurement Point
KMP	Key Measurement Point
LWR	light water reactor
MBA	material balance area
MC&A	material control and accounting
MGAU	multigroup analysis for uranium
MOX	mixed uranium–plutonium oxide
NDA	nondestructive assay
NRC	US Nuclear Regulatory Commission
OIML	Organization of Legal Metrology
PIV	physical inventory verification
Pu	elemental plutonium
PWR	pressurized water reactor
SEID	standard error of the inventory difference
SNM	special nuclear material
SQ	significant quantity
S/R	shipper-receiver
SRD	shipper–receiver difference
TID	tamper-indicating device
TRISO	tristructural isotropic
U	elemental uranium
^{233}U or U-233	isotope for uranium-233
^{235}U or U-235	isotope for uranium-235
^{238}U or U-238	isotope for uranium-238

1. INTRODUCTION

In preparation for non-light water reactor (non-LWR) activities, US Nuclear Regulatory Commission (NRC) staff are advancing risk-informed and performance-based licensing approaches and addressing key policy issues. One non-LWR reactor concept is a pebble bed reactor (PBR). This reactor design uses spherical fuel elements (pebbles) that are continually added to and removed from the reactor core. The free movement of the fuel in this design presents new challenges for material control and accounting (MC&A) programs. Therefore, an assessment of MC&A program features and measures for a PBR was performed to help NRC staff develop associated MC&A regulations or regulatory guides.

The current regulatory framework for non-LWR fuel cycles excludes support for licensing reviews for MC&A programs for PBRs. Licensing reviews of an MC&A program for PBRs can be facilitated by (1) a model MC&A program for a PBR based on identification and assessment of MC&A program features and recommended measures for a reference PBR and (2) a methodology for assessing MC&A performance that can help assess different MC&A program features and measures.

This report supports the NRC's non-LWR Vision and Strategy Near-Term Implementation Action Plans (ADAMS Accession No. ML17165A069).

2. SCOPE OF WORK AND STRUCTURE OF REPORT

This report is provided under NRCHQ2514D0004-NRCHQ2517T0001, Non-Light Water Reactor Policy and Technical Guidance Support, Technical Direction #5, Task 2.6 – *Model MC&A Program for Pebble Bed Reactors*.

This report provides a model of an MC&A plan for PBRs, as well as the basis, methodology, and process for the development of the outline. Specific MC&A issues and challenges are discussed, as well as thoughts and approaches on how to address these challenges. See Appendix A for the MC&A plan outline and analysis. The model is based on a combination of NUREG-2159 [1], Regulatory Guide 5.29, Revision 2 [2], and ANSI N15.8-2009[1] [3]. The sections of the outline that are taken from the NUREG are in boldface type and are placed in text boxes. The assessments and comments are in regular type.

The following sections provide the assumptions, basis, and analyses that were used for developing the model MC&A plan for PBRs provided in Appendix A. These sections also provide discussion about the adequacy of inspection methodology that is currently used for non–fuel cycle facilities. The final sections provide conclusions and insights about whether regulatory changes may be needed to accommodate MC&A for PBRs.

Note: For a discussion of PBR technology, see the deliverable for Tasks #2.2 and #2.3 – *Assessment of Current MC&A Regulations and Guidance and Challenges for Pebble Bed Reactors* [4].

3. ASSUMPTIONS AND BASIS

Power reactors are considered utilization facilities because they produce energy (such as electricity) as a product, and they "utilize" fissile material to do so. As such, they are licensed under Title 10 US Code of Federal Regulations 10 CFR Part 50. Additionally, the handling of special nuclear material (SNM)

---

[1] DG-5057 cannot be used as a reference because it was developed anticipating the revision of 10 CFR Part 74. With that revision being cancelled, DG-5057 was also cancelled (private communication from G. Tartal, US NRC, to P. Gibbs, Oak Ridge National Laboratory, July 30, 2019).

requires a 10 CFR Part 70 license; consequently, all power reactors are required to have a Part 70 license to receive, store, or transfer SNM at the site, including fresh fuel for loading into the reactor. Part 70 references sections in 10 CFR Part 74 for material control and accounting requirements, but Part 70 excludes reactors from the requirements of Part 74 that require a licensee to have an MC&A plan. Additionally, Part 74 specifically excludes reactors from those same requirements. MC&A plans are only required for fuel-cycle facilities that handle Category I/II/III SNM. Therefore, because PBRs would likely be considered utilization facilities, the license holder might claim exemption from the requirement to have an MC&A plan and to follow the more rigorous controls imposed by the sections of Part 74 for fuel cycle facilities. Even though certain aspects of current LWR MC&A approaches were found to be applicable, MC&A approaches in use for fuel-cycle facilities are more closely aligned with anticipated PBR designs. This dichotomy may pose a regulatory challenge. From a domestic safeguards perspective, PBR fuel is more portable or concealable than traditional LWR fuel assemblies.

However, although each pebble is more portable and concealable, each one only contains a small amount of SNM, so a large quantity of pebbles (i.e., not concealable) would need to be taken in abrupt theft scenarios to equal the quantity of nuclear material in a low enriched uranium fuel assembly. Protracted theft scenarios would require many attempts to obtain a significant quantity by current domestic or international definitions.

MC&A approaches discussed herein reflect the differences between LWR fuel and PBR fuel. Below are some specific scenarios [5] that the MC&A approaches discussed will address:

- Fresh fuel for receipts and inventory—Diversion or theft, with or without substitution with non-fuel items (both domestic and international).

- Reactor core (domestic and international)—Theft/diversion of core fuel. Internationally, this would include undeclared introduction of fertile materials for undeclared production.

- Spent fuel transfer, storage, and shipments—Diversion or theft, with or without substitution, with non-fuel items (both domestic and international).

For reference purposes, using TRISO fuel as an example, the total quantity of SNM contained in 60 mm fuel pebbles—in which each pebble has a total mass of 200 g and is enriched to 9.6% ^{235}U—will be between 7 and 9 g of low enriched uranium, or just under 1g ^{235}U before irradiation. After irradiation (between 80 and 90 GWD/MT), the pebbles contain less than 0.12 g of plutonium and less than 8.2 g of residual uranium at 3.8% ^{235}U. Although the TRISO fuel is provided as one example, other PBR designs are expected to utilize fuel with U enrichments from normal up to <20%, and some designs plan to combine pebble enrichments across that range.

NRC regulations for categorization of SNM define Category III material as 10 kg or more of uranium enriched above natural but less than 10% and Category II material as 10 kg or more of uranium enriched to 10% but less than 20%. For nuclear reactors, the facility categorizations have historically been based on the fresh fuel and not on the content of plutonium in the spent fuel.

Licensing for use of Category II SNM (fresh fuel) under 10 CFR Part 70 may require PBRs to adhere to the requirements in 10 CFR Part 74 Subpart D: Parts 74.41, Special Nuclear Material of Moderate Strategic Significance; 74.43, Internal Controls, Inventory, and Records; and 74.45, Measurements and Measurement Control. Those sections require an operator to develop and submit an MC&A plan. This is a departure for regulations that are applicable to typical power reactors (with fuel enriched to <5%) and research reactors (with fuel enriched to <20%) (i.e., utilization/non–fuel cycle facilities) that only have to meet the more general reporting requirements of 10 CFR 74.11, 74.13, 74.15, and 74.19 and are not required to develop MC&A plans.

Based on the anticipated designs, the MC&A approaches for a PBR are likely to be a hybrid of those required and used for non-reactor and reactor facilities. However, the requirements in Subpart D are based on a facility that handles Category II material in bulk (loose) form, where the bulk material does not lend itself to being identified as discrete pieces or being uniquely identified. Materials in bulk form such as powders or solutions cannot be individually counted and can change chemical and physical properties and isotopic concentrations as they pass through certain types of plant processes. A PBR will not have bulk material of this type. The production of PBR fuel is not addressed in this assessment.

Fuel pebbles are discrete objects that can be counted. In a PBR, the fuel will not change chemical or physical properties unless the fuel pebbles are physically damaged. The fuel pebbles will, however, undergo significant isotopic changes, as in any power reactor that consumes and produces fissile and fertile isotopes. Therefore, all the requirements in 10 CFR 74.41 may not be applicable to PBRs, and approaches for inventory and the standard error on any inventory difference (ID) would need to consider this difference in design.

Similarities to accounting for fuel pellets in an LWR fuel manufacturing facility can be made for cases in which weight measurements are used for material accountancy on pellets. The pellets are not counted individually during pellet manufacture and shipments/transfers, but they are counted when being assembled onto trays for loading into pins. An 1,100 MWe PWR core [6] may contain 193 fuel assemblies comprised of more than 50,000 fuel pins and some 18 million fuel pellets. Therefore, a fuel fabrication facility handles tens of millions of fuel pellets, in addition to handling bulk material in solid, liquid, and powder forms. In contrast, a core for a 100 MWe PBR unit will contain approximately half a million fuel pebbles in the core. Also, considering fresh and spent fuel pebbles, the total number for a PBR unit will be at least an order of magnitude less than that of an LWR fuel fabrication facility. This indicates that counting fuel pebbles might be more easily accomplished in a PBR since the number of pebbles would be much less. The combination of counting pebbles and weight measurements in certain points in a PBR would provide a more robust measurement method than relying only on weight measurements alone.

4. KEY MC&A CONSIDERATIONS FOR PEBBLE BED REACTORS

Among other MC&A topics, this report discusses the application of an item control program for PBRs as outlined in 10 CFR 74.43(5). The regulatory intent of an item control program would have applicability to both the fresh and spent fuel areas of the PBR. However, one potential regulatory challenge is found in 10 CFR 74.43(6), in which items below a certain threshold (i.e., 200 g Pu/U^{233} or 300 g U/U^{235}) or that exist for less than 14 days are exempted from these requirements. As discussed in Section 3 for the TRISO fuel example, each individual pebble is well below the material quantity thresholds and would thus be exempt from an item control program. The number of pebbles to be grouped or containerized into what would constitute the "item" would determine if the "item" exceeded that threshold. This is a key example of the challenge with PBRs regarding balancing their portability vs. their low SNM content per pebble when determining what MC&A controls are needed.

A key consideration for MC&A for both inventory and item control could be approached from the perspective of item, bulk, or hybrid. The fuel pebbles would be received at the facility in containers with a declared quantity of nuclear material that would be received as an item. It is unknown if the number of pebbles would be identified in the shipper's documentation. The nuclear material accounting and pebble count may be stated on a batch basis, and a batch would be comprised of one or more containers. Containers of pebbles would be stored to await transfer of a set number of pebbles into the feed mechanism (e.g., a feed hopper) of the reactor. After the reactor is loaded with pebbles, the reactor itself could become a defined containment boundary. However, unlike a traditional LWR, the PBR probably would not be considered an item because it will have a continual flow of nuclear material into and out of it. Because of differences in timing of additions and removals of nuclear material (i.e., fresh fuel feed, intact pebble withdrawal, damaged pebble withdrawal, and possible disintegration and loss of pebbles in the reactor systems), the inventory of the reactor will fluctuate. The PBR is more analogous to a *unit process* as defined in 10 CFR Part 74.4 instead of an item, and it behaves similarly to the dynamic inventory in an enrichment facility. However, while the PBR is dynamic in that pebbles are moving through the reactor and the recycle loops, during the initial loading, the inventory of pebbles will stay in the reactor for an extended period. This makes it unclear how the concept of *active inventory*, which is used in MC&A to set limits on standard error of the inventory difference (SEID), will be applied to meet the regulatory intent.

The concept of Active Inventory has been traditionally used in 10 CFR Part 74 for setting acceptable thresholds for SEID. Active Inventory is a way to capture the additive and relative nature of measurement errors with respect to the SNM throughput of a processing facility. As throughput increases, so does the absolute value of the SEID in a relative fashion. Because of this, the regulatory requirement for SEID is expressed for Category I and II facilities as a percentage of Active Inventory.

Active inventory is defined as BI + A + R + EI (with all common items excluded)

BI - Beginning Inventory
A - Additions
R - Removals
EI - Ending Inventory

The challenge for PBRs is that although the SNM inventory in the reactor is dynamic, in some respects it could also be considered static. At the time of initial loading, pebbles will be placed in the reactor and will circulate (dynamic) within the core and the associated recycle loops for the first year of operation, with few other additions or removals (static) to that process unit.

It is true that this will change in subsequent years with pebbles being added and removed. However, the concept of throughput in this facility is different than that which has been applied in other types of non-reactor facilities. Therefore, the challenge is to define active inventory (or throughput) while also determining if the definition is still consistent with the goals of MC&A when applied to a PBR.

In the inventory section, this report suggests two possible approaches for the reactor vessel. The first approach is more complex and is based on a variation on the concept of process monitoring used in Category I facilities that uses reactor operating parameters. Limits would be established based on observed variability of the selected reactor operating parameters to establish some statement of confidence about the SNM inventory in the PBR vessel. The second approach is simpler and is based on integration of MC&A containment and surveillance with physical protection. It assumes that adequate assurance could be provided from these controls such that no credible diversion paths or diversion scenarios exist. The SNM inventory would be based on the difference between pebbles added to and removed from the reactor system. This approach is not unlike the one used for existing LWRs or containers, albeit the PBR inventory will change more frequently, making inventory cut-off times and coordination with other areas of the process more challenging.

Pebbles that exit the reactor will be sorted according to whether they are damaged or intact. Damaged pebbles will be sent to a separate area and could be loaded into a container that could be sealed and counted as an item. Each intact pebble will be measured individually to determine if the burnup exceeds a pre-established level, and the pebbles will then be either recycled back to the reactor core or sent to a collection area for storage in spent fuel containers. After the nuclear material content of each container is determined, the container could be counted as an item with a quantity of nuclear material and a pebble count. The average burnup of the spent fuel in a container, along with a corroborating burnup measurement on the container, could be used to determine the nuclear material content. When pebbles have been damaged in the reactor, small pieces will enter the coolant stream and will collect in other reactor components and ultimately will be removed as a waste stream.

During the initial fuel loading, the inventory in the reactor can be established from the number of pebbles required to fill the reactor. After a PBR has achieved an equilibrium operating level, the contained fissile mass and average burnup could be calculated. Until equilibrium is reached, the average burnup would need to be estimated by the location of the control rods (assuming operation of the reactor at a constant power level). Nuclear material quantity in a spent fuel container can be determined from the number of pebbles exiting the reactor and being placed in a container or by weighing the filled container and then determining the burnup. This can be done by using the values from the burnup measurements used to discharge the pebbles, by calculating the average burn-up of the pebbles in the container, by nondestructive assay measurements (e.g., total neutron and total or specific isotope gamma measurements), or by some combination of these methods. The amount of plutonium produced per pebble is likely to be less than a full reportable quantity, but across large groups, it will be reportable, so approaches for aggregating would need to be implemented. The term *reportable quantities* refers to the aggregate amount in the MBA. Individual pebbles would still be below the exempt amounts for item control as noted for fresh fuel.

Regarding measurements in a PBR, the regulatory language for Category II facilities is intended more for non-reactor facilities where measurement systems are used for verification and reporting of SNM quantities. Most measurement systems in a PBR are more likely to be used for confirmation purposes because of the nature of the fuel as discrete pieces. Confirmation purposes means that some attribute would be verified to check for scenarios involving substitution or theft of fuel pebbles versus actual changes to declared values of individual pebbles.

For a facility that possesses only items, the ID should be zero. For an LWR, an ID different from zero may be a serious problem if it is due to either an assembly or pins from an assembly being lost, diverted, or misplaced, or if the bookkeeping practice is inadequate. Since pebbles are discrete objects, in theory, in the absence of any theft or diversion (assuming no errors in pebble counting), the ID for PBRs should also always equal zero. However, some counting errors are expected for a PBR. In addition, because the reactor cannot be shut down for physical inventory taking, the number of pebbles in the feed hopper and withdrawal container attached to the reactor, as well as the content of broken pebble and waste containers, may not be directly verifiable. Therefore, there will be uncertainty associated with the pebble counts and a potential ID. This uncertainty is similar to that in a bulk-handling facility (such as an LWR fuel assembly manufacturing plant that receives pellets for loading into pins and constructing assemblies), where a non-zero ID is expected, either positive or negative, because of many contributing factors, including measurement uncertainties, measurement mistakes, recording errors, or unmeasured material holdup and losses.

For areas of a PBR where pebbles can be individually counted or measured and placed in sealed containers, such as the fresh fuel storage and the spent fuel storage areas, these can be item control areas. These areas could use an item-based approach or a bulk quantity-based approach for managing the pebbles using weight or other measurements. The initial assessment indicated it may be reasonable to obtain high confidence in counting fresh and irradiated fuel pebbles with corrections for partial pellets in containers of broken pellets and nuclear material in waste. This approach would be consistent with that found in ANSI N15.8-2009 [3] in discussions about *fuel component containers* and approaches for managing *fuel components*.

However, as a caution, historical literature that was reviewed from the PBRs operated in Germany and China indicate that there was some uncertainty about the ability to accurately count the large numbers of pebbles fed to and removed from the reactor vessel. The way this affects inventory and SEID is discussed in the example MC&A approaches. For the non-reactor vessel parts of the PBR, an item approach to accounting is discussed in the model MC&A plan (Appendix A, Section A.8) with the goal of introducing methods to control the pebble-counting uncertainty.

The approach applied to the reactor vessel and potential scrap and waste flows will likely follow a hybrid approach—item and bulk. As discussed in *Assessment of Current MC&A Regulations and Guidance and Challenges for Pebble Bed Reactors* [4], reactor physical inventory as described in current regulations will not apply because it assumes item accounting by serial number and location. The reported quantity of pebbles and SNM values within the vessel are likely to be based on a reference number of pebbles established when the reactor was initially loaded, along with additions or removals. Other MC&A elements, such as material containment and surveillance for this part of the process and the physical characteristics of the product (heat/radiation), would be relevant in discussions about the overall system's ability to provide sufficient assurance of detection of theft or diversion.

There are other aspects of MC&A, such as measurement errors and biases, that would be much simpler for a PBR than for a Category II facility that handles bulk/loose material. Unlike a traditional bulk-processing facility where a bias in measurement techniques can lead to SNM balances being overstated or understated in various parts of the processes that involve different methods, most transfers will consist of an integral number of pebbles. In these cases, transfers are based on the combination of the values assigned to the group of pebbles involved in the transfer. If the accuracy of the pebble count is maintained, then any measurement bias in the SNM quantity would be transferred with the group and would cancel out statistically.

With that said, one exception to this logic in the reactor operations could be for the measurement methods or calculation approaches applied to the inventory strata of broken pebbles, process holdup, and waste. These strata are the result of pebbles that have lost their integrity, so calculation of SNM quantities would be based on a more traditional bulk inventory approach and potentially some bias in determining the numbers of pebbles lost to this output stream. The numbers of pebbles lost to this stream would be subtracted from the pebble count assigned to the reactor. Any bias, positive or negative, would therefore be reflected in the pebble count assigned to the reactor vessel. Historical data seem to indicate this stream of failed pebbles will not be large.

There is also a potential bias in calculating and assigning burnup SNM values to the spent fuel pebbles. This calculation is complicated by the unique burnup history of each pebble, because pebbles will have different residence times in different locations of the reactor. They would have been recycled through the reactor a varying number of times. However, the effect of this bias would likely only be realized if the spent fuel pebbles were reprocessed. This situation also occurs for traditional LWRs, so it would not be unique to PBRs. The existing regulatory guidance for handling such bias or correcting these values would apply, and no changes are anticipated to be needed.

For shipper/receiver (S/R) differences, the goal of the MC&A system would be to provide some level of assurance that no theft or diversion (with or without substitution) occurred during the shipping and receiving processes for both fresh and spent fuel. Again, the difference between LWRs and PBRs is the portability of the fuel. The report contains some discussion on receipt/shipment. Most of the approaches currently in use for LWRs will apply as outlined in ANSI N15.8-2009, Section 6.2, Receipt of SNM [3]. An additional application of a confirmatory or verification measurement technique on a sampling basis may be warranted to address potential substitution scenarios again given the portability of the fuel.

Sampling plans and measurement approaches would be based upon a desired level of detection for loss of material.

Regarding performing physical inventories for the reactor, since the PBR operates on a continuous basis, physical inventories would be performed while the reactor was online. This is not analogous to a physical inventory verification (PIV) at an LWR where the reactor vessel is sealed and is considered an item for domestic safeguards. For international safeguards the physical inventory of a reactor is performed when the core is open and the contained fuel assemblies can be counted. PIVs at certain types of non-reactor facilities, such as enrichment facilities, are also performed while process operations continue. This report provides options and recommended approaches for the reactor and each inventory strata, and it includes references to applicable NRC regulations and guidance for conduct of physical inventories.

The terms *Material Balance Area* (MBA) and *Item Control Area* (ICA) are used throughout the report. These terms do not appear in 10 CFR Part 74 but are used in different NRC guidance documents (e.g., NUREG-1065, Revision 2 [7]) and the term *MBA* appears in IAEA NSS-25G, *Use of Nuclear Material Accounting and Control for Nuclear Security Purposes at Facilities*. The current regulatory requirement only has the concept of "internal control areas" as used in 74.43(c) and 74.45(b) of the Category II regulations. Whether the terms *MBA* and *ICA*, as appearing in other guidance documents, are used or the term "*internal control area*" is used, the regulatory intent is the same: that is, subdividing the process in such a way that any loss or diversion of SNM has a higher probability of being detected.

5. CONCLUSIONS

Based on historical reactor designs using fuel assemblies, nuclear reactors (utilization facilities) are only required to meet the more general MC&A requirements of 10 CFR 74.11, 74.13, 74.15, and 74.19 and are not required to develop MC&A plans. Therefore, PBRs would likely not be subject to Subpart D as are fuel cycle facilities. Section 74.11 requires nuclear power plant licensees to notify the NRC of loss, theft, or attempted theft of SNM. Sections 74.13 and 74.15 require nuclear power plant licensees to report SNM balances and transactions, respectively, to the NRC. Section 74.19 contains the requirements for the MC&A program at nuclear power plants. These requirements can be summarized as follows:

- Establish, maintain, and follow written procedures sufficient to account for all SNM possessed under license.
- Keep records concerning receipt, inventory (including location and unique identity), acquisition, transfer, and disposal of all SNM possessed.
- Perform physical inventories of all SNM possessed at least every 12 months.

The NRC assesses the acceptability of reactor MC&A programs through its inspection program rather than requiring that the licensee submit a Fundamental Nuclear Material Control Plan (FNMCP) document [7]. For fuel cycle facilities, the FNMCP is implemented at the facility, and compliance is assessed by evaluating the conformance of the procedures and processes with the commitments made in the FNMCP. In the case of nuclear reactors, compliance is assessed by evaluating the conformance of the licensee's procedures and processes with the regulations themselves. In this case the inspectors determine whether the procedures and processes adequately implement the requirements of the regulations as well as assessing the conformance of the licensee's processes with its procedures. This provides the NRC with considerable flexibility in how it assesses compliance with the regulations.

As can be seen from the discussion above, in 10 CFR 74.19, "Recordkeeping":

…all licensees that possess SNM in a quantity exceeding 1 effective kg shall establish, maintain, and follow written material control and accounting procedures that are sufficient to enable the licensee to account for the SNM in its possession under license.

This is in conjunction with the requirement in 10 CFR 74.11, that:

. . . *Each licensee who possesses one gram or more of contained uranium-235, uranium-233, or plutonium shall notify the NRC Operations Center within 1 hour of discovery of any loss or theft or other unlawful diversion of special nuclear material which the licensee is licensed to possess, or any incident in which an attempt has been made to commit a theft or unlawful diversion of special nuclear material*.

Taken together, these passages mean that a PBR must meet the same standard of nuclear material accountancy as an LWR. However, the accountancy methods in an LWR are much simpler than those in the proposed PBR designs due to the reasons described in this report. MC&A for a PBR will be more complex due to the continual moving nature of the fuel. Therefore, since MC&A for a PBR will be somewhere between that of a nuclear reactor and a fuel cycle facility, in order to meet the current MC&A standard for LWRs, PBRs will need to employ aspects of MC&A approaches applied to Category I, II, and III facilities, in a graded fashion.

The material accountancy and reporting limits for Category I/II/III fuel cycle facilities are based on bulk throughput processes in which differences are expected due to processing losses, measurement uncertainties, and continuous movement of material throughout the facility. For a Category II facility, if this approach is extrapolated to a PBR, then the differences would amount to hundreds or thousands of pebbles. Losing or being unable to account for this number of pebbles would indicate a serious failure in operations or material handling and would therefore be unacceptable from the perspective of safe operation of the plant. Therefore, the NRC could provide guidance to PBR operators on the limits appropriate for this type of non-fuel cycle facility regarding the amount of material and/or number of pebbles which, if not accounted for, would require reporting to the NRC and subsequent corrective action. This could be assessed and verified via licensing performance and inspection processes.

Because of the flexibility of assessing the adequacy of MC&A programs for reactors, the NRC could provide guidance to licensees of PBRs on how to account for SNM based on some of the analyses and recommendations provided in this report. The appendix of this report provides a model MC&A plan for PBRs based on a combination of NUREG-2159 [1], Regulatory Guide 5.29 (Rev. 2) [2], and ANSI N15.8-2009 [3]. It also identifies challenges for implementing a robust MC&A program for PBRs and provides approaches that may be used to address those challenges. Several alternatives, including item, bulk, and hybrid options for managing the SNM inventory in a PBR are compared and contrasted.

REFERENCES

[1] *Acceptable Standard Format and Content for the Material Control and Accounting Plan Required for Special Nuclear Material of Moderate Strategic Significance,* US Nuclear Regulatory Commission NUREG-2159, 2013.

[2] *Regulatory Guide 5.29, Special Nuclear Material Control and Accounting Systems for Power Plants,* US Nuclear Regulatory Commission, 2013.

[3] American National Standard - Special Nuclear Material Control and Accountig Sysems for Nuclear Power Plants, ANSI N15.8-2009.

[4] L. Scott, D. Kovacic, P. Gibbs, and G. Hirsch, "Assessment of Current MC&A Regulations and Guidance and Challenges for Pebble Bed Reactors," Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, ORNL/SPR-2018/1083, 2018.

[5] P. C. Durst et al., "Nuclear Safeguards Considerations for the Pebble Bed Modular Reactor (PBMR)," Idaho National Laboratory (INL), INL/EXT-09-16782, 2009, Available: https://www.osti.gov/servlets/purl/968683.

[6] World Nuclear Association. (2019). *Nuclear Fuel and its Fabrication*. Available: https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/fuel-fabrication.aspx

[7] *Acceptable Standard Format and Content for Fundamental Nuclear Material Control (FNMC) Plan Required for Low-Enriched Uranium Facilities,* US Nuclear Regulatory Commission NUREG-1065, Revision 2, 1995.

[8] J. Hockert and T. Bjornard, "Material Control and Accounting Design Considerations for High-Temperature Gas Reactors," Idaho National Laboratory (INL), Idaho Falls, ID, INL/EXT-11-22622, 2011.

[9] AREVA NP Inc., "Pebble Bed Reactor Technology Readiness Study," Technical Data Record 12-9151714–000, October 18, 2010.

[10] J. Disser, "Preliminary Safeguards Assessment for the Pebble-Bed Fluoride High-Temperature Reactor (PB-FHR) Concept," Idaho National Laboratory (INL), Idaho Falls, ID, INL/COM-16-38642, 2016.

[11] E. T. Gitau and W. S. Charlton, "Safeguards System Development for a Pebble-Fueled HTGR," presented at the 52nd Annual Meeting of the Institute of Nuclear Materials Management, Palm Desert, CA, July 17–21, 2011.

[12] *Instructions for the Preparation and Distribution of Material Status Reports (DOE/NRC Forms 742 and 742C),* US Nuclear Regulatory Commission NUREG/BR-0007, Revision 8, 2019.

[13] NRC Inspection Manual Chapter 2683, "Material Control and Accounting Inspection of Fuel Cycles Facilities"

[14] 10 CFR Part 37, Appendix A - "Category 1 and Category 2 Radioactive Materials."

[15] J. Fast, J. Chenault, B. Glasgow, D. Rodriguez, B. VanDevender, and L. Wood, "Spent Fuel Measurements," Pacific Northwest National Labortory (PNNL), Richland, WA, PNNL-23561, 2014.

APPENDIX A. MODEL MC&A PLAN OUTLINE

APPENDIX A. MODEL MC&A PLAN OUTLINE

This annex contains the model of a material control and accounting (MC&A) plan for pebble bed reactors (PBRs). Topical areas of MC&A in which the authors expect challenges include additional discussion and initial thoughts and approaches to address these challenges. The outline is based on NUREG-2159, Regulatory Guide 5.29 Revision 2, and ANSI N15.8-2009. The sections of the outline taken from the NUREG are shown in **boldface text inside boxes**. Assessments and comments are contained in regular text.

Note: for the outline, the report uses NUREG-2159 as a guide for the MC&A plan format, which was drafted in anticipation of the proposed rule change in Title 10 Code of Federal Regulations (CFR) Part 74. While the proposed rule change was discontinued in 2019, the NUREG template was used because the language is considered useful and the regulatory intent is still the same.

A.1. INTRODUCTION

The Atomic Energy Act of 1954, as amended, directed the US Atomic Energy Commission (AEC) to regulate the receipt, manufacture, production, transfer, possession, use, import, and export of special nuclear material (SNM) to protect the public health and safety and to provide for the common defense and security. The Energy Reorganization Act of 1974 transferred all the licensing and related functions of the AEC to the US Nuclear Regulatory Commission (NRC).

The principal requirements for SNM licensing are found in Title 10 of the Code of Federal Regulations (CFR) Part 70, "Domestic Licensing of Special Nuclear Material," and 10 CFR Part 74 (10 CFR Part 74), "Material Control and Accounting of Special Nuclear Material. "Regulations in 10 CFR 70.22 (b) specify that a full description of the applicant's program for the control and accounting of such SNM must be contained in a license application to show how compliance with the graded material control and accounting (MC&A) requirements of 10 CFR Part 74, Subparts B–E, will be accomplished. This document describes the standard format and content suggested by the NRC for use in preparing MC&A plans for facilities authorized to hold SNM of moderate strategic significance.

This introduction describes the basis of the four general performance objectives of 74.41(a) "General Performance Objectives" and the MC&A system features and capabilities needed to meet the objectives. Chapters 3–11 address the program capabilities needed to maintain accurate, current, and reliable information on—and confirm the quantities and locations of—SNM in the licensee's possession. Chapters 13 and 14 address the program capabilities needed to promptly investigate and resolve anomalies indicating a possible loss of SNM and provide information to aid in the investigation and recovery of missing SNM. Chapter 15 addresses recordkeeping requirements. These 15 chapters are intended to provide an outline for an acceptable MC&A plan for facilities authorized to hold SNM of moderate strategic significance.

The acceptance criteria are for the use of applicants (or licensees) and NRC licensing reviewers. An application or proposed revisions that meet these criteria should be acceptable to the NRC staff. However, comprehensive criteria are included as examples, and each applicant or licensee should develop an MC&A program and plan that take into account the unique features of its particular operation. When additional guidance is available on particular topics, an appropriate reference is included in the acceptance criteria section. Recommendations in this document provide guidance to applicants and licensees. Licensees may use this guidance when making changes to their existing approved MC&A plans.

In preparing MC&A plans, applicants should keep in mind the capabilities specified in 10 CFR 74.41, "Nuclear Material Control and Accounting for Special Nuclear Material of Moderate Strategic Significance," 10 CFR 74.43, "Internal Controls, Inventory, and Records," and 10 CFR 74.45, "Measurements and Measurement Control." They should also consider the general performance objectives specified in 10 CFR 74.41(a), "General Performance Objectives." Because 10 CFR 74.41, 74.43, and 74.45 are performance-oriented regulations, they do not contain a detailed set of technical specifications. With this flexibility, applicants and licensees have many alternatives for how their overall MC&A program is designed, managed, and operated, which permits a risk-informed, performance-based approach that focuses on MC&A activities most important to safeguards. Accordingly, this document does not cover all possible methods that a licensee might use to meet the MC&A requirements. Instead, this document provides examples of acceptable MC&A approaches that may be used. This guidance is intended for use by applicants,

licensees, and the NRC safeguards licensing reviewers. Users should not regard acceptance criteria as rigid, fixed standards. That is, a lower effectiveness of one capability relative to a particular aspect is acceptable if there is a compensating system feature, or combination of features, that provides an overall effective safeguards system. In the final analysis, an NRC reviewer must find that the applicant's or licensee's MC&A plan provides adequate assurance that all applicable regulatory requirements will be met.

The contents of an MC&A plan are discussed in Chapters 3–15 below. The body of an approved MC&A plan will be made a condition of license in accordance with 10 CFR 70.32(c), and compliance with the MC&A plan commitments and pertinent procedures will be inspectable. Explanations and discussions appearing in the body of the plan should be sufficiently detailed and precise so that NRC licensing reviewers, NRC inspectors, and licensee personnel responsible for developing and implementing the plan have a clear and common understanding of what the MC&A plan requires.

The annex (or appendix) of an MC&A plan should provide supplementary and general information about the facility and the MC&A program and subsystems (e.g., copies of blank record forms, site map, process diagrams, an example of standard error of the inventory difference [SEID] calculation, etc.). The annex will not be incorporated as a condition of license and will not be the basis for inspection. Thus, descriptions presented by the applicant or licensee to meet regulatory requirements must be in the plan itself, rather than the annex, and must provide adequate detail so as not to be largely dependent on examples or supplementary information in the annex for proper understanding. Procedures detailed in the annex may be changed without NRC approval or notification provided that the changes do not degrade plan commitments and capabilities.

Preparation of an MC&A plan with this standard format will assist the NRC in evaluating the plan and in standardizing the licensing and review process. However, the NRC does not require conformance with the standard format. An applicant may use a different format if it provides an equal level of completeness and detail.

A.2. GENERAL PERFORMANCE OBJECTIVES, RELATED REQUIREMENTS, COMMITMENTS, AND ACCEPTANCE CRITERIA

The following information discusses the basis of these general performance objectives in Subpart D, "Special Nuclear Material of Moderate Strategic Significance," of 10 CFR Part 74 (applicable to NRC licensees authorized to hold special nuclear material (SNM) of moderate strategic significance).

Since these are general performance objectives, the majority of these performance objectives and requirements will apply to PBRs. Current practices for addressing this section of the MC&A plan would be applicable for PBRs if the following observation is considered.

Section 74.41(a)(3)(ii) states that the facility personnel must be able to rapidly determine whether the actual loss of "10,000 g or more of uranium-235 contained in uranium enriched up to 20%" has occurred. This limit seems more appropriate for a fuel cycle handling bulk uranium than a PBR. For example, this limit is equivalent to approximately 10,000 TRISO fuels pebbles at 10% enrichment and 5,000 pebbles at 20% enrichment. A limit set this high would likely not be meaningful when applied to controlling fuel in a PBR. Sections in this report on item control will discuss the application of a lower limit of 300 g, as used in other parts of Subpart D, and its potential applicability.

A.2.1 MAINTAIN ACCURATE, CURRENT, AND RELIABLE INFORMATION ON, AND CONFIRM THE QUANTITIES AND LOCATIONS OF SNM IN THE LICENSEE'S POSSESSION

Current practices for addressing this section of the MC&A plan would be acceptable for a PBR. See the discussion about the use of a dynamic inventory, concept of active inventory, and SEID limits as a percentage of active inventory.

The purpose of this objective is to verify the presence of all SNM held by the licensee, and to detect the occurrence of any significant loss, including possible theft or diversion. To maintain current information on all such SNM, licensees should have in place a program that provides timely, accurate, reliable information about the quantity and location of

SNM in their possession. Accurate information means that item quantities for plutonium, the element uranium, and the isotopes uranium-235 (^{235}U) and uranium-233 (^{233}U) are based on measured values or on reliable information. Reliable information means that the quantity of SNM in an item and the location of all items are known (except for items in solutions with a concentration of less than 5 grams of ^{235}U per liter and items of waste destined for burial or incineration). The location designations must be specific enough to provide for the retrieval of the items in a prompt manner. *Reliable information* also means that the quantities and locations of all nonexempt SNM material, and items listed in the accounting records, are correct and verifiable.

The licensee or applicant should accurately account for all SNM that is received and shipped by maintaining reliable records based on accurate measurements. When a shipment is received, the licensee should begin monitoring movement and location of the material within the facility using item control procedures (1) to monitor the location and integrity of items until they are processed, and (2) to ensure all SNM quantities of record associated with receipts, shipments, discards, and ending inventory are based on measurements. Monitoring the material in process may involve the use of process or material control data. Licensees and applicants should maintain a detailed and accurate recordkeeping system for the generated data that provides knowledge of the material's location in a timely manner.

The licensee must conduct total plant physical inventories at intervals not to exceed 9 calendar months, in accordance with 10 CFR 74.43(c)(7). Each physical inventory must be conducted in a manner so that the detection of any actual significant loss, including possible theft or diversion, would be assured by evaluating each inventory difference (ID) using a standard error of the inventory difference (SEID) that is less than 0.125 percent of the active inventory. As a result, the investigation and reporting of any ID that exceeds three times the SEID is equivalent to a hypothesis test that provides 90 percent power for detecting a discrepancy as small as 0.4 percent of active inventory at a 5 percent false alarm rate.

The licensee should verify the presence of all Category II SNM held under license, as documented in its accounting records. This verification is normally accomplished by the following means:

- **a shutdown and cleanout of processing equipment;**
- **measurement of cleanout materials and measurement of any materials not previously measured in their existing form;**
- **visual verification (on a 100 percent basis) of the presence of all possessed SNM items (by means of unique item identities); and,**
- **confirming the SNM quantities associated with unencapsulated and unsealed items on ending inventory.**

However, a dynamic (i.e., non-shutdown) inventory of some or all processing equipment may be used if the measurement uncertainty associated with the total material balance (for the inventory period) is within the 0.125 percent of active inventory constraint specified in 10 CFR 74.43(c)(8)(iii) and 10 CFR 74.45(c)(4).

Chapter 7 of this document details recommendations pertaining to physical inventories. In summary, a total plant physical inventory involves:

- **verifying the presence, on a 100 percent basis, of all uniquely identified SNM items listed in the accounting records;**
- **measuring (by direct measurement or, if direct measurement is not feasible, by indirect measurement) all bulk SNM quantities on hand (i.e., all SNM not in item form);**
- **measuring any items not previously measured;**
- **verifying the identity and integrity of all encapsulated items and items affixed with tamper-indicating devices (TIDs); and**
- **measuring an SNM-related parameter for a sample of randomly selected unencapsulated and unsealed items, based on a statistical sampling plan, to verify the previously measured quantities of SNM contained in such items.**

The physical inventory program should be managed and maintained independent of the production or operations organization, but it should not be excluded from using process monitoring and production control data.

There is some question about the value of a 9-month physical inventory frequency, which is required for Category II facilities under the current regulation, versus the 12-month inventory frequency that is used for LWRs. The 9-month period is intended for a traditional fuel cycle facility. The sections on physical inventory discuss potential applications of containment surveillance that might provide sufficient control against credible diversion scenarios such that an increased inventory frequency may or may not add value.

The statement above about dynamic (i.e., non-shutdown) inventory is useful because it illustrates another difference between PBRs and current facilities: the dynamic versus static nature of the inventory in the reactor. Because the reactor will not be shut down for inventory, there is some question as to how “active inventory” should be calculated because traditional approaches likely will not meet the original intent when applied to a PBR. The report revisits these differences in the sections on SEID and physical inventory. The section on physical inventory for the reactor vessel discusses possible approaches for establishing the physical inventory values contained within.

This topic of shut down and clean out is not appropriate for the PBR reactor systems. A reactor, even when shut down, will likely never be cleaned out, and certainly not for nuclear material inventory purposes. There may be parts of the pebble flow and processing systems that could be shut down and cleaned out for inventory, but how or why this might be necessary is not clear.

A.2.2 CONDUCT INVESTIGATIONS AND RESOLVE ANY ANOMALIES INDICATING A POSSIBLE LOSS OF SPECIAL NUCLEAR MATERIAL

The regulatory intent, while not articulated in this section of NUREG 2159, is found in Sections A.2.3 and A.2.4. That intent is the licensee, regardless of category of SNM, should have a formalized program to investigate and resolve anomalies indicating a possible loss of SNM.

A.2.3 PERMIT RAPID DETERMINATION OF WHETHER AN ACTUAL LOSS OF A SIGNIFICANT QUANTITY OF SNM HAS OCCURRED

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

As discussed further in Chapter 13, to meet the requirements of 10 CFR 74.41(a), the license or applicant should have a formalized program to promptly investigate and resolve any anomaly that may indicate a possible loss of SNM. Resolution of such anomalies means that the licensee has made a rapid determination as to whether an actual loss of a significant quantity of SNM has occurred, including possible theft or diversion. An anomaly detected during a material balance closure needs to be investigated and resolved in accordance with 10 CFR 74.43(c)(8)(iii).

Resolution of an anomaly depends on the type of indicator. Various types of anomalies at plants could occur from a wide range of possible underlying scenarios (e.g., from unidentified or inadequately monitored loss mechanisms, simple theft, or complex diversions). The investigation and resolution process should begin with a thorough review of the MC&A records to locate obvious errors. These might include omissions of entire items, incorrect entries to computer programs or records, transcription errors, incorrect estimates of the amount of holdup in equipment, or calculation errors. A detailed examination of the MC&A records for each material type should identify gross errors. The next stage in the resolution process would be to isolate the process or storage area that appears to be causing the anomaly. Once this is done, all of the information that contributed to the SNM quantities for that location should be verified.

If resolution still is not accomplished, the licensee should re-measure and sample material in the process or storage areas to verify quantities. If the investigation of an indicator results in a determination that an actual loss or theft has occurred, the loss or theft must be reported to the NRC in accordance with 10 CFR 74.11, “Reports of Loss or Theft or Attempted Theft or Unauthorized Production of Special Nuclear Material.”

A.2.4 GENERATE INFORMATION TO AID IN THE INVESTIGATION AND RECOVERY OF MISSING SNM IN THE EVENT OF AN ACTUAL LOSS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

If the NRC or other government agency deems it necessary to conduct an investigation of actual (or highly suspected) events concerning missing material, the licensee should provide any information it deems relevant to the recovery of material involved in a loss, theft, or diversion. **The burden shall be on the licensee to provide all information that it recognizes as being relevant, as opposed to providing only information that the investigators request. Chapter 14 provides additional information and recommendations concerning the provision of information to investigations.**

A.2.5 CONTROL ACCESS TO MC&A INFORMATION THAT MIGHT ASSIST ADVERSARIES TO CARRY OUT ACTS OF THEFT, DIVERSION, MISUSE, OR RADIOLOGICAL SABOTAGE INVOLVING SNM

This section was included in NUREG 2159 (September 2013) in anticipation of the rule change to add 10 CFR 74.3, "General Performance Objectives". With that change being terminated in 2019, this requirement does not appear here, but the intent would be covered in section A.15.3 and A.15.4 on the MC&A Record System and performance objectives of 10 CFR 74.41(a). Current practices for addressing the regulatory intent in the MC&A plan would be applicable for PBRs. However, <u>this is not a general performance objective</u>.

A.3. MANAGEMENT STRUCTURE

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs. This applies to the entirety of Section A.3.

The intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43(b)(1) through (4) is to require licensees to implement a management structure that permits effective functioning of the material control and accounting (MC&A) system and assures that the MC&A program performance will not be adversely affected by the plant management structure. Documentation, review, and approval of critical MC&A procedures, and the assignment of the key functions to specific positions, eliminate ambiguities about what is to be done by whom. The management structure is meant to separate key MC&A functions from each other to incorporate checks and balances that increase MC&A system reliability and make the theft or diversion of SNM less likely. It is also meant to free MC&A management personnel from conflicts of interest with other major functions, such as production. **Regulations in 10 CFR 74.43(b)(2) require that a single individual be responsible for the overall planning, coordination, and administration of MC&A functions. All licensee personnel who work in key MC&A positions must be trained to maintain a high level of safeguards awareness in accordance with 10 CFR 74.43(b)(4).**

A.3.1 CORPORATE ORGANIZATION

Licensees should describe the corporate structure and should identify all corporate organization positions that have responsibilities related to MC&A at the licensee's site. A description of the corporate-level functions, responsibilities, and authorities for MC&A program oversight and assessments should be provided. At least one corporate official should have responsibility for the control and accounting of all SNM possessed by the licensee.

A.3.2 PLANT OR SITE ORGANIZATION

Licensees should provide a description of the site's management structure emphasizing MC&A. The site management structure should be described to the extent that it can be clearly shown that the MC&A organization is independent of potentially conflicting responsibilities. This description should also indicate how responsibilities are assigned for the following functions:

- **The overall MC&A program,**
- **SNM custodianship,**
- **receiving and shipping of SNM,**
- **analytical laboratories,**
- **bulk and nondestructive assay (NDA) measurements,**
- **sampling operations,**
- **measurement control system,**
- **physical inventories, and**
- **onsite SNM handling operations.**

A brief description should be provided for each site-level position outside of the MC&A organization that has responsibilities for MC&A activities (e.g., sampling, mass measurements, analytical measurements, and measurement control). For each position, licensees should clearly describe the functions, responsibilities, and authorities.

A.3.3 MC&A ORGANIZATION

An organizational chart and position-by-position description of the entire MC&A organization should be provided. A licensee should designate an individual as the overall manager of the MC&A program, and the MC&A plan must demonstrate the assurance of independence of action and objectivity of decision for the MC&A manager. Two options for meeting the organizational independence are: (1) report directly to the plant or site manager, or (2) report to an individual who reports to the plant or site manager through a management chain with no production responsibilities.

A.3.3.1 Responsibilities and Authority

Licensees should provide a description that clearly indicates the responsibilities and authority of each supervisor and manager for the various functions within the MC&A organization. The description should indicate how the activities of one functional unit or individual serve as a control over, or checks on, the activities of other units or individuals. The MC&A plan should explain how coordination is achieved and maintained between the MC&A organization and other plant organizational groups that perform MC&A-related activities. A definitive statement should be made specifying how the MC&A manager assures appropriate review and approval for all written procedures pertaining to MC&A-related activities, and to any future revisions thereto, which are issued both within and outside of the MC&A organization. In addition to the MC&A manager function, the plan should address, at a minimum, the following functions:

- **nuclear material accounting,**
- **measurement control system,**
- **item control system, and**
- **statistical applications.**

Whenever more than one key MC&A function is assigned to the same person, the MC&A plan should clearly describe the checks and balances that preclude the following:

(A) performance of accounting or record control functions by individuals who also generate source data, and

(B) assignment of sole authority to any individual to overcheck, evaluate, or audit information for which he or she is responsible.

For individuals in management or supervisory positions, some modifications to procedures, such as restricting unescorted access to some areas, may be necessary to provide sufficient assurance that the system cannot be compromised.

A.3.3.2 MC&A Procedures

Regulations in 10 CFR 74.43(b)(3) require that the use of written MC&A procedures that are critical to the effectiveness of the MC&A system be described, and the approved MC&A plan must identify such procedures. Critical MC&A procedures are those written procedures that, if not performed correctly, could result in a failure to achieve one or more of the performance objectives of 10 CFR 74.41(a) and the program capabilities of 10 CFR 74.41(c). A licensee's development of its critical MC&A procedures, and any changes later made to them, should involve technical review by cognizant licensee personnel, be approved by line management directly affected, and also be approved by a level of management above the level responsible for executing the procedures. The MC&A plan should contain a definitive statement that the procedures will be followed. This set of critical MC&A procedures should, at a minimum, include procedures addressing the inventory control requirements listed in 10 CFR 74.43(c)(1)-(8), regardless of which facility organizational group is responsible for the particular MC&A system being addressed. Additionally, MC&A procedures should address:

- **accountability record system,**
- **sampling and measurements,**
- **measurement control system,**
- **item control system,**
- **physical inventories,**
- **investigation and resolution of loss indicators,**
- **determination of SEID, active inventory, and inventory difference**
- **providing information to aid in investigations**
- **MC&A recordkeeping**
- **independent assessment of the effectiveness of the MC&A program**
- **tamper-safing, and**
- **designation of material balance areas (MBAs) and item control areas (ICAs) and custodial responsibilities**

A.3.4 TRAINING AND QUALIFICATION REQUIREMENTS

This section of the MC&A plan should describe the training programs to be established and maintained to provide qualified personnel and to provide for the continuing level of qualification with respect to personnel assigned to MC&A responsibilities. Training procedures and qualification criteria should be discussed in definitive statements. Minimum qualification requirements should be stated for each key MC&A position.

A.3.5 MC&A PROGRAM DESCRIPTION

The length of this section and its level of detail will depend on the information provided in the previous sections of this chapter. The overall MC&A organization should be described in a way that explains how the general performance objectives of 10 CFR 74.41(a) and the capabilities of 10 CFR 74.41(c) will be effectively achieved. The individual who has responsibility for each of the following MC&A-related functions should be specified by title:

- **overall MC&A program management (Note: This individual should have no major responsibilities not related to MC&A.)**
- **measurements (Note: Responsibility may be divided on the basis of type of measurements [e.g., analytical laboratory measurements, NDA measurements, bulk measurements, and sampling]),**
- **measurement control,**
- **statistics,**
- **accountability records,**
- **item control,**
- **physical inventories,**
- **custodial responsibilities (e.g., SNM storage and movement controls),**
- **investigation and resolution of indicators that suggest possible loss of SNM,**
- **receiving and shipping of SNM,**
- **analytical laboratories, and**
- **MC&A recordkeeping system and controls.**

The MC&A program description should include a description of the policies, instructions, procedures, duties, responsibilities, and delegation of authority in sufficient detail to demonstrate the separation of duties or overchecks built into the MC&A program.

A.3.6 MATERIAL CONTROL BOUNDARIES

Although the concepts and definitions of Material Balance Areas (MBAs) and Item Control Areas (ICAs) are used in different NRC (e.g., NUREG-1065, Revision 2) and IAEA guidance documents (e.g., NSS-25G, *Use of Nuclear Material Accounting and Control for Nuclear Security Purposes at Facilities*), they are not a regulatory requirement in 10 CFR Part 74. The current regulatory requirement only has the concept of *internal control areas* as used in 10 CFR 74.43(c) and 74.45(b) of the Category II regulations.

Whether the terms MBA and ICA as appearing in other guidance documents are used or the term *internal control areas* is used, the regulatory intent is the same. This concept would apply to PBRs based on current practices.

This section of the MC&A plan should describe how the licensee establishes various material control boundaries to minimize the occurrence of, and facilitate resolution of, MC&A anomalies, such as IDs, missing items of SNM, and potential theft or diversion of SNM.

The MC&A plan should describe the establishment of MBAs and ICAs because they are the basis for the control and accounting for all nuclear material in the facility. An MBA or ICA should correlate to physical or administrative boundaries and monitored locations. The MBA or ICA should be designed to limit losses to a specific area, (i.e., the MBA should not be so large that it cannot localize inventory or process differences to a manageable level). Materials transferred into and out of an MBA or ICA must have quantitative measurements.

The MC&A plan should describe roles and responsibilities of nuclear material custodians for MBAs and ICAs. The material custodian should have direct interaction with the MC&A organization and should be located within the physical operations area. Custodians who are responsible for more than one MBA or ICA should not have the ability to make material transfers between MBAs or ICAs under their direct control.

A.3.7 COMMITMENTS AND ACCEPTANCE CRITERIA

In its MC&A plan, the applicant or licensee should provide definitive commitments that adhere to the regulatory requirements and meet acceptance criteria applicable to management structure. A finding that the licensee's MC&A plan for management structure is acceptable and in accordance with the internal control requirements of 10 CFR 74.43(b)(1) through (4) will be based on, but not limited to, the following acceptance criteria:

- **The authorship, approval authorizations, and effective dates of MC&A policies and procedures will be documented and will involve appropriate management and technical staff.**
- **The responsibilities and authorities for each position assigned a function having a significant impact on SNM control and accounting (including all positions authorized to control SNM movement, generate source data, define or implement measurement control requirements, and conduct data analysis) are clearly defined in a written position description that spells out the responsibilities for that position.**
- **The qualifications and experience required for each position assigned an SNM control and accounting function will be sufficient to permit adequate performance of the duties required of that position.**
- **The descriptions of the management structure and assignment of duties and authorities show that those responsible for each MC&A function will have sufficient authority to perform the function in the intended manner.**
- **The MC&A organization is separate from the production organization and also separate from organizations that generate source data, if practical; otherwise, independence of the functions is attained by suitable controls and overchecks.**
- **The responsibility for MC&A program management is designated to an individual at an organizational level sufficient to assure independence of action and objectiveness of decisions.**
- **No two key MC&A functions are assigned to the same person unless sufficient checks and balances are provided. As a consequence of this criterion:**
    - **Individuals who generate source data, such as performing measurements or perform shipping and receiving activities do not perform any accounting or record control functions unless suitable overchecks are provided to prevent falsification of both source data and accounting records, and**

- No individual has the sole authority to overcheck, evaluate performance, or audit information for which he or she is responsible.

- **Sufficient checks and balances are incorporated to detect falsification of data and reports that could conceal theft or diversion of SNM by a single individual, including an employee in any position and collusion between two individuals, one or both of whom have access to SNM.**

- **The responsibility for each MC&A function is assigned to a specific position in the organization, and the organization is structured in a way that the key functions are separated or overcheck one another. The position descriptions are available in writing to the personnel affected.**

- **All current critical MC&A procedures are made easily accessible to all affected individuals and are maintained to show for each procedure the following:**

  - **revision number,**
  - **date issued,**
  - **person who prepared the procedure, and**
  - **person who approved the procedure (as indicated by signature and date signed).**

- **Management policies are established, documented, and maintained to ensure that all critical MC&A procedures are adhered to, including measurement procedures used for accountability purposes.**

A.4. MEASUREMENTS

Current practices for addressing this section of the plan will be mostly applicable to PBRs. However, from a measurement perspective, PBRs are less complicated than fuel cycle facilities. Therefore, parts of this section written for more complex measurement systems would not apply. The NRC is not likely to see measurement systems proposed that warrant some of the more rigorous measurement and measurement control approaches outlined. For each part of Chapter 4, examples are provided.

REGULATORY INTENT

The intent of the 10 CFR 74.45(b) measurement capability requirements is to ensure licensees establish, maintain, and use a system of measurements to ensure that all quantities of SNM (both element and fissile isotope) in their accounting records are based on reliable measurements. Generally, licensees should follow written procedures for measuring SNM. These procedures should incorporate the use of reference standards, instrument calibration, and sampling. Licensees should ensure that procedures exist for all measurement systems to be used at the facility.

The regulatory language as expressed is intended more for fuel cycle facilities where measurement systems are used for verification and reporting of SNM quantities. The majority of measurement systems in a PBR are more likely to be used for confirmation purposes, with SNM quantities based on values established during the fuel manufacturing process.

For PBRs, reasonable approaches are likely to suggest some type of confirmation of an attribute to check for scenarios involving substitution or theft of fuel versus actual changes to declared values for individual pebbles. Also, since some designs propose to use a range of enrichments, measurements are likely to be used to manage or confirm pebbles are grouped according to correct strata of enrichment for both operational and MC&A purposes. The one exception would be the measurement systems or calculation methods used to establish burnup measurements for the spent pebbles. The measurement systems likely to be proposed and their use in establishing SNM content is discussed in the sections on physical inventory and shipper/receiver (S/R) confirmations.

A.4.1 MEASUREMENT POINTS

The material control and accounting (MC&A) plan should identify and describe each measurement that is used for accounting purposes. Measurements (1) establish the quantities in each custodial area, material balance area (MBA), or item control area (ICA) and in the facility as a whole, and (2) contribute to the desired capability to localize losses and to generate and assess alarms. Measurement points or sampling stations should be selected to provide quantitative information about material flows and inventories that will permit detection and localization of any loss or diversion or to confirm that no theft or diversion has occurred. Typically, three functional types of MBAs and ICAs are present: (1) processing, (2) storage, and (3) receiving and shipping.

Typical processing MBAs include: (1) processing areas, (2) decontamination and recovery areas, (3) laboratory areas, and (4) feed and product sampling and transfer areas. The NRC requires identification and definition of measurement points for processing MBAs because of the physical or chemical changes of the nuclear materials that occur in these MBAs. The storage, receiving, and shipping areas are typically ICAs.

See Section A.7 on Material Balance Areas. Functional MBAs for PBRs will not include a change in the physical or chemical form of the SNM. They will, however, result in changes in the isotopics of the fuel. In a sense, the fuel pebbles will be “processed” between the time after receipt, insertion into the reactor system and loops, and then exiting the reactor system as spent fuel. However, this is not what is meant by a processing MBA. Therefore, the concept of a processing MBA may not be applicable to PBRs.

A.4.2 MEASUREMENT SYSTEMS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The MC&A plan should describe in detail each measurement system used for nuclear material accounting purposes. The principal elements and operations involved in the measurement systems for MC&A encompass mass (or weight) or volume determination, sampling, chemical analyses for element and isotope, and nondestructive assay (NDA). Each measurement system also should be defined or identified by its unique set of the following parameters: (1) measurement device or equipment used, (2) standards used for calibration, and (3) standards used for control. Additionally, for analytical laboratory measurements, the following should be identified as well: (1) sampling technique and equipment used, (2) sample aliquoting technique, and (3) sample pretreatment methodology. Chapter 5 describes elements of the measurement control program (e.g., standards traceable to a national system) used for validating and determining control limits, precision, and accuracy levels for each measurement system used for accountability.

The MC&A plan should provide descriptions for each measurement system associated with bulk, analytical, and NDA measurements, and should identify, where applicable, any other measurement systems used for accounting purposes that do not fall within these categories. These descriptions should provide sufficient information to demonstrate how the systems are implemented to ensure the licensee’s capability to meet the precision and accuracy limits. The following sections provide examples of the types of information necessary for selected measurement systems.

A.4.2.1 Bulk Measurement Systems

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

For each weighing system, the applicant or licensee should specify the type of weighing device, the type of container(s) weighed, material within the containers being weighed, capacity of the weighing device (e.g., capacity not to exceed X kilograms), range to be used, sensitivity of the device (e.g., sensitivity is +/- Y grams), and the calibration frequency.

For each volume measurement system, the MC&A plan should identify the vessel (e.g., tank, column), capacity of the vessel to which the measurement applies (e.g., capacity not to exceed X liters), the material being measured, the volume

measuring device and instrumentation, the sensitivity of each device and system (e.g., sensitivity is +/- Y milliliters), the range of operation or calibration (or both), and the calibration frequency.

Weighing systems are expected. Their application is expected for *fuel component containers* shipped, received, and being inventoried (although not necessarily required). Volume measurement systems are likely not applicable because volume measurements are typically applied to bulk processes involving liquids or gasses. However, it is not clear if volume type measurements may be used in a PBR process, such as in the feed hopper or spent fuel extraction containers. Section A.7 includes a discussion about a hybrid bulk measurement system that will probably be relevant for the reactor vessel or perhaps more in line with dynamic inventory approaches used in enrichment facilities. However, rather than being used to derive SNM content, its purpose is more likely going to be to establish some statement of confidence about numbers of pebbles in the reactor vessel and its feed and withdrawal system containers. SNM quantities for the reactor vessel and perhaps associated recycle loops would likely be based on a summation of the pebbles originally reported SNM content. Section A.6.2 on statistics and Section A.7 on physical inventory further discuss the approach under consideration.

A.4.2.2 Analytical Measurement Systems

For each analytical measurement system, the MC&A plan should specify the following:

- **type of material or chemical compound (e.g., plutonium oxide (PuO_2), plutonium metal or alloy, PuO_2-uranium dioxide (UO_2), uranium hexafluoride (UF_6), uranium alloy, UO_2, uranyl nitrate solution) being sampled and measured,**
- **sampling technique(s),**
- **sample handling (i.e., pre-analysis sample storage and treatment),**
- **analytical method used,**
- **characteristics measured (e.g., grams of uranium or plutonium per gram sample, or ^{235}U or ^{233}U isotopic concentration),**
- **measurement interferences,**
- **expected measurement uncertainty, and**
- **types of calibration standard(s) and calibration frequency.**

This section will likely not be applicable for PBRs. Currently, the authors do not expect significant use of destructive analysis for MC&A purposes because presumably a pebble would have to have its integrity compromised to collect a sample. Although this would be possible for fresh fuel pebbles, it would likely not be needed. NDA can be used to perform confirmatory measurements, and accepting the shipper values will likely be sufficient. For spent fuel pebbles, this would require significant effort because of the fission products and would generate a different stratum of high-level waste with little benefit. NDA will already be used to estimate burnups, and the uranium and plutonium content per pebble is very low.

A.4.2.3 NDA Measurement Systems

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

For each NDA measurement system, the MC&A plan should identify the following:

- **the NDA equipment package (i.e., type and size of detector and type of associated electronics and computer interface, as appropriate),**
- **the type of container measured,**
- **SNM material type within container**
- **sampling technique(s), if applicable**
- **attribute measured**
- **measurement configuration (including source to detector distance)**
- **calculation method, and**
- **expected measurement uncertainties.**

There are several potential applications for NDA measurement systems which are likely to be applicable for confirmatory measurements of fresh fuel assay and spent fuel burnup. NDA measurement systems have also been suggested in methods to establish scrap (e.g., broken pebble) values. Burnup codes and NDA measurements on spent fuel pebbles would provide values for plutonium production and uranium depletion.

A.4.2.4 Other Measurement Systems

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

If applicable, the MC&A plan also should identify any other measurement systems used for accounting purposes that do not fall within the three categories covered by Subsections 4.2.1, 4.2.2, and 4.2.3.

Pebble counters, which are sometimes referred to as *fuel flow meters* for PBRs, would also be considered a measurement system in this process. In the literature reviewed, these types of devices are proposed to monitor the movement of pebbles through parts of the process.

A.4.3 MEASUREMENT UNCERTAINTIES

Measurement uncertainties are typically used to calculate S/R differences or SEID. This might have limited or a different type of applicability to control this process because many of the Key Measurement Points (KMPs) may be based on counting integral *fuel components* or pebbles, a process which is similar to item control. Current practices for addressing this section of the MC&A plan would be applicable for PBRs, as noted below.

Licensees should provide the expected measurement uncertainties of the described measurement systems. Variance components for calibration, sampling, random, and systematic error for each measurement system should be stated. Licensees should clearly identify the units in which the errors are expressed.

For the SNM content in an individual pebble given its low SNM content, measurement uncertainties in terms of absolute or gram values will be below a reportable quantity. Recall the example which used the proposed TRISO fuel where the total quantity of SNM will be between 7 and 9 g of low enriched uranium, or just under 1g ^{235}U before irradiation. After irradiation (between 80 and 90 GWD/MT) the pebbles contain less than 0.12 g of plutonium and less than 8.2 g of residual uranium at 3.8% ^{235}U. From a relative perspective using fixed energy, response function analysis with multiple efficiencies (FRAM) or multigroup analysis for uranium (MGAU), which are gamma-spectroscopy–based isotopic codes, measurement uncertainties on the order of 3–5% would be expected for the fresh fuel pebbles, which is more than sufficient for this material strata.

For weighing operations in which the gross weight of the container is used to infer the pebble count, the measurement or count uncertainty will depend upon two things: (1) the gross weight of the container with respect to the scale resolution and (2) the total mass consistency of the pebbles. The table below provides some example scale ranges and potential miscounts if the pebble weight is biased 1% for illustration purposes.

Table 1. Example Scale Ranges and Uncertainties with Respect to Fuel Pebbles

	PFK989-C600	PFK989-ES 1500	PFK989-ES3000	Unit
Max Capacity	600,000	1,500,000	3,000,000	g
Legal for Trade (Organization of Legal Metrology [OIML]) Readability	50	100	200	g
Legal for Trade (OIML) Resolution	12,000	15,000	15,000	divisions
Readability (min)	1	2	5	g
Resolution (max)	600,000	750,000	600,000	divisions
Repeatability at max load	1.2	5.0	10.0	g
Error of Indication at max load	+/- 7	+/- 25	+/- 50	g
Individual Pebble Weight	250	250	250	g
Max # of Pebbles	2,400	6,000	12,000	pebbles
Mass of Pebble if 1% low	247.50	247.50	247.50	g
Total Mass	594,000	1,485,000	2,970,000	g
Total Weight difference	6,000	15,000	30,000	g
Pebble Miscount	24	61	121	pebbles

In the case of calculated values for the irradiated pebbles, burnup codes for PBRs are not well benchmarked according to literature reviewed. This report includes some discussion of the impact of this uncertainty on the key measurement point for spent fuel transfers. The effect of this measurement uncertainty may be difficult to quantify without a better understanding of the final disposition path for the spent pebbles (e.g., repository versus reprocessing).

In the case of reprocessing, Section 9, SNM Calculations of ANSI N15.8-2009, the following language which also appears in 10 CFR Part 74 would apply:

> *9.2 Analysis of Results*
>
> *Refinement of the element and isotopic computations used in determining the SNM content of irradiated fuel should be considered as new technologies evolve. For reprocessed fuel, this may include a collection and comparison of reprocessing plant*

measurement data with computed data for fuel assemblies (note: in this case fuel assemblies would be fuel pebbles).

Pebble counters (versus conventional accounting methods such as mass determination) have a potential impact on measurement uncertainties with respect to the declared SNM inventory values for the PBR vessel and associated recycle loops. Historically, these have had some level of uncertainty. It is unclear what that level of uncertainty would be, and particular attention during the licensing process is warranted for these devices. It would likely make more sense to express the pebble counter uncertainty as "number of failures / number of operations" versus the traditional random, systematic approach used for other MC&A measurements.

The concept of measurement uncertainties and how they are traditionally propagated to determine the SEID will be different for PBRs because they are integral components. While an uncertainty on the total SNM in the facility could be determined, the MC&A system's goal is ultimately to determine if all of the pebbles are there. If all the pebbles are present in the form as expected, then it follows that all the SNM is present. This is based on an assumption that taking part of a pebble is not a credible scenario.

A.4.4 MEASUREMENT PROCEDURES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs, albeit with a more graded approach to reflect the non-bulk aspects of the PBR.

The licensee or applicant should define how it ensures that it establishes, approves, and maintains measurement procedures (i.e., methods). It can accomplish this by (1) making a definitive statement that it establishes and maintains an approved measurement procedure (i.e., method) manual or a set of approved manuals, (2) stating which organizational units are responsible for the preparation, revision, and approval of measurement procedures, and (3) defining the requirements for periodic review of the procedures.

Licensees and applicants should make a clear statement defining how their facilities ensure that a measurement procedure cannot be used for accountability purposes without documented approval. Each procedure should be approved by the overall MC&A manager and by the manager of the organizational unit responsible for performing the measurement. Measurement procedures also should be approved by the measurement control program manager.

The MC&A plan should provide a definitive statement that all SNM quantities in the material accounting records are based on measured values and that measurement systems are maintained for the measurement of SNM associated with the following:

- **additions to inventory (e.g., receipts),**
- **removals from inventory (e.g., shipments and measured discards), and**
- **material on ending inventory.**

For receipt of material, the licensee may use the shipper's measured values rather than its own measurements, provided that (1) a shipper–receiver comparison, based on attributes or confirmatory measurements, shows no significant shipper–receiver difference (SRD) as defined by 10 CFR 74.43(b)(7), (2) in the case of a significant difference between shipper and receiver, no significant difference exists between the shipper's value and the umpire value used to resolve the difference, or (3) the material in question is exempted from shipper–receiver comparison requirements (e.g., sealed sources and samples). However, when booking shipper's values, a licensee should use the shipper's measurement uncertainty when determining standard error of the inventory differences (SEID).

This section includes language that is more appropriate for fuel cycle facilities. For these facilities, the goal of the measurement systems and their control is to manage the impact of the measurement on SEID. As mentioned previously, for a PBR, the purposes of the measurement systems are more likely to be confirmatory and to assure an accurate count of the total numbers of pebbles. Therefore, the concept of

SEID and its application to PBRs will likely require a different approach. Further discussion can be found in Section 7 on physical inventory. Regardless, even confirmatory measurements proposed by the licensee should be covered by relevant measurement procedures.

A.4.5 SCRAP CONTROL

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Heterogeneous scrap that cannot be accurately measured in its received form need not be measured until after dissolution within 18 calendar months of receipt. In accordance with regulations in 10 CFR 74.45(b)(1)(iv), the after-dissolution measurement must include measurement of both the resulting solution and any undissolved residues before any co-mingling with other scrap solutions or residues. In the meantime, a licensee should use the shipper's value or an appropriate factor-based value for inventory purposes.

Scrap in the PBR is expected to be in the form of broken or non-integral pebbles. The guidance currently contained in ANSI N15.8-2009 under damaged cladding seems adequate with appropriate clarifications to match this type of fuel. The following paragraph is from ANSI N15.8-2009:

> *Section 7.6 Damaged Cladding – Severe damage to cladding, where rod structural integrity has not been maintained, has the potential to result in inadvertent physical separation and dispersal of fuel components from the fuel rod. Upon visual identification of inadvertent physical separation, an estimate of the SNM quantity and an engineering judgement concerning the origin of the SNM should be made and documented. The amount of irretrievable or inadvertent loss should be reported, if the quantity is reportable, as required in 10 CFR 74.13. Methods used to estimate SNM quantities include, for example, engineering calculation, engineering judgement, physical measurement of length, destructive or nondestructive measurement, and count of the number of pellets retrieved or missing.*

The following alternate wording could be used:

> *Section 7.6 Damaged Pebbles—Severe damage where pebble structural integrity has not been maintained, has the potential to result in inadvertent physical separation and dispersal of SNM from the pebble. Upon visual identification of inadvertent physical separation, an estimate of the SNM quantity and an engineering judgement concerning the origin of the SNM should be made and documented. The amount of irretrievable or inadvertent loss should be reported, if the quantity is reportable, as required in 10 CFR 74.13. Methods used to estimate SNM quantities include, for example, engineering calculation, engineering judgement, physical measurement examination, and destructive or nondestructive measurement.*

A.4.6 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs, noting the relevant comments in previous sections.

In its MC&A plan, the applicant or licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to measurements. For the NRC to find that a licensee's MC&A plan for assuring that all quantities of SNM are based on reliable measurements is acceptable and in accordance with 10 CFR 74.45(b), its decision will be based on, but not limited to, the following acceptance criteria:

- **A program of measurement procedures and methods is maintained for all SNM receipts, removals, and inventory items, and the licensee has based all quantities of SNM in the material accounting records on measured values.**

- **The licensee will identify measurement systems that are the key contributors to the total measurement standard error. It will review the list annually and update it as necessary. These are considered key measurement systems, and their standard deviations should be monitored and controlled by the measurement control program.**

- **A basic description or summary of each key measurement system that is used to generate SNM values for accountability purposes is provided. A *measurement system* is defined as any instrument or device, or combination of devices, used to derive (1) an element concentration, (2) an isotope quantity, (3) an ^{235}U enrichment or isotopic distribution, (4) a bulk material mass (weight), or (5) a bulk material volume. This system can be characterized by its random and systematic error components.**

- **The set of key measurement systems, based on recent (or anticipated) measurement control data and modes of process operations, is expected to account for at least 90 percent of the total measurement uncertainty contribution to the SEID.**

- **The recalibration frequency for each measurement system is compatible with its expected stability. Recalibrations for all measurement systems should be performed at frequencies compatible with widely established, or licensee demonstrated, stability for each particular system.**

- **All calibrations are made with the use of primary standards or primary reference materials (certified and issued by the National Institute of Standards and Technology, New Brunswick Laboratory, or equivalent organization) or with reference standards traceable to primary standards. The standards used for calibrations need not be representative of the unknowns to be measured by the system, unless they are to be regarded as a bias-free system that is calibrated during each time of use, in which case the calibrations standards must be representative.**

When determining an SNM quantity by weighing, sampling, and analyses, the net weight of material in each item within a uniform material batch (or lot)—such as blended plutonium oxide PuO_2 or UO_2 powder, plutonium metal, or sintered UO_2 pellets—must be determined by direct mass measurement. However, the element or isotope concentrations for the batch need not be determined for each container, but instead may be derived by sampling procedures, including:

- **Analysis of composite samples or measurements of representative items, objects, or samples selected by statistical sampling**

- **Use of concentration or enrichment factors determined from historical averages, controlled input specifications values, or empirical relationships where such values or relationships are periodically tested, their uncertainties or bounds have been determined to be within 2 percent of the factor value, and where diversions with material substitution are improbable.**

A.5. MEASUREMENT CONTROL SYSTEM

Practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed. There are comments under each section where the intent is geared more to measurement systems found in fuel cycle facilities versus what is expected for PBRs.

REGULATORY INTENT

The intent of the measurement control requirements in Title 10 of the Code of Federal Regulations (10 CFR) 74.45(c) is to ensure that measurement systems (described in Chapter 4) used to establish special nuclear material (SNM) accountability quantities be controlled by a formal measurement control system that results in a total measurement standard error within 0.125 percent of the active inventory quantity. In terms of a 95 percent confidence level, twice the standard error associated with a material balance total material control and accounting (MC&A) measurement uncertainty (for uranium-235 (^{235}U), plutonium, or uranium-233(^{233}U)) must be less than 0.25 percent of the active inventory. The U.S. Nuclear Regulatory Commission (NRC) also intends that the system provide bias estimates for licensees to use for adjusting inventory difference (ID) results and correcting shipper-receiver measurements for significant measurement biases.

The regulatory language as expressed is intended more for fuel cycle facilities that use measurement systems for verification, reporting of SNM quantities, and SEID calculation. As stated in Section 4, most measurement systems in a PBR are more likely to be used for confirmation purposes. Confirmatory measurement systems would still require some form of measurement control to monitor and provide assurance that they could accomplish their intended purpose.

An example would be a scale used to confirm the weight of a shipping container, which could be used along with verification of the integrity of the shipping container, to accept shipments. The NDA systems used to measure burnup and nuclear material content in the spent fuel pebble containers would be another example.

A.5.1 ORGANIZATION AND MANAGEMENT

Current practices for this section would be applicable for PBRs, but in a more graded fashion than implemented in a fuel cycle facility.

The organization and management of the measurement control system should be described in sufficient detail to show how licensees assign the measurement quality assurance function and how independence from the analytical laboratory and other units performing either sample taking or measurements is maintained. The measurement control system manager should be at a management level that is sufficiently high to ensure objectivity and independence of action. Thus, the measurement control system manager could either report directly to the overall MC&A manager, or if in a different organizational unit, be on the same level as the MC&A manager.

The licensee's measurement control system should be properly managed to ensure adequate calibration frequencies, sufficient control of biases, and sufficient measurement precision to achieve the capabilities required by 10 CFR 74.45(c).

The regulatory intent, as stated in Section A.5, is geared toward bulk-handling facilities where measurement systems are more complex and have a large potential impact on the SEID and thus the ability of the MC&A system to detect loss/diversion. This is an area that could be applied in a more graded fashion because of the nature and purpose of the measurement systems likely to be used in a PBR.

A.5.1.1 Functional Relationships

The relationship and coordination between the measurement control system manager, the analytical laboratory, and other measurement performing groups needs to be clearly defined. Adequate assurance should be provided so that the measurement control system manager has the authority to enforce all applicable measurement control requirements.

A.5.1.2 Procedures

The measurement control system procedures should be established and maintained in a manual that the licensee keeps current and readily available. This manual should contain all the currently applicable written procedures on measurement control and measurement quality assurance. The licensee should specify who has responsibility for preparation, revision, and approval of manual procedures. Individual measurement control procedures should have documented approval by the measurement control system manager. The procedures should address the following:

- **calibration frequencies and methods,**
- **standards used for calibration (i.e., description and storage controls),**
- **standards used for control (i.e., method of obtaining or preparation, and traceability),**
- **control standard measurements,**
- **replicate sampling and replicate measurements,**
- **verification of process control instrumentation through comparison with other process instruments,**
- **generation and collection of control data,**
- **control limits and control responses, and**
- **recordkeeping controls and requirements.**

A.5.1.3 Contractor Program Audits and Reviews

If measurement services are provided by an outside contractor or offsite laboratory, the review program used to monitor the offsite measurements must be described in accordance with 10 CFR 74.45(c)(2). The licensee should ensure that the contractor or offsite laboratory performing such reviews has an acceptable measurement control system to the extent that use of the contractor's measurements will not compromise the licensee's ability to meet any measurement or measurement control requirement in its MC&A plan. An initial review of the contractor's measurement control system should be conducted before licensee use of measurements performed by the contractor or offsite laboratory.

All contractor or offsite laboratory assessment findings and recommendations should be documented and submitted to both the measurement control system manager and the overall MC&A manager within 30 days of completion of the review. The two managers should arrive at an agreement on corrective actions to take based on their evaluation of the report, and they should transmit these findings to the contractor or offsite laboratory in writing. The licensee should not use measurements performed by such contractors or offsite laboratories until it has verified that the corrective actions have been instituted.

The persons who conduct a contractor review need not be employed by the licensee, but they should not be employed by, or in any way associated with, the contractor or offsite laboratory so that the independence of the conclusions may be maintained.

A.5.2 CALIBRATIONS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed.

The MC&A plan should summarize the licensee's calibration program and confirm that the licensee has written procedures covering the following topics:

- **calibration frequency for each measurement device or system,**
- **identification of the standards used for calibration of each measurement device or system,**
- **protection and control of standards used to calibrate measurement systems to maintain the validity of their certified or assigned values, and**
- **the range of calibration for each measurement device or system and the minimum number of calibration runs (observations) needed to establish a calibration.**

Unlike control standards, standards used for calibrating measurement systems need not be representative of the process material or items to be measured by the calibrated device or system. If practical, the standard used during the calibration process should be subjected to all the steps involved in the measurement process that the process unknowns are subjected to (e.g., sample pretreatment), but this need not always be the case. It is the primary measurement device, not necessarily the entire measurement system, that needs to be calibrated, especially when the primary measurement device is common to two or more measurement systems.

For example, the Davies & Gray titrimetric method is often used to analyze samples for uranium concentration of two or more different material types (e.g., UF_6, UO_2, uranyl nitrate hexahydrate solutions). In this case, more than one measurement system is involved because different sampling and sample pretreatment methods and different control standards are used. The potassium dichromate ($K_2Cr_2O_7$) titrant, however, is common to the systems; thus, the titrant is what is calibrated (or standardized) with a primary reference material such as certified $K_2Cr_2O_7$, certified U_3O_8, or certified uranium metal.

In the case of non-consumable standards used to calibrate measurement systems (e.g., weight standards), the frequency of recertification of assigned values should be specified. The recertification frequency should depend on how often the standards are handled, the standard's stability, and the adequacy of the controls used to maintain the integrity of the standards. The NRC usually considers biennial recertification of such standards to be acceptable.

The MC&A plan should contain a definitive statement that no SNM accountability value is based on a measurement that falls outside the range of calibration. The MC&A plan also should identify those measurement systems that are point calibrated. A point-calibrated measurement system is one in which the following are true:

- **The entire measurement system is calibrated with a standard or set of standards that is representative of the process unknowns that the system measures. That is, the representative calibration standard(s) undergoes all the measurement steps, and in the same manner, that the unknowns undergo.**
- **One or more calibration standards are processed and measured along with each unknown or set of unknowns measured. That is, the system measures both the standard(s) and unknown(s) during the same general time interval, with the same individual measuring methods.**
- **The measurement values assigned to the process unknowns are derived from the measurement response observed for the standard(s) that was measured along with the unknown(s).**
- **The measurement response for each unknown should fall within plus or minus 10 percent of the response for a standard measured at the same time as the unknown, or, as in the case of a low concentration unknown, the difference between the unknown's response and the standard's response should be less than four times the standard deviation associated with the standard's response.**

A.5.3 CONTROL STANDARDS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed.

For those measurement systems that are not point calibrated, a defined method for the periodic measurement of control standards should be established and followed. Control standard measurements serve the dual purpose of (1) monitoring the stability of a previously determined calibration factor, and (2) estimating the average system bias over a period of time (e.g., an inventory period). Licensees need to specify the minimum total number of control standard measurements during the time period, as well as the typical frequency, for each measurement system. Generally speaking, for each key measurement system, a minimum of two control standard measurements should be made during each week that the system is in use. For those key systems that are used infrequently during a given material balance period, more than two control standard measurements per week of system use may be necessary to provide a measurement system performance that is controlled such that the SEID will not exceed 0.125 percent of the active inventory.

The measurement control system should produce data that are representative of actual operating conditions and all errors that impact ID. The larger uncertainty estimates that collectively contribute 90 percent or more to the SEID estimator will be based on a minimum of 15 standard or replicate process material measurements, as appropriate.

Included within the set of key measurement systems should be any system used to measure an SNM quantity (during an inventory period) greater than 25 percent of the active inventory, regardless of its contribution to SEID. The minimum number of control standard measurements for any system used to measure an SNM quantity (during an inventory period) greater than 25 percent of the active inventory should be determined based on the system's characteristics, use, and frequency of control standard measurements. In any case, it should be greater than eight (i.e., the minimum number of control standard measurements may need to be set at a higher number than eight to ensure proper performance). The minimum number of control standard measurements is eight for non-key measurement systems that measure from 10 to 25 percent of the active inventory, and the minimum number of control standard measurements can be reduced to four, respectively, for those non-key systems used to measure less than 10 percent of the active inventory quantity.

Key measurement systems for the current inventory period are any set of designated measurement systems (of the licensee's choosing) that, based on the most recent previous period, account for at least 90 percent of the total measurement variance contribution to SEID. Included within the set of key measurement systems should be any system used to measure an SNM quantity (during an inventory period) greater than 25 percent of the active inventory, regardless of its contribution to SEID.

Control standards should be representative of the process material or items being measured. To be representative, the standards need not always be identical to the process unknowns; but any constituent of the process material, or any factor associated with a process item, that produces a bias effect on the measurement should be present to the same degree in the control standards. For scales used to weigh very large items, the control standard weights should be artifact standards (e.g., both empty and full containers) of certified mass to avoid a bias effect caused by buoyancy or point loading.

For each measurement system that is not point calibrated, the control standards that licensees should use for control standard measurements should be identified and described. Along with material composition and matrix factors, biases also can be induced by changes in (among other things) temperature, humidity, line voltage, and background radiation. Biases also can be operator or analyst induced. Therefore, the scheduling of control standard measurements should be based on the following considerations:

- **Does the variation between analysts or operators need to be considered and monitored?**
- **Can environmental variables contribute to measurement bias?**
- **Is bias likely to vary with respect to the time of day?**
- **Is a particular bias likely to be long term, short term, or cyclic in nature?**

- **Is bias a function of the process measurement values over the range of calibration (i.e., is the relative percent bias nonuniform over the range of calibration)?**

- **What controls or procedures are needed to ensure that sampling or aliquoting of the control standard is representative of the sampling or aliquoting of the process material?**

- **To estimate the bias for each measurement system, how much alike—in terms of chemical composition, uranium concentration, density, homogeneity, and impurity content—should the control standards be relative to the process unknowns?**

Control standards for weight/NDA measurements at PBRs must account for temperature, humidity, background radiation, etc. This will be significant for PBRs because a PBR is a power reactor, in which bulk type measurements are not typically performed. Therefore, variables such as temperatures (high), humidity, and background radiation (high) will need to be considered.

A.5.4 REPLICATE SAMPLING

Based on the measurement methods reviewed in previous designs, it was not clear whether replicate sampling in 10 CFR 74.45(c)(7) would apply to PBRs. Replicate sampling is typically used in measurements for bulk materials to determine the sampling error or the ability of the sampling method to obtain a representative sample of the nuclear material strata being analyzed. The sampling error is factored into the total measurement uncertainty for the method as applied to the strata. This in turn is one of the errors included in the SEID calculation. Again, since pebbles are discrete objects and are not bulk material, it was not clear whether replicate sampling would apply. The possible exception might be the measurement systems and approaches used for broken or scrap pebbles.

For systems involving sampling, duplicate measurements performed on single samples or measurements of replicate samples are necessary to estimate the combined analytical plus sampling random error. For non-sampling measurement systems such as nondestructive assay (NDA) and weight measurement systems, the random measurement variance component can be derived either from (1) replicate measurements performed on process items, or (2) the data generated from the measurement of control standards.

The licensee should ensure that replicate samples are independent of one another. The number of replicate samples measured for each analytical measurement system should be described. The number of replicate samples measured for each analytical measurement system during an inventory period should be equal to at least one of the following:

1) **100 percent of the accountability batches sampled (when less than 15 batches)**
2) **the greater of 15 samples or 15 percent of the accountability batches sampled**
3) **50 samples (when 15 percent of the batches is greater than 50)**

For non-key analytical measurement systems, the minimum number of replicate samples to be measured during an inventory period should be equal to one of the following:

4) **100 percent of the accountability batches sampled (when less than eight batches)**
5) **the greater of eight samples or 10 percent of the accountability batches sampled**
6) **25 samples (when 10 percent of the batches is greater than 25)**

For each measurement system involving sampling and analysis, the MC&A plan should indicate (1) how many samples are taken and measured for each accountability batch measurement, and (2) how many analyses are performed on each accountability sample. If two or more samples are used and the licensee performs one or more analyses per sample for each accountability batch measurement, replicate requirements are automatically met. If, however, one sample per batch is normally used for accountability purposes, then the replicate program should include a periodic taking of a second (i.e., replicate) sample.

For NDA and mass (weight) measurement systems, replicate data can be obtained either from the repeat measurements on production items or by using the data generated from the control standard program. That is, each

consecutive pair of control standard measurements (for a given NDA or mass system) can be regarded as a replicate pair. The minimum number of replicate measurements performed during an inventory period for a given key NDA or mass system should be as given in items (1), (2), or (3), above, except that the numbers or percentages are in terms of items measured, rather than batches sampled. Likewise, for non-key NDA and mass measurement systems, the minimum number of replicate measurements should be as given in items (4), (5), or (6) above.

The scatter in the repeat measurements is used to estimate the random error variance using a statistical technique known as the one-way analysis of variance. (The NRC recommends the statistical methods described in "Statistical Methods for Nuclear Material Management," NUREG/CR-4604, for satisfying the statistical requirements of 10 CFR 74.45, "Measurements and Measurement Control"; see also Chapter 6 of this document.) Replication not only improves the precision of results obtained from the statistical analysis of the measurement data; it also can detect gross errors in the data.

A.5.5 CONTROL LIMITS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed.

The licensee should establish both 0.05 (warning) and 0.001 (out-of-control) limits to use for control standard measurements for those measurement systems used for nuclear material accountability in accordance with 10 CFR 74.45(c)(10). Out-of-control limits are also to be used for replicate measurements and measurement of replicate samples. However, warning limits are optional for the replicate program. For point-calibrated systems, the assigned value of the standard(s) measured, along with the unknown(s), is assumed to be valid. If the standard's true value could change because of factors such as evaporation, moisture pickup, or oxidation, then the value of the standard should be checked periodically. Therefore, control limits for the verification measurements associated with such standards should be established. This is especially true for those point-calibrated systems that use a single standard, or aliquots from a single standard, over any extended period of time.

When a system generates a control measurement that falls beyond an out-of-control limit, the system should not be used for accounting purposes until it has been brought back into control (i.e., within the upper and lower warning limit).

Control limits should be recalculated at a predetermined frequency and modified, if required. The MC&A plan should clearly explain how control limits are established and the frequency for redetermining them.

A.5.5.1 Measurement Control Data Analysis

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Licensees should plot measurement control data, such as control standard measurement results, and the differences between measurement values of replicate pairs for generation of control charts. All control charts should be reviewed at least once every 2 weeks unless a measurement system was not used during that period. The review should assess the frequency of control data exceeding either the warning or the out-of-control limits and should also provide an evaluation for any significant trends.

A.5.5.2 Response Actions

Current practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed.

Either the analyst or the operator performing a control measurement or his or her supervisor should have the responsibility for promptly reporting any control measurement that exceeds an out-of-control limit. Such reporting should be made to the measurement control program manager (or his or her designee), who should have the responsibility and authority to carry out or direct the necessary response and corrective actions.

Minimum response and minimum corrective action requirements should be clearly defined. In addition, the measurement control manager (or his or her designee) should be responsible for, and have the authority for, determining and executing additional response and corrective actions, as deemed appropriate.

The minimum response to a reported incident of a control measurement exceeding an out-of-control limit should consist of the following:

1) **Verifying that the measurement system in question has been taken out of service with respect to accountability measurements.**

2) **Documenting the occurrence of the event.**

3) **Performing at least two additional control measurements.**

4) **Performing additional control measurements, if results of item 3 do not show the system to be back in control, using a different control standard or different replicate sample (as appropriate), recalibrating the measurement system, or making any necessary system repairs.**

5) **Reviewing measurements performed on the system in question since the last in-control run to determine if there is a need to remeasure any items.**

For those measurement systems that make a significant contribution to the SEID, the response to an out-of-control condition also should include the remeasurement of any samples (or items) the licensee measured before the out-of-control condition but after the last within-control measurement. The validity of the previous measurements may be established without a complete remeasurement of all the samples (or items) involved if remeasurement on a "last in, first out" basis is used. That is, the last sample (or item) measured before the out-of-control measurement should be the first to be re-measured, and review should continue in reverse order until two consecutive re-measurements are found to be in agreement with their initial measurement at the 95 percent confidence level.

A.5.6 COMMITMENTS AND ACCEPTANCE CRITERIA

This section is written with a strong focus on active inventory and SEID, which is more applicable to a bulk facility. Current practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed.

In its MC&A plan, the applicant or licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to the measurement control program. A finding that the licensee's MC&A plan for maintaining measurement quality and estimating measurement uncertainty values is acceptable and in accordance with 10 CFR 74.45(c) will be based on, but not limited to, the following acceptance criteria:

- **A measurement control system is followed by which all measurement biases associated with key measurement systems are estimated and any significant biases are eliminated from ID values and shipper or receiver differences.**

- **The measurement control system produces data that are representative of actual operating conditions and all errors that impact the ID estimate. The larger uncertainty estimates that collectively contribute 90 percent or more to the SEID will be based on a minimum of 15 standard or replicate process material measurements, as appropriate.**

- **The method to be used for estimating the SEID for the typical material balance, as shown in the annex, meets the following criteria:**

    - **All reasonable and probable sources of measurement error for the key measurement systems affecting IDs are included.**

- **The selection of the key measurements whose variances are to be included in calculating the standard error is justified by an analysis of the relative magnitudes of the variance components of a typical ID and their comparative effect on the SEID.**

- **Any measurement error standard deviations not actually determined by the measurement control program are shown to be reasonable, either by comparison with published state-of-the-art measurement performance in similar applications—see such sources as NUREG/CR-2078, "Handbook of Nuclear Safeguards Measurement Methods," dated September 1983—or with records of past performance data from the licensee's facility. Records showing these data must be available to the NRC.**

- **The total measurement uncertainty is controlled so that the SEID for each material balance period will be less than 0.125 percent of the active inventory for the material balance period. The calculation of the measurement contributions to SEID are traceable to the appropriate measurement error data and to the calibration standards used.**

- **The calculation of the SEID is performed in accordance with a recognized error propagation method. Such methods have been published in the recommended NUREG/CR-4604, Statistical Methods for Nuclear Material Management, dated December1988, as well as in TID-26298, "Statistical Methods in Nuclear Materials Control," 1973, and the IAEA statistics handbook (1989).**

- **Program data on the performance of each measurement system is used during the current material balance period, including estimates of bias, variance components for calibration, sampling, and replicate measurements (of the same sample).**

- **The approach used for bounding the total measurement standard error for a typical material balance period meets the following criteria:**

  - **All reasonable and probable sources of measurement error affecting inventory difference are included.**

  - **Any assumed measurement standard deviations are shown to be reasonable. They may be shown to be reasonable by comparison to either records of the licensee's past performance data or to published measurement performance in similar applications.**

  - **The calculation of the total measurement standard error is performed in accordance with a recognized error propagation method. Such methods have been published in the recommended NUREG/CR-4604 (1988), as well as in TID-26298 (1973) and the IAEA statistics handbook (1989).**

- **The measurement systems have adequate calibration frequencies, sufficient control of biases, and sufficiently small standard deviations to achieve the requirements of 10 CFR 74.41(c). A measurement control program is used—by both in-house activities and any contractor who performs MC&A measurement services for the licensee—to ensure that the quality of the measurements is maintained on a level consistent with the NRC requirements.**

- **The licensee should confirm that the accountability measurements provided by a contractor are controlled by a measurement control program, and the licensee should confirm that the contractor's measurement control program is adequate by conducting audit and assessment reviews of the contractor's program at intervals not to exceed 18 months.**

A.6. STATISTICS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs commensurate with the measurement systems proposed.

REGULATORY INTENT

Proper use of statistics is important to ensuring that the regulatory requirements in Title 10 of the Code of Federal Regulations (10 CFR) 74.41 ("Nuclear Material Control and Accounting for Special Nuclear Material of Moderate Strategic Significance"), 10 CFR 74.43 ("Internal Controls, Inventory, and Records," and 10 CFR 74.45 ("Measurements and Measurement Control"), are met. An effective statistical program will ensure measurement systems perform within control limits, measurement uncertainties are calculated and propagated, the inventory difference (ID) and standard error of the inventory difference (SEID) are properly determined, and significant shipper-receiver differences are identified. For example, 10 CFR 74.43(c)(8)(i) requires licensees to calculate the ID and SEID for the material balance period terminated by each physical inventory. Proper use of statistics is important to correctly propagate the uncertainties from all measurements into an accurate SEID value.

In theory, in the absence of any theft or diversion or measurement errors, the ID should always equal zero. For a facility that possesses only items, the ID should be zero. For an LWR, an ID different from zero is a serious problem because either there is a missing item that has been lost, diverted, or misplaced, or the bookkeeping practice is inadequate. For a process (bulk) facility, a non-zero ID is expected and can be either positive or negative as a result of many contributing factors, such as measurement uncertainties, measurement mistakes, recording errors, or unmeasured material holdup and losses.

A PBR could be considered a "bulk fuel facility" because the fuel pebbles in some designs are not identifiable as individual items.[1] In these designs, the pebbles logically match the concepts of *fuel components*, and their containers are analogous to *fuel component containers* as defined in ANSI N15.8-2009. This approach tracks the pebbles as either piece count as part of an item or as piece count or bulk quantity within a containment (e.g., feed hopper, reactor vessel, withdrawal container). As such, there may be some non-zero ID in a PBR. Timing for introduction of pebbles and removal of intact or broken pebbles may introduce possible uncertainties that could lead to an ID; therefore, particular attention should be paid to how physical inventory cutoff times are established and implemented. MC&A procedures should be developed to manage this.

A.6.1 DETERMINATION OF MEASUREMENT UNCERTAINTY

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

To achieve the objectives and capabilities of 10 CFR 74.41, each licensee or applicant should institute a statistical program that evaluates the measurement control and accounting (MC&A) data to ensure that (1) the measurement data are analyzed in a rigorous manner and (2) statistical tests and inferences concerning the status of the nuclear material possessed are appropriately tested. The NRC sponsored the development of a comprehensive reference that specifically addresses the statistical treatment of MC&A data. The statistical methods described in NUREG/CR-4604, as well as in TID-26298 and the IAEA statistics handbook (1989), are recommended by the NRC for satisfying the statistical requirements of 10 CFR 74.41, 74.43, and 74.45.

The MC&A plan should cover the following:

- **Contain a detailed discussion of the procedures and methodologies for estimating measurement variance components;**

[1] Although, some designs are considering uniquely identifying pebbles.

- **Discuss how biases are determined and how bias corrections are applied, including:**
  - **how often biases are estimated,**
  - **how the effect of the bias on the measured quantity of material in an item is determined,**
  - **when and how bias corrections to items are made,**
  - **how their effect on ID is determined,**
  - **when and how bias corrections are applied to the ID,**
- **Describe the procedure and means for determining active inventory;**
- **Provide all relevant information regarding the determination of the SEID; and**
- **Specify the methodology for determining ID threshold values as required by 10 CFR74.43 (c)(8)(iii). (See Chapter 7 for additional information on inventory difference limits and response actions.)**

A.6.2 DETERMINATION OF STANDARD ERROR OF THE INVENTORY DIFFERENCE

This section is challenging for PBRs because the traditional concept of SEID may be difficult to apply or may not be applicable. The reason is that pebbles are discrete objects. In areas of the PBR process such as fresh and spent fuel, where pebbles can be counted, the process is expected to follow approaches for item facilities, with the exception of the reactor vessel. See discussion and approaches for different strata expected within a PBR.

As defined in 10 CFR 74.4, the *standard error of inventory difference* means the standard deviation of an inventory difference that takes into account all measurement error contributions to the components of the ID. For special nuclear material (SNM) of moderate strategic significance, licensees should not include non-measurement contributors to the ID in the SEID calculation. Including only measurement uncertainty, SEID (for either uranium, ^{235}U, plutonium or ^{233}U, as applicable) can be expressed as follows:

$$\boldsymbol{SEID} = [\sum_{i=1}^{k} (G_i)^2 \{(\sigma_i)_s{}^2 + \frac{(\sigma_i)_r{}^2}{n}\}]^{\frac{1}{2}}$$

where

k = number of measurement systems,

G_i = total grams uranium (or ^{235}U) measured during inventory period by measurement system i,

$(\sigma_i)_s$ = systematic error standard deviation for measurement system i,

$(\sigma_i)_r$ = random error standard deviation for measurement system i, and

n = number of batches (items) measured by measurement system i.

In theory, SEID provides the uncertainty, at the 67 percent confidence level, of the ID estimate.

The MC&A plan should provide all relevant information on the determination of SEID. Licensees should also commit to having at least two individuals independently verify the accuracy of the SEID calculation for each total plant material balance. If the SEID value is calculated by a computer, then the verification by two or more persons involves a checking for correctness of the input data used by the computer to calculate SEID.

Fresh and Spent Fuel Areas

The fresh fuel and spent fuel receipts, shipments, and storage areas will have containers with established quantities of nuclear material. These containers would be sealed during receipt and storage. They would be opened during fuel feed operations. If the facility is divided into more than one internal control area or MBA, then these areas could be considered ICA(s) as defined in NRC guidance documents. For the parts of the process where pebbles can be individually counted or measured, because of the size and weight of the pebbles these are expected to have similarities with accountancy for item facilities. The initial assessment indicates it may be reasonable to obtain high confidence in counting fresh and irradiated fuel. However, literature reviewed for historical operations in both Germany and China indicated there was some uncertainty about the ability to accurately count large numbers of pebbles. The approach and design used for fuel flow (i.e., pebble counting) monitoring and system redundancy was not clear. Therefore, this may or may not be an issue for more modern designs.

Assuming the uncertainty in pebble counting, these two areas of the process can be addressed, unless there is a missing pebble, the ID should be zero, and so should the SEID in the non-reactor parts of the process. An item approach to accounting is discussed in Section A.8 with the goal to introduce ideas on controlling the pebble-counting uncertainty. The reported quantities of SNM would be based on the sum of values of the pebbles. Those values themselves would be based, depending upon strata, on a combination of book, measured, or calculated values. To calculate the item difference, Eq. (1) demonstrates a simple balance equation.

$$ID = BI + A - R - EI \tag{1}$$

where

BI = beginning physical inventory,
EI = ending physical inventory,
A = additions to beginning inventory,
R = removals from inventory, and
ID = inventory difference.

From Eq. (1), the SEID is calculated as the square root of the variances for each term in the ID, as shown in Eq. (2).

$$SEID = \sqrt{Var\ (BI) + Var(A) + Var(R) + Var(EI)}, \tag{2}$$

where SEID is the standard error of the ID.

If there is an SEID for these parts of the process, it would be a function of the uncertainty in the pebble counts and could be converted to a gram value based on the amount of material in a pebble. For this part of the process, thinking about the ability to detect missing intact pebbles may be more useful than taking part of a pebble if it is determined this is not a realistic or credible scenario.

Although the total numbers of pebbles may be well known, there will be still be some uncertainty about the total quantity of SNM contained in those pebbles. This uncertainty would not affect detection of theft or diversion of SNM in pebble form. Only if the pebbles were reprocessed would uncertainty in the nuclear material quantity calculated from fuel burnup have an impact. In a case of reprocessing, Section 9.2, *Analysis of Results, SNM Calculations* of ANSI N15.8-2009, the following language would apply:

Refinement of the element and isotopic computations used in determining the SNM content of irradiated fuel should be considered as new technologies evolve. For reprocessed fuel, this may include a collection and comparison of reprocessing plant measurement data with computed data for fuel assemblies (note: in this case fuel assemblies would be fuel pebbles).

Fuel in the Reactor Vessel

SEID approaches applied to the reactor vessel and potential scrap flows could follow a hybrid approach that is used in some bulk facilities. As stated previously, reactor physical inventory as described in current regulations for power reactors will not apply because it assumes item accounting by fuel assembly serial number and location.

The simplest approach for inventory and reporting the quantity of pebbles and SNM values within the vessel could be based on inputs/outputs. For this part of the process, other MC&A elements such as material containment and surveillance, in addition to the physical characteristics of the product (heat/radiation), would need to address credible diversion paths and diversion path scenarios. If it is determined that the overall system has the ability to provide sufficient assurance of preventing or detecting theft or diversion, then this approach may be adequate.

If not, a more complex or alternate approach would be needed to monitor and inventory the reactor to determine SEID, along with options for making some statement of confidence in the declared reactor vessel inventory values. Although currently only applicable to higher category facilities, the concepts found in 10 CFR Part 74.51 Subpart E, "Formula Quantities of Strategic Special Nuclear Material" and elaborated in NUREG-1280 Rev. 1, "Process Monitoring," may be useful for consideration. The intent of this approach would be to provide early indications of abrupt or protracted theft or diversion. One challenge from a regulatory perspective is that this is a Category I requirement, so detection requirements as currently stated may be overly burdensome. A graded approach applying key concepts from this method would be useful to consider.

The option under consideration for inventory is a material control test using process control parameters. This method uses reactor output parameters (monitoring of the process/operations) to determine if one of the parameters (e.g., the amount of fuel) is inconsistent, which would indicate possible loss of nuclear material. Removing pebbles from a PBR without replacement would change the core flux/power level. This would certainly be the case for abrupt removal of a large number of pebbles. A protracted removal of pebbles might be possible without affecting core power because fuel is constantly flowing from the reactor for testing and recycle or withdrawal. Some application of trend analysis would be necessary to address this potential theft/diversion scenario.

For the South African pebble bed modular reactor design [9], a sensitivity study was performed for the detection of fertile targets inserted for a single pass in the core. This study assessed the effect of introducing, in addition to normal fuel, target pebbles loaded with natural uranium particles. Target pebbles are mixed with the fuel pebbles in order to have a homogenous distribution of these pebbles in the core. Calculations have been performed for two densities of target pebbles: one that represents an additional uranium mass of 0.1% (in natural uranium) to the total enriched uranium mass of the fuel core, and one that represents an additional mass of 0.4%. The added natural uranium increases the number of neutron captures in the core, which have to be compensated by increasing the number of normal fuel pebbles added every day (and consequently sending the same increased number of spent fuel pebbles in a spent fuel bin) to keep the same reactivity margin (in the initial core) in order to be able to continue its operation in a sustainable way. The result of the calculation is that the daily number of fresh fuel pebbles must be increased 21% in the first case and 95% in the second case. Moreover, the quantity of plutonium produced in the target pebbles is very low, and it would take 92 years in the first case to get a significant quantity (SQ), and in the second case it would take 23 years. This shows that even with a very low plutonium production, the introduction of target pebbles would be easily detected by the fresh fuel consumption; there would also be abnormal signals for the core flux and burnup measurements, but their sensitivity has not been determined.

In conclusion, Eq. (3) demonstrates the relationship between the alarm threshold for process monitoring and specific goal quantities for this concept. The equation could be used with changes as needed to desired detection probabilities:

$$A = -G + \bar{x} + K\sigma_x, \tag{3}$$

where

A = alarm threshold,
G = goal quantity,
x = test statistic,
$\bar{x}$ = test statistic mean,
K = factor based on probability of detection per formula kilogram, and
σ_x= standard deviation of the test statistic in formula kilogram.

Specifically, how this process monitoring might be applied to support MC&A for PBRs is not known at this point, and further analysis is needed.

A.6.3 BIAS CORRECTIONS

From a statistical perspective, biases that are not statistically significant (at the 95 percent confidence level) should never be applied as adjustments (corrections) to the accounting records. To obtain the best estimate of the true inventory difference value, such insignificant biases should be applied as a nonaccounting adjustments to the initially calculated inventory difference (as obtained from the ID equation: ID = BI + A − R − EI). Such practice is not deemed necessary, however, for material balances pertaining to SNM of moderate strategic significance and is thus optional.

For biases that are statistically significant (at the 95 percent confidence level), it is common practice to adjust the accounting values for individual items if the bias effect (as grams element and grams isotope) on the item is more than the rounding error for that item, and if less than the rounding error, to apply the bias as a nonaccounting adjustment to the ID. Under a well-designed and well-managed measurement control system, bias corrections to the accounting records should seldom, if ever, be necessary under the above-mentioned approach. Although the effect on an individual item from a statistically significant bias should be negligible, the effect of that bias across hundreds or thousands of items (whose SNM values were derived from the biased measurement system) could have a very significant impact on the ID value.

Nevertheless, in view of the very large quantity of SNM of moderate strategic significance that is of a safeguards significance, the NRC acceptance criteria does not normally call for applying bias corrections to either the accounting records or as an adjustment to ID unless the effect of a single significant bias or the net sum of all significant biases is unusually large.

As a minimum, to meet NRC acceptance criteria, a bias correction for a single key measurement system should be considered "significant," and thus applied either as corrections to the accounting records or as an adjustment to the inventory difference if (1) such bias is statistically significant at the 95 percent confidence level, and (2) either or both of the following are also true:

- **applying the correction would cause the ID to exceed three times SEID**
- **the bias is greater than 0.01 percent relative**

Additionally, the net algebraic sum (expressed as grams SNM) of all statistically significant (95 percent confidence level) biases from key measurement systems not defined as bias free, that have not been applied as a correction or

adjustment under either or both condition above, is considered to be "significant" and is to be applied as a net adjustment to the ID if applying such correction would cause the ID to exceed three times the SEID.

Unlike a traditional bulk-processing facility, in which a bias in measurement techniques can lead to situations that overstate SNM balances or understate various parts of the processes that involve different methods, most transfers will consist of integral pebbles. The number of pebbles transferred would be determined by either pellet counting or by weight. If a pebble-counting system tends to not count every pellet or to double count pellets, then a bias in the number of pebbles transferred would be created. Each instrument for determining the number of pebbles would have its own level of accuracy.

The measurement methods or calculation approaches applied to the inventory strata of scrap and process holdup can also produce potential biases. These strata are the result of pebbles that have lost their integrity, so calculation of SNM quantities would be based on a more traditional bulk inventory approach with some potential bias in determining the numbers of pebbles or detritus from pebbles lost to these output streams. The numbers of pebbles lost to these streams would be added to the pebble count removed from the reactor. Any bias, positive or negative, would therefore be reflected in the pebble count removed from the reactor. Historical data seem to indicate this stream will not be large, but this is an area to be reviewed during the licensing and assessment process.

Outside the MC&A systems for the reactor facility, there is discussion about potential bias in calculating burnup and correcting the SNM in the spent fuel pebbles to account for the burnup. This bias would only be identified if the spent fuel pebbles were reprocessed. Because this situation also occurs for traditional LWRs, it would not be unique to PBRs. The existing regulatory guidance for handling such bias or correcting these values would apply, and no changes are anticipated to be needed.

A.7. MATERIAL BALANCE AREAS, ITEM CONTROL AREAS, AND PHYSICAL INVENTORIES

Note that this Section A.7 combines the Section 7 (Physical Inventories) and Section 12 (MBAs, ICAs, Custodians) from NUREG-2159.

As also discussed in Section A.3.6, Material Control Boundaries, although the concept and definition of *Material Balance Areas* (MBAs) and *Item Control Areas* (ICAs) are used in different NRC guidance documents (e.g., NUREG-1065, Revision 2 and IAEA NSS-25G, Use of Nuclear Material Accounting and Control for Nuclear Security Purposes at Facilities), they are not a regulatory requirement in 10 CFR Part 74. The current regulatory requirement only has the concept of *internal control areas* as used in 74.43(c) and 74.45(b) of the Category II regulations.

Whether the terms *MBA* and *ICA* as they appear in other guidance documents are used, or if the term *internal control area* is used, the regulatory intent is the same, which is to establish material control boundaries that are designed to limit and localize potential losses to a specific area. Current practices for addressing this section of the MC&A plan would be applicable for PBRs for both the fresh and spent fuel areas. Approaches for the reactor vessel and associated recycle loops more closely resemble a dynamic inventory seen in an enrichment facility, where the pebbles would be considered in-process or in the process.

REGULATORY INTENT

Regarding MBAs and ICAs, the intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43 Internal Controls, is to ensure that the licensees establish controls that will enable them to identify inventory differences and item locations on a scale smaller than that of the entire plant. Licensees should designate MBAs and ICAs and assign custodial responsibilities for these areas to provide internal controls to deter or detect any diversion or misuse of special nuclear material (SNM) at the licensee's facility.

It is anticipated that the MBAs, ICAs, and custodians described in Section 12 of NUREG-2159 will apply to PBRs.

Regarding Physical Inventories, the requirements of Title 10 of the Code of Federal Regulations (10 CFR) 74.43(c)(1)-(8) pertain to the need to maintain inventory control by conducting periodic physical inventories to confirm that a loss, theft, or diversion of a significant quantity of special nuclear material (SNM) of moderate strategic significance has not occurred. Licensees are required by 10 CFR 74.43(c)(7) to conduct physical inventories at intervals not to exceed 9 calendar months. The principal method of confirming the presence of SNM is to establish and maintain inventory control and to periodically perform a physical inventory and compare it to the book (record) inventory. If all SNM is included, the expected difference between the book inventory and the physical inventory is zero plus or minus the measurement uncertainty associated with both the physical and book inventories. In any actual case, the size of the inventory difference (ID) and its uncertainty depends on measurement errors, as well as on various non-measurement contributors, such as recording errors, unmeasured losses, unmeasured residual holdup (see the glossary for definition of *residual holdup*). Licensees must maintain and follow the physical inventory procedures and instructions in 10 CFR 74.43(c)(5)-(8).

A.7.1 GENERAL DESCRIPTION

Current practices for addressing this section of the MC&A plan would be applicable for PBRs for the fresh and spent fuel parts of the process. See discussion on approaches for the reactor vessel and associated recycle loops.

The applicant or licensee should provide a general description of how physical inventories of the plant will be planned, conducted, assessed, and reported.

The material control and accounting (MC&A) plan should contain a definitive statement that physical inventory functions and responsibilities are reviewed comprehensively with the involved individuals before the start of each physical inventory.

The applicant or licensee should generate a book inventory listing, derived from the MC&A record system, just before the actual start of each physical inventory. Such listing shall include all SNM that the records indicate should be possessed by the licensee at the inventory cutoff time.

The licensee must report inventory difference and related information associated with each physical inventory of moderate strategic significance, pursuant to 10 CFR 74.17, "Special Nuclear Material Physical Inventory Summary Report," on an NRC Form 327. In addition, if any material associated with material codes 20-E3 and 20-E4 (i.e., high-enriched uranium), 70 (^{233}U), 50 (plutonium), or 83 (^{238}Pu) is possessed by the licensee, such material is subject to the physical inventory requirements. The licensee should report each material code inventory difference and associated information on separate NRC 327 Forms.

A.7.2 ORGANIZATION, PROCEDURES, AND SCHEDULES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The MC&A plan should explain the makeup and duties of the typical physical inventory organization. The individual having responsibility for the coordination of the physical inventory effort should be identified by position title. The MC&A plan also should indicate how the preparation and modification of inventory procedures are controlled.

The MC&A plan should contain a definitive statement that specific inventory instructions are prepared and issued for each physical inventory.

A.7.3 CUSTODIANS

No special considerations are expected for this process compared to other existing processes.

The MC&A plan should describe the roles and responsibilities of the custodians for MBAs and ICAs. Each custodian should have direct interaction with the MC&A organization, and such individuals should be located within the physical operations area. Custodians who are responsible for more than one MBA or ICA should not have the authority to make material transfers between MBAs or ICAs that are both under their direct control.

A.7.4 MATERIAL CONTROL BOUNDARIES

The MC&A plan should describe how the licensee establishes various material control boundaries to minimize the occurrence of, and facilitate resolution of, MC&A anomalies. Examples of such anomalies are IDs, missing items of SNM, and potential theft or diversion of SNM.

Because MBAs and ICAs are important foundations for controlling and accounting for all SNM in a facility, the MC&A plan should describe the process for how their locations are chosen. An MBA or ICA should correlate to physical or administrative boundaries and monitored locations. The MBA or ICA should be designed to limit losses to a specific area, i.e., the MBA should not be so large that the licensee cannot localize inventory or process differences to a manageable level. Materials transferred into and out of an MBA or ICA must be subject to quantitative measurements.

Figure A.1 shows an example of a PBR facility flow diagram illustrating how the fuel pebbles move around the reactor systems [10]. The fuel would be received in the facility within a container that could be counted as an item with a defined nuclear material content and number of pebbles. This would be in the fresh fuel receipts and storage area and may be an item control area. Then, a set number of pebbles is prepared for loading into the reactor through transfer into a feed hopper. As necessary to replace pebbles removed from the reactor inventory, pebbles would be loaded into the reactor. When the reactor vessel of a traditional LWR is closed, safeguards practices in the United States consider the reactor vessel to be an item; however, the reactor vessel of a PBR will have a continual flow of nuclear material into and out from the reactor vessel and cannot be considered an item [11]. At reactors under International Atomic Energy Agency (IAEA) safeguards, reactor vessels, even when sealed, are not considered to be an item, and the spent fuel content in the vessel is verified during every physical inventory performed while the core is open. There is some discussion regarding the definition of the reactor MBA for a PBR and whether recycle loops, feed hoppers, and withdrawal containers would be included in the MBA. Each of these areas will have a continually changing quantity of nuclear material.

When pebbles exit the reactor vessel, they are sorted according to whether they are damaged or intact. Damaged pebbles are sent to a withdrawal station, where they are deposited into a container. After this container is filled and its nuclear material contents are determined, it would become an item that would be transferred to a storage area. The burnup of each intact pebble is measured individually, and the pebbles are either recycled back to the reactor core or sent to a withdrawal station for loading into spent fuel containers. After a container is filled and its nuclear material contents have been determined, it would become an item that would be transferred to a storage area. The spent fuel and damaged pebbles storage area(s) constitutes an ICA(s). It should be noted that bulk cooling may be implemented initially before transferring to containerized storage. As cooling that enables access to the pebble surfaces would be more effective, containerization may not occur for the first few years after removal from the core. In this case the contents of the cooling bins/hoppers/racks would need to be assessed/monitored.

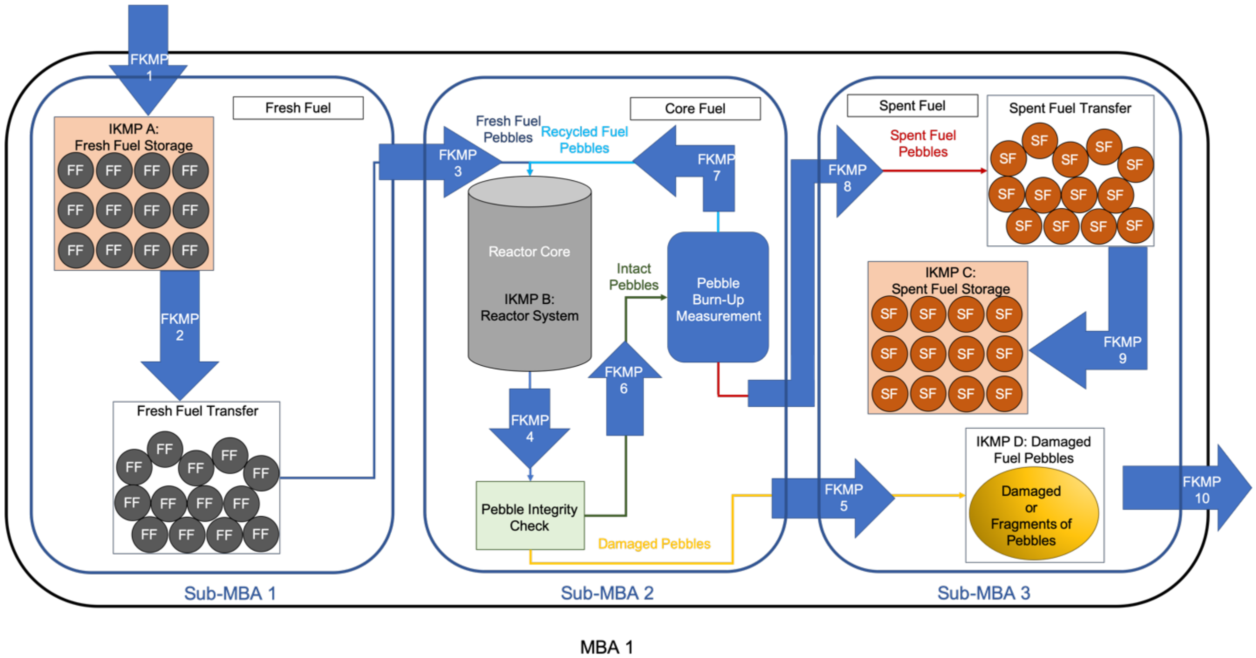

Figure A.1. Example schematic for a PBR facility.

The following is one potential arrangement of accounts (sub-MBAs), inventory KMPs (IKMPs), and flow KMPs (FKMPs) for a one-MBA PBR.

- MBA-1: PBR facility
- Sub-MBA-1: Fresh fuel receipt and storage
- Sub MBA-2: Reactor vessel system
- Sub-MBA-3: Spent fuel storage
- IKMP A: Fresh fuel storage area (items)
- IKMP-B: Reactor system
- IKMP C: Irradiated damaged fuel and waste storage area (items)
- IKMP D: Irradiated intact fuel storage area (items)
- FKMP 1: Fresh fuel receipt (items)
- FKMP 2: Recategorization of fresh fuel through transferred to reactor pebble feed system
- *FKMP 3: Fresh fuel insertion into reactor core
- *FKMP 4: Irradiated fuel removal from reactor core
- FKMP 5: Recategorization of irradiated damaged fuel and waste transferred to damaged pebble storage area
- *FKMP 6: Irradiated intact fuel transfer to burnup measurement system
- *FKMP 7: Irradiated intact fuel re-insertion to reactor core
- FKMP 8: Irradiated intact fuel removed from reactor system
- FKMP 9: Recategorization of irradiated intact fuel transferred to spent fuel storage area
- FKMP 10: Spent fuel, broken pebble, and waste shipment (items)

* These FKMPs are for recording internal flows and are not required for material accountancy.

A.7.5 TYPICAL INVENTORY COMPOSITION

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Licensees should specify the typical expected in-process inventory within the equipment for plutonium, uranium, ^{235}U, and ^{233}U at the time of the physical inventory. A typical composition of SNM as stored items at the time of a physical inventory also should be presented. Plants may be divided into a number of MBAs and ICAs to reflect the functional activities as follows: **Processing—An MBA in which occurs (1) routine transfers of nuclear material from one container to another, (2) changes in chemical assay, or (3) changes in chemical or physical form. Various measurements are required to define material flows through the process and to perform physical inventories so that periodic material balances can be completed for the MBA. Because these measurements have associated uncertainties, a processing MBA will normally have a nonzero ID for each inventory. Of the total plant MBAs and ICAs, a relatively small number might be processing MBAs. Examples are the decontamination and recovery operations; analytical laboratory; and material re-batching, blending, and sampling operations. Physical inventories for the decontamination and recovery operations are the most complex and involve the most coordination and careful timing.** **Storage—ICAs in which all materials are within containers with measured values and are being stored for future processing or shipment. Some minor sampling of containers can occur in a storage ICA. Because nuclear materials in a storage ICA are primarily accounted for on an item basis, a true storage ICA typically will have a zero ID for each inventory period when all items are accounted for and their integrity and previously documented measured values are confirmed.** **Receiving and shipping—An ICA from which materials are shipped or into which materials are received from offsite and which normally serves as an interim storage area.** **This type of ICA will normally see more activity (i.e., changes in current inventory) than the typical storage ICA. At some facilities, sampling and re-batching of items may occur in this type of ICA.**

This section in the NUREG-2159 discusses processing and storage MBAs. A PBR must have a processing MBA because PBRs will perform routine transfers of nuclear material from one container to another, even though they will not perform processing activities that change the chemical assay or chemical and physical form.

A.7.6 DESCRIPTION OF TYPICAL ITEM STRATA

The MC&A plan should describe the expected item population in terms of the following: • **type(s) of item (i.e., stratum)** • **expected range of the number of items within each stratum** • **average elemental and isotopic content of the items within each stratum** • **the expected rate of item generation and consumption for each stratum**

There are five main expected inventory strata for proposed designs. The following expected strata and the inventory approach are shown in Figure A2:

1. Fresh fuel or unirradiated pebbles—item
2. Spent fuel or irradiated pebbles—item
3. Reactor vessel and associated recycle loops—bulk/dynamic
4. Scrap (e.g., damaged or broken pebbles or other residues)—bulk
5. Process holdup—bulk

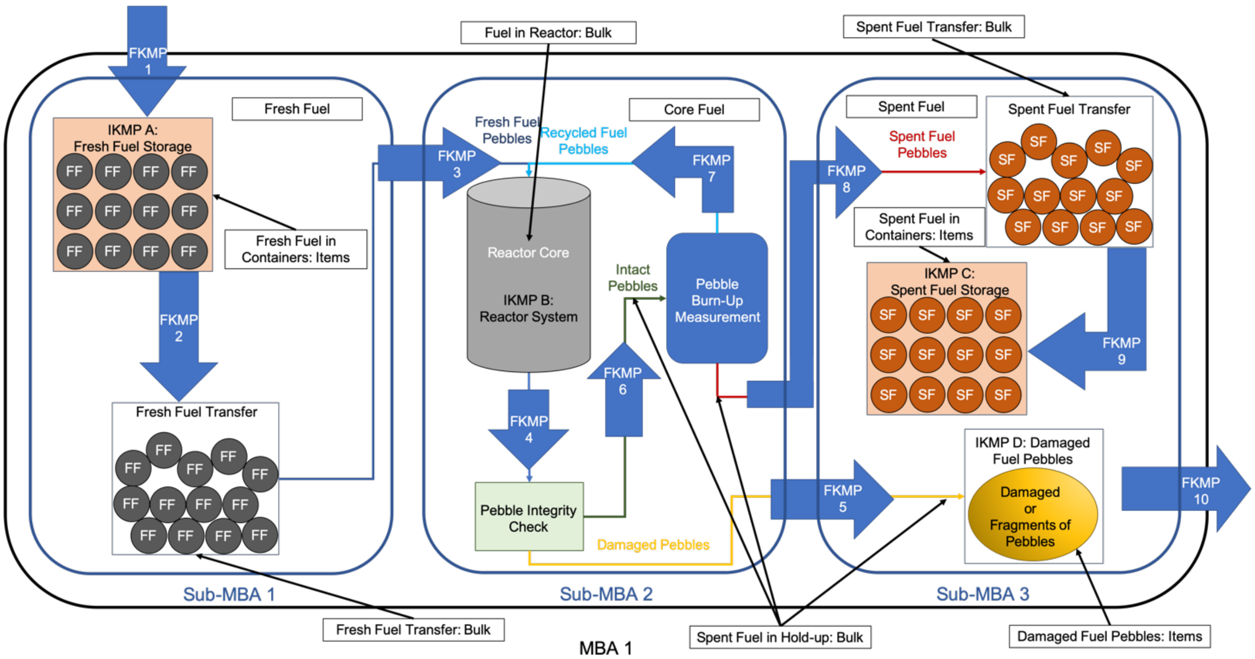

Figure A.2. Example schematic for a PBR power reactor facility with fuel strata.

A.7.7 CONDUCTING PHYSICAL INVENTORIES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs for the fresh and spent fuel areas. The reactor vessel is discussed separately.

Licensees should present a description of the methodology, including cutoff and inventory minimization procedures, and they should identify all measurements (including sampling) sufficient to meet the requirements of 10 CFR 74.43(c)(7). The MC&A plan should contain sufficient information to show how licensees obtained the total in-process inventory for both elemental and isotopic content.

The means for measuring or estimating residual process material should be addressed in detail. The change or variation in such deposited holdup from one physical inventory to the next should also be discussed. This information is important to ensure that no SNM held under license (except for waste materials assigned to holding accounts in accordance with the exception provided in 10 CFR 74.43(c)(6) and US Department of Energy (DOE)/NRC Form 741 instructions) will be omitted, and no quantity will be counted more than once.

The MC&A plan also should contain adequate commitments to ensure that each physical inventory will be organized and coordinated so that all involved persons are instructed in the use of uniform procedures for checking SNM quantities and recording observations. The means for conducting the inventory should ensure that any SNM held under license (except for waste materials, as noted above) is properly inventoried.

A detailed inventory notice should be prepared for each physical inventory. The notice should be issued to all involved parties and should contain instructions that define the timing and performance of various inventory steps and

conditions under which the inventory is to be taken. The notice should identify specific sampling points throughout the process and instructions on data submission to the accountability organization. The instructions should highlight any required deviation from normal inventory procedures contained in the plant's operating procedures.

A description of the procedures and methodologies associated with performing physical inventories should be provided in sufficient detail to demonstrate that valid physical inventories are conducted. Such description should include a general outline of the following:

- **organization and separation of functions**
- **assignment of inventory teams and their training in the use of uniform practices**
- **obtainment, verification, and record of source data**
- **control of inventory forms**
- **assurance that item counts verify the presence of each item while preventing any item from being counted more than once**
- **implementation of cutoff and material handling procedures**

Decontamination and recovery are complex operations involving the disassembly and decontamination of failed pieces of process equipment and recovery of uranium from various types of scrap materials. The basic inventory procedure should involve establishing a cutoff of movement of materials into the area and the processing all materials to a measurable form, such as containers of solution or oxide. Except for a decontamination enclosure in which in- process solutions are mixed, sampled, and measured volumetrically, the inventory process should involve emptying and flushing of process systems and piping, which then could be measured using nondestructive assay (NDA) techniques to establish levels of residual holdup, if such holdup is significant.

Licensees also should describe special item storage and handling or tamper-indicating methods which are used to ensure that the previously measured and recorded SNM content values can be used for inventory purposes without remeasurements. In addition, the MC&A plan should provide a description of how item identities are verified and how tampering with the contents of items will be detected or prevented.

Items that are not encapsulated, affixed with tamper-indicating device (TIDs), or otherwise protected to ensure the validity of prior measurements need special attention. Licensees should present the basis for determining which items are to be measured at physical inventory time and the justification of any proposed alternatives to measurement of any SNM included in the inventory. If statistical sampling is proposed as an alternative method to 100 percent verification, the MC&A plan should describe the sampling plan. Such description should include the following:

- **the method of stratifying the types of items to be sampled (i.e., selected for remeasurement)**
- **the procedure for calculating the sample size (i.e., the number of items) for each stratum**
- **the parameter to be measured (e.g., gross weight or total ^{235}U content)**
- **the quality of the measurement methods used to verify original measurement values (for the parameter being measured)**
- **the procedure for reconciling discrepancies between original and remeasurement values and for scheduling additional tests and remeasurements**
- **the basis for discarding an original SNM value and replacing it with a remeasurement value**

One acceptable means for establishing the number of items (to be randomly selected for remeasurement) from a given stratum to give the required 90 percent power of detecting a loss of a significant quantity is given by the following equation:

$$n = N\,[1 - (0.10)^{x/g}]$$

where

n = number of items to be remeasured

N= total number of items in the stratum

x = maximum SNM content per item (kilograms)

g = SQ = significant quantity for statistical sampling plans, which is either one formula kilogram of strategic SNM or 10,000 grams of ^{235}U contained in uranium enriched to 10 percent or more, but less than 20 percent

When using such a statistical sampling plan to confirm the validity of prior measurements, the remeasurement value obtained for each item (among the n items remeasured) must be compared to its original value. If the difference for a given item exceeds some pre-determined limit (usually three times the standard deviation of the measurement, or 3 sigma), that item is designated as a "defect." To achieve the 90 percent power of detection capability for detecting a loss as small as a significant quantity (SQ), there must be at least a 90 percent probability that one or more "defects" will be encountered among the items remeasured across all involved strata if an actual loss of an SQ has occurred.

If, across all strata, the licensee encounters one or more defects, a second set of n randomly selected items (or all remaining items if n is greater than 0.5 N) from each stratum should be remeasured. If one or more defects are encountered (across all item strata) while performing any second round of remeasurements, the licensee should remeasure all unsealed and unencapsulated items not yet remeasured. Any item, regardless of if there are any defects, whose remeasured value differs from its original measurement by more than two sigma (2σ) should have its accounting value revised to reflect its remeasured quantity.

The MC&A plan also should contain a definitive statement that all items on ending inventory that have not been previously measured are measured for inventory purposes.

Licensees should present in the MC&A plan their reason for determining when the element and isotope factors for items, objects, or containers are measured directly for inventory and when they may be based on other measurements. For example, if the ^{235}U contained in liquid waste batches is derived by applying an average enrichment factor to the measured uranium element content, then the rationale for such practice (as opposed to measuring each batch for both uranium and ^{235}U content) should be discussed, and the plan should describe the method for establishing the average enrichment factor.

If the content of items is established through prior measurements and those items are sealed with TIDs or access to them is controlled, then the SNM quantity in those items may be based on those measured values. Otherwise, verification of SNM content can be achieved by reweighing either (1) all items within a given stratum or (2) randomly selected items from the stratum based on a statistical sampling plan. The NRC will not accept a statistical sampling plan if there is any likelihood of any significant change in the elemental concentration (or weight fraction) or in the isotopic distribution because of such factors as oxidation, change in moisture content, commingling with materials of different enrichments, or different compositions.

Item Areas

For fresh and irradiated fuel storage areas, the MC&A item-based approach for inventory will rely upon various concepts discussed in Sections A.4, A.5, A.6, and A.8 and application of ICAs. This is because the large volume of fuel pebbles will present challenges like those seen for pellets in a fuel fabrication process. As mentioned in Section A.6, there is likely to be some uncertainty in the ability to accurately count numbers of pebbles, even in these parts of the processes. For the MC&A approach, the options for applying containerization and tamper-safing to manage these challenges would be applicable. This would be analogous to the concept of *fuel component container* as discussed in ANSI N15.8-2009.

Ideally there should not be any IDs in these two areas if high confidence in counting "whole" and broken pebbles can be achieved. However, if that is not the case, the MC&A plan and regulatory approach should discuss what level of accuracy is desired to meet domestic safeguards goals.

The approach for assigning the SNM content to the fresh and spent fuel strata for inventory purposes is likely to be similar, if not identical, to that used for LWRs, which does not require changes to regulatory guidance. For fresh fuel, the assigned SNM content (and measurement uncertainty) in each pebble would or could be based on the value assigned by the fuel fabricator. The reactor facility may choose to perform independent confirmatory measurements, not with the goal of changing the assigned pebble value, but rather to look for potential theft of pebbles, with and without substitution scenarios. These measurements might involve weighing containers and performing NDA measurements to verify the fissile content of the container or a sample from the container.

For spent fuel, the assigned SNM content is typically a calculated number based on weight, initial nuclear material content, and burnup calculations. However, since a design feature of a PBR is the measurement of individual pebbles to determine burnup to decide when to remove it from core circulation, this measurement could be used to replace, or augment, the calculated number, depending upon which is deemed the most accurate or appropriate for the application. If the burn-up of each pellet being transferred into the spent fuel container is accurately measured, then an average burn-up for all of the pebbles loaded in the container could be calculated. However, if this is only a determination that the burn-up of a pellet is above or below a certain value or that the radiation from a certain isotope exceeds a given level, then a separate measurement of burn-up of the filled spent fuel container would be required.

Reactor and Associated Recycle Loops

For the nuclear material quantities in the reactor vessel and potential scrap flows, a material balance based on measured inventories and flows would need to be established. Therefore, the procedure for performing a reactor physical inventory as described in current regulations would need to be changed because it assumes item accounting on spent fuel assemblies by serial number and location. The SNM in this part of the process would be considered *material in process* as defined in 10 CFR 74.4 and would be exempted from item control.

The initial reported quantity of pebbles within the vessel would be based on the quantity of pebbles used to fill the reactor vessel before the reactor went critical. After that, it would be based on additions and removals. The reported SNM content would be a sum of the nuclear material content of the pebbles. Entering the plutonium content and burnup into the accounting records upon removal of the spent fuel container from the withdrawal station is probably preferred because declaring a running quantity of plutonium would likely not be practical or add value for MC&A purposes.

Using this approach, the SNM content reported for the reactor for MC&A purposes would be the quantity of unirradiated nuclear material representing the number of pebbles in the reactor. The quantity of nuclear material transferred into the spent fuel container for the physical inventory taking would be based on the fresh fuel values to enable a direct balancing with the input quantities. The plutonium and uranium depletion would be entered into accounting after this balancing. In summary, this approach determines and balances the inventory based on numbers of pebbles fed into, withdrawn from, and in the inventory of the reactor MBA.

> *Note: Section A.6.0 discussed possible approaches for monitoring and providing some statement of confidence about the quantity of pebbles in the reactor MBA, which correlates directly to amount of nuclear material.*

The physical inventory process for the reactor must also address the quantity of nuclear material in damaged or broken pebbles collected into a container at the withdrawal station and collected waste. The quantity of nuclear material in the damaged pebble strata would need to be determined during a physical inventory taking. The concept of damaged cladding as found in ANSI N15.8-2009 and other guidance would apply to PBRs.

Documentation and SNM Element and Isotopic Calculations for Reporting

The regulations for reporting burnup (isotopic calculations) that support physical inventory declarations need to be updated or clarified to support anticipated PBR operations scenarios. The NRC regulations state that the net quantity of plutonium produced in the fuel of a reactor during the reporting period should be reported on the Material Status Report line 21, PRODUCTION [12].

Instructions for reporting production of plutonium and depletion of uranium on the Material Status Report were written based on LWRs. If followed, these instructions would likely require that Pu values for the PBR reactor vessel or in-process pebbles to be declared at least every 9-months. While technically this could be done, the accuracy with which it could be done and the need to do this for MC&A purposes is questionable. The report recommends recognition of isotopic changes upon discharge of pebbles from the reactor based on the burnup measurement point as noted in a previous section.

Another challenge is that while the amount of plutonium produced over a large group of pebbles is significant, an individual pebble is anticipated to be less than one-half of a reporting unit.[2] Further discussion about approaches for grouping and assigning plutonium values across a batch or group of pebbles is needed. This is not new for nuclear processes. The MC&A plan should discuss the approach used to manage the plutonium content reporting.

A.7.8 INVENTORY DIFFERENCE LIMITS AND RESPONSE ACTIONS

This section was written for a bulk process and would need to be adjusted for application to PBRs. See discussion below.

Each licensee should have a well-defined system for evaluating total plant IDs and for taking actions when IDs exceed certain predetermined thresholds. As a minimum, there should be two response levels for excessive IDs. The following would be an acceptable approach for two increasing levels of response actions with respect to material balances closed by physical inventories:

Warning-level ID

^{235}U ID ≥ 1.7(SEID) + (300 grams of ^{235}U or 200 grams of plutonium or ^{233}U), or

U ID ≥ 1.7 (SEID) + 10 kg U

Significant ID problem

U, Pu, ^{235}U or ^{233}U ID ≥ 3(SEID)

All of the above limits are expressed in terms of absolute values of ID without regard for algebraic sign. The minimum response for a warning-level ID should be a documented licensee investigation conducted by the MC&A organization. Such an investigation should provide a conclusion for the probable cause of the excessive ID and would give recommendations for avoiding recurrences. When a warning-level ID is positive, licensees should regard it as being equivalent to an indicator of a possible loss that requires investigation and resolution.

[2] Assumes a reporting unit for plutonium = 1 gram.

For a significant ID problem, a licensee should conduct an extensive investigation. If a significant ID problem cannot be satisfactorily explained, then a re-inventory may be needed to resolve such an anomaly.

The NRC considers a significant positive ID (loss) problem to be a serious condition that calls for corrective action.

The MC&A plan should fully describe in definitive statements the minimum response actions for each ID action level.

Recommendations and approaches that consider both abrupt and protracted theft or diversion scenarios have not been developed. The challenge is that current regulations express limits for ID and SEID in the form of absolute gram quantities. An approach that expresses limits in numbers of pebbles is likely more applicable to PBRs.

A.7.9 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its MC&A plan, the applicant or licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to the physical inventories. A finding that the licensee's MC&A plan for conducting physical inventories is acceptable and in accordance with 10 CFR 74.43(c) will be based on, but not limited to, the following acceptance criteria:

- **An MC&A system will be maintained that is capable of confirming, at intervals not to exceed 9 calendar months, the presence of all SNM expected to be present (at a given time) based on accurate, current, and reliable information.**

- **Unless otherwise required by facility attachments that satisfy 10 CFR Part 75, "Safeguards on Nuclear Material—Implementation of US/IAEA Agreement," physical inventories will be performed at least every 9 calendar months and will be used as the basis for reconciling and adjusting the book inventory, which is done within 60 calendar days after the start of each physical inventory.**

- **For each physical inventory, inventory procedures are clearly written and are reviewed and approved by the individual responsible for the conduct of the physical inventory.**

- **The individual responsible for the conduct of the physical inventory is either free from potential conflicts of interest or is over-checked sufficiently to prevent compromising the validity of the physical inventory.**

- **Each physical inventory listing will include all SNM possessed (on the inventory date), with the possible exception of waste materials assigned to holding accounts (in accordance DOE/NRC Form-741 instructions), and that all such listed SNM quantities shall be based on measurements.**

- **Within 60 calendar days after the start of each physical inventory, the inventory difference will be determined. Any ID that exceeds three times SEID and 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U will be reported to the appropriate NRC safeguards organizational units.**

- **Discrepancies in the identity, quantity, or location of items, objects, or containers of SNM that are detected during a physical inventory will be corrected.**

- **Inventory difference values will be corrected for (1) accounting adjustments resulting from prior period activity, and (2) significant biases that have not previously been taken into account. (NOTE: See the definition of *significant bias* in Chapter 6 of this plan).**

- **Adjustments made to reconcile the book inventory to the physical inventory are in accordance with standard accounting practices and are traceable and auditable in the MC&A records.**

- **Whenever a finalized ID (after applying any appropriate bias corrections and prior period adjustments) exceeds three times SEID and 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U and is not resolved within the 60-day**

reconciliation period, all SNM processing should be halted unless otherwise authorized by the NRC. (NOTE: This applies to both positive and negative ID values.)

- **The results of all physical inventories and of investigations and resolution actions following any excessive ID are recorded and auditable. An excessive ID is one (regardless of the algebraic sign) that exceeds both three times SEID and 300 grams of ^{235}U or 200 grams of plutonium or ^{235}U.**

- **The licensee may propose alternatives to remeasurement. The MC&A plan should describe the circumstances under which each proposed alternative may be used. The proposed alternatives should satisfy at least one of the following criteria:**

  - **SNM content is verified by statistical sampling and measurement of representative items, objects, or samples of the material. The total overall sampling plan shall support the capability for detecting any loss in excess of the pertinent SQ with 90 percent (or better) probability.**

  - **The previous measurement results are accepted because the items are stored in a controlled access enclosure that provides protection equivalent to tamper-safing.**

  - **Residual holdup in significant amounts which remains after cleanout or drain-down may be estimated if the estimate is based on previously measured values and it is periodically verified or validated.**

  - **For material whose SNM content has been previously measured, and there is no likelihood of any significant change in the uranium concentration (or weight fraction) or in the uranium enrichment because of such factors as oxidation, change in moisture content, commingling with materials of different enrichment or different composition, etc., the previously determined SNM content may be accepted without verification—provided the gross weight or net weight of all items within the population is confirmed by (1) a 100 percent reweighing of all such items, or (2) reweighing an adequate number of randomly selected items (based on a statistical sampling plan) to provide a 90 percent (or better) probability of detecting a loss equal to or greater than the current SQ.**

- **As an additional alternative to re-measurement (of unsealed SNM) at physical inventory time, a program of routine process monitoring will be acceptable when the combination of the process monitoring program and the inventory procedures will achieve the same level of loss detection capability as that provided by a physical inventory in which all unencapsulated items are either tamper-safed or remeasured.**

- **Any previously measured but unsealed (or unencapsulated) SNM that is on hand at the time of the physical inventory, and which is to be introduced into subsequent processing steps before inventory reconciliation should be re-measured or have its prior measurement value confirmed (by an acceptable alternative) before the subsequent processing is initiated.**

- **The SQ for statistical sampling plans will be one formula kilogram of strategic SNM or 10,000 grams of ^{235}U contained in uranium enriched to 10 percent or more, but less than 20 percent.**

- **The MC&A plan should state that the threshold of three times SEID for identifying an excessive ID will result in a 90 percent (or better) probability of detecting a discrepancy equal to or greater than 0.4 percent of the active inventory for the inventory period in question. In general, a licensee may assume the ID distribution approximates a normal distribution. Acceptable methodology for calculating the measurement error contribution to the SEID by error propagation is found in NUREG-4604, TID-26298, and the IAEA statistics handbook (1989). Special attention is given to inclusion of all measurable sources of error to avoid underestimating the SEID.**

- **In addition to the three times SEID ID limit required by 10 CFR 74.43(c)(8), there is an excessive ID warning level limit that, when exceeded, will require an investigative response action. The resources and level of effort a licensee should commit to the investigation of an excessive ID will be proportional to the magnitude and material type and enrichment of the ID, and it will be sufficient to reassess the results of the physical inventory, the accounting records, and the measurement control program data; to confirm the relevant calculations and data analysis; and, when necessary, to carry out searches for unmeasured inventory such as residual holdup and measurement discards. Investigations are to be completed within 60 calendar days after initiating the inventory (except when additional time is granted by the NRC for extenuating circumstances).**

A.8. ITEM CONTROL

This section would only apply to the fresh and spent fuel areas of the PBR. Pebbles in the reactor or recycle loops would be considered *material in process* as defined in 10 CFR 74.4 and would be exempted from item control.

REGULATORY INTENT

The intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43(b)(5) and (6) is to require licensees to establish, document, and maintain an item control system to protect against unauthorized and unrecorded removal of items, or of material from items, and to enable timely location of items. *Items*, as defined in 10 CFR 74.4, "Definitions," mean any discrete quantity or container of special nuclear material or source material, not undergoing processing, having a unique identity and also having an assigned element and isotope quantity. Examples of items are known quantities of special nuclear material (SNM) in well-defined and uniquely identified containment such as cans, drums, and canisters, or fixed units such as fuel assemblies. Un-containerized solid SNM, such as uranium metal ingots or buttons, are also items if they are uniquely identified. To promptly locate a given item, licensees must record sufficient current information.

For Category II facilities, 10 CFR 74.43(b)(5)(ii) states that the licensee shall establish, document, and maintain an item control program that:

> *Assures that SNM items are stored and handled, or subsequently measured, in a manner such that unauthorized removal of 200 grams or more of plutonium (Pu) or uranium-233 (U-233), or 300 grams or more of uranium-235 (U-235), as one or more whole items and/or as special nuclear material (SNM) removed from containers.*

While the detection threshold requirement is expressed in grams, this regulatory limit was developed based on processes at bulk handling facilities. The question that remains unanswered is whether these limits, which are meant for bulk handling facilities, meet the MC&A intent when applied to PBRs for detection of theft or diversion.

For the PBR, if the limit is expressed in numbers of pebbles [4] using the TRISO pebble example, this translates to a detection threshold of approximately:

- 300 pebbles (^{235}U) for unirradiated pebbles, with a gross weight approximately 80 kg, or
- 2,000 pebbles (Pu) for irradiated pebbles, with a gross weight over 500 kg.

These physical characteristics are useful for informing MC&A considerations about credible diversion paths (i.e., scenarios) and diversion strategies. The concepts of diversion paths and strategies are expressed in NRC Inspection Manual Chapter 2683, "Material Control and Accounting Inspection of Fuel Cycles Facilities" [13].

The sections in this report discussing the inventory for fresh and spent fuel suggest a much lower loss detection threshold may be achievable. It would not be unrealistic, given the integral nature of pebbles, that a loss of a single or a few pebbles might be achievable if fuel component containers and handling procedures are implemented with this goal in mind. Then the question becomes whether this lower detection threshold is warranted for MC&A purposes.

To answer that question the radiological aspects of theft of the pebbles must be considered. Focusing on bulk amounts or groups does not address the potential consequence of the loss of an individual pebble if used in a radiological exposure device or radiological dispersion device. A spent TRISO pebble will have radiation levels equivalent to a Category I/II radiological source [14] per the calculation described below:[3]

> If it is assumed that each fuel pebble contains 7 g of uranium and will be burned up to 90 GWd/tU, the strongest radiation coming out of used fuel is ^{137}Cs [15]. The specific activity of ^{137}Cs for a 30 GWd/tU PWR fuel assembly is 3.2e15 Bq/kg. Ignoring the nonfuel part of a PWR assembly:
>
> 1. Multiply the specific activity of ^{137}Cs by 3 to account for the increased burnup from 30–90 Gwd/tU, and then
>
> 2. Multiply by 7/1,000 to convert the activity from kilograms to grams for a single fuel pebble.
>
> This yields ~70 TBq/pebble. This is close to the NRC Category I limit provided in the DOE Standard of 100 TBq of ^{137}Cs for a single pebble. Therefore, a loss of some number of pebbles, potentially much less than the number required to reach the detection threshold, could represent a significant radiological concern.

A.8.1 ORGANIZATION

The material control and accounting (MC&A) plan should identify the individual responsible for overseeing the item control system by position title. Positions of those individuals who have significant item control system responsibilities also should be identified.

Program organization is likely to be a combination of approaches implemented in existing fuel fabrication and reactor facilities.

A.8.2 GENERAL DESCRIPTION

Current practices for addressing this section of the MC&A plan would be applicable for PBRs. However, given the small of amount of SNM per pebble, approaches used by the licensee for storing and aggregating pebbles could affect implementation. See discussion below.

The applicant or licensee should state that the overall MC&A system maintains a record of all SNM items, regardless of quantity or duration of existence. In addition, the item control system should provide current knowledge of the location, identity, and quantity of all SNM contained in all items that are not exempt from item control. Items that can be exempt from item control system coverage are:

- **containers of waste designated for burial or incineration**

- **containers of solutions in which the plutonium, uranium-235 (^{235}U) or uranium-233 (^{233}U) concentration is less than 5 grams per liter**

- ***items whose time of existence is less than 14 calendar days****

- ***any plant-identified items listed by material type containing less than 300 grams of ^{235}U, or 200 grams of plutonium or ^{233}U, but not to exceed a plant total of one formula kilogram of strategic SNM or 17 kilograms of ^{235}U contained in uranium enriched to 10.00% or more, but less than 20.00%****

Each item that is not exempt from the item control system should be stored and handled in a manner that enables detection of, and provides protection against, unauthorized or unrecorded removals of SNM. All items, whether or not

[3] Private communication from A. Holcomb, ORNL, to D. Kovacic, Oak Ridge National Laboratory, April 2019.

they are subject to item control system coverage, should have a unique identity. For items subject to the item control system, the following are acceptable means for providing unique identity:

- **a unique alpha-numeric identification on a tamper-indicating device (TID) applied to a container of SNM**
- **a unique alpha-numeric identification permanently inscribed, embossed, or stamped on the container or item itself**
- **a uniquely pre-numbered (or bar-coded) label applied to each item having good adhesive qualities such that its removal from an item would preclude reuse of the label**

Location designations shown by the MC&A records need not be unique, but location designations should be specific enough so that any item may be located within 1 hour. Longer times may be acceptable but should be further justified in the MC&A plan. The MC&A record system should be controlled in such a manner that the record of an item's existence cannot be destroyed or falsified without a high probability of detection.

** Note: The italicized bullets do not appear in the discontinued NUREG-2159 and were added from 74.43(b)(6).*

The applicability of item control based on current regulations will be impacted by the licensee's approaches to group and store pebbles. The regulations currently exempt items with less than 300 grams ^{235}U or 200 grams Pu from item control. Using TRISO fuel as an example, before irradiation, each pebble contains less than 1 gram of ^{235}U. After irradiation, the amount of ^{235}U and Pu in TRISO fuel is projected to be approximately 0.4 of grams ^{235}U and 0.1 of grams Pu, respectively. Groupings or containers of less than 300 fresh pebbles (300 grams ^{235}U / 1 gram ^{235}U per pebble) and 750 spent pebbles (300 grams ^{235}U / 0.4 grams ^{235}U per pebble) would be exempt from item control. Larger groupings would not be exempt. The ^{235}U content would likely be the constraining isotope in this analysis.

At this point, the design and operating approaches for staging pebbles loaded into and from the reactor are also not known. If approaches like pellet trays used in fuel fabrication facilities to move pellets between steps in manufacturing processes are used to transfer pebbles, then they may exist for less than 14 days and/or also be below the gram threshold for item control.

A.8.3 ITEM IDENTITY CONTROLS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs. The ANSI N15.8-2009 discussions on *fuel component containers* include approaches and examples that would be applicable.

Descriptions should be provided of the item records showing how items are identified for each material type and each type of container. If the unique number on a TID is the basis for providing unique item identity, the MC&A plan should:

- **Describe the type of TID used.**
- **Describe how the TIDs are obtained and what measures are implemented to ensure that duplicate (counterfeit) TIDs are not manufactured.**
- **Describe how the TIDs are stored, controlled, issued, and accounted for**
- **Describe how TID usage and disposal records are maintained and controlled.**

Licensees should provide similar information for other methods of unique item identity (e.g., labels).

A.8.4 STORAGE CONTROLS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The MC&A plan should fully describe item storage areas and controls. In particular, controls that are used as the basis for ensuring the values of prior measurements, as opposed to remeasuring the item at inventory time, should be discussed in detail and the rationale for accepting prior measurements explained. Any controls used to ensure the validity of prior measurements should be equivalent to the protection provided by *tamper-safing*, which is defined by 10 CFR 74.4 as the use of devices on containers or vaults in a manner and at a time that ensures a clear indication of any violation of the integrity of previously made measurements of the SNM in the container or vault.

Both administrative controls (e.g., custodian assignments and limiting authorized access to storage areas) and physical controls (e.g., locked or alarmed doors) should be identified.

A.8.5 ITEM MONITORING METHODOLOGY AND PROCEDURES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

As part of the item control system, a licensee should maintain a system of item monitoring that achieves the following:

- **verifies that items shown in the MC&A records are actually stored and identified in the manner indicated in the records**
- **verifies that generated items and changes in item locations are properly recorded in the MC&A record system in a timely manner**
- **detects, with high probability, any real loss of items or uranium from items.**

The item monitoring system should conduct the following activities at least every 2 weeks for strategic SNM and on a monthly basis for ^{235}U contained in uranium enriched to 10 percent or more, but less than 20 percent:

- **For each item inventory stratum, compare the actual storage status to the recorded status of a sufficient sample of randomly selected items from the item control program records.**
- **For each item inventory stratum, check the accuracy of the MC&A records for a sufficient sample of randomly selected items from each storage area.**
- **Check the accuracy of a sufficient sample of randomly selected production records of created and consumed items**

The actual frequency of the above activities and the size of the random sample should be functions of the expected discrepancy rate based on prior observations. The MC&A plan should specify (1) minimum monitoring frequencies associated with each storage area, (2) discrepancy rates that trigger more frequent monitoring frequencies, and (3) commitments for resolving discrepancies.

Although the underlying regulatory guidance is clear, some challenges have been documented in literature along with some indications of historical performance that may make implementation difficult.

There is also the possibility for the use of tamper-indicating seal checks, redundant measurements, and comparison between the pebble counting and other independent measurements, such as weight and radiation, to address these challenges. The number of pebbles that are supposed to be in a container based on a count could be compared with weight measurements to make sure the weights correspond with the number of pebbles that were counted. Restated more simply, the pebble-counting systems could be correlated with the weight measurements to support item control.

A.8.6 INVESTIGATION AND RESOLUTION OF ITEM DISCREPANCIES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The applicant or licensee should provide definitive statements of the procedures and controls that will ensure that all incidents involving missing or compromised items or falsified item records will be investigated. A compromised item is (1) an item displaying evidence of tampering or (2) an unencapsulated and unsealed item assigned to a controlled, limited-access storage area that is found outside its documented location.

If any unencapsulated and unsealed item is located after having been determined to be missing, or if an item is found to be compromised, its contents should be reestablished by measurement (e.g., by NDA or by weighing, sampling, and analysis). Licensees should follow recommendations on resolution of indicators (Chapter 13) of this document to resolve item discrepancies.

A.8.7 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its MC&A plan, the licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to maintaining current knowledge of items and detecting unauthorized removals. A finding that the licensee's MC&A plan for the item control system is acceptable and in accordance with 10 CFR 74.43(b)(5) and (6), will be based on, but not limited to, the following acceptance criteria:

- **The item control system uses statistical sampling, as an alternative to 100 percent verification, at least every 2 weeks for strategic SNM, and on a monthly basis for ^{235}U contained in uranium enriched to 10 percent or more but less than 20 percent.**

- **The licensee's item record system should uniquely identify items. The records should include information about the chemical form, quantity of material (element and isotope), physical description, identification label or number, and location. The system should provide reasonable assurance of detecting falsification or destruction of records of an item's existence.**

- **In its MC&A plan, a licensee may propose that certain groups of items that are produced, stored, processed, or otherwise handled together as a unit, such as a batch or sublot of material, may be uniquely identified and stored as a separate group under conditions such that group identity, composition, and quantity will be maintained constant.**

- **The record of the status of an item can be completed or updated in sufficient time to allow the licensee to meet the requirements for promptly locating an item.**

- **For items that will not be remeasured at inventory time, the item control procedures provide reasonable assurance that the SNM contents stated in the records are valid and that unauthorized removal of SNM from the item has not occurred. Remeasurement is not necessary if the SNM content of the item was measured previously and the licensee provides reasonable assurance that the SNM content has not subsequently changed.**

- **A current accounting is maintained of the total quantity of SNM contained in items that are exempted from item control. The accounts identify the quantities by material type category for both controlled and exempted items.**

- **For items not exempted from the item control system, the licensee maintains a record system to provide knowledge of the current status of such items. For items subject to this commitment, the item control and records system provides the capability to promptly locate and confirm the existence of any specific item or group of items upon demand. The item record system is secured in such a manner that the record of an item's existence cannot be destroyed or falsified by a single individual without a high probability of detection.**

- **For items not exempted from the item control system, each item is stored and handled in a manner that enables detection of or provides protection against unauthorized or unrecorded removals of SNM. Otherwise, knowledge**

of the SNM content is assured by TIDs or by maintaining the item as a sealed source (i.e., as encapsulated material).

- **All incidents involving missing or compromised items or falsified item records are investigated. A compromised item is one for which there is evidence of tampering or which is found outside its assigned controlled access area.**

- **The contents of a compromised item or an unsealed, unencapsulated item located after it has been missing will be redetermined by measurements (i.e., by NDA or by weighing, sampling, and analysis).**

A.9. SHIPPER-RECEIVER COMPARISONS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs. Section 6.0 of ANSI N15.8-2009 on input control provides examples and acceptable approaches.

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs with the exception that the limit of 300 g of uranium is more applicable to bulk processes. The limits for PBRs are more logically expressed in numbers of pebbles, and the acceptable limits are much lower and achievable. Because pebbles are integral fuel components as defined in ANSI N15.8-2009, there was some question about whether the detection level should be set as low as a single pebble.

The intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43 (b)(7) is to require the licensee to conduct and document shipper–receiver comparisons for all special nuclear material (SNM) receipts—on both an individual batch basis and total shipment basis—and ensure that any shipper–receiver difference (SRD) that is statistically significant and exceeds twice the estimated standard deviation of the difference estimator and 200 grams of plutonium or ^{233}U, or 300 grams of ^{235}U is investigated and resolved.

A.9.1 RECEIVING PROCEDURES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The first action taken on receipt of SNM should be to verify the number of items, the item identities, and the integrity of individual items and of tamper-indicating devices (TIDs). All SNM shipments received from an external supplier are subject to shipper–receiver comparisons.

Such comparisons involve measurement of received material by the receiver, or by the receiver's contractor (who is independent of the shipper) and comparing the receiver's total receipt measurement for element and isotope to that of the shipper's.

Previously, in approving material control and accounting (MC&A) plans, the NRC staff has recognized situations in which the cost of conducting and documenting shipper–receiver comparisons outweighs the safety benefit of doing so, and it has accordingly granted relief in the form of exemptions notwithstanding the 10 CFR 74.43 (b)(7) provision that the requirement applies to "all SNM receipts." Examples of situations in which such relief has been granted are as follows:

- **Shipments containing less than 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U;**

- **Individual items containing less than 15 grams ^{235}U, plutonium or ^{233}U;**

- **Encapsulated items whose encapsulation integrity has not been compromised, and which are to be retained by the licensee as encapsulated items**

- **Fuel assemblies and fuel rods previously shipped by the licensee that are being returned, provided that the original encapsulation has not been compromised;**

- **UF_6 cylinders that are empty except for a heel quantity of UF_6;**

- **Heterogeneous scrap that must be subject to dissolution before a meaningful accountability measurement can be obtained. Both shipper and receiver should agree to accept the "after dissolution plus residue" measurements for accounting purposes.**

Should licensees in the future seek similar relief from the 10 CFR 74.43 (b)(7) requirements, they will need to submit specific exemption requests in accordance with 10 CFR 74.7, "Specific Exemptions." If the law authorizes the granting of such exemption requests and doing so would not endanger life or property or the common defense and security and would otherwise be in the public interest, the NRC will consider such exemptions, to be determined on a case-by-case basis.

The goal of the MC&A system would be to provide some level of assurance that no theft, diversion, or substitution occurred during the shipping and receiving processes for both fresh and spent fuel. The difference between LWRs and PBRs is the portability of the nuclear material items and the potential for removal of some nuclear material from an item. Consideration should be given to receipt/shipment procedures and options or approaches for inspection and verification. This will range from confirming correctness of serial number, TID, and item count to an additional application of a confirmatory or verification measurement techniques on sampling basis to address potential theft, with and without substitution scenarios. Sampling plans and measurement approaches would be based upon a desired level of confidence.

A.9.2 DETERMINATION OF RECEIVER'S VALUES

Licensees should measure SNM receipts for total quantity (mass), element concentration (such as for plutonium dioxide, uranium dioxide, or uranyl nitrate solutions), and fissile isotope abundance (^{235}U or ^{233}U).

The validity of the shipper's data should be substantiated with appropriate and timely receiver checks and measurements, including gross weight, adequate sampling techniques, NDA measurements (if appropriate), and destructive measurements (scrap excepted). (See Chapter 4 on measurements above.) Shipper's values may be accepted and booked without receiver element or isotope measurements for encapsulated items, such as fuel elements or rods, if NDA measurement is not feasible.

At this point in the analysis, the authors expect the receiver to accept the fuel fabricator values on elemental and isotopic assays for the pebbles for accounting purposes. The pebbles will be the equivalent of sealed nuclear material sources because of the graphite coating. This does not preclude some confirmation of the nuclear material content, but full independent SNM determination by destructive analysis is unnecessary to detect theft or diversion, and likely could not be performed at a reactor. The reactor would still need to verify the bulk quantity of the received nuclear material. For unsealed items from which pebbles could have been removed or replaced with dummies, the receiver should also verify that the nuclear material content of a sampling of items in the received batch is correct. This could be performed either by an NDA measurement of the fissile content of the intact container or by taking a random sampling of pebbles from the container and verifying that they contain the stated nuclear material.

Items to be shipped should be sealed with a TID after the nuclear material content of the item is determined. If the item and the seal remain intact, then the container could be received on this value without a bulk quantity measurement.

A.9.3 EVALUATION OF SHIPPER-RECEIVER DIFFERENCES

When shipper's measurement uncertainty (or standard error) information is available, then the following should define the estimated standard deviation of the difference estimator or combined standard error:

combined standard error = $[(\sigma_S)^2 + (\sigma_R)^2]^{1/2}$

where

σ_S = shipper's measurement standard error
σ_R = receiver's measurement standard error

If the shipper's measurement uncertainty values are not available, then the receiver can assume that the shipper's measurement uncertainty is equal to (but no greater than) its own uncertainty. In this situation (i.e., both shipper and receiver have the same measurement uncertainty), the following becomes the combined measurement standard error:

combined standard error = $[2\,(\sigma_R)^2]^{1/2} = 1.414\,\sigma_R$

The difference between the shipper's value and the receiver's value (i.e., the SRD), in terms of the total shipment, must be regarded as significant whenever the SRD exceeds both 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U and twice the combined standard error. Licensees also must regard as significant an SRD in excess of both 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U and twice the combined standard error with respect to an individual batch within the shipment.

The authors expect no difficulty in this area as differences, if any, are likely to be missing pebbles. Therefore, procedures and approaches may be more similar to that used for verification of items in inventory.

A.9.4 RESOLUTION OF SIGNIFICANT SHIPPER-RECEIVER DIFFERENCES

The MC&A plan should describe the steps involved with the investigation of a significant SRD and discuss how such difference is resolved. The plan also should present criteria for defining a resolved SRD. Generally, resolution of a significant SRD could involve a referee (or umpire) measurement of a retainer sample(s) but not of the material weight. The resolution process should specify whose weight value is used in the resolution process if shipper's and receiver's weights differ by more than one-half of the total combined standard error.

See discussion in Section A.9.3.

A.9.5 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its MC&A plan, the licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to shipper–receiver comparisons. A finding that the licensee's MC&A plan for conducting SRD evaluations and resolving significant SRDs is acceptable and in accordance with 10 CFR 74.43 (b)(7) will be based on, but not limited to, the following acceptance criteria:

- **Each shipping container is inspected within 5 working days after receipt for loss or damage to the container or TIDs to determine if SNM could have been removed. If the integrity of a container is questionable, then the presence of all items that were packaged in the shipping container will be confirmed within 24 hours of discovering the questionable integrity. Only acceptable tamper-safing methods will be used as described in Section 11.1 of this document and as agreed to with the receiver.**

- **Complete the receipt of nuclear material within 60 calendar days, except in the cases of scrap that cannot be representatively sampled and irradiated material (see Section 4.5).**

- **Conduct and document shipper–receiver comparisons for nonexempt SNM receipts, both on an individual batch basis and a total shipment basis, and ensure that any SRD that exceeds twice the estimated standard deviation of the difference estimator and 200 grams of plutonium or ^{233}U or 300 grams ^{235}U is considered statistically significant, and is investigated and resolved within 90 days of material receipt or, if not resolved within that period, the unresolved difference is reported to the NRC.**

- **The significance of an SRD is based on statistical tests.**

- **Measurements of the quantity of SNM received in each shipment are performed and the SRD is tested for statistical significance. The element and isotopic content of SNM shipped or received by the licensee are based on measurements obtained from measurement systems subject to the measurement control program. Occurrences of statistically significant SRDs in excess of 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U, and missing items are reported to the shipper promptly.**

- **Measurement results for shipments and receipts are corrected for biases that are significant at the 0.05 level (i.e., for any bias that exceeds two times the standard error associated with a mean) and which impact individual items by more than their rounding error in terms of plutonium, ^{233}U, ^{235}U, or uranium content.**

- **Confirmatory measurements of scrap shipments are performed by the receiver to determine the amount of plutonium or uranium element and fissile isotope consistent with the accountability needs of the shipper. However, heterogeneous scrap that cannot be accurately measured in its received form need not be measured until after dissolution, within 18 months of receipt (see Section 4.5 of this document).**

- **For SNM received, SRDs that are statistically significant and also greater than 300 grams ^{235}U or 200 grams of plutonium or ^{233}U on a total shipment basis (or on a batch basis) are detected within 30 days of receipt, except for those materials granted an exemption by the NRC.**

- **SNM shipments for which the licensee has been granted an exemption from the shipper–receiver comparison requirements are clearly identified.**

- **The investigation procedure for significant SRDs is sufficiently comprehensive to ensure that the difference will be resolved. Comprehensiveness is sufficient if the licensee shows the capability to verify records, resample, perform remeasurements, establish liaison with the shipper, provide samples to a referee laboratory, and perform the statistical analysis needed to evaluate the measurements.**

- **The documentation of shipments and receipts should be completed and transmitted within the time specified in NUREG/BR-0006.**

A.10. ASSESSMENT AND REVIEW OF THE MATERIAL CONTROL AND ACCOUNTING PROGRAM

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43(b)(8) is to require independent assessments of the material control and accounting (MC&A) program. Licensee management must periodically (at least every 18 months) review and assess the performance of the MC&A program, evaluate its effectiveness, and document management's action on prior assessment recommendations and any identified deficiencies. The NRC intends that the review will be performed by knowledgeable, technically competent individuals free from conflicts of interest and that the deficiencies will be brought to the attention of plant management so that they will be corrected. It should be emphasized that this review process is intended to be much more than a routine audit for compliance with existing procedures and commitments. The review must draw conclusions and make recommendations relative to overall program effectiveness and to the adequacy of the MC&A program—including that of any contractor who performs special nuclear material (SNM) measurements on the licensee's behalf.

A.10.1 GENERAL DESCRIPTION

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The capabilities, performance, and overall effectiveness of the licensee's MC&A program should be independently reviewed and assessed at least every 18 months. The MC&A plan should describe the assessment and review program in terms of:

- **maximum interval between assessments**
- **selection procedures for the assessment team**
- **number of team members to be selected**
- **qualification and expertise of team members**
- **independence of individual team members from the MC&A responsibilities and activities they are reviewing and assessing**
- **maximum elapsed time and minimum actual effort to be used for completion of the assessment and issuance of a final team report**

The licensee generally should review and evaluate the entire MC&A program during each assessment. When this occurs, intervals between assessments can be as much as 18 calendar months. However, if individual assessments only cover part of the MC&A system, individual subsystems should be assessed at intervals no greater than 9 calendar months. The schedule should ensure the entire program is reviewed over the course of 18 calendar months. Thus, the MC&A plan should specify the type of assessment (partial or total) and the maximum interval between assessments. "*Interval*" means the elapsed time between either the start of or termination of successive assessments.

The responsibility and authority for the assessment program should be at least one level higher in the licensee's organizational structure than that of the MC&A manager. Such responsibility should include selecting the assessment team leader and initiating corrective actions. Team members may be selected from the facility staff or from outside, but an individual member should not participate in the assessment of the parts of the MC&A system for which that person has direct responsibility. Hence, the MC&A manager may not be a team member. Also, a given individual should not assess the parts of the system that are the responsibility of another team member if the other team member is assessing the given individual's area. The leader of the assessment team should have no responsibilities for managing any of the MC&A elements being assessed.

The actual number of team members for any given assessment should depend on the knowledge and expertise of the team members relative to MC&A activities and their experience in conducting assessments. Personnel assigned to the assessment team should have demonstrated an understanding of the regulatory objectives and requirements of the MC&A program and should have sufficient knowledge and experience to be able to judge the adequacy of the parts of the system they review. The team should have authority to investigate all aspects of the MC&A system and should be given access to all necessary information.

To provide a meaningful and timely assessment, the review and evaluation process should not be protracted. The actual review and investigation activities should be completed in 30 calendar days, with an additional 15 calendar days allowed for completing and issuing a final team report.

A.10.2 REPORT OF FINDINGS AND RECOMMENDATIONS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The areas to be reviewed should encompass the entire MC&A system, and the level of detail of the reviews should be sufficient to ensure the assessment team has made an adequate and reasoned judgment of the MC&A system effectiveness. The team report, as a minimum, should state findings pertaining to:

- **organizational effectiveness to manage and execute MC&A activities**
- **management responsiveness to indications of possible losses of uranium**
- **staff training and competency to carry out MC&A functions**
- **reliability and accuracy of accountability measurements made on SNM**
- **effectiveness of the measurement control system in monitoring measurement systems and its sufficiency to meet the requirements for controlling and estimating both bias and SEID**
- **soundness of the material accounting records**
- **effectiveness of the item control program to track and provide current knowledge of items**
- **capability to promptly locate items and effectiveness in doing so**
- **timeliness and effectiveness of shipper–receiver difference (SRD) evaluations and resolution of excessive SRDs**
- **soundness and effectiveness of the inventory-taking procedures**
- **capability to confirm the presence of SNM**
- **capability to detect and resolve indications of missing SNM**

On completion of each assessment, the evaluation team should document findings and recommendations for corrective action, if any. It should distribute the written report to the plant manager, the MC&A manager, and other managers affected by the assessment.

A.10.3 MANAGEMENT REVIEW AND RESPONSES

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Management should review the assessment report and take the necessary actions to correct MC&A system deficiencies. The management review should be documented within 30 days following the submittal of the assessment team's report, and it should include a schedule for the correction of deficiencies. Corrective actions, if any, that pertain to daily or weekly activities should be initiated promptly after the submittal of the final assessment report.

The MC&A plan should address resolution and follow-up actions associated with concerns identified in the assessment report. The individuals responsible for resolving identified concerns, and the timeliness of such resolution, should be specified.

A.10.4 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its MC&A plan, the licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to independent assessments of the MC&A program. A finding that the licensee's MC&A plan for such assessments is acceptable and in accordance with 10 CFR 74.43(b)(8) will be based on, but not limited to, the following acceptance criteria:

- **The capabilities and performance of the MC&A program will be reviewed, and its effectiveness will be independently assessed at least every 18 months. This means that the nominal elapsed time from the completion of one review or assessment to the completion of the next will not exceed 18 months.**

- **The periodic assessments will be comprehensive and sufficiently detailed to enable the assessment team to rate the MC&A system accordingly. The overall assessment objectives are to determine that the MC&A system, as designed and implemented, is continuing to meet the general performance objectives, and to identify weaknesses or deficiencies in the system design or performance that may need correcting.**

- **The areas to be reviewed encompass the entire MC&A program, and the level of detail of the reviews is sufficient to ensure that the assessment team has adequate information to make reasoned judgments of the MC&A system effectiveness, which includes:**

    - **organizational effectiveness and management responsiveness to indicators of possible SNM losses**

    - **staff training and competency to carry out MC&A functions**

    - **soundness of the material accounting records**

    - **capability to promptly locate items;**

    - **timeliness and effectiveness of SRD evaluations and resolution of significant SRDs**

    - **soundness of physical inventory procedures and practices**

    - **effectiveness of the measurement control system to monitor key measurement systems, establish bias estimates and measurement uncertainties, and meet the requirements for controlling the total MC&A measurement uncertainty associated with ID.**

    - **capability to confirm the presence of SNM**

    - **capability to investigate and resolve anomalies and aid in any government-led investigation of missing SNM and to provide information that would aid in the recovery of missing SNM**

- **Generally accepted auditing principles are used to check each type of record in which a representative sample (of a sufficient number) of randomly selected records is examined.**

- **Reviews and assessments are performed either by qualified individuals from outside the facility or qualified individuals from inside the facility organization whose work assignments and positions within the organization will not impair their ability to make objective judgments of the MC&A program capabilities and performance. Personnel assigned to the assessment team will have an adequate understanding of the regulatory objectives and requirements of the MC&A system and will have sufficient knowledge and experience to be able to judge the adequacy of the parts of the system they are asked to review. The team will have authority to investigate any aspect of the MC&A program and will have access to all relevant information.**

- **An individual team member will not participate in the assessment of any part of the MC&A system for which he or she has direct responsibility. Also, an individual, *A*, will not assess any part of the system that is the responsibility of person *B* if person B is assessing an area under the responsibility of person A.**

- **The entire MC&A program will be reviewed and evaluated during each single assessment (to be completed within an elapsed time that is short relative to the time between changes in the MC&A system and is demonstrated to be able to include any such changes made during the review/assessment). Conducting two or more assessments during an 18-month interval, in which only part of the MC&A system is covered in each, is acceptable if each subsystem is covered at 9-month (or less) intervals. It is important to assess the MC&A program as a whole to evaluate how individual systems interact. Therefore, if more than one assessment is to be conducted, the review should include consideration of how well the other components currently interact.**

- **The leader of the assessment team will have no responsibilities for performing or managing the functions being assessed. The assessment team leader will have no responsibility for managing or performing any of the MC&A functions.**

- **The responsibility and authority for the assessment program and for initiating corrective actions should be: (1) at least one level higher in the organization than the MC&A manager, or (2) at a level equal to that of the on-site plant manager.**

- **Each overall review and assessment will be conducted and completed in a time frame that is short with respect to the time for changes to have occurred in the MC&A program and will include any such changes made during the time the review or assessment is being conducted.**

- **The completion date for any review and assessment is defined as the date when the team submits its final written report (of findings and recommendations) to plant management. The start date is the first day in which one or more team members actually inspect records or interview MC&A personnel, and the team will document such start date.**

- **The results of the assessment and recommendations for corrective action, if any, will be documented and reported to the plant manager and other managers affected by the assessment. Management will review the assessment report and take the necessary actions to correct MC&A program deficiencies. Such corrective actions (if any) that pertain to daily or weekly activities will be initiated within 30 calendar days following the submittal of the review and assessment final report.**

- **Management's response to recommendations from the review and assessment, including any corrective actions ordered by management and the expected time frame for completing such actions, will be documented within 30 calendar days following the submittal of the team's report.**

A.11. TAMPER-SAFING

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs. Language found in ANSI N15.8-2009 about the handling and use of *fuel component containers* is applicable to PBRs.

The intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43(c)(3) is to require licensees to maintain and follow tamper-safing procedures for special nuclear material (SNM) containers and vaults, including controlling access to, and distribution of, unused seals and records. The intent of such procedures is to document the distribution, application, and destruction of tamper-safing devices, as well as routine inventory of unused tamper-safing devices. Licensees should retain records for at least 3 years or longer if specifically required by regulations external to 10 CFR 74.41, "Nuclear Material Control and Accounting for Special Nuclear Material of Moderate Strategic Significance"), thereby providing a means for assessing the performance of the tamper-safing program and inspecting for compliance with regulatory requirements.

A.11.1 CHARACTERISTICS OF TAMPER-SAFING DEVICES

The use of tamper-indicating devices (TIDs) on containers or vaults is one such level of protection licensees use to secure the integrity of SNM either when it is in transit or stored on site. The one overriding objective of TIDs is to ensure that no tampering or entry has occurred while the TID is on the container. Therefore, for material control and accounting (MC&A) purposes, the degree of confidence in the selection of a TID sealing system will vary depending on its unique characteristics and intended use.

When selecting TIDs, licensees should consider the following:

- **Intended use: the determination of whether the TID is appropriate for the tamper-safing of the container and withstanding the working environment, (i.e., temperature, moisture, repeated handling).**

- **Application: the relative ease or difficulty of physically applying the TID.**

- **Substitution: the ability of a TID to be destructively removed and replaced by a new TID without detection.**

- **Removal and reapplication: the ability of a TID to be removed and reapplied without detection.**

- **Alteration of label data: the ability to alter recorded data on the TID without the alteration being apparent.**

- **Integrity verification: the degree of effort required to verify the TID is intact or indicates tampering.**

The licensee should confirm the manufacturer's claims that the removal of a TID is not possible without detection by testing potential TIDs to see if they can be removed from the containers on which they are to be used. The licensee should confirm the results by using the manufacturer's documented procedures and the samples used. The experiments should be documented, both with regard to what techniques the licensee used to attempt to defeat the TID and observations as to the degree of success in defeating the TID. In lieu of testing by the licensee, similar tests conducted by an independent third party may be considered acceptable.

A.11.2 USE OF TAMPER-SAFING DEVICES

The MC&A plan may allow the use of TIDs to achieve the following:

- **Ensure the long-term validity of measurement data. The application of a TID to an item containing measured quantities of nuclear materials may allow the licensee to maintain the validity of the original measurement value, thus eliminating or decreasing the frequency of the need to remeasure the items to verify their nuclear material content.**

- **Reduce the effort to conduct physical inventories or item control activities. The application of a TID to a container housing multiple items may allow the licensee to maintain the validity of the container's contents, thus minimizing the number of items required to be verified during a physical inventory or item control activity.**

- **Provide assurance of integrity of in-transit material. The application of a TID to a shipping container may allow the licensee to maintain the validity of shipping container's contents and provide assurance that the integrity of the shipment has not been violated. To achieve this goal, the shipper must apply the TID(s) to the shipping container, verify the integrity of the TID(s) shortly before departure of the shipment, and provide the appropriate information—shipping container serial number(s), TID(s) type(s), and serial number(s)—to the receiver. Upon receipt of the shipment, the receiver should verify the shipping container serial number(s), TID(s) type(s), serial number(s), and TID(s) integrity. Any discrepancies should be considered an MC&A anomaly and be addressed by the facility's MC&A resolution program.**

A.11.3 DESCRIPTION OF TAMPER-SAFING RECORDS

The tamper-safing system should identify all records, forms, reports, and standard operating procedures used throughout the program. Such records should include, but are not limited to, the following:

- **receipt of purchased TIDs**

- **issuance of TIDs**

- **identification of the person applying the TIDs**

- **identification of the person who verified the application of the TID**

- **identification of the container to which the TIDs was applied, including the TIDs serial identification (if applicable)**

- **removal and destruction of TIDs**

- **routine inventory of unused and unissued TIDs**

- **identification of roles and responsibilities, including:**
  - **designation of the TID control officer(s)**
  - **personnel approved to apply, verify, and destroy TIDs**
- **training of personnel in the application, verification, and destruction of TIDs.**

A.11.4 COMMITMENTS AND ACCEPTANCE CRITERIA

The acceptability of a TID is based on an evaluation of the attributes of the device in relation to time to defeat the tamper-indicating features. TIDs the NRC has already deemed acceptable include: Type E, pressure-sensitive, tamper-evident wire seals, fiber optic seals, and steel padlocks. Other TIDs may be equally acceptable. Licensees proposing to use TIDs not currently approved by the NRC must provide the appropriate information, including references, to enable licensing reviewers to assess the adequacy of the proposed TID type.

In its MC&A plan, the licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to the use of tamper-safing devices. A finding that the licensee's MC&A plan for tamper-safing is acceptable and in accordance with 10 CFR 74.43(c)(3), will be based on, but not limited to, the following acceptance criteria:

- **Only TIDs that are controlled and accounted for are used to maintain the validity of previously established SNM quantities associated with items.**
- **Written procedures are maintained to ensure that individuals authorized to handle TIDs are properly trained.**
- **Preferably, a single individual, but no more than three individuals (none of whom have any responsibility for seal application or destruction), is/are designated as the tamper-safing device control officer(s).**
- **TIDs are only applied and removed by individuals authorized for that purpose.**
- **Unused TIDs are controlled and inventoried. Unissued tamper-safing devices are stored in a locked container within a room that is locked when unoccupied or in an approved repository. Blocks of tamper-safing devices issued to designated individuals are stored in a locked container within a room that is locked when unoccupied or in an approved repository.**
- **When TIDs are not in storage, they are in the possession of authorized individuals (i.e., the tamper-safing device control officer or person responsible for applying the tamper-safing device.) As a rule, the number of available seals issued to these individuals should be limited to a single day's use.**
- **The licensee has in its possession a commitment from the seal manufacturer that plates and dies and production residuals are controlled and protected.**
- **Upon removal, TIDs are destroyed (i.e., crimped, flattened, or otherwise rendered unusable) and properly disposed.**
- **Records of TID application, verification, removal, and destruction are documented, and control measures are implemented to prevent alteration of records concerning containers protected by TIDs.**

A.12. THIS SECTION IS RESERVED

Note that that this section in NUREG 2159 (Designation of Material Balance Areas, Item Control Areas, and Custodians) was combined with Section A.7 (Physical Inventories) in this report. This section was reserved to maintain consistency with the numbering of the sections in this report with the numbering in NUREG 2159.

A.13. RESOLVING INDICATIONS OF LOSS, THEFT, DIVERSION OR MISUSE OF SPECIAL NUCLEAR MATERIAL

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The intent of the general performance objectives in Title 10 of the *Code of Federal Regulations* (10 CFR) 74.41 (a) is that licensees be able to promptly investigate and resolve any indications of a possible loss, theft, diversion, or misuse of special nuclear material (SNM), whether arising from errors or deliberate actions.

A.13.1 METHODS AND PROCEDURES FOR IDENTIFYING INDICATORS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The material control and accounting (MC&A) plan should discuss the means by which the licensee will resolve indicators of a possible loss, theft, diversion, or misuse of SNM. The licensee's resolution program should address the possible indicators of missing SNM. The MC&A plan should enumerate all the potential indicators that can be postulated and develop resolution procedures for each. Any anomaly could potentially be an indicator of loss, theft, diversion, or misuse of SNM. An anomaly is an unusual observable condition (such as excessive discrepancies, missing items, broken tamper-indicating devices, or other possible indicators) that might result from theft, diversion, or other misuse of SNM. The terms "indicator" and "anomaly" may be used interchangeably to describe a condition that may require further investigation to determine if an actual loss, theft, diversion, or misuse of SNM occurred.

The following are examples of possible indicators of missing SNM:

- **lack of agreement between a physical inventory and its associated book inventory in which the inventory difference (ID) is positive and exceeds three times the standard error of the inventory difference (SEID) and more than 300 grams of ^{235}U or 200 grams of plutonium or ^{233}U,**
- **determination through the item control system that one or more items are not in their designated locations and the actual locations are not immediately known**
- **discovery that an item's integrity or its tamper-indicating device (TID) was compromised**
- **information from the process control system[4] indicating potential loss of material from the process system**
- **an allegation of theft or diversion**

A.13.2 SYSTEM AND PROCEDURES FOR INVESTIGATING AND RESOLVING LOSS INDICATORS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

One or more MC&A procedure(s) should address the system and practices for investigating and resolving loss indicators. The licensee should have well defined procedures for promptly investigating and resolving indications of possible missing SNM and procedures for rapidly determining if an actual loss of SNM has occurred. These procedures should include criteria for determining when to conclude an investigation of loss indicators.

[4] Care should be taken not to confuse the concept of formal process monitoring (Category I) with the fact that MC&A often uses operational alarms (process controls) to inform if some anomaly has occurred.

Resolving a loss indicator means that the licensee has made a determination that loss, including possible diversion or theft, has not occurred and is not occurring. For each type of indicator, the licensee should develop detailed resolution procedures and should describe or outline them in the MC&A plan.

Any investigation of an indication of a loss or theft should provide, whenever possible, (1) an estimate of the quantity of SNM involved, (2) the material type or physical form of the material, (3) the type of unauthorized activity or event detected, (4) the time frame within which the loss or activity could have occurred, (5) the most probable cause(s), and (6) recommendations for precluding reoccurrence.

For indications that a loss or theft may have occurred, the resolution process should include (1) thoroughly checking the accountability records and source information, (2) locating the source of the problem, (3) isolating the exact reason for the problem within the area or processing unit, (4) determining the amounts of SNM involved, and (5) making a determination that the indication is or is not resolved. The licensee should prepare the resolution procedures in such a manner that no individual who could have been responsible for the potential loss also would be responsible for its resolution. If an investigation of an indicator results in a conclusion that the indication is true, such conclusion must be reported to the U.S. Nuclear Regulatory Commission (NRC) within 1 hour of its determination pursuant to 10 CFR 74.11, "Reports of Loss or Theft or Attempted Theft or Unauthorized Production of Special Nuclear Material." The MC&A plan should specify the time allowed for resolution. In general, a time not exceeding 72 hours should be adequate.

A.13.3 RESPONSE ACTIONS FOR UNRESOLVED INDICATORS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Response actions to unresolved indicators should be clearly defined and should be implemented on a graded scale appropriate to the level of potential safeguards significance. Licensees also should define the responsibility and authority for initiating and executing such escalating levels of response actions.

For indicators of missing SNM, the level of safeguards concern is related to such factors as:

- **the potential quantity of SNM involved**
- **the material attractiveness of the potential missing uranium or plutonium (in terms of fabricating a nuclear explosive device) relative to its type, enrichment, composition, or form (e.g., U metal, U_3O_8, uranyl nitrate solution, UF_6, scrap, or waste)**

A.13.4 DOCUMENTATION REQUIREMENTS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The MC&A plan should identify all documentation requirements associated with the licensee's program for the reporting, investigation, and resolution of missing SNM indicators. Review and approval requirements and document custodial responsibility also should be defined. As a minimum, the plan should include documentation of the following:

- **investigation procedures**
- **resolution procedures**
- **reporting of the indicator to MC&A management, including date and time the indicator was reported, the name of individual who discovered the indicator, and a description of indicator**
- **investigation findings and conclusion, including resolution status, date issued, name and signature of principal investigator, and approval signature of MC&A manager**

- **reports made to the NRC for unresolved indicators and for indicators determined to be real, including the date and time the report was made, the method of communication, and the name of the NRC individual contacted.**

Section 14.3 of this document provides additional types of information that may be necessary.

A.13.5 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its MC&A plan, the licensee should provide definitive commitments that adhere to regulatory requirements and meet the acceptance criteria applicable to investigating and resolving anomalies indicating possible missing SNM. A finding that the licensee's MC&A plan for resolving indications of loss, theft, diversion, or misuse of SNM is acceptable and in accordance with 10 CFR 74.41(a), will be based on, but not limited to, the following acceptance criteria:

- **Adequate commitments are provided to ensure a high probability that any indicator of missing SNM will be (1) recognized as an indicator, (2) investigated, and (3) resolved.**
- **A prompt investigation will be conducted by the licensee for all indications of possible loss, theft, diversion, or misuse of SNM.**
- **A cause or probable cause that is based on objective evidence will be assigned to each indication of possible loss that is investigated by the licensee.**
- **Investigation and resolution procedures will provide for adequate overchecks to ensure that no individual who could have been responsible for a possible loss or theft of SNM would be the sole or primary individual responsible for resolving the indicator.**
- **No investigation relative to an indication of a loss or theft of SNM exceeding the current significant quantity (SQ) shall be declared as completed but unresolved without first conducting a shutdown, cleanout inventory in which all unsealed SNM is remeasured for element and isotope contents.**
- **The results of all investigations of alleged thefts, and any indications of a loss of SNM that remain unresolved after 30 calendar days, will be reported by the licensee to the appropriate NRC MC&A licensing authority.**

A.14. INFORMATIONAL AID FOR ASSISTING IN THE INVESTIGATION AND RECOVERY OF MISSING SPECIAL NUCLEAR MATERIAL

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The intent of the general performance objective in Title 10 of the *Code of Federal Regulations* (10 CFR) 74.41(a)(4) is for licensees to have ready and provide to investigators any information deemed relevant to the recovery of special nuclear material (SNM) involved in a loss or theft. The burden is on the licensee to provide (without being asked) all information that it recognizes as being relevant, as opposed to only providing information that the investigators are knowledgeable enough to request. This objective pertains to investigations and recovery operations, relating to actual (or highly suspected) events pertaining to missing SNM, which would be conducted by the U.S. Nuclear Regulatory Commission (NRC) and other government agencies, such as the U.S. Federal Bureau of Investigations.

The 10 CFR 74.41(a)(4) performance objective states that the licensee must be able to provide, in a timely manner, information to aid in the investigation and recovery of missing SNM in the event of an actual loss, theft, diversion, or misuse.

A.14.1 TYPES OF INFORMATION

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The kinds of information that may aid the investigation and recovery effort are:

- **data or observations that led the licensee to determine that a loss or theft of uranium or plutonium may have occurred**
- **data, observations, and assessments associated with attempts to resolve the indication of missing material**
- **the time period during which the material may have left the facility**
- **the path and means by which the material may have left the facility**

A.14.2 INFORMATION INDICATING POSSIBLE LOSSES OF SNM

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Information indicating that a loss of uranium or plutonium may have occurred can come from process or production yield data, physical inventory results, item control, and shipper–receiver comparisons. This information could include:

- **material accountability data records and reports**
- **inventory records**
- **inventory difference and propagation of error calculations**
- **inventory reconciliation reports**
- **indications of unrecorded or unauthorized removals of SNM from storage or process locations**
- **reports of apparent destruction or falsification of records concerning SNM**
- **records of broken tamper-indicating devices (TIDs) or compromised item integrity**
- **indications of unauthorized entry into SNM storage areas**
- **reports from monthly item status inspections**
- **material receipt and log records**
- **results from shipper–receiver difference evaluations**
- **process quality assurance or production control records**
- **documentation relating to an alleged or confirmed theft**

A.14.3 INFORMATION ON RESOLVING INDICATIONS OF MISSING SNM

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

Chapter 13 discusses resolving indications of missing SNM. Information that may be of aid in the recovery of missing material, would include the following:

- **the type of unauthorized activity detected**
- **the interval during which the loss may have occurred**
- **the amount of material and form of the material involved in the loss**
- **results of measures to validate indicators**
- **results of extended measures to resolve indicators**
- **results from special inventories (or re-inventories) and tests performed**
- **audit results of the SNM accountability source data**
- **assessments of measurement data and measurement controls**
- **results from reviews of the material control and accounting program and status of corrective actions**
- **history of indicator investigation and resolution activities**
- **anomaly investigation and resolution procedures and conclusions**
- **probable cause of the loss**
- **any abnormal events that may have contributed to or caused the loss**
- **the names of individuals who could have been responsible for the loss**

Much of the backup information necessary to assist in an investigation would be records maintained in the facility records system described in Chapter 15.

A.14.4 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its material control and accounting (MC&A) plan, the licensee should provide definitive commitments that adhere to regulatory requirements and meet the acceptance criteria applicable to providing information to assist in the investigations and recovery of missing uranium. A finding that the licensee's MC&A plan for providing informational aid is acceptable and in accordance with 10 CFR 74.41 (a)(4), will be based on, but not limited to, the following acceptance criteria:

- **Procedures are in place for the efficient and timely gathering of relevant information to be provided to government investigators so as to aid them in the investigation and recovery activities associated with missing SNM.**
- **Information will be provided to appropriate government authorities to aid in their investigation of indications or allegations of missing material and in the recovery of SNM in the event of a loss that could include theft or diversion.**

A.15. RECORDKEEPING

REGULATORY INTENT

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The intent of Title 10 of the Code of Federal Regulations (10 CFR) 74.43(d) is to require licensees to establish and maintain records that demonstrate that the general performance objectives of 10 CFR 74.43, "Internal Controls, Inventory, and Records," and 10 CFR 74.45, "Measurements and Measurement Control," have been met. In accordance with 10 CFR 74.43(d), records must be retained for a minimum of 3 years (or longer if specifically required by 10 CFR Part 75, "Safeguards on Nuclear Material— Implementation of US/IAEA Agreement.") Note that, in accordance with 10 CFR 74.19(b), material control and accounting (MC&A) procedures (as documented in licensee records) must be retained until the Commission terminates the license. Records should include those documenting the following information:

- **receipt, shipment, disposal, and current inventory of the special nuclear material (SNM) held under license**
- **quantities of SNM added to and removed from process**
- **shipper–receiver evaluations associated with SNM receipts.**

Records provide a means for assessing the performance of the MC&A system and inspecting for compliance with regulatory requirements.

A.15.1 DESCRIPTION OF RECORDS

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The MC&A plan should identify all records, forms, reports, and standard operating procedures that show compliance with the requirements of 10 CFR Part 74, "Material Control and Accounting of Special Nuclear Material." Such records should include, but are not limited to, the following:

- **documents that define changes in the MC&A management structure or changes in responsibilities relating to MC&A positions**
- **procedures pertaining to any accountability-related measurement or sampling operation**
- **forms used to record or to report measurement data and measurement results, including source data**
- **forms and notebooks used to record calibration data associated with any accountability measurement system**
- **forms and notebooks used to record quantities, volumes, and other data associated with the preparation of standards, both calibration and control, used in connection with accountability measurement systems**
- **forms and official memos used to record or report measurement control program data, control limit calculations, and out-of-control investigations**
- **forms listing and providing instructions associated with physical inventories**
- **forms and formal worksheets used in the calculation of standard error of the inventory difference (SEID), inventory difference (ID), and active inventory values**
- **ledgers, journals, and computer printout sheets associated with the accountability system**
- **ledgers, journals, and computer printout sheets associated with the item control program, including tamper-indicating device (TID) usage and "attesting to" records**

- **U.S. Department of Energy/U.S. Nuclear Regulatory Commission (NRC) Forms 741 and 742 and NRC Form 327**
- **forms, memos, and reports associated with identification of, investigation of, and resolution of significant shipper–receiver differences (SRDs)**
- **loss indication and alleged theft investigation reports**
- **investigation reports related to excessive IDs**
- **official reports containing the findings and recommendations of MC&A system assessments and any letters or memos on response actions to assessment team recommendations**
- **forms used for recording data associated with the item monitoring programs**
- **monitoring program status or summary reports**
- **records of training sessions, including date given, topics covered, name of instructor(s), names and signatures of those attending**
- **training, qualification, and requalification reports and records**

Licensees should list examples of MC&A forms to be retained in the MC&A plan annex or appendix. The retained records and reports should contain sufficient detail to enable NRC inspectors to determine that the licensee has implemented the program and plan capabilities of 10 CFR 74.43 and 10 CFR 74.45 and has met the general performance objectives of 10 CFR 74.41 (a).

A.15.2 PROGRAM AND CONTROLS FOR ENSURING AN ACCURATE AND RELIABLE RECORD SYSTEM

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

The MC&A plan should describe the controls used to ensure that records are accurate and reliable.

The record system also should provide a capability for easy traceability of all SNM transactions from source data to final accounting records.

The following topics should be addressed:

- **the auditing system or program to verify the correctness and completeness of records**
- **the overchecks and balances for preventing or detecting missing or falsified data and records**
- **the plan for reconstructing lost or destroyed SNM records**
- **the access controls used to ensure that only authorized persons can update and correct records**
- **the protection and redundancy of the record system such that any act of record alteration or destruction will not eliminate the ability to provide a complete and correct set of SNM control and accounting information needed to achieve the performance objectives of 10 CFR 74.41 (a).**

A.15.3 COMMITMENTS AND ACCEPTANCE CRITERIA

Current practices for addressing this section of the MC&A plan would be applicable for PBRs.

In its MC&A plan, the licensee should provide definitive commitments that adhere to the regulatory requirements and meet the acceptance criteria applicable to recordkeeping.

A finding that the licensee's MC&A plan for recordkeeping is acceptable and in accordance with 10 CFR 74.43(d) will be based on, but not limited to, the following acceptance criteria:

- **A record retention system is maintained for those records necessary to show that the MC&A system requirements of 10 CFR 74.43(d) have been met. Licensees should retain such records for at least 3 years, unless a longer retention time is specified by 10 CFR 74.15(b), by 10 CFR Part 75 or by a specific license condition. The records referred to in 10 CFR 75.22, "Accounting Records," and 75.23, "Operating Records," and generated during any period in which the facility is under International Atomic Energy Agency (IAEA) safeguards will be retained for at least 5 years. Licensees will retrain and maintain current versions of the following records for at least 3 years:**

    - **management structure, MC&A job descriptions, and MC&A policies and procedures**

    - **accounting source data records (Accounting source data normally consist of shipping and receiving forms, physical inventory forms, and the forms used for initially recording measurement and measurement control data. After an item is destroyed, the item location record needs to be retained for an additional 14 calendar days but then may be destroyed.)**

    - **records of shipments and receipts and investigations of significant shipper–receiver differences, plus the information used to resolve them**

    - **measurement data for receipts, shipments, discards, and inventory**

    - **calibration of measurement systems, measurement control data, bias estimates, and the statistical analyses of the measurement control data**

    - **data used to demonstrate that the measurement system performance achieves the SEID limits required by 10 CFR 74.45(c)(4)**

    - **physical inventory listings and inventory work sheets**

    - **calculations of detection thresholds for excessive IDs of a safeguards significance (i.e., any ID that exceeds three times SEID and specified minimal quantities)**

    - **calculations of the standard error of the ID and information used to reconcile an excessive ID**

    - **reports of investigations and resolution of indications of loss of SNM**

    - **the results of independent assessments and management action taken to correct any deficiencies identified**

- **In accordance with 10 CFR 74.19(b), MC&A procedures (as documented in licensee records) must be retained until the Commission terminates the license.**

- **Sufficient protection and redundancy of the record system is provided so that an act of record alteration or destruction will not eliminate the capability to provide a complete and correct set of SNM control and accounting information that could be used to confirm the presence of SNM, resolve indications of missing material, or aid in the investigation and recovery of missing material.**

- **All SNM transactions, from source data to final accounting records, will be readily traceable.**

- **The source data will be retained in its original form until the physical inventory and any subsequent ID investigations have been completed. After this time, any readable facsimile is acceptable for the remainder of the required retention period. All other records may be retained as hard copy, microfiche, permanent computer readable forms, or other permanently readable forms.**

- **The records will be retrievable, sufficiently complete and detailed to permit auditing all parts of the MC&A system, and traceable back to original source data.**

- **The records of the data that are the basis of the calculated SEID will permit traceability to the sources of the variances caused by calibrations, bias adjustments, and random effects in the measurements. These records may be summaries of calibrations, bias tests, and variance monitoring data or control charts.**

- **The record system will have sufficient redundancy to enable reconstruction of lost or missing records so that knowledge of the SNM inventory is always available. The primary records, as contrasted with duplicate or backup records, will be provided security against computer failure, fire or water damage, vandalism, and access by unauthorized persons.**

- **All retained MC&A records are to be readily accessible to meet time restraints relative to their use. In general, the record retention system is to possess the capability to retrieve records used for measurement control or accountability within 24 hours if the record was generated within the past 12 months, and within 7 calendar days if generated more than 12 months ago. Licensees must make physical inventory available within 24 hours for the latest two physical inventories. Item control records are to be retrievable in time to satisfy the criteria in Section 8.7.**

- **Overchecks or other controls, including access controls for updating and correcting records, are provided so as to prevent or detect errors in the records that would affect inventory difference and item location.**

- **Checks and balances are incorporated that are sufficient to detect falsification of data and reports that could conceal diversion of SNM, as required by 10 CFR 74.41 (c).**

A.16. GLOSSARY

The following terms are defined in the context of (1) their usage in this document or (2) how they should be used if contained in the material control and accounting (MC&A) plans submitted pursuant to 10 CFR 74.41, “Nuclear Material Control and Accounting for Special Nuclear Material of Moderate Strategic Significance.”

ACTIVE INVENTORY – the sum of additions to inventory, beginning inventory, ending inventory, and removals from inventory, after all common terms have been excluded. Common terms are any material values which appear in the active inventory calculation more than once and come from the same measurement.

ADDITIONS TO INVENTORY—Quantities of SNM, of a given material type code, added to a “plant” inventory and which, before such addition, were not part of the plant’s total possessed quantity for the material type code in question.

ANOMALY—An unusual observable condition (such as excessive discrepancies, missing items, broken tamper-indicating devices or other possible indicators) that might result from theft, diversion, or other misuse of special nuclear material (SNM).

ARTIFACT STANDARD—A container or item, of certified mass, having a size, shape, and mass that is representative of a particular type of process-related item or container. Weighing error caused by buoyancy is eliminated by the use of artifact standards for scale calibrations.

ASSIGNED VALUE—A value for mass, volume, SNM concentration, SNM quantity, etc., assigned to a standard weight, standard material, etc., used for calibrating or controlling a measurement device or system. An assigned value may not necessarily be a certified value, but if it is not, it should be traceable to a certified standard. In any event, *assigned value* is the best estimate of the standard’s true value.

CERTIFIED STANDARD—A standard weight, material, device, or instrument having an assigned value that is guaranteed to be within specified limits by a nationally or internationally recognized organization (e.g., bureau, laboratory, etc.) that issues or certifies standards.

CHECK STANDARD (BENCH STANDARD, WORKING STANDARD)—A standard, not necessarily traceable to a primary standard, that is used routinely (e.g., daily or weekly) to check (or verify) the reliability of a measurement

device, instrument, etc. (including those of accountability measurement systems). Such standards are not, however, used for the actual calibration or control of accountability measurement systems.

COMBINED STANDARD ERROR—An error band derived from the respective standard error values associated with each of two measurements (usually independent of each other) performed on a given material quantity. For both measurement values (of the pair) to be regarded as being in agreement, they must not differ from each other by more than the calculated combined standard error, which is normally calculated by taking the square root of the sum of squared individual standard errors. That is:

Combined Standard Error $= [(\sigma_S)^2 + (\sigma_R)^2]^{1/2}$

where

σ_S **= shipper's measurement standard error**
σ_R **= receiver's measurement standard error**

CONFIRMATORY MEASUREMENT—A measurement that confirms (within measurement uncertainty at the 95 percent confidence level) a previously established parameter, such as net weight, enrichment, etc., associated with an SNM item (or SNM quantity), but which does not thoroughly verify the previously established element or isotope quantity assigned to such item. Confirmatory measurements are sometimes used as the basis for concluding that previous measurement values for plutonium, uranium (U), and ^{235}U **or** ^{233}U **(or element and isotope) quantities are still valid.**

CONTROL STANDARD—A standard that (1) is representative of the process material being measured, and (2) is itself measured periodically to monitor for and to estimate any bias associated with the measurements of the process material in question. A control standard must be traceable to a primary standard or to a primary reference material.

CRITICAL MATERIAL CONTROL AND ACCOUNTING (MC&A) PROCEDURES—Those written procedures that, if not performed correctly, could result in a failure to achieve one or more of the four general performance objectives of Title 10 of the Code of Federal Regulations (10 CFR) 74.41(a) and the program and plan capabilities of 10 CFR 74.41(c).

DEPLETED URANIUM—Any uranium-bearing material whose uranium isotopic distribution can be characterized as being (1) less than 0.700 weight percent (wt %) in combined ^{233}U **plus** ^{235}U**, and (2) at least 99.200 wt %** ^{238}U**.**

ENDING INVENTORY (EI)—The total itemized quantity of SNM of a given material type code possessed by a "plant" at the end of a material balance period, as determined by a physical inventory. The EI quantity for any given material balance period is (by definition) exactly equal to the beginning inventory quantity for the next period.

ENRICHED URANIUM—Any uranium-bearing material that does not qualify as natural or normal uranium, and whose combined ^{233}U **plus** ^{235}U **isotopic content is 0.725 percent or higher by weight, relative to total uranium element content.**

INVENTORY RECONCILIATION—The adjustment of the book record quantity of both element and fissile isotopes to reflect the results of a physical inventory. In the broad sense, inventory reconciliation also includes the activities of calculating (1) the inventory difference (ID) for the material balance period in question, (2) the uncertainty (i.e., SEID) value associated with the ID, (3) the active inventory for the period, and (4) any bias adjustment or prior period adjustment associated with the ID value.

ITEM CONTROL AREA (ICA)[5]—An identifiable physical area for the storage and control of SNM items. Control of items moving into or out of an ICA is by item identity and SNM quantity as determined by a previous measurement.

KEY MEASUREMENT POINT (KMP) – a measurement that is used for accounting purposes. Measurements (1) establish the quantities in each custodial area, material balance area (MBA), or item control area (ICA) and in the facility as a whole, and (2) contribute to the desired capability to localize losses and to generate and assess alarms. Measurement points or sampling stations should be selected to provide quantitative information about material flows and inventories that will permit detection and localization of any loss or diversion or to confirm that no theft or

[5] This definition is from NUREG-1065 Rev. 2.

diversion has occurred. An Inventory KMP (IKMP) provides a measurement of inventory in an ICA and a Flow KMP (FKMP) provides measurements of material passing between ICAs or MBAs.

KEY MEASUREMENT SYSTEM—Any set of designated measurement systems (of the licensee's choosing) which, based on the most recent previous period, account for at least 90 percent of the total measurement variance contribution to SEID. Included within the set of key measurement systems should be any system used to measure an SNM quantity (during inventory period) greater than 25 percent of the active inventory, regardless of its contribution to SEID.

MATERIAL BALANCE AREA (MBA)[6]—An identifiable physical area for the physical and administrative control of nuclear material such that the quantity of nuclear material being moved into or out of the MBA is represented by a measurement value (for both element and isotope).

MATERIAL BALANCE PERIOD—The time span to which a material balance or physical inventory relates.

MEASURED DISCARD—A batch or quantity of waste whose SNM content has been determined by measurement that (1) has been shipped to a disposal site, released to the environment, or stored on site, and (2) has been taken off the accounting ledgers as part of the current inventory of possessed SNM.

MEASUREMENT CONTROL PROGRAM—A managed program for monitoring and controlling both accuracy and precision of SNM accountability measurements.

NATURAL URANIUM—Any uranium-bearing material whose uranium isotopic distribution has not been altered from its naturally occurring state. Natural uranium is nominally 99.283 wt % ^{238}U, 0.711 wt % ^{235}U, and 0.006 wt % ^{234}U. However, the terms *natural uranium* and *normal uranium* are practically used interchangeably for nuclear materials management and safeguards system purposes in the use of material code 81 for source material other than thorium.

NORMAL URANIUM—Any uranium-bearing material having a uranium isotopic distribution that can be characterized as being (1) 0.700 to 0.724 wt % in combined ^{233}U plus ^{235}U and (2) at least 99.200 wt % in ^{238}U. (NOTE: All natural uranium having a ^{235}U isotopic abundance in the range of 0.700 to 0.724 wt % is normal uranium, but not all normal uranium is natural uranium.) (see NATURAL URANIUM.)

POINT-CALIBRATED MEASUREMENT SYSTEM—A measurement system in which the measurement value assigned to an unknown measured by the system is derived from the response obtained from the measurement of a representative calibration standard(s) that was measured along with (i.e., at the same time as) the unknown. The standard(s) must undergo all the measurement steps (e.g., aliquoting, sample pretreatment, etc.), and in the same manner, as the unknown. Point-calibrated measurement systems can be regarded as bias free, provided that adequate controls are in place to ensure the validity of the standard's assigned value.

PRIMARY STANDARD—Any device or material having a characteristic or parameter (such as mass, uranium concentration, uranium isotopic distribution, etc.) whose value is certified (within a specified uncertainty) by a nationally or internationally recognized bureau, laboratory, etc., that issues or certifies standards.

PRIOR PERIOD ADJUSTMENT—Any correction (i.e., adjustment) to an ID value because of a correction applied to a component of beginning inventory after the inventory period started. Such corrections may be because of resolution of a shipper–receiver difference (SRD) on material received during a prior inventory period, correction of a recording error, etc. Because these types of corrections have nothing to do with current period losses or errors, and because the official beginning inventory value is not adjusted, an adjustment to the ID value (derived from the ID equation) is necessary to obtain an ID that reflects only current period activity.

RESIDUAL HOLDUP—Any depleted uranium, safeguards material, or SNM that remains within processing equipment (including ventilation filters and ductwork) after system draindown or cleanout. If, at the time of physical inventory, the total quantity of residual holdup is significant, such holdup must be measured (or estimated on the basis of partial measurements and engineering calculations) and included in the physical inventory listing. The uncertainty associated with a total measured or estimated residual holdup quantity must be included in the calculation of the SEID.

[6] This definition is from NUREG-1065 Rev. 2

RESOLUTION OF AN INDICATOR—A definitive determination (with auditable evidence) by the licensee that an indicated possible theft or loss of uranium or plutonium was a false indicator.

SHIPPER–RECEIVER DIFFERENCE (SRD)—The difference between what a sending facility (i.e., shipper) claims was contained in a shipment (of SNM) and what the receiving facility claims was received, where both shipper's and receiver's values are based on measurement.

SIGNIFICANT QUANTITY (SQ) OF SNM OF MODERATE STRATEGIC SIGNIFICANCE—More than 1 formula kilogram (FKG) of strategic SNM, or 10,000 grams or more of ^{235}U contained in uranium enriched to 10 percent or more, but less than 20 percent in the ^{235}U isotope. (Note: For statistical sampling plans, however, SQ is conservatively set to 1 FKG for strategic SNM and 10,000 grams ^{235}U for Category II amounts of low-enriched uranium.)

STANDARD—See definitions for CERTIFIED STANDARD, CHECK STANDARD, CONTROL STANDARD, PRIMARY STANDARD, and STANDARD REFERENCE MATERIAL.

STANDARD DEVIATION—The random error (at the 67 percent confidence level) associated with a single value of a data set, which in turn is also a measure (or indication) of the precision relating to a set of measurements (or set of data) concerning the same item or sample of material. Standard deviation is calculated as follows:

Standard Deviation: =

$$s = \left\{ \left[\sum_{i=1}^{n} (x_i - \bar{x})^2 \right] / (n-1) \right\}^{½}$$

Where

***n* = number of measurements performed**

x_i = the value obtained for the i^{th} measurement for i = 1, 2, 3, ...n

$\bar{x}$ = the average value for all *n* measurements

STANDARD ERROR—The random error (at the 67 percent confidence level) associated with the average, or mean, value of a data set derived from repetitive determinations on the same item or sample. Mathematically, *standard error* is the standard deviation divided by the square root of the number of individual measurements used to derive the mean value.

STANDARD REFERENCE MATERIAL—A material or substance that qualifies as a primary standard and whose concentration with respect to a nuclide or isotope, a chemical element, or chemical compound is certified within a specified uncertainty.

SYSTEMATIC ERROR—A unidirectional error that affects all members of a data set. The terms *bias* and *systematic error* are often interchanged. However, any determined bias (i.e., a bias estimated from control standard measurements) has an uncertainty value associated with it. Thus, after correcting for any estimated bias, the uncertainty of that bias can be regarded as a systematic error. If an estimated bias is not applied as a correction, the combination of the bias plus its uncertainty should be regarded as the systematic error.

VERIFICATION MEASUREMENT— (1) A nondestructive assay (NDA) measurement of an item conducted to verify that a previous NDA measurement value for isotope content of that item is still valid. (2) The re-weighing and re-sampling of an item, batch, lot, or sublot and performing chemical assays of the re-sample for element and isotope concentrations so as to verify a previously measured value for element and isotope content of the item (batch, lot, or sublot). Verification is achieved if the original and verification measurement values (for element and isotope quantities) agree within the range of measurement uncertainty (at the 95 percent confidence level).

A.17. REFERENCES (FOR MODEL MC&A PLAN)

International Atomic Energy Agency (IAEA), *IAEA Safeguards Statistical Concepts and Techniques*, 4th revised edition, 1989, Vienna, Austria.

NUREG/BR-0096, "Instructions and Guidance for Completing Physical Inventory Summary Reports (NRC Form 327)," January 1992.

NUREG/BR-0006, "Instructions for Completing Nuclear Material Transfer Reports (DOE/NRC Forms 741, 741A, and 740M)," Revision 8, May 2018 or Draft Rev. 9, July 2019.

NUREG/BR-0007, "Instructions for the Preparation and Distribution of Material Status Reports (DOE/NRC Forms 742, and 742C)," Revision 7, May 2018 or Draft Rev. 8, July 2019.

NUREG/CR-2078, "Handbook of Nuclear Safeguards Measurement Methods," September 1983.

NUREG/CR-4604, "Statistical Methods for Nuclear Material Management," December 1988.

NUREG/CR-5550, "Passive Nondestructive Assay of Nuclear Materials," March 1991.

NUREG/CR-0602, "Active Nondestructive Assay of Nuclear Materials," January 1981.

TID-26298, "Statistical Methods in Nuclear Material Control," 1973.

Title 10 of the Code of Federal Regulations (10 CFR) Part 74, "Material Control and Accounting of Special Nuclear Material," Subpart D, "Special Nuclear Material of Moderate Strategic Significance."