National Nuclear Security Administration

OFFICE OF NONPROLIFERATION AND ARMS CONTROL (NPAC)

International Perspectives on Safeguards

December 4, 2020

INTERNATIONAL NUCLEAR SAFEGUARDS
Build capacity of the international atomic energy agency and partner countries to implement international safeguards obligations.

NUCLEAR EXPORT CONTROLS
Build domestic and international capacity to implement export control obligations.

NUCLEAR VERIFICATION
Support negotiation of and implement agreements and associated monitoring regimes to verifiably reduce nuclear weapons and nuclear programs.

NONPROLIFERATION POLICY
Develop policies, programs, and strategies to address emerging nonproliferation and arms control challenges and opportunities.

Summary

- NNSA's Office of Nonproliferation and Arms Control (NA-24) has been engaged with advanced reactor designers for over a decade
- A Safeguards-By-Design Working Group has been formed to formalize our outreach with the focus on US designers
- The focus of international safeguards is different from domestic safeguards due to who is the potential adversary and the commitment to the NPT
- There is a wide range of potential safeguards challenges depending on advanced reactor designs
- Safeguards challenges are best addressed through the early consideration of safeguards in the design process
- We are coordinating our Safeguards-By-Design effort with a parallel Security-By-Design effort

DOE/NNSA Safeguards-By-Design (SBD) Goal – Help ensure international safeguards requirements are fully integrated into the design process of a new nuclear facility from the initial planning through design, construction, operation, and decommissioning.

PROGAM ACTIVITIES

Technical & Policy Analysis	• *Survey of International Safeguards Challenges Posed by Small Modular Reactors* (BNL) – 2013 • *International Safeguards for Microreactors* (PNNL) - 2017
Recommendations	• *Implementing Safeguards-by-Design* (INL) - 2010 • *Safeguards-By-Design: Guidance and Tools for Stakeholders* (INL) - 2012
Industry Design Concepts	• Microreactors • Small Modular Reactors • Molten Chloride Fast Reactors

Safeguards-By-Design Working Group (SBD-WG)

The SBD-WG is an **interlaboratory working group** that will support NNSA SBD activities.

- Funded by NA-24 Concepts and Approaches
- Brings together SBD and IAEA expertise from across the lab complex
- Focused on identifying stakeholders and needs

Goals:

1. **Advance adoption of SBD**
2. **Provide clear and consistent messaging**
3. **Facilitate communication and collaboration**

Value to U.S. Industry

- Communicate the tangible applications of SBD
- Articulate the value of SBD for each stakeholder
- Source of knowledge and information

Value to Concepts and Approaches

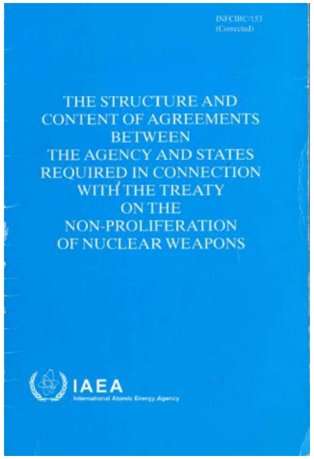
- Identify stakeholders and document priorities
- Collect and disseminate lessons learned
- Leverage partnerships across the USG

SBD is a Voluntary Collaboration

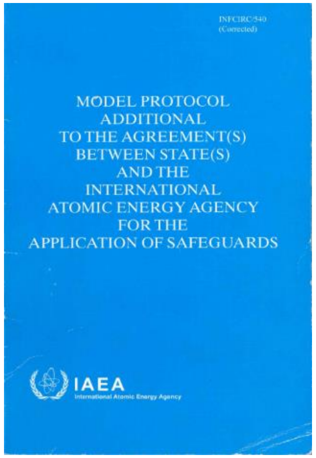
- Sharing of information for the SBD approach precedes the legal requirements for provision of design information
- Success relies on each stakeholder's understanding of the benefits that can be realized by active participation in the process

IAEA Safeguards

- The IAEA is an independent international organization that is responsible for verifying through the implementation of safeguards that States are honoring their international legal obligations
- Purpose: To allow the IAEA to verify that nuclear materials & technologies are used only for peaceful purposes
- Applies to all nuclear activities *within a State's territory, under its jurisdiction or carried out under its control anywhere*
- Should avoid hampering the economic & technological development related to peaceful nuclear activities
- The IAEA & the State shall cooperate on implementation

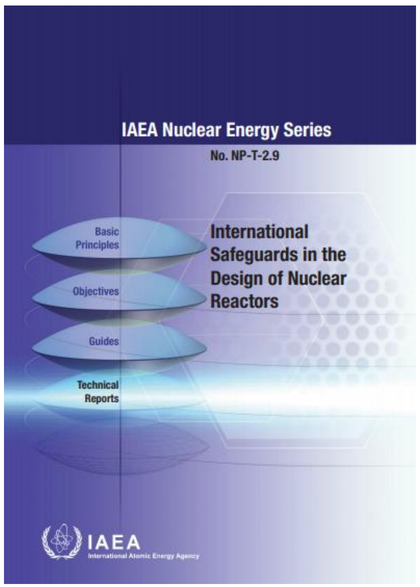


Comprehensive Safeguards Agreement (INFCIRC/153)



Model Additional Protocol (INFCIRC/540)

IAEA Safeguards Measures



https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1669_web.pdf

- Intensity of safeguards measures chosen by the IAEA will evolve over time
  - Depends on type of safeguards agreement in the country
- Acquisition path analysis (APA)
  - IAEA considers all potential pathways that a State could pursue to acquire direct use nuclear material to manufacture a nuclear explosive device
  - How the existing nuclear capabilities of the State could be misused or diverted
- Verification activities
  - Design information
  - Accountancy system
- Facility infrastructure requirements
  - Physical space, uninterruptible power, and a data transmission backbone

Stakeholder Responsibilities

- IAEA
  - Verify that nuclear materials & technologies are used only for peaceful purposes
- Designers and vendors
  - Understand export control requirements and nonproliferation policy when exporting to a country
  - Understand the safeguards, security, and safety requirements
  - Keep safeguards considerations in mind (required access, installation of instrumentation, and key measurement points)
- Operators
  - Facilitate communication between the facility, State, and implementing nuclear material accountancy and safeguards at the facility level; complying with State regulations and assisting IAEA inspection
- State or Regional Safeguards Authority
  - Fulfil the obligations of the State as defined by treaties and agreements, including formal communications with the IAEA

Safeguards Considerations for Designers

- For both domestic nuclear material accountancy and control (NMAC) and IAEA safeguards there are common design themes that could apply to both:
  - **Access Controls** – Engineered access controls or ease of applying administrative controls to nuclear material.
  - **Material Balances and Physical Inventories** – Incorporate principles of compartmentalization and points where measurements could be taken.
  - **Key Measurement Points** – Adequate points in the system where material can be readily measured including element concentrations and isotopic compositions.
  - **Material Containment** – Arrange material flows and forms of material to simplify and facilitate access controls, TIDs, and detection of breach.
  - **Surveillance Systems** – Facilitate application of video, heat sensors, radiation monitors, laser monitors, RFIDs, motion detectors, etc.

Safeguards Considerations for Designers

- **Item vs. Bulk** – Maximize containerization and item counting of material.
- **Measurement Systems** – Ease of application of systems such as scales and volume measurements with a high degree of accuracy.
- **Reduce Measurement Uncertainties** – Design features that reduce MUF/ ID and uncertainties to aid in material balance evaluation.
- **Movement of NM** – Carefully consider how NM will be received and shipped as well as movement within and between MBAs/ item control areas.
- **Minimization of Waste Streams** – Considerations for minimizing accidental or unauthorized removal of NM from waste streams.

General IAEA Safeguards Considerations

Distinction between Domestic and International Safeguards is the Threat Basis

- Domestic: Sub-National & Insider
- International: State (The most challenging adversary)

Applicable to all nuclear fuel cycle related activities

- International Atomic Energy Agency (IAEA) defined nuclear material
  - Source Material – Natural Uranium, Depleted Uranium, Thorium
  - Special Fissionable Material – Pu-239, U-233, U Enriched in U-233/235
  - Fuel cycle R&D, including R&D not involving nuclear material (may be declarable under U.S. AP declaration)

General IAEA Safeguards Considerations

Generic objectives – Detection of:

- Diversion – The removal of declared source or special fissionable material from a facility
  - Reactor Examples: fresh, core, spent/used fuel
- Misuse – Using a facility to process undeclared nuclear material
  - Reactor Example: Transmuting undeclared U-238 targets to Pu-239 in the core
  - Reprocessing/Separation Example: Separating Pu-239/U-233 from undeclared spent fuel using excess reprocessing capacity
- Significant Quantities (SQ) of Concern: 8Kg Pu & U-233, 25Kg HEU, 75kg LEU, 10T NU, 20T DU & Th
  - Approximate amount of nuclear material for which the possibility of manufacturing a nuclear explosive device cannot be excluded

Generic Considerations for Reactors

Item - Material is in item form and consists of individually identifiable units (Serial numbered: e.g. fuel assembly, bundle, pin, plate or coupon) that are kept intact during their stay in the facility.

- Safeguard Challenge is LOW to MODERATE
  - Simple item counting and attribute verification (serial number, gamma-ray).

Bulk - Material is material in loose form, such as liquid, gas or powder, or in a large number of small units (e.g. pellets or pebbles) that are not individually identifiable units.

- Safeguards Challenge could be MODERATE to HIGH
  - Quantification, if possible, with known measurement uncertainty (NDA, DA, weight). If not possible, intrusive process monitoring with containment/surveillance (C/S).

Generic Considerations for Reactors (cont.)

- Long lived cores in item facilities enable the use of C/S that reduce the IAEA safeguards burden over time.
  - Eliminating fresh and spent/used fuel on-site outside of core dramatically reduces the IAEA safeguards burden. Terrapower traveling wave reactor is an example *(~20-year core lifetime).*
- Transportable reactors may increase the safeguards challenge.
- High temperatures, high radiation, corrosive/pyrophoric/opaque coolants all challenge verification systems.

Reference Reactor for IAEA Safeguards

Light Water Reactors: Pressurized and boiling water designs

- Over 400 reactors are under IAEA safeguards
- Fresh and spent/used fuel is visible all of the time as well as core fuel during refueling

Item Type - Advanced Reactor

HTGR/TRISO Prismatic type fuel assembly

Safeguards Challenge is **LOW**

- Prismatic blocks do have a unique identification number
- The IAEA is already safeguarding this type of reactor in Japan known as the HTTR (High Temperature Test Reactor)
- Unlike LWR assemblies, blocks are typically stacked on top of each other covering unique identification number
- Fewer verification tools available than LWR

Advanced Reactor

Pebble Bed, not item but placed here with prismatic as it also uses TRISO

HTGR/ TRISO/Pebble Bed

Safeguards Challenge is **LOW**

- While a moving core is challenging, each pebble contains a very small amount of enriched uranium (on the order of ~10g but varies till equilibrium reached); therefore, to obtain an IAEA SQ will require the diversion of hundreds of thousands of pebbles.
- Pebbles are expected to have burn up in the 80-120 GWd/ton, burning much of the U-235/Pu-239.
- As the pebbles are a graphite sphere, counting of pebbles as they move through the transfer system can be measured by capacitance and other techniques are also being explored (authentication by the IAEA further emphasizes the need for SBD).
- The Chinese HTR-PM twin (250 MWTh each for 210 MWe) just finished cold testing.
    - Spent/Used pebbles will be stored in a tank at the reactor for the life of operation. The height of the pebbles can be estimated using, for example, a collimated gamma detector in a side tube.
    - No current plan to reprocess.

Item Type - Advanced Reactor (cont.)

Metal Coolant Reactors: SFR & LFR (i.e. opaque coolants)

Safeguards Challenge is **MODERATE**

Here we include Na and Pb/PbBi as coolants

- The IAEA is already safeguarding SFRs in Japan at Joyo and Monju (undergoing decommissioning).
- Imaging in a metal coolant has been explored using ultrasonics, but this has never been commercialized.
  - The possibilities are not only fuel movement but possibly unique identification of each assembly with an ultrasonic name plate.
  - Radiation systems are used to track all fuel movements.

Bulk Type - Advanced Reactor

Molten Salt Reactor with NM(Th/U) in the cooling loop & separation of U-233

Safeguards Challenge is **HIGH**

- May be possible to take a Blackbox approach to this type of reactor with C/S
- Nuclear Material accountancy at bulk handling facilities are challenging
  - Current bulk handling facility is Japanese Rokkasho Reprocessing Plant and is significant safeguards burden *(~15% of IAEA inspectorate)*

Using the ORNL reference 400MWTh MSR:

- Calculation of salt quantity to obtain 8kg Pu are: Fast Reactor = 100 liters (0.25% of inventory), Thermal Reactor = 40 liters (0.1% of inventory)
- Approximate total salt inventory of 40,000 liters so the SQs calculated represent very small quantities
- This small quantity drives one toward process monitoring (PM)
- Added complication is the production of Pa233 (non-NM) with ~27-day half-life decays to U233 (NM)

Conclusions

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