Pacific Northwest NATIONAL LABORATORY

Leveraging IAEA Safeguards Experience for U.S. Advanced Reactors

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Project motivation

- Well-recognized MC&A issues for advanced reactors:
    - Accountancy for liquid or pebble fuel
    - Inaccessibility of nuclear material
    - SNM not in item form, which may require more robust MC&A measures similar to those at fuel cycle facilities
- IAEA faces similar challenges in its international safeguards activities.
    - DOE/NNSA programs support IAEA safeguards mission
- Accounting for differences between domestic MC&A and IAEA safeguards, what can we learn from overlapping areas?

Image: IAEA

Questions to be answered

1. Where are the intersections and distinctions between U.S. domestic and IAEA safeguards?

2. What advanced reactors have been under IAEA safeguards and what can we learn from the IAEA safeguards approaches? What R&D from the IAEA safeguards domain might be relevant?

3. How can U.S. reactor developers prepare for potential IAEA safeguard requirements?

IAEA safeguards fundamentals

- Required in all Non-Nuclear Weapons States under the 1968 Treaty for Nonproliferation of Nuclear Weapons
- U.S. has “Voluntary Offer Agreement”
- Set out in legal safeguards agreements
- Purpose is to detect diversion of nuclear material or undeclared activities (with timeliness/significant quantity standards)
- State authorities declare information (accounting records, design information), and IAEA verifies correctness and completeness

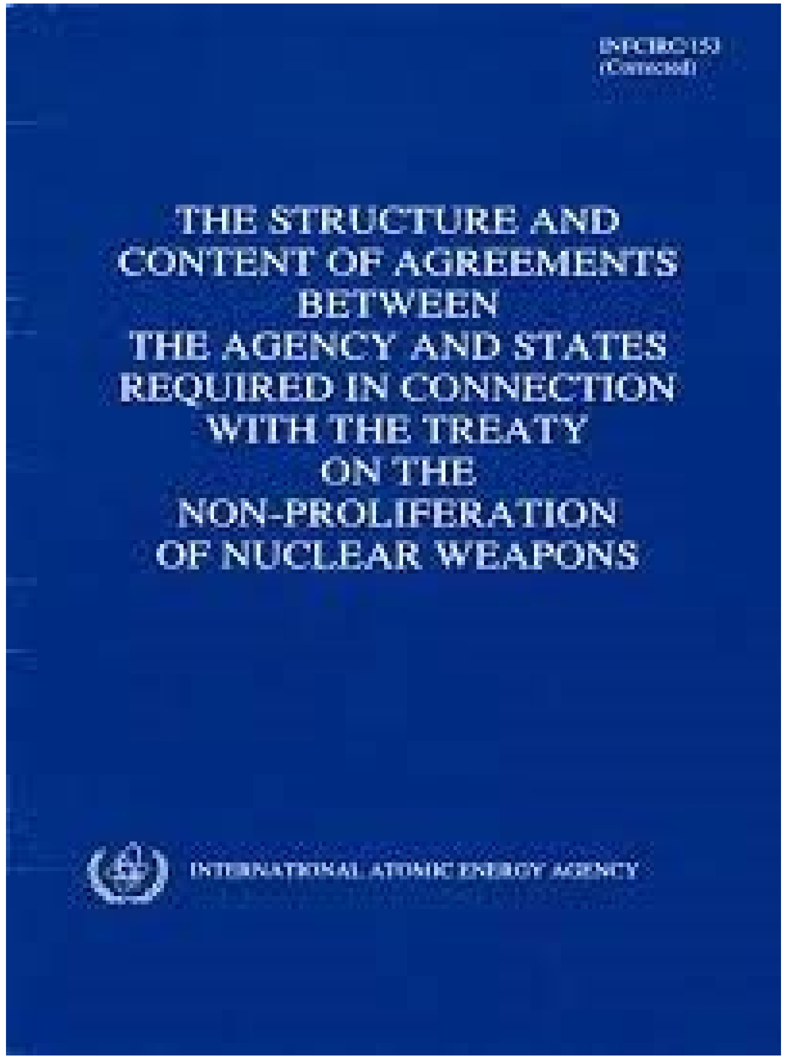


Image: IAEA

Comparing domestic and international requirements

	Domestic safeguards	IAEA safeguards
Adversary	Malicious insider or outside adversary	State authorities with full cooperation of facility operator
Threat	Unauthorized removal or sabotage of nuclear material	Diversion of nuclear material, undeclared activities
Role of physical protection	Deter, detect, delay, or respond to malicious acts	None
Role of MC&A	• Track material inventories and characteristics • Detect and localize unauthorized removals of nuclear material	• Confirm correctness and completeness of State accountancy declarations • Detect and deter diversion or misuse

International safeguards assumptions

- No assumed limitations on the number, authority, or technical capabilities of the adversary.
- Physical protection does not exist as a complementary system
- Facility operator is potential adversary

Leads to:

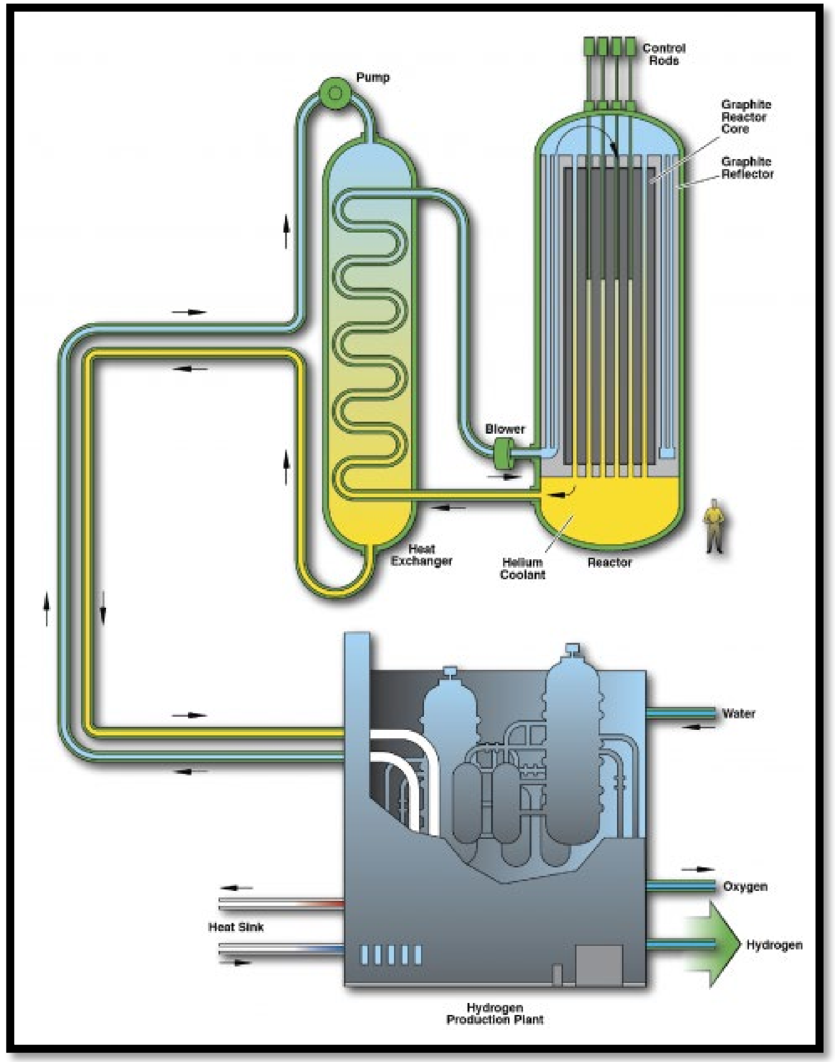
  - Wider range of potential diversion scenarios
  - Greater emphasis on multiple layers of independent verification for IAEA safeguards

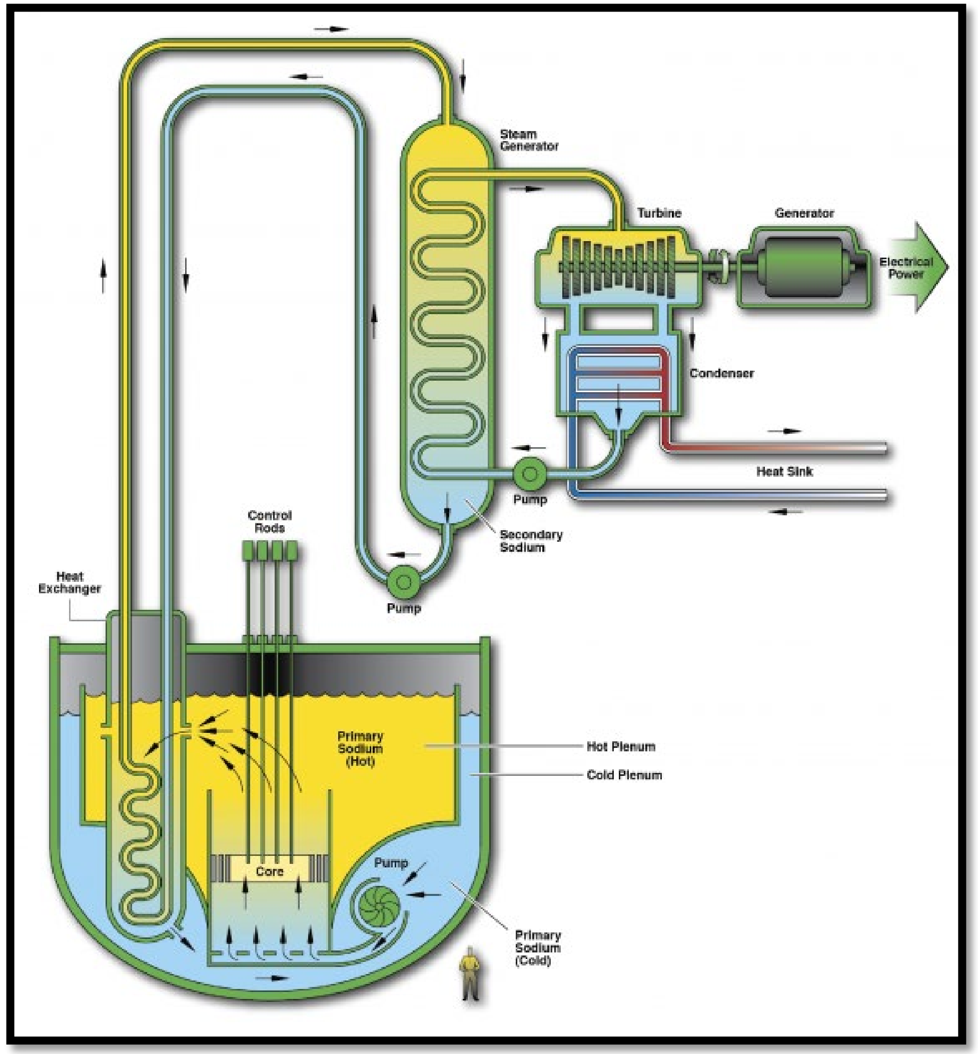
Case studies

High Temperature Gas Reactors (*Pebble Bed*)

Sodium-cooled Fast Reactors (SFR)

Molten Salt-fueled Reactors (MSR)





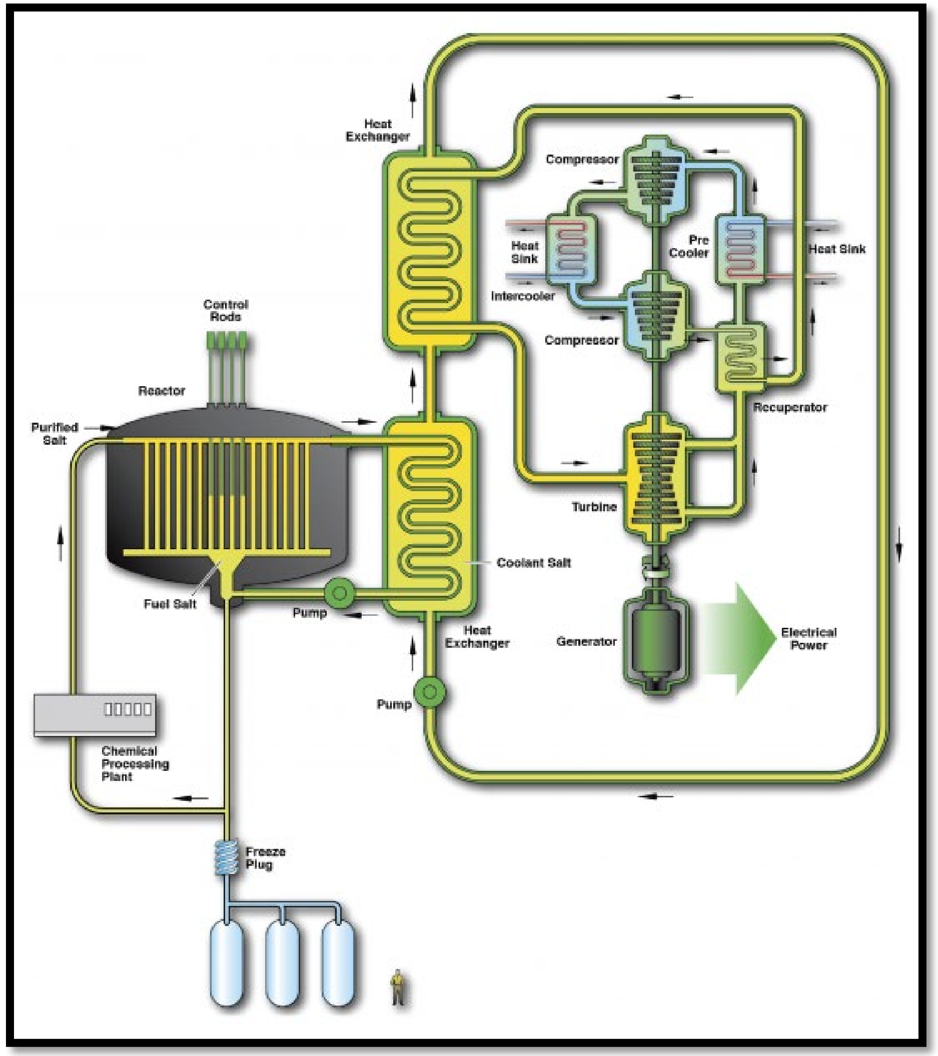
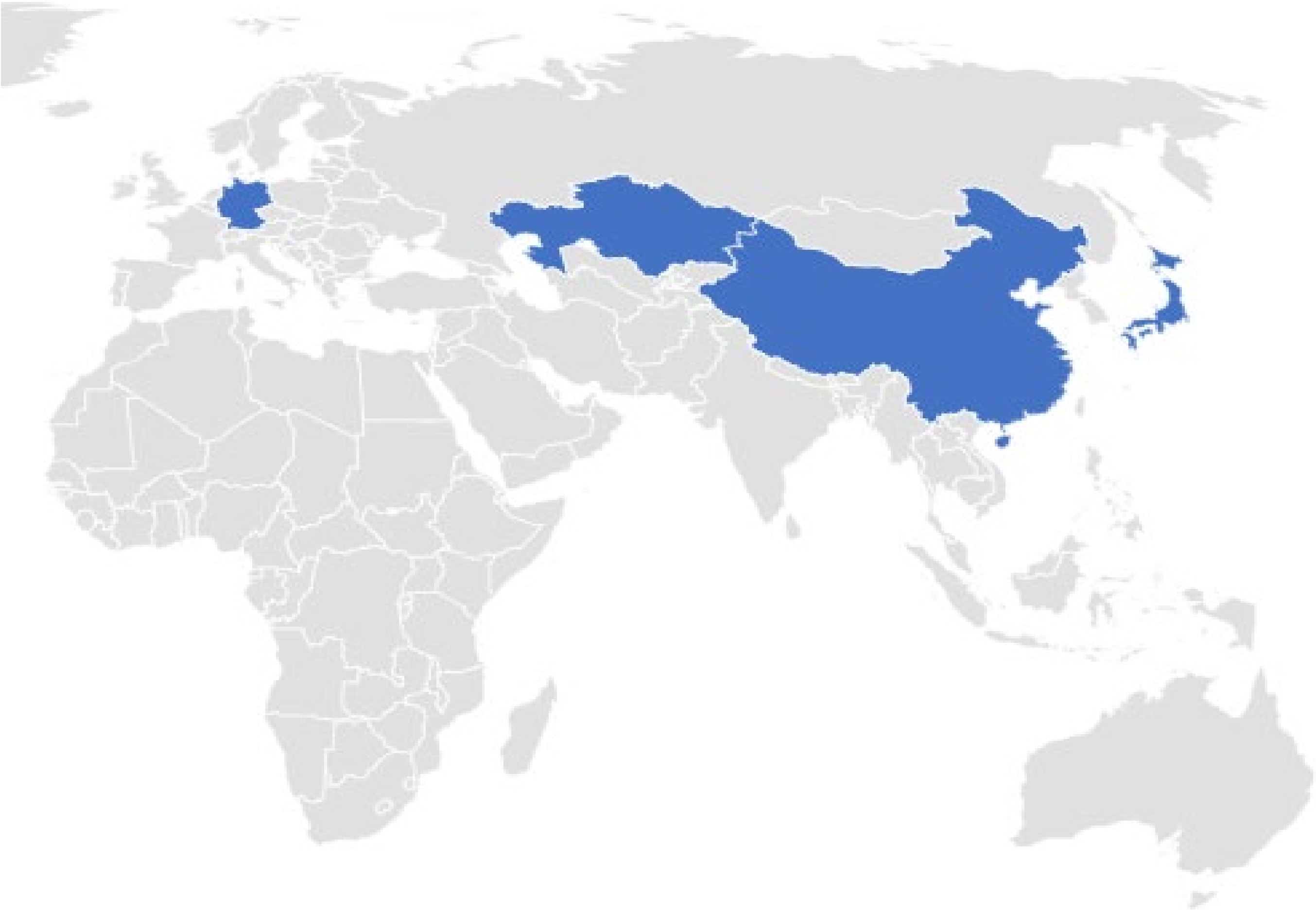


Image: Gen IV International Forum

Reactors were selected for their nontraditional fuel types and their prospects for U.S. and international deployment.

IAEA safeguards experience at selected reactor types



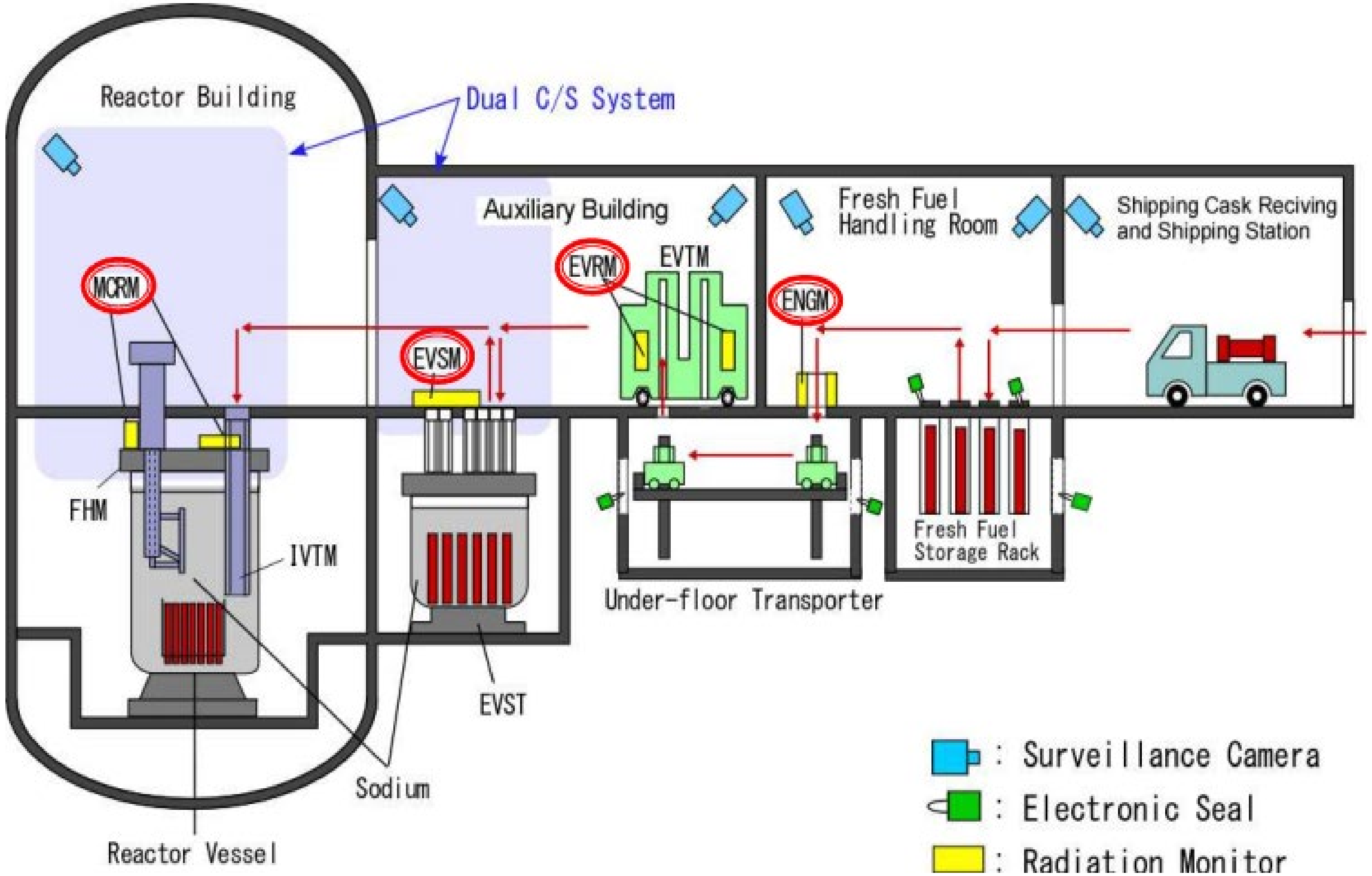
SFR	PBR	MSR
Joyo (Japan)	AVR (Germany)	No direct experience
KNK-II (Germany)	THTR-300 (Germany)	*(Analogous experience from reprocessing)*
BN-350 (Kazakhstan)	Cooperation with China on HTR-10 and HTR-PM	
Monju (Japan)		

Case Study 1: Sodium Fast Reactors

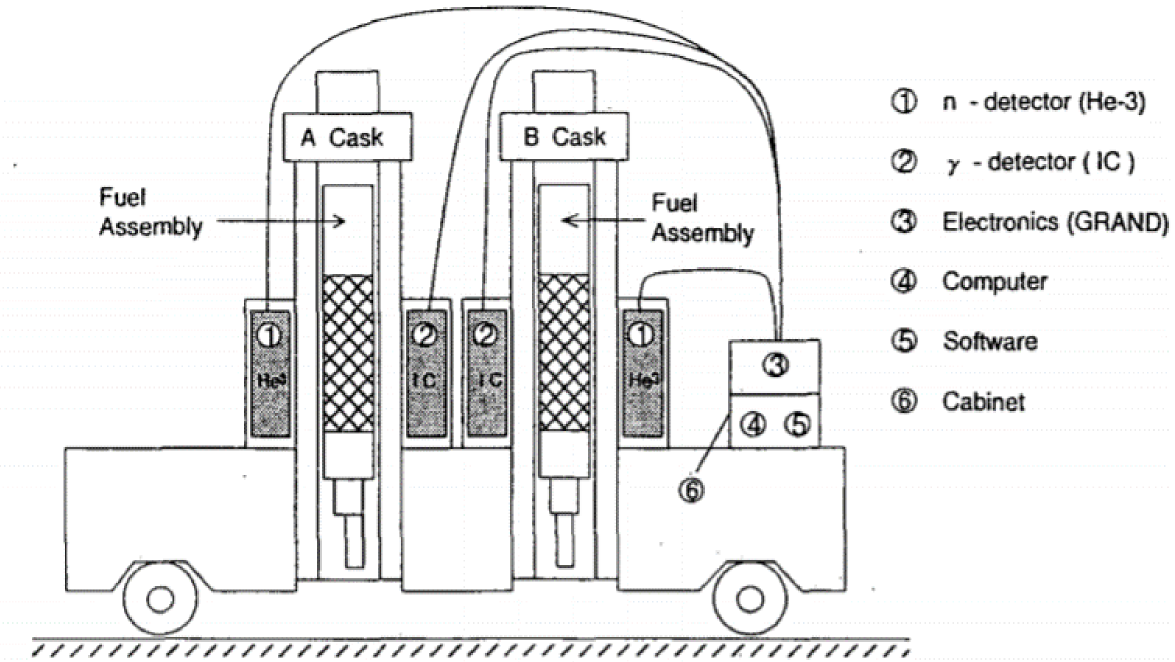
- Representative safeguards approach: Monju Fast Breeder Reactor (Japan)
- Key IAEA safeguards issues:
  - Inaccessible fuel
  - Material types
- Relied on sequence of custom systems for continuous containment, surveillance, and unattended measurement

Image: IAEA

Containment and surveillance systems at Monju



Fresh fuel flow pathway



Ex-Vessel Transfer Machine (EVTM) with instruments

Images: Umebayashi, et al. (2013). "Safeguards in Prototype FBR Monju."
Deshimaru, et al. (1994). "Safeguards in the prototype fast breeder reactor Monju." IAEA-SM-333/50.

SFR case study findings

For domestic MC&A

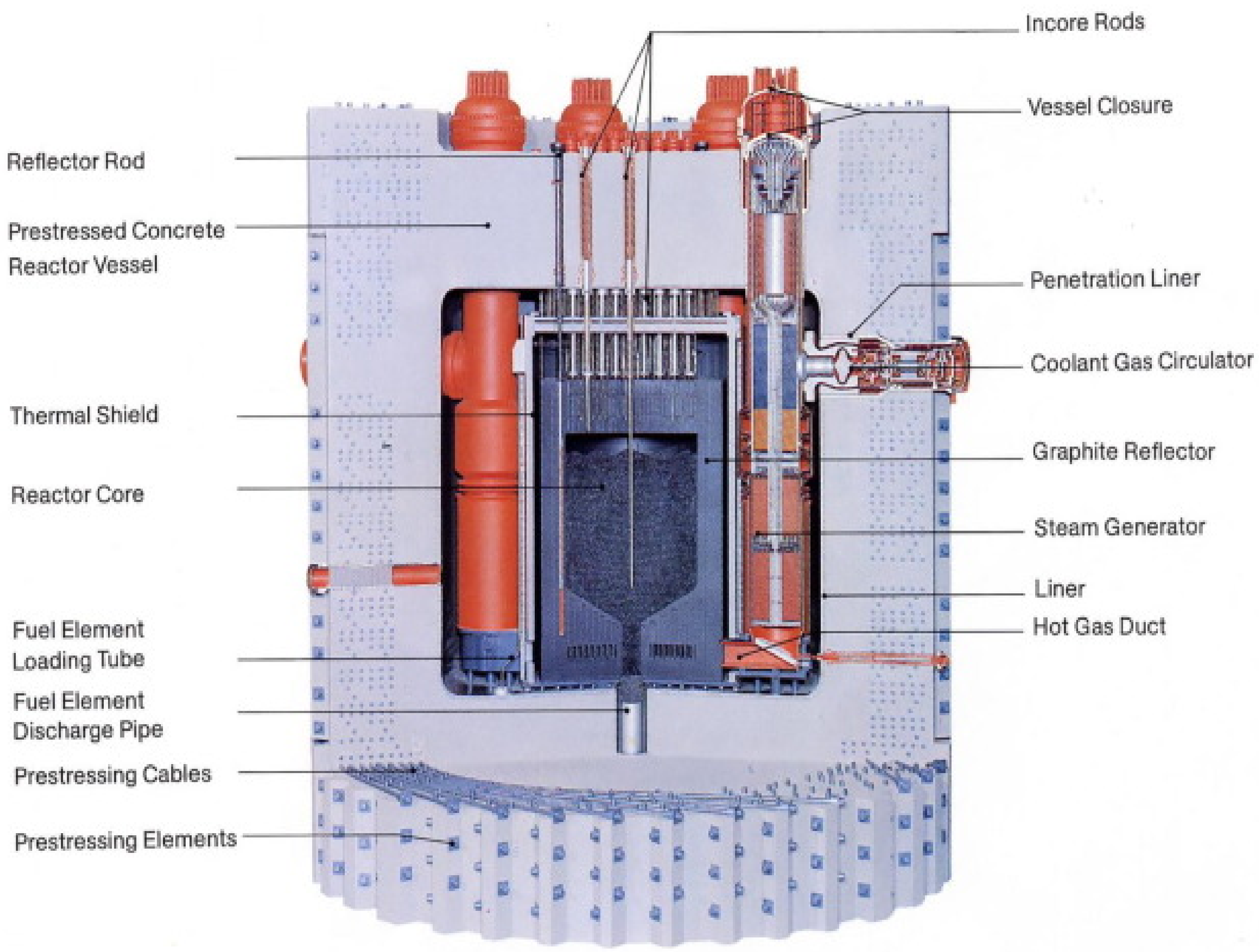
- Current power reactor MC&A practices are based on item accounting and would basically apply at SFRs
- Challenge of identifying items in sodium, requiring new techniques or increased C/S
- C/S approach used at Monju likely excessive for domestic goals (ref: ANSI N15.8)

For IAEA safeguards

- IAEA safeguards practices have emphasis on operating independently of operator systems in unattended mode -- requiring **extensive C/S built into operator systems**
- Key challenges include: unattended assay, robustness, authentication, reestablishing continuity of knowledge if lost, safeguards costs

Case Study 2: Pebble Bed Reactors

- Historical safeguards approach: THTR-300, Germany
- Used atypical materials (Th, HEU) but illustrated basic safeguards concept for handling ~10^5 pebbles with gram-scale quantities of nuclear material
- Safeguards issues:
  - Direct assay of core or spent fuel inventories
  - Complicated flow paths
  - Robustness of instruments
- Other IAEA safeguards work with Chinese HTGRs, South African HTGR (canceled)



THTR-300 core

Image: Schwartz and Bäumer, 1988

Safeguards systems at THTR-300

- Sealed fresh fuel cylinders are verified as items
- Fuel elements in reactor loop are counted during input and removal using fuel flow machines
- Discrimination between different types of elements (fuel, graphite)
- Spent elements measured at discharge and stored under C/S
- Key feature: Large number of pebbles needed (~10^4) for 1 significant quantity

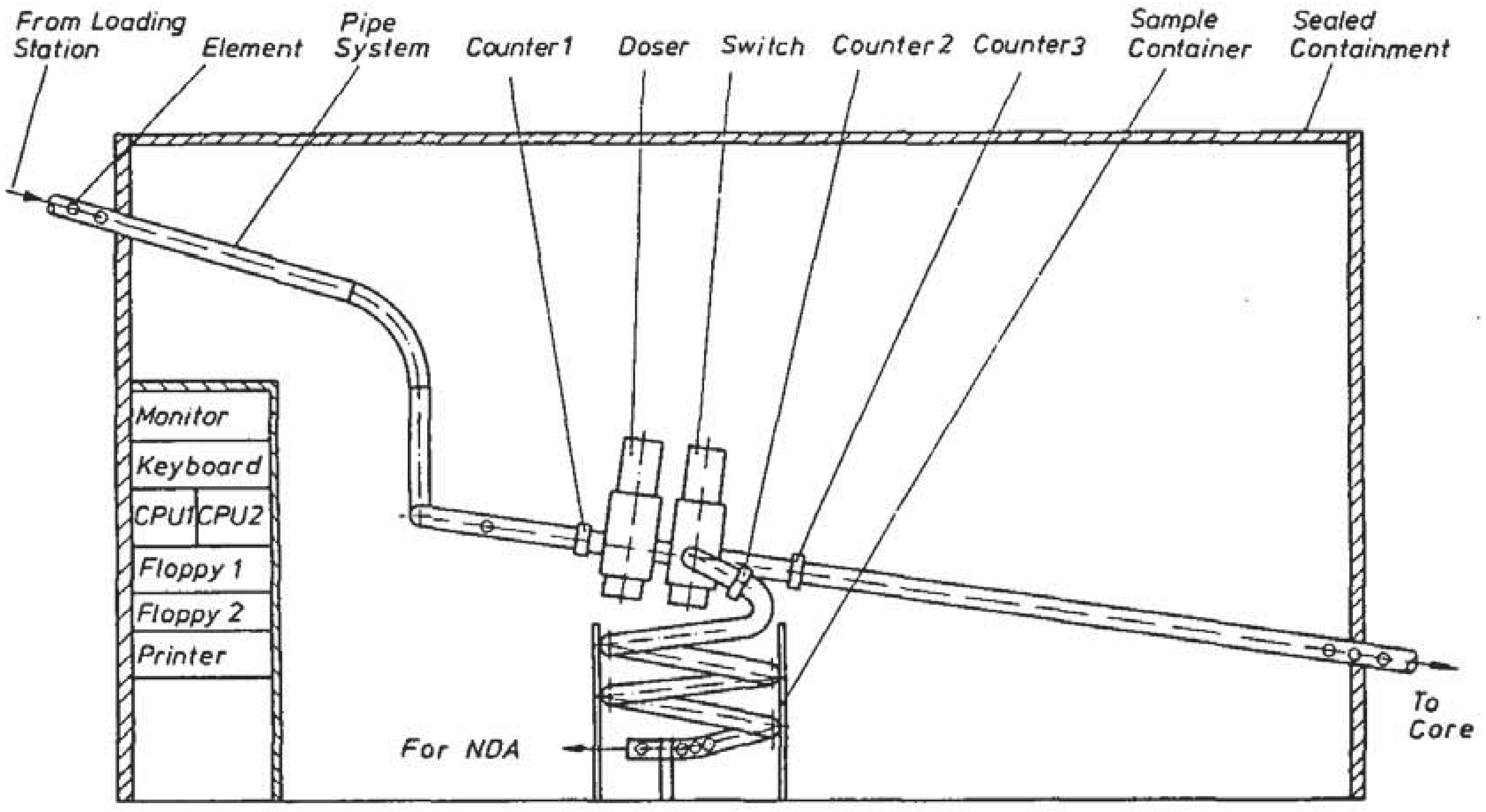


FIG. 2. Sampling machine.

Input fuel counter and measurement system used at THTR-300

Image: Martin, 1987

PBR case study findings

For domestic MC&A

- Most actual or proposed IAEA safeguards approaches for PBRs have used hybrid item/bulk accountancy approach for different segments of the facility inventory
- Accountancy used in past IAEA approaches are not compatible with current 10 CFR 74 regs, but basically align with notional nuclear material control plan proposed by ORNL (2020)

For IAEA safeguards

- Key challenges include data integrity from fuel handling machines, robust C/S, need for operator/IAEA system duplication, role of design information verification
- Design of fuel storage areas could aid in IAEA verification (e.g., allowing NDA of stored pebbles or height measurements)

Ref: Kovacic, Gibbs, and Scott. (2020). “Model MC&A Plan for Pebble Bed Reactors.” Oak Ridge National Laboratory. ORNL/SPR-2019/1329.

Case Study 3: Molten Salt Reactors

- Case study has different focus since there is no IAEA experience with MSRs, no baseline safeguards approach, and later commercial deployment dates
- Focus of ongoing case study is overlap between MSRs and potential analogs --- primarily aqueous and electrochemical reprocessing.
- Key reference point is the Rokkasho Reprocessing Plant
- IAEA safeguards of liquid-fuel MSRs will likely involve some form of process monitoring to estimate material in the core and in processing/storage areas
  - Document IAEA safeguards tools and techniques – which could be adapted to MSR safeguards?
  - What were the deployment considerations and lessons learned?
- Key areas include: cooperation with operator, regulator, and IAEA for joint use instruments and extensive design information verification

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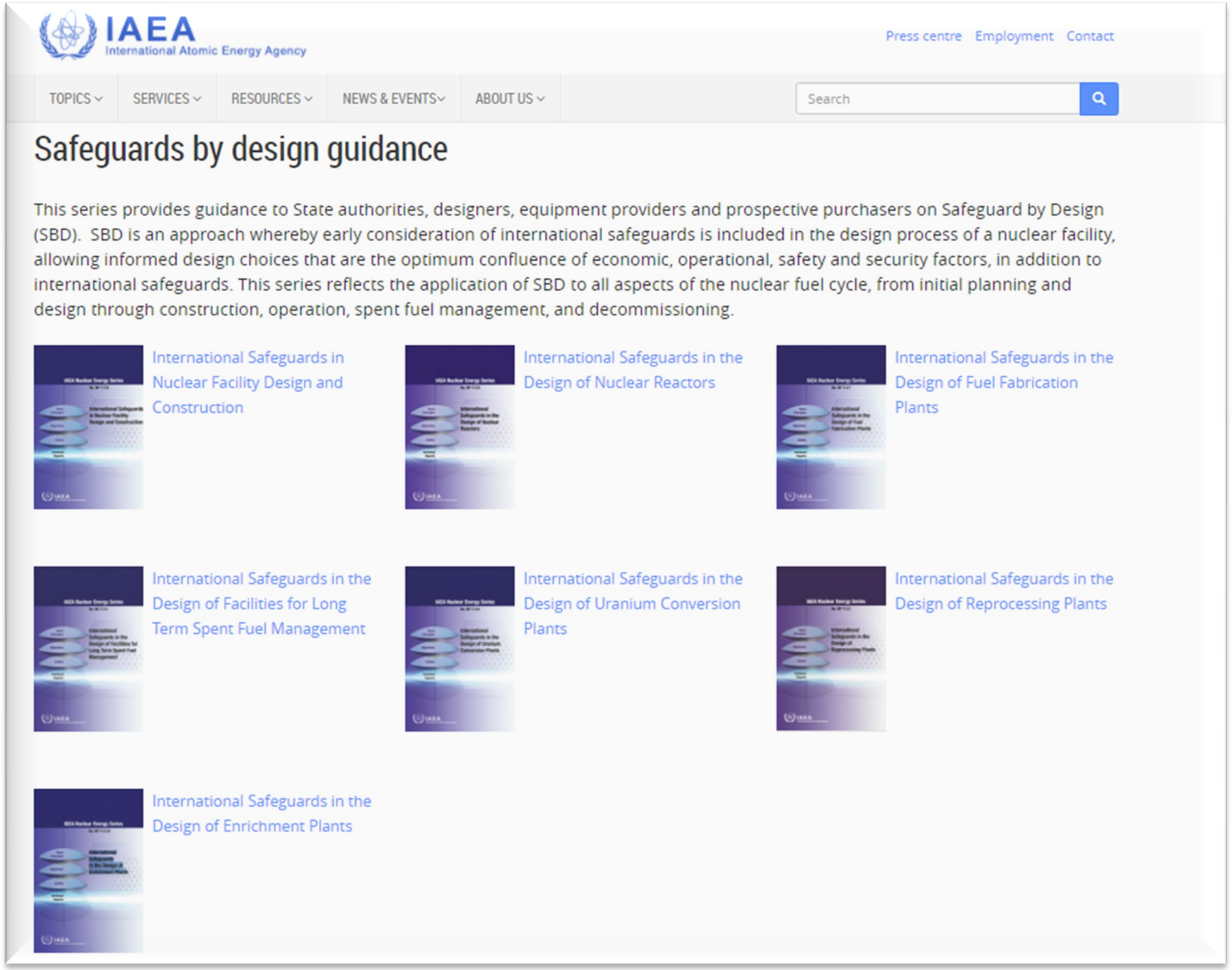
Key takeaways

- International examples provide informative case studies, but key details for U.S. deployment remain unknown
- Common themes for IAEA safeguards include: robust C/S, redundant measurement capabilities, and authenticated operator data --- ***having potentially important interfaces with operator measurement and fuel handling systems***
- Benefits to considering international SG requirements when developing MC&A systems (cost, simplicity, readiness, performance)



IAEA guidance on international “safeguards by design”

https://www.iaea.org/topics/assistance-for-states/safeguards-by-design-guidance

Next steps in study

Forthcoming report details:

- The status of IAEA safeguards implementation.
- Current areas of R&D, anticipated challenges and technical gaps
- Relevance to U.S. domestic safeguards mission
- Implications for U.S. advance reactor designs that may be subject to IAEA safeguards under domestic or export scenarios

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Thank you!