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Technical and Regulatory Considerations for Microreactor NDA Measurements

Advanced Reactor Safeguards and Security Meeting

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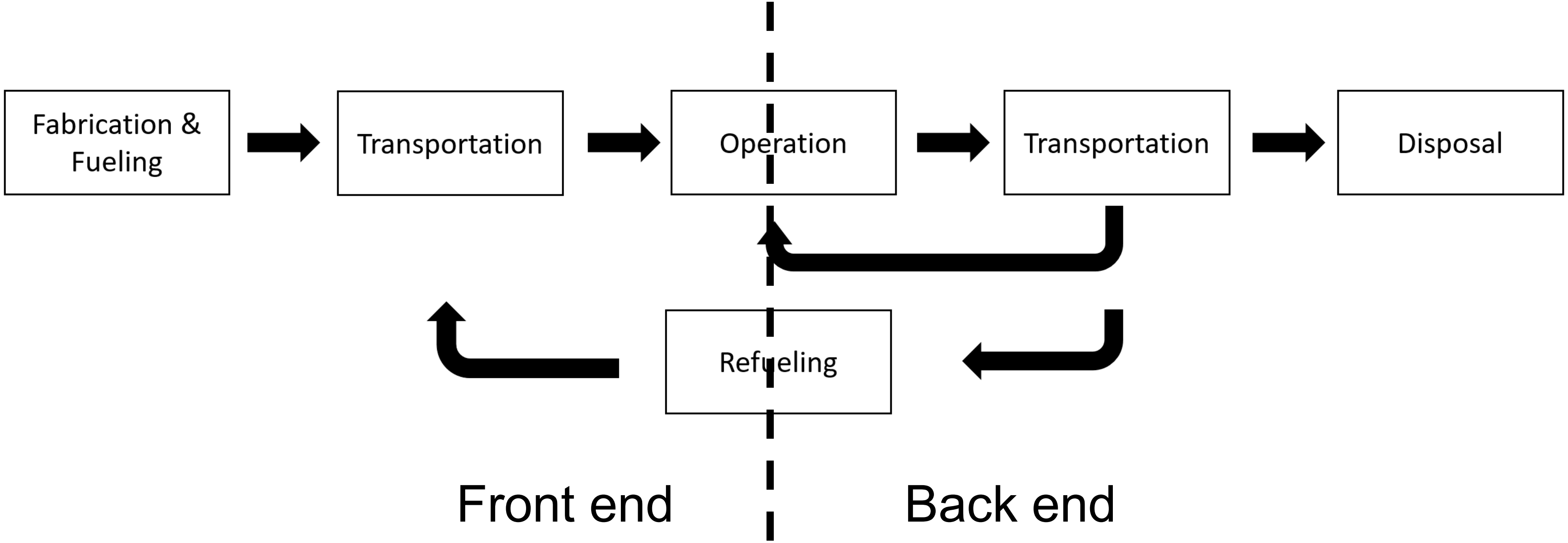
Motivation

- Evaluate MC&A approaches for microreactors given their unique life cycle
- Identify to what extent, if any, NDA measurements of nuclear fuel would be required for physical inventory
- Investigate technical approaches for NDA of fuel given long term sealed cores

Outline

- Microreactor MC&A
  - Unique features
  - Domestic MC&A – 10 CFR 74
  - Other scenarios
- Physical inventory – NDA of nuclear fuel
  - Material Control
  - Cost and performance tradeoffs
  - Active and passive techniques
- Passive measurements using in-core neutron instrumentation

Microreactor life cycle



- Not all Microreactors will have all steps

MC&A regulations

- 10 CFR 74 – Physical inventory every 12 months
- Reg Guide 5.29 – ANSI N.15-8.2009 is acceptable guidance
- ANSI N15.8-2009 – reactors considered one item. Physical inventory performed by item counting
- Computation shall be utilized for determining isotopic composition of irradiated fuel for documents required by 10CFR74.13 and 10CFR74.15

U.S. NUCLEAR REGULATORY COMMISSION

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REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

REGULATORY GUIDE 5.29

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SPECIAL NUCLEAR MATERIAL CONTROL AND ACCOUNTING SYSTEMS FOR NUCLEAR POWER PLANTS

A. INTRODUCTION

Purpose

This guide describes a method that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable to implement special nuclear material control and accounting system requirements for nuclear power plants. This guide applies to all nuclear power plants.

Applicable Rules and Regulations

Title 10, of the *Code of Federal Regulations*, Part 74, "Material Control and Accounting of Special Nuclear Material" (10 CFR Part 74) (Ref. 1), Subpart B, "General Reporting and Recordkeeping Requirements," establishes the material control and accounting performance requirements for special nuclear material at nuclear power plants. The regulations at 10 CFR 74.11, "Reports of loss or theft or attempted theft or unauthorized production of special nuclear material," require, in part, that nuclear power reactor licensees notify the NRC of any such events within one hour of discovery. The regulations at 10 CFR 74.13, "Material status reports," require nuclear power reactor licensees to submit material status reports for certain quantities of special nuclear material. The regulations at 10 CFR 74.15, "Nuclear material transaction reports," require nuclear power reactor licensees to complete transaction reports when transferring, receiving, or making adjustments to specified quantities of special nuclear material. The regulations at 10 CFR 74.19, "Recordkeeping," require, in part, that nuclear power reactor licensees keep records that show the receipt, inventory (including location and unique identity), acquisition, transfer, and disposal of all special nuclear material in their possession. Additionally, 10 CFR 74.19 requires, in part, that licensees establish, maintain, and follow written material control and accounting procedures, and that they conduct physical inventories of special nuclear material at intervals not to exceed once every 12 months.

Microreactor differences

- 2,000 rods vs 200 fuel assemblies. Item level is rod instead of assembly?
- Remote siting, minimal staffing
- 20 year sealed core significantly different from 1.5 year sealed LWR
- Still, everything indicates **item counting is sufficient** for 10 CFR 74

Other fuel NDA scenarios

- Benchmarking of burnup codes – little available measurement data
- Reestablish continuity of knowledge
  - 20 years, remote locations, minimal staffing, shipping. Something could happen
- Long term disposal
  - How many decades of central temporary storage? Transfer to DOE
- For international markets, fuel subject to IAEA safeguards
  - Large research effort on spent fuel dry storage – similar dynamic
  - Direct measurements of fuel could address this

Physical inventory – NDA of fuel

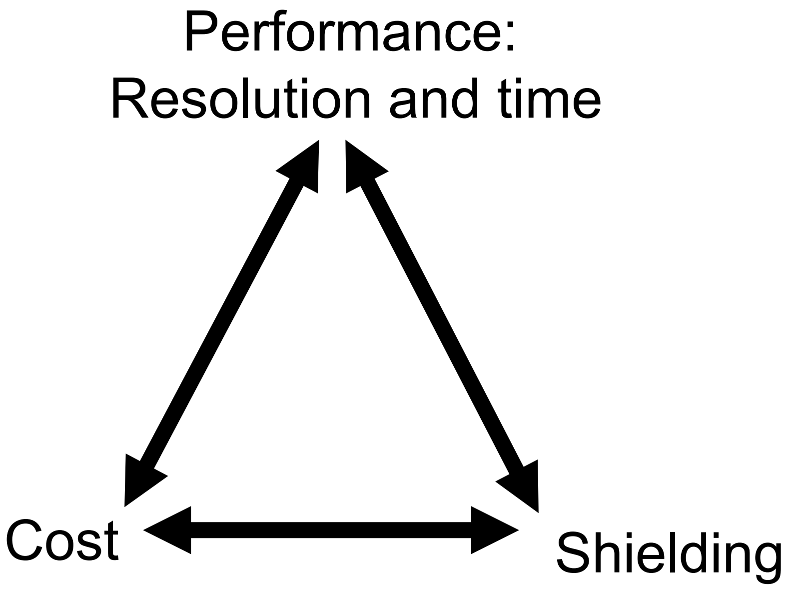
- How to take fuel inventory, if needed
- Fresh fuel – with access – item counting
- Once the core is sealed
- Once the fuel is burned

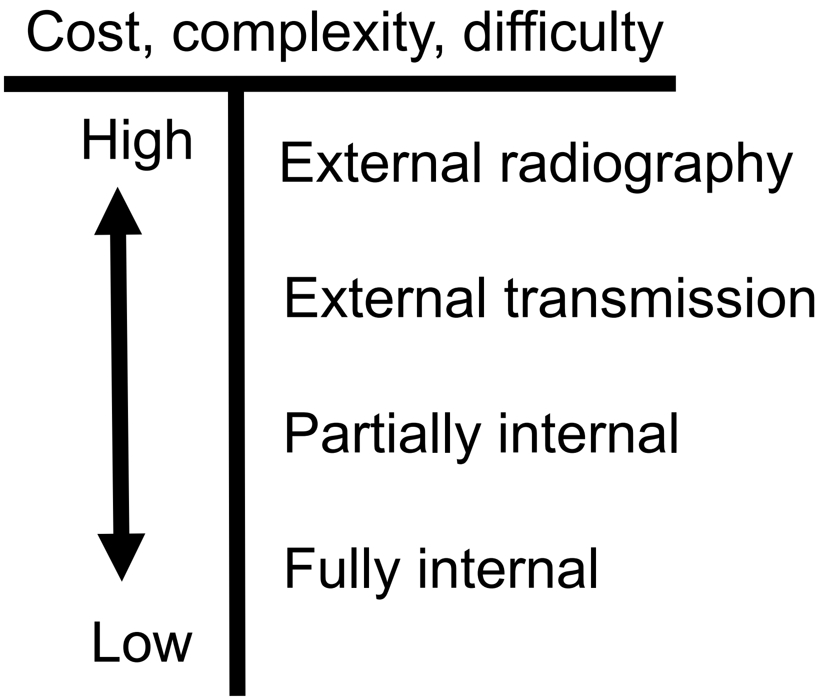
Material control approaches

- Increase confidence that fuel is present

- Tamper indicating devices
- Surveillance and containment
- Simple NDA – weight measurements
- Nuclear fuel measurements – most direct

Fuel measurement summary

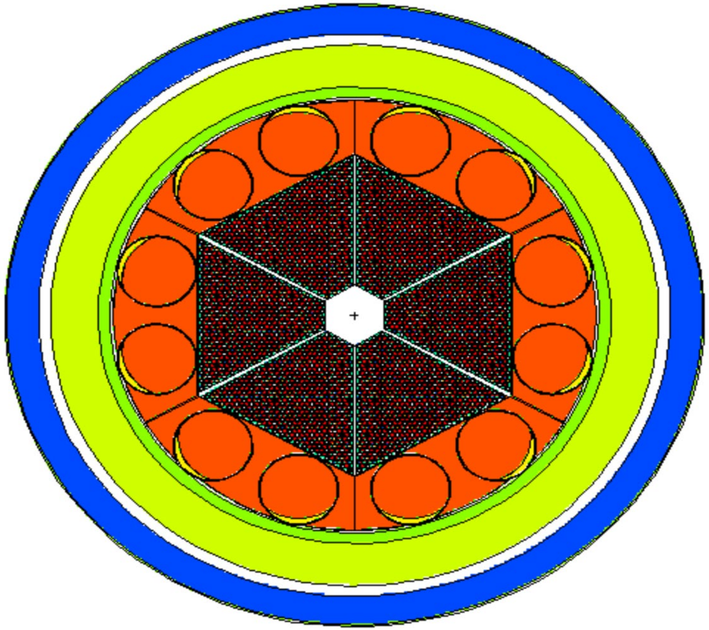




Design basis reactor - LANL Megapower

- 5 MW thermal, 5 year full power lifetime
- Fast neutron spectrum
- 5.2 metric tons of UO_2 in 2,112 fuel pins
- Stainless steel and heat pipe monolith
- 15cm B_4C neutron shield
- 10cm lead gamma shield

- Can expand to evaluate other reactor types, including ANL's MiFi

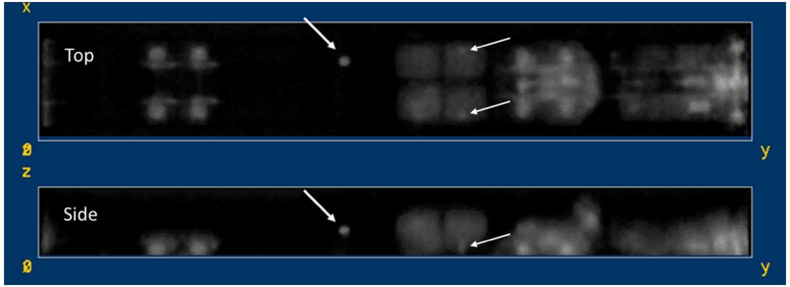


LANL Megapower model

Muon radiography

- Muon radiography measures density (NM has high density)

- Estimate a ~$1-1.5m tracker
- 3D image of the interior – 10cm resolution
- 2 week measurement



Muon radiography measurement and result

Gamma radiography

- 15 MeV X-ray generator
- High dose – safety issue
- Challenge: Imaging detector ‘film’ location

- ~$5m cost
- Better than 1cm resolution
- ~4 hour measurement

Linatron 15 MeV x-ray generator

Neutron interrogation

- 14 MeV neutron generator
- Neutrons interact in low Z materials – not image fuel
- Instead, induce fission and measure emissions
- Questions of efficiency, detector placement, dose, resolution

Phoenix high yield D-T neutron generator

Passive in-core instrumentation measurements

- Fresh fuel – measure ^{238}U spontaneous fission and ^{235}U induced fission
- Spent fuel – measure transuranic spontaneous fission (Cm)
- Use the in-core neutron instrumentation

- Minimal cost
- Opportunity for safeguards by design
- We are currently studying feasibility / sensitivity

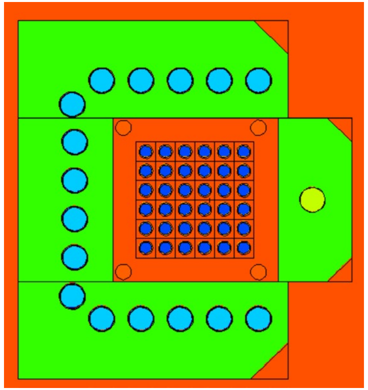
Passive in-core, expected performance

- 4,500 kg of U in the core
- 68,000 n/s emission rate when fresh

- 0.04% detection efficiency in one channel
- 30 n/s count rate
- 5.5 minute measurement time for 1% uncertainty

Fuel assembly benchmarking

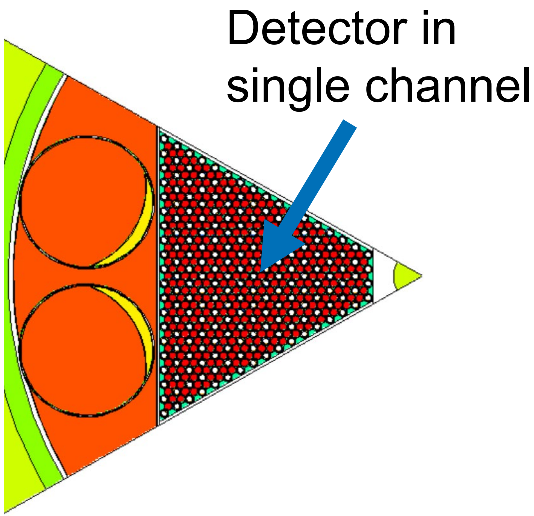
- Measured and simulated 6x6 BWR fuel assembly at LANL
- Neutron count rate matched simulations to within 6%
- Gives confidence in neutron physics, can be applied to Megapower configuration



LANL 6x6 BWR fuel assembly measurement and simulation

1/6th core passive measurement simulations

- Simulated single in-core boron proportional counter in center of 1/6th core section
- Count rate – 30 n/s per channel
- Developing full core simulations with specific in-core instrumentation
- Interested in coupling of measurement time, sensitivity, uniformity, and detector layout
- Results suggest the approach is feasible



Megapower fuel section

Future work

- Interested in vendor needs to measure fuel – confidence building, IAEA safeguards, burnup code validation
- Preferred approach, in-core instrumentation?
- Full core Megapower simulations with fresh fuel
- High fidelity reactor design and in-core instrumentation design simulations
- Irradiated fuel measurement performance
- Evaluating burnup code needs

Conclusions

- 10 CFR 74 requires 12 month NM inventory
- Item counting likely acceptable
- How to handle off-normal recovery, international safeguards, long term disposal?

- Range of approaches to measure nuclear fuel directly
  - Range of cost and performance
- In-core neutron measurements are promising
- Currently evaluating feasibility and demand