Burnup Measurements – the Industry Perspective

Steve Nesbit (Duke Energy)
on behalf of the
Nuclear Energy Institute

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Overview of Presentation

- Introduction
- Core Design Calculations
- In-Core Burnup Measurements
- Accuracy and Quality of Reactor Records
- In-Pool Burnup Measurements
- Conclusion

Spent Fuel Project Office Position

- Limited credit (so far theoretical only) for fuel burnup when demonstrating compliance with cask criticality limits
- ISG-8, Rev. 2
  - "Administrative procedures ... should include a measurement that confirms the reactor record for each assembly."
  - Sampling may be considered
  - Include in-pool measurement uncertainty

Industry Position

- Fuel assembly burnup information is already well characterized
  - Derived from measurements during operation
  - Validated against computer codes
  - Provide reasonable assurance
- Division of Spent Fuel Storage and Transportation (SFST) requirement for in-pool burnup measurements is unnecessary and has adverse consequences
- STST should revise its regulatory guidance to delete the requirement for in-pool burnup measurements

Uses of Reactor Burnup Data

- Part 50
  - Core design
  - Criticality calculations
    - Fuel pool
    - Fuel cask (RIS 2005-05)
    - Core reload fuel handling
  - Core and fuel pool decay heat calculations

Uses of Reactor Burnup Data (cont.)

- Part 74 (special nuclear material accountability)
- Part 72
  - Compliance with cask burnup limits
  - Decay heat calculations

Uses of Reactor Burnup Data

- No requirement for validation of fuel assembly burnups against in-pool measurements (except for cask criticality limits per ISG-8 Rev. 2)
- No known instance of a safety concern related to the use of burnup data

Sources of Burnup Data

- Core design calculations
- In-core burnup measurements
- In-pool burnup measurements

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Core Design Calculations

- Core design
  - State of the art methods (NRC approved)
  - Detailed calculations to ensure compliance with reactor power peaking (thermal limits)
- Core follow
  - State of the art methods
  - Validates accuracy of predictions against plant data

Accuracy of Calculations

- Predicted boron concentrations within tens of ppm over a cycle
- 95/95 assembly radial power uncertainties on the order of 2%
- Startup physics testing consistent with ANSI/ANS-19.6.1

Representative Core Follow End-of-Cycle Burnup Comparison

	H	G	F	E	D	C	B	A
8	44.75 44.80 **-0.10**	44.40 44.50 **-0.22**	46.73 46.44 **0.62**	25.76 25.53 **0.90**	46.89 46.54 **0.74**	46.24 45.72 **1.14**	23.46 23.56 **-0.41**	51.55 51.69 **-0.28**
9	44.40 44.50 **-0.22**	23.98 23.89 **0.40**	45.86 45.71 **0.32**	48.04 47.78 **0.55**	25.28 25.05 **0.95**	46.27 46.10 **0.36**	24.41 24.51 **-0.40**	44.40 44.40 **0.01**
10	46.73 46.44 **0.62**	45.85 45.89 **-0.09**	47.58 47.47 **0.23**	25.26 25.08 **0.72**	49.26 49.12 **0.29**	25.15 25.19 **-0.16**	23.47 23.48 **-0.04**	45.24 45.13 **0.24**
11	25.76 25.53 **0.90**	48.05 47.79 **0.56**	25.26 25.20 **0.25**	49.14 49.23 **-0.18**	26.34 26.31 **0.13**	45.10 45.11 **-0.03**	21.61 21.69 **-0.40**	45.93 45.63 **0.66**
12	46.89 46.54 **0.74**	25.28 25.01 **1.09**	49.26 49.35 **-0.17**	26.33 26.32 **0.05**	46.14 46.31 **-0.37**	23.39 23.53 **-0.57**	37.65 37.40 **0.67**	
13	46.24 45.72 **1.14**	46.25 46.06 **0.41**	25.15 25.25 **-0.37**	45.09 45.04 **0.11**	23.38 23.36 **0.07**	40.08 40.05 **0.07**	50.03 49.95 **0.16**	
14	23.46 23.56 **-0.41**	24.44 24.63 **-0.78**	23.47 23.75 **-1.16**	21.60 21.64 **-0.17**	37.65 37.38 **0.73**	50.04 50.05 **-0.02**		
15	51.55 51.69 **-0.28**	44.44 44.66 **-0.49**	45.24 45.16 **0.19**	45.91 45.87 **0.09**	**predicted** **measured** **relative deviation, %**			

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General Description

- Key inputs
  - Total reactor power (heat balance)
  - Reactor power distribution (incore detectors)
  - Fuel assembly heavy metal mass
- Assembly-specific powers
  - Used to ensure compliance with thermal limits
  - Integrated to provide assembly burnups
- Details may vary plant to plant

Data Management (Typical)

- Burnup information is generated in the plant computer system
- Data is downloaded at end of cycle into the special nuclear material database

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Accuracy of In-Core Burnup Measurements

- Calculated power distributions (core follow) are routinely compared to in-core measured assembly powers to ensure fidelity of predictions
- Discrepancies between in-core measured burnups and calculations would be evident

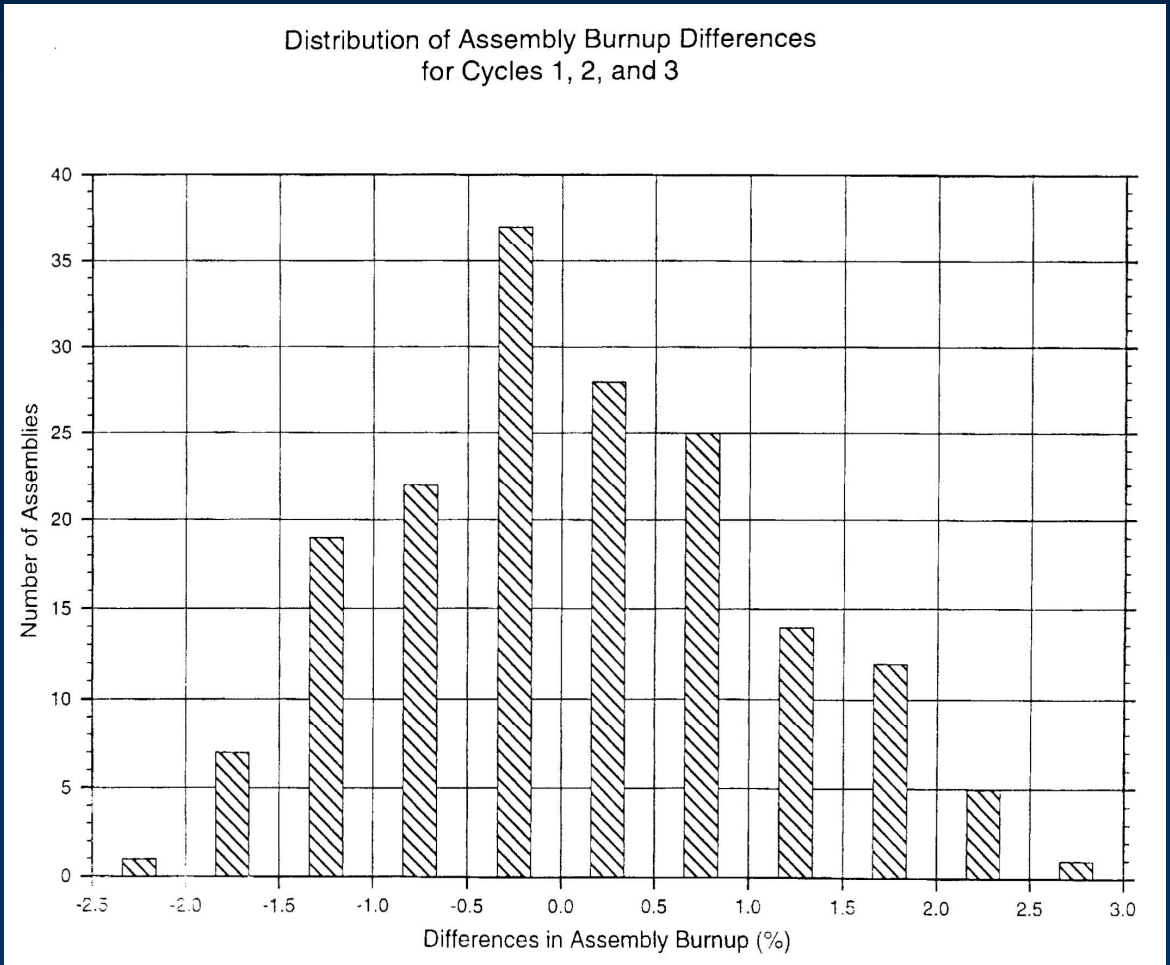
Systematic Burnup Comparisons

- Two publicly available comparisons of in-core measured burnups to calculated burnups indicated close agreement
  - Comparison by the Electric Power Research Institute (EPRI TR-112054, 1999)
  - McGuire Nuclear Station comparison by Duke Power (Duke letter to U. S. NRC, April 22, 2004)

EPRI Comparison

- 3411 MW_{th} pressurized water reactor
- 171 assembly burnups over three cycles
- End-of-cycle in-core measured burnups compared against CASMO-3/SIMULATE-3 predictions
- 95/95 uncertainty = 1.89% (one-sided tolerance)

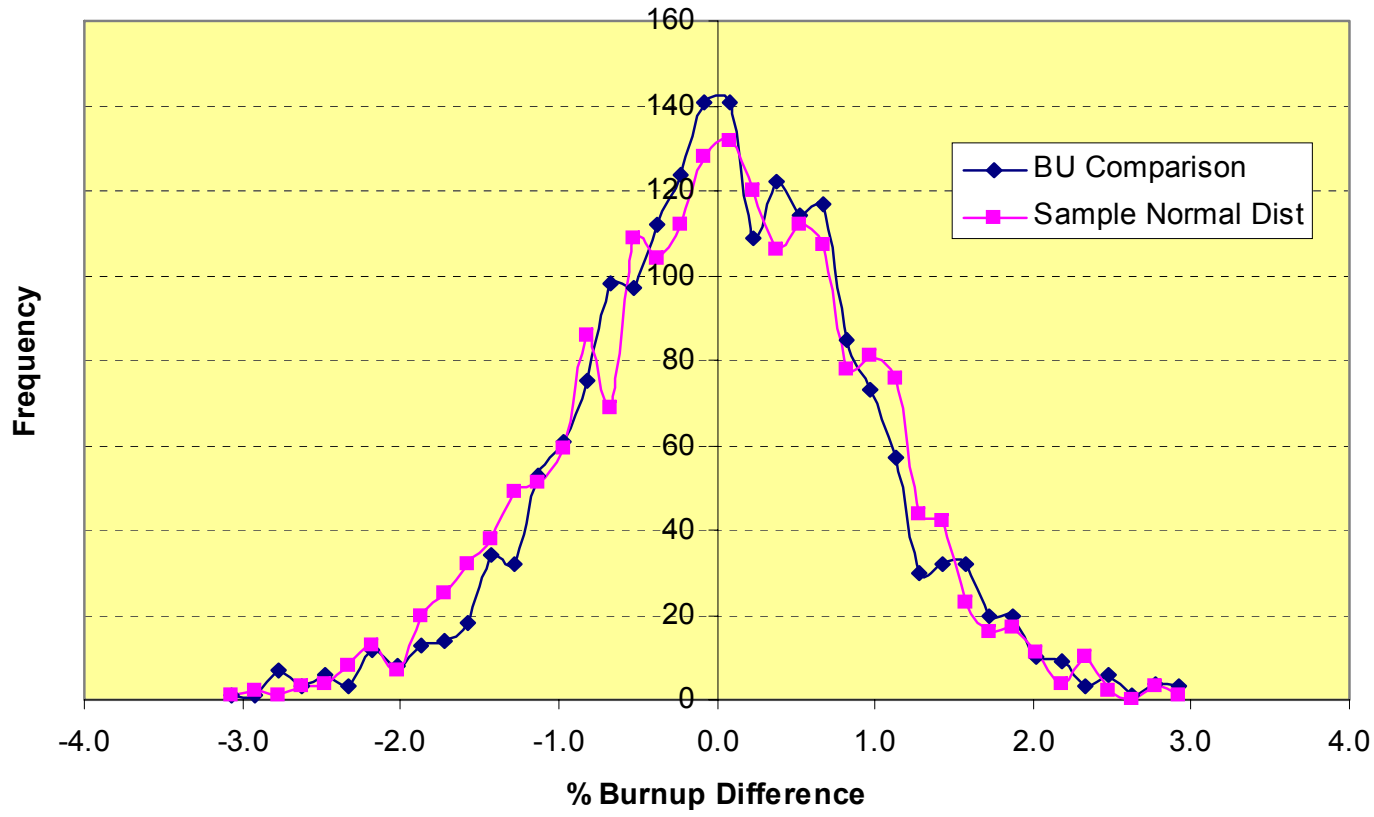
EPRI Burnup Comparisons



McGuire Comparison

- Performed to support license amendment request for fuel pool burnup credit
- 3411 MW_{th} pressurized water reactor
- 1909 assembly burnups over 27 cycles
- End-of-cycle in-core measured burnups compared against CASMO-3/SIMULATE-3 predictions
- 95/95 uncertainty = 1.6% (one sided tolerance)

McGuire Burnup Comparisons



Quality of Records

- 10 CFR 50 Appendix B quality assurance requirements apply to measured burnups used for safety-related applications
- Utility 10 CFR 50 QA programs are applied to 10 CFR 71 and 72 activities
- It is reasonable for NRC to require that data used for storage and transportation burnup credit be obtained and maintained under the utility QA program

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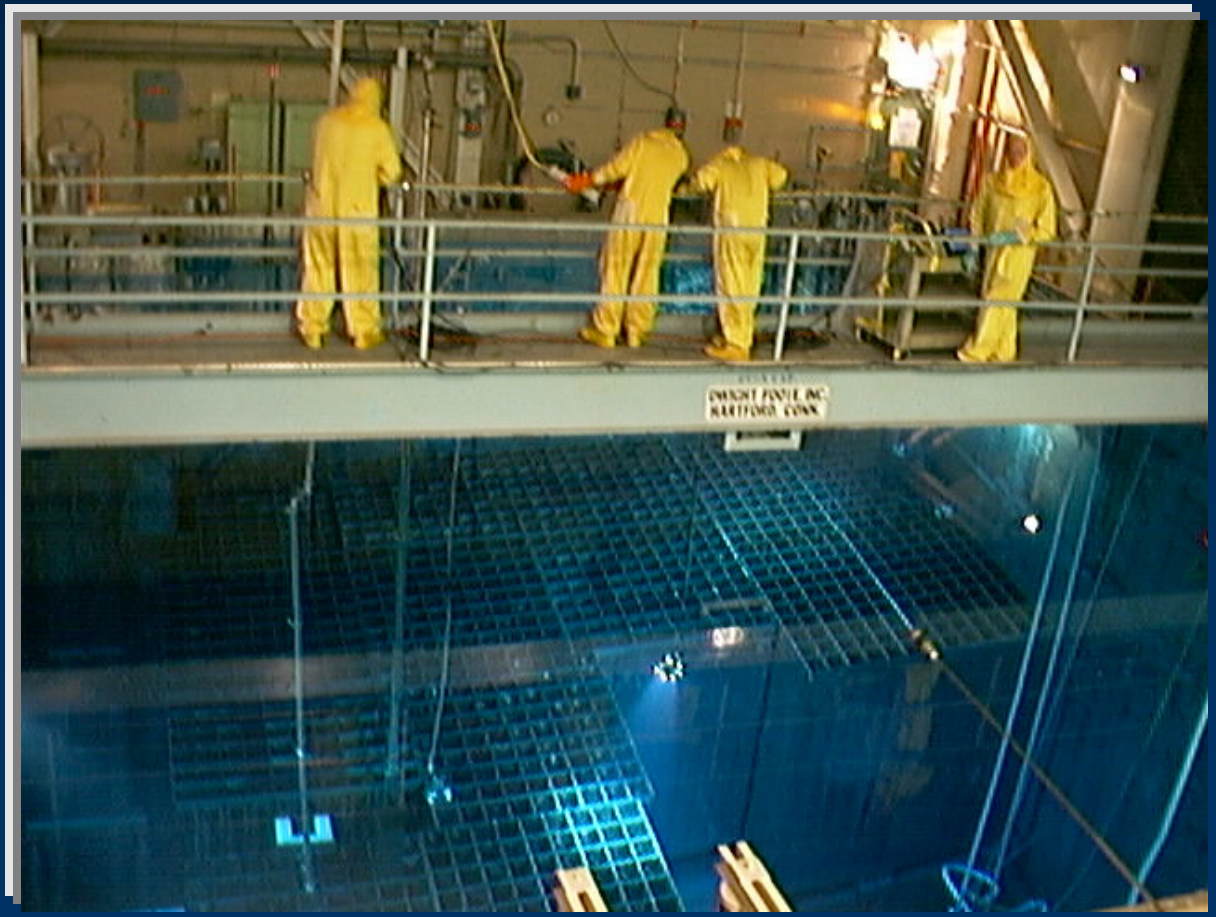
In-Pool Burnup Measurements

- Burnup is an integral property: power produced over time by a given mass of fuel
- There is no such thing as a direct burnup measurement
- Burnup systems simply measure a radiation source that is related back to burnup
- Reliance on reactor records varies with method
  - Simpler approaches require fuel data such as enrichment and cooling time
  - More sophisticated approaches use gamma spectral analysis and can be made independent of fuel data

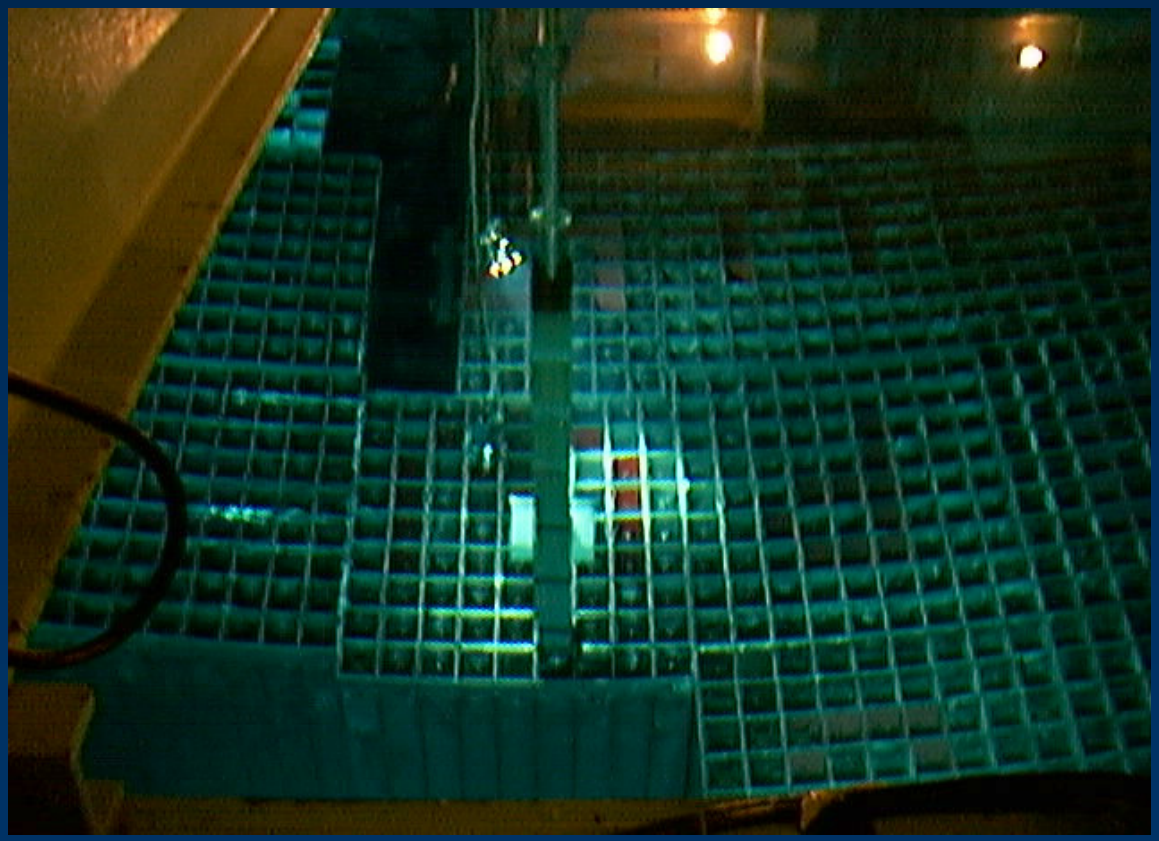
In-Pool Burnup Measurements

- Burnup measurements at U.S. utilities:
  - Fork
    - Measurements of gross gamma ray and neutron emissions
  - Fork+ prototype
    - Measurements of thermal neutrons, epithermal neutrons, gross gammas, and collimated Cs-137 gammas
  - BNFL system
    - Measurements of gross gammas and collimated gammas for Cs-137, Cs-134, and Ru-106
- Other systems have been used in nuclear facilities in Europe

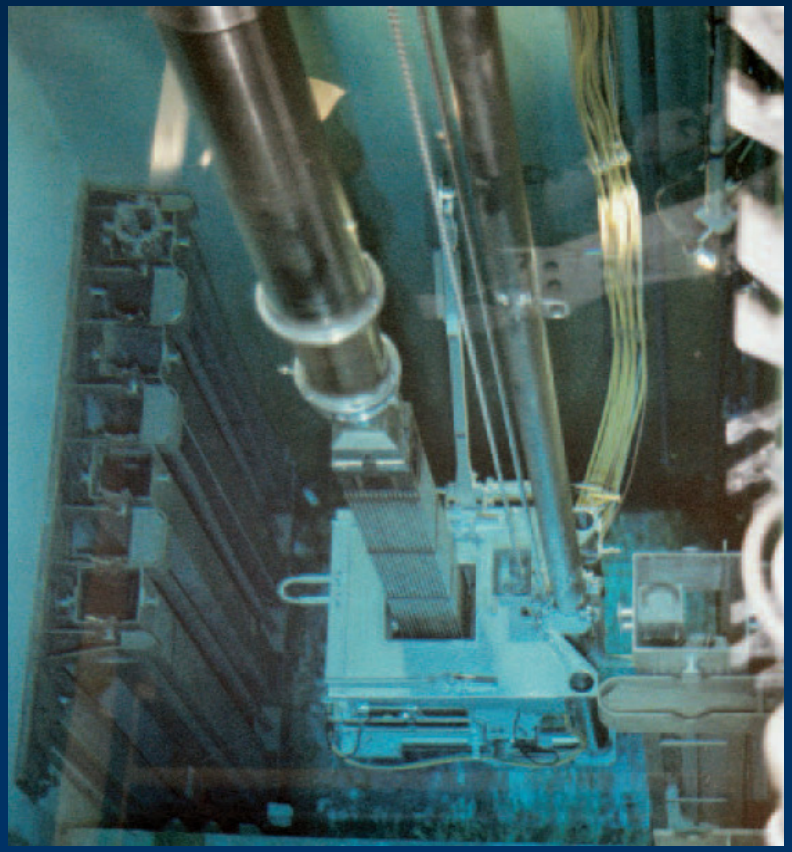
Burnup Measurement in US Reactor Pool



Fork Detector in US Reactor Pool



Burnup Measurement at the Karlsruhe Reprocessing Plant



Some Industry Experience with In-Pool Burnup Measurements

- Surry
- Oconee
- ANO
- Maine Yankee

Surry Nuclear Station (1983)

- Developmental program with Westinghouse and DOE
  - Based on neutron count rate only
- 50 Westinghouse 15x15 used fuel assemblies
- 14-41 GWd/t
- 1.9 - 3.4% enrichment
- Required cooling time and initial enrichment information
- Data enabled correlation of burnup with count rate, enrichment, and cooling time

Oconee Nuclear Station (1993)

- 93 assembly burnup measurements with Sandia and Los Alamos National Laboratory Fork detector
- B&W 15x15 fuel
- 20 - 58 GWd/t
- 2.9 - 3.9% enrichment
- Required enrichment information and calibration against reactor records
- Average deviation of 2.2%
- Two outlier readings – appears that reactor records were correct and measured burnups were too high

ANO (1996-97)

- 403 assembly burnup measurements in five campaigns
- B&W 15x15 and CE 16x16 fuel
- 12.3 - 46.9 GWd/t
- 1.9 - 3.9% enrichment
- Required enrichment information and calibration against reactor records
- Agreement generally good (most differences within 1 GWd/t)

Maine Yankee (1998)

- 26 assembly burnup measurements with Fork+ detector
- Combustion Engineering 14x14 fuel
- 2.8 - 49.2 GWd/t
- 1.9 - 3.7% enrichment
- Goal - independent burnup technique
  - Not achieved; too much background
- Significant outliers using Fork only

Observations Based on In-Pool Burnup Measurements

- Provides only a relative measure of burnup
- Results generally consistent with reactor records
- Resource intensive (about one hour per assembly at ANO)
- Requires extensive fuel handling
- Increases personnel exposure

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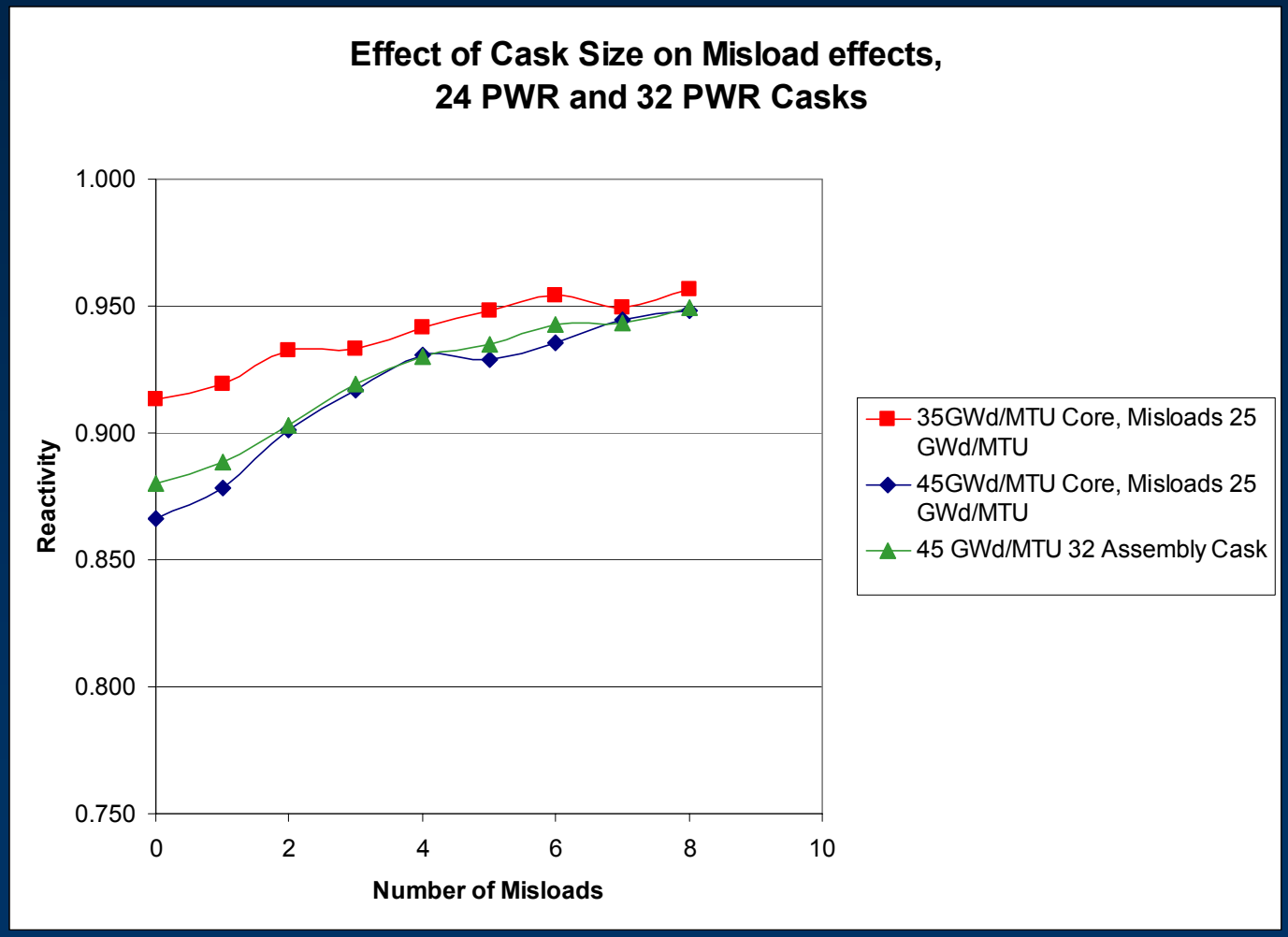
Why Require In-Pool Burnup Measurements?

- Provide another indication of fuel assembly burnup?
  - Multiple sources of quality assurance records of fuel assembly burnup exist (in-core burnup measurements <u>and</u> core design calculations)
  - At best, in-pool burnup measurements can provide relative burnup information
    - Requires initial enrichment information
    - Requires calibration against reactor records

Why Require In-Pool Burnup Measurements?

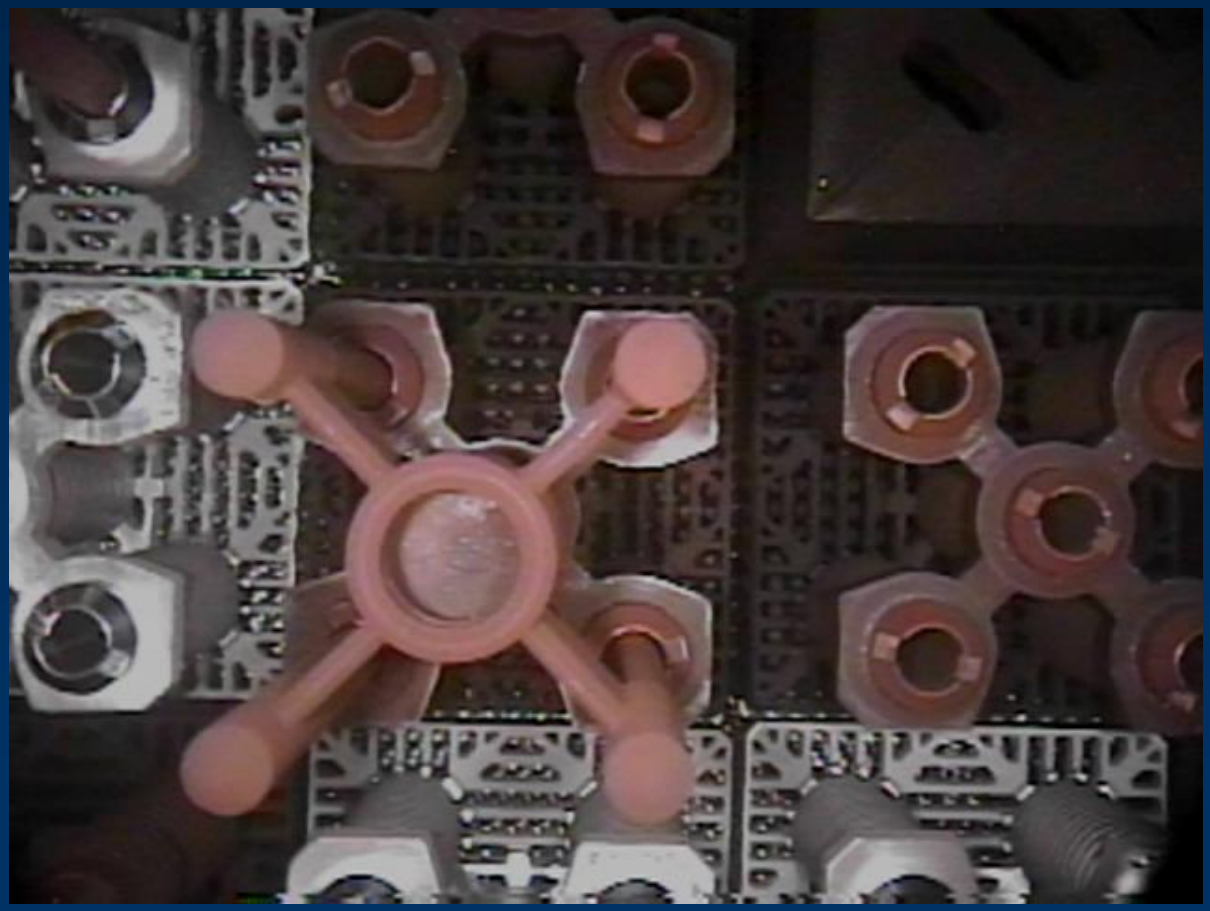
- Provide protection against a misloading event?
  - If so, why does ISG-8 seem to allow sampling?
  - No value unless in-pool measurement data is immediately validated and assembly is immediately loaded into a cask
  - EPRI work indicates that realistic criticality risk due to misloading requires multiple fresh fuel assemblies (not a credible scenario)

Misloads and Reactivity



Burnup Credit – Technical Basis for Spent-Fuel Burnup Verification – Interim Report, EPRI, Palo Alto, CA: 2003, 1003418

Fresh and Used Fuel Assemblies



Why Require In-Pool Burnup Measurements?

- To be consistent with Office of Nuclear Reactor Regulation practice for spent fuel pools?
  - Many spent fuel pools use burnup curves (based on burnup credit)
  - Reactors are allowed to rely upon reactor records without in-pool burnup measurements
  - Therefore, the SFST requirement is inconsistent with NRR

An In-Pool Burnup Measurement Requirement Would Have Adverse Impacts

- Additional cost and time required to support dry storage loading
- More personnel access to a plant Vital Area
- Additional fuel assembly manipulations
- Additional occupational exposure
- Additional low level waste generation

Sufficiency of Burnup Measurements

- Quality records – in-core measurements - already exist
- Comparisons show good agreement relative to diverse records (calculated burnups)
- Consistent with current regulatory practice for compliance with fuel pool subcriticality requirements
- Existing reactor records provide for reasonable assurance of public health and safety
  - No demonstrable benefit from requirement for in-pool burnup measurements

Conclusion

The requirement to perform in-pool burnup measurements in order to take burnup credit for storage or transportation casks is burdensome without a commensurate benefit to the health and safety of the public. In fact, the additional activities needed to satisfy the requirement marginally increase overall risk.