BWR OWNERS' GROUP ALTERNATIVE SOURCE TERMS

PRESENTATION FOR

NRC MEETING

April 28, 2004

GREG BROADBENT
(ENTERGY-Grand Gulf)

Committee Chairman

MEETING PURPOSE

- **Background on BWROG AST Committee.**
- **BWROG plans for BWROG Fuel Gap Fraction Licensing Topical Report (LTR) submittal.**
- **Preliminary review of LTR submittal.**
- **Collect NRC observations.**

BWROG AST COMMITTEE

- <u>Committee Formed:</u> 1995
- <u>Committee Membership:</u> 14 (of 20) BWR Utilities
- <u>Committee Objective:</u>

  Support generic aspects of BWR plant AST NRC application submittals and develop specific generic products necessary for future BWR AST applications.

BWROG AST COMMITTEE

- **Past Committee Products:**
  - "Prediction of the Onset of Fission Gas Release from Fuel in Generic BWR", NEDC-32963, July 1996
    - Submitted as part of Entergy Grand Gulf-Unit 1 AST Submittal (May 1997)
    - NRC issued acceptance SER, September 9, 1999.
  - "BWROG Generic Source Terms", NEDC-33043P. June 2001
    - Defined isotopic inventories for bounding BWR fuel design for radio-nuclide groups in NUREG-1465.
    - Designed to assist BWR plants with NRC AST applications.

BWROG AST COMMITTEE

- <u>Current Committee Focus:</u>
  - Current NRC-approved fuel gap fractions for non-LOCA events [RG 1.183] are contingent on a maximum linear heat generation rate (LHGR) of 6.3kW/ft peak rod average power for rod burnups exceeding 54 GWd/MTU.
  - Many BWRs are projecting rod power levels exceeding this currently-approved requirement.
  - The BWROG has recently performed fuel gap fraction analyses based on BWR peak rod power histories that bound anticipated rod powers throughout BWR plant life.

BWROG AST COMMITTEE

- **Current Committee Focus (Continued):**
  - **A final LTR is planned for NRC submittal following BWROG approval (~End of May).**
  - **NRC approval will allow BWR licensees to reference the approved LTR/SER and methodology for future AST applications.**
  - **A Review Fee Waiver request is planned on the basis that NRC LTR approval should assist the Staff with a RG 1.183 revision to address high burnup fuel.**

future AST app in event licensees exceed footnote.

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- BWROG Contractors: NISYS Corporation and KW Consulting were contracted to perform high burnup fuel gap fraction analysis for the BWROG.

- Analysis Approach: Identical to the gap fraction approach used to develop the current RG 1.183 values except:

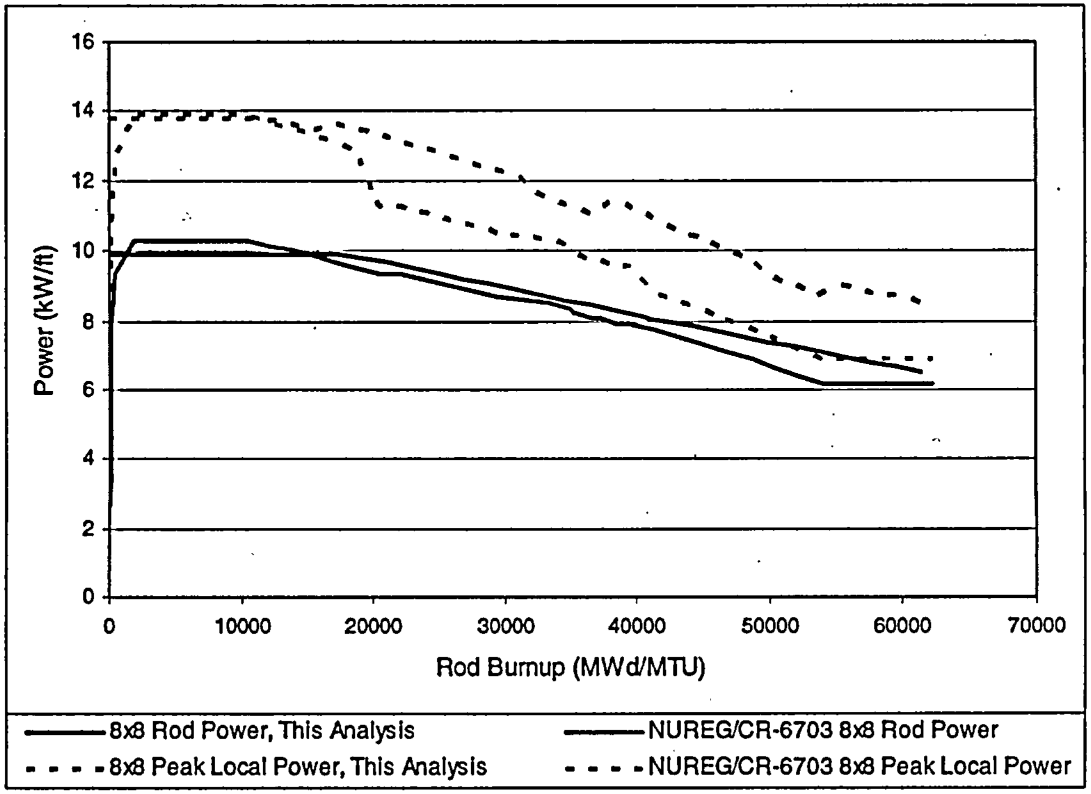
More Fuel Types

- **BWR Fuel Designs That Span BWR Industry Experience**
  - GE 8x8
  - GE 11/13 (9x9)
  - GE 12/14 (10x10)
  - Framatome ATRIUM-9 (9x9)
  - Framatome ATRIUM-10 (10x10)
  - ABB SVEA-96/96+
  - ABB SVEA-96 Optima2

Higher Exposure

- **Higher Exposure:**
  - **Current RG 1.183 Gap Fractions Applicable up to 62 GWd/MTU**
  - **New Analysis Applicable to:**
    - **65 GWd/MTU for full-length rods**
    - **68 GWd/MTU for partial-length rods**

More Aggressive Power History



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Technical Presentation

- Objective
- Gap Release Fraction Analysis Methodology
- Gap Release Fraction Analysis Inputs
- Typical Results
- Conservatisms

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Objective

- To extend the gap release fraction analyses described in the NRC High Burnup Environmental Impact Statement (EIS) (NUREG/CR-6703), using the methodology described in the High Burnup EIS, to:
  - Higher rod burnups
  - Higher rod powers at high burnups
  - Complete spectrum of current BWR fuel designs

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High Burnup EIS Methodology

- FRAPCON-3 fuel rod performance code
- Best estimate fuel rod performance models and nominal fuel rod fabrication parameters
- Normalization of the FRAPCON-3 gap release fraction results
- Gap release fractions for long-lived isotopes (Kr-85, Cs-134 and Cs-137) given by stable fission gas release fractions

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Normalization of Gap Release Fraction Results

- FRAPCON-3 has two gas release models:
  - "Massih" model
    - Predicts only stable fission gas release
    - Validated against high burnup stable fission gas release data
  - ANS-5.4 model
    - ANS standard for radioactive isotope gap release fractions
    - Predicts stable fission gas release and radioactive isotope gap release fractions

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Normalization of Gap Release Fraction Results (cont'd)

- ANS-5.4 model developed in late 70's, early 80's
  - Not validated against high burnup stable fission gas release data
  - Over-predicts high burnup stable fission gas release
- Compensate for over-prediction by multiplying the gap release fractions by the ratio of the Massih to the ANS-5.4 stable gas release predictions

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Additional Code Modifications

- At start of project, PNNL personnel responsible for FRAPCON-3 expressed concerns about the FRAPCON-3 implementation of the ANS-5.4 model
- KW Consulting review found coding errors dating back to the initial ANS-5.4 model implementation for FRAPCON-2
  - Used only the beginning-of-life axial power distribution
  - Did not use fuel pellet radial burnup distribution when calculating the gas diffusion coefficients

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Additional Code Modifications (cont'd)

- Gap release fractions calculated using a FRAPCON-3 code version that corrects these errors
  - Code modifications discussed with and evaluated by PNNL personnel
- Also modified gap release fraction output to give results in a more easily used format

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Gap Release Fraction Analysis Inputs

- Fuel rod geometry
  - Provided by the fuel vendors
- Nominal plant operating conditions (coolant temperature, flow rate, reactor coolant system pressure)
- Fuel rod power histories
  - Bounding power histories for both rod average and local powers needed to obtain bounding results for the gap release fractions
  - Bounding rod average power histories provided by the BWROG
  - Bounding local power histories based on the Technical Specification LHGR limits for each fuel design

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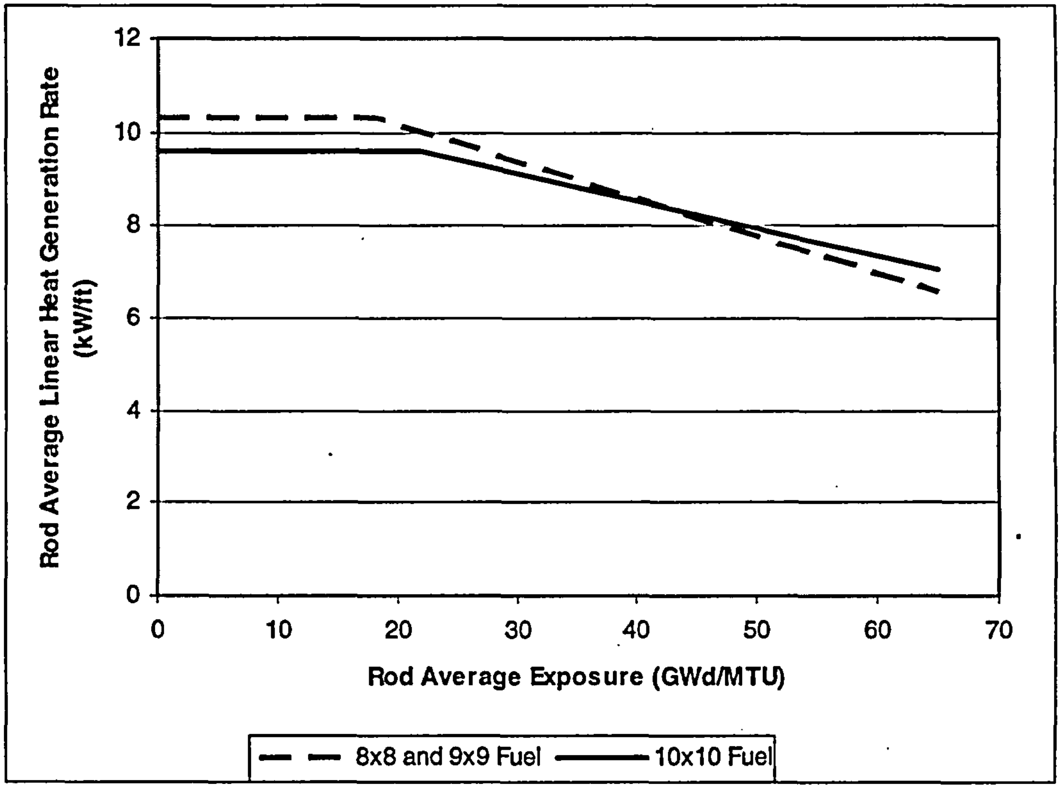
Bounding Rod Average Power Histories

Full Length Rods



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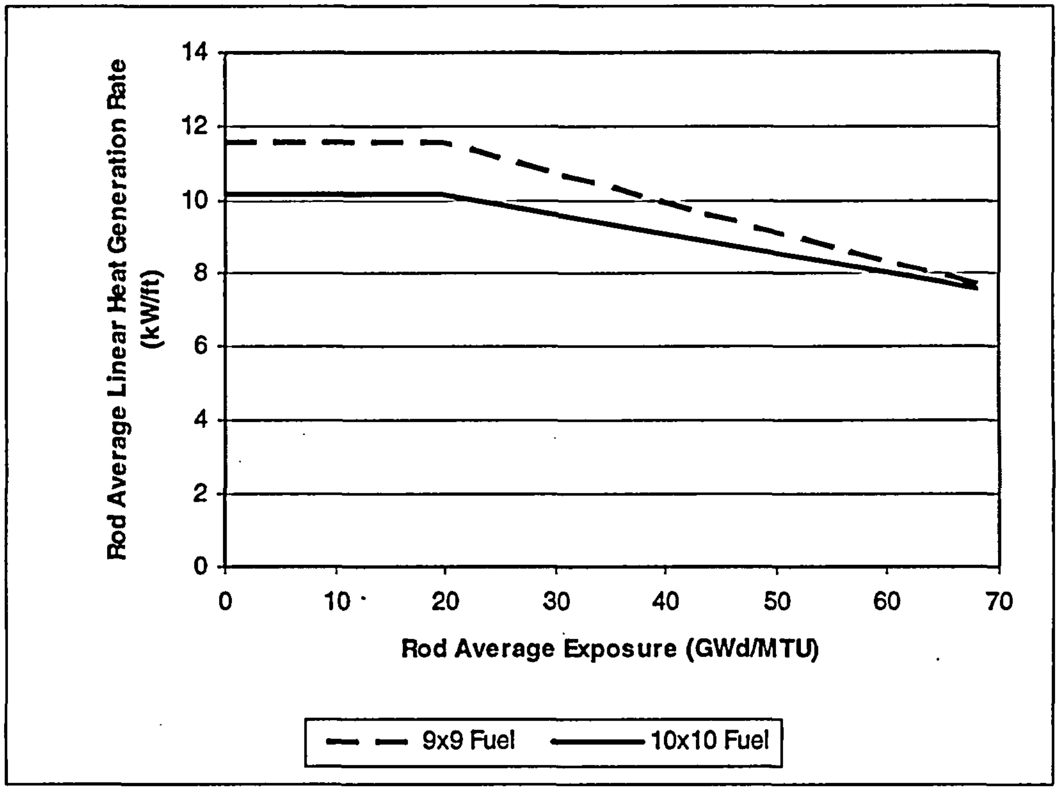
Bounding Rod Average Power Histories

Part Length Rods



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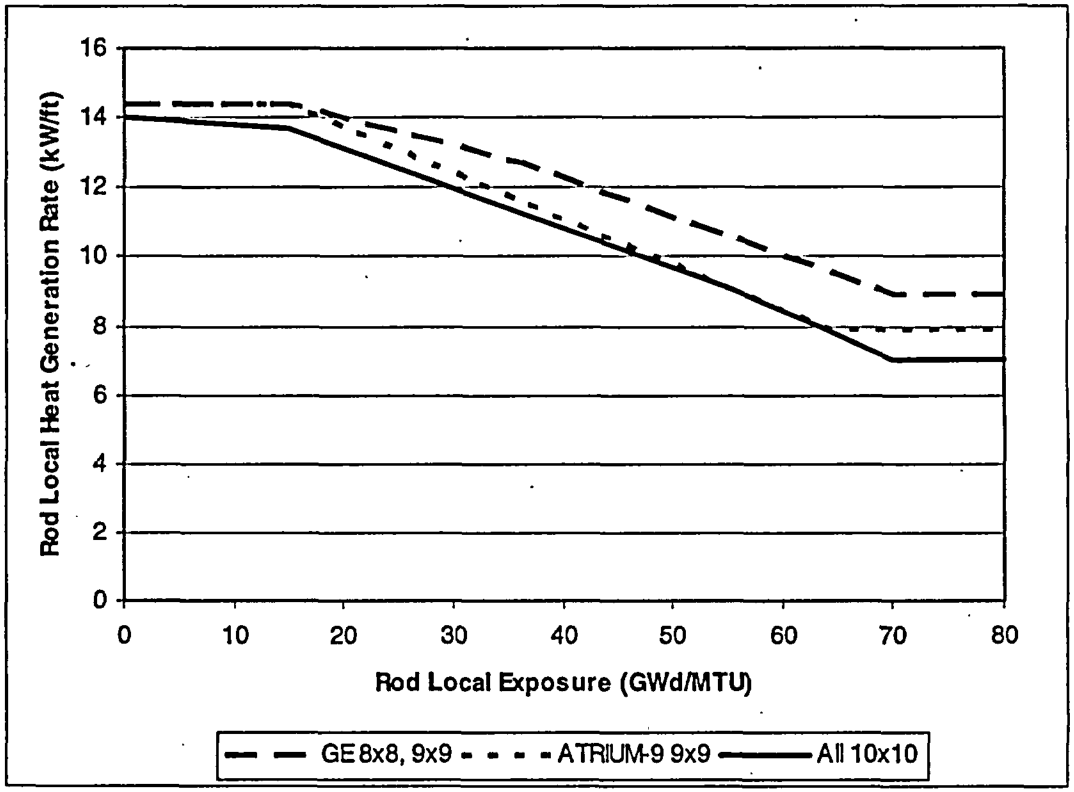
Bounding Local Power Histories



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FRAPCON Axial Power Shape Inputs

- Generated from bounding rod average and local power histories
- Cycle from bottom-peaked to mid-peaked to top-peaked through each operating cycle
- Eighteen month cycles assumed
- Assure that rod powers used in the gap release fraction analysis are bounded by both the bounding rod average and local power limits

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Gamma Heating

- Bounding power history limits are based on the total heat generation rates
    - Include both energy deposited in the fuel and heat generated by gamma heating of the coolant and core structural components
- FRAPCON power history inputs are the energy deposited in the fuel
- FRAPCON gap release fraction analysis power history inputs adjusted to compensate for gamma heating of the coolant and core structural components

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Gadolinia Fuel Rods

- Operate at lower power and attain lower burnups than non-gadolinia fuel rods
- Recent field observations show that gap release fractions of gadolinia rods are less than half those of near-by non-gadolinia rods
- Very little qualification of FRAPCON-3 for gadolinia fuel
- Conservatively assumed that the gadolinia fuel rod gap release fractions are the same as the non-gadolinia fuel rod gap release fractions

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Gap Release Fraction Results

- Bundle average gap release fractions calculated from Beginning-of-Life to End-of-Life
  - Bundle average conservatively assumes all rods in the bundle are at the lead rod burnup
  - Contribution of part-length rods are weighted by their relative fuel mass

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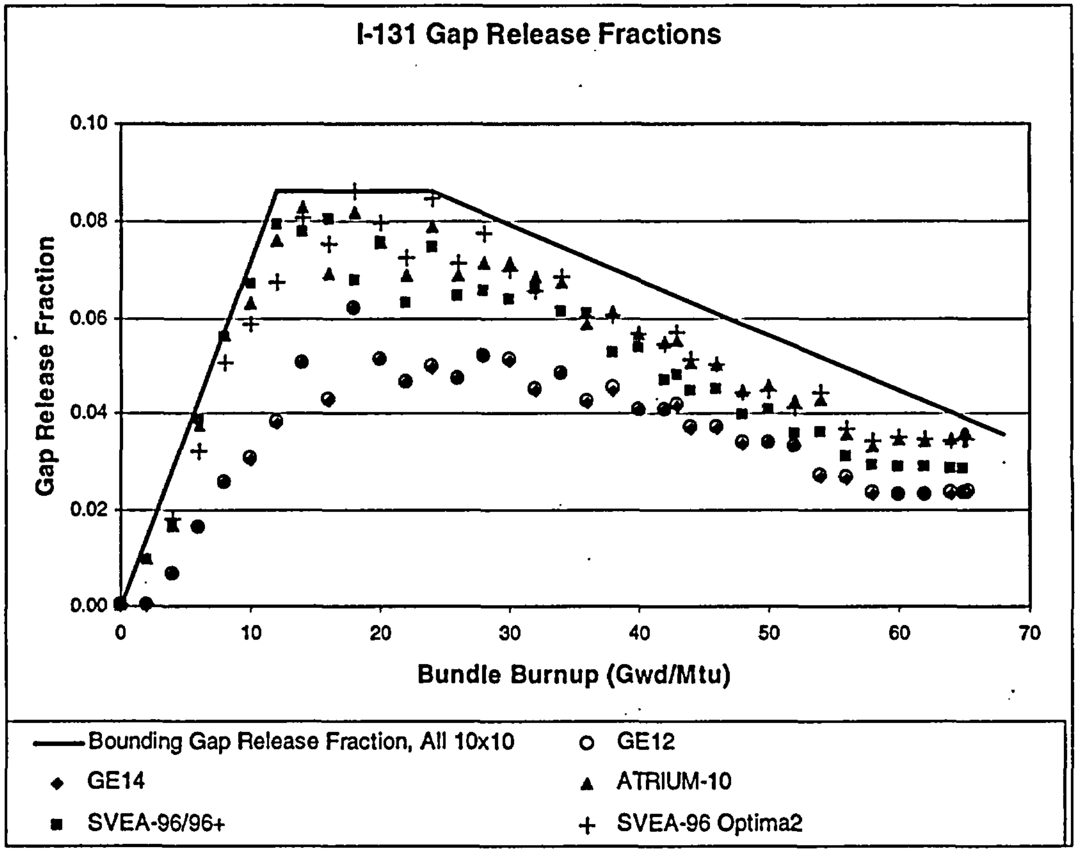
Gap Release Fraction Results for 10x10 Fuel



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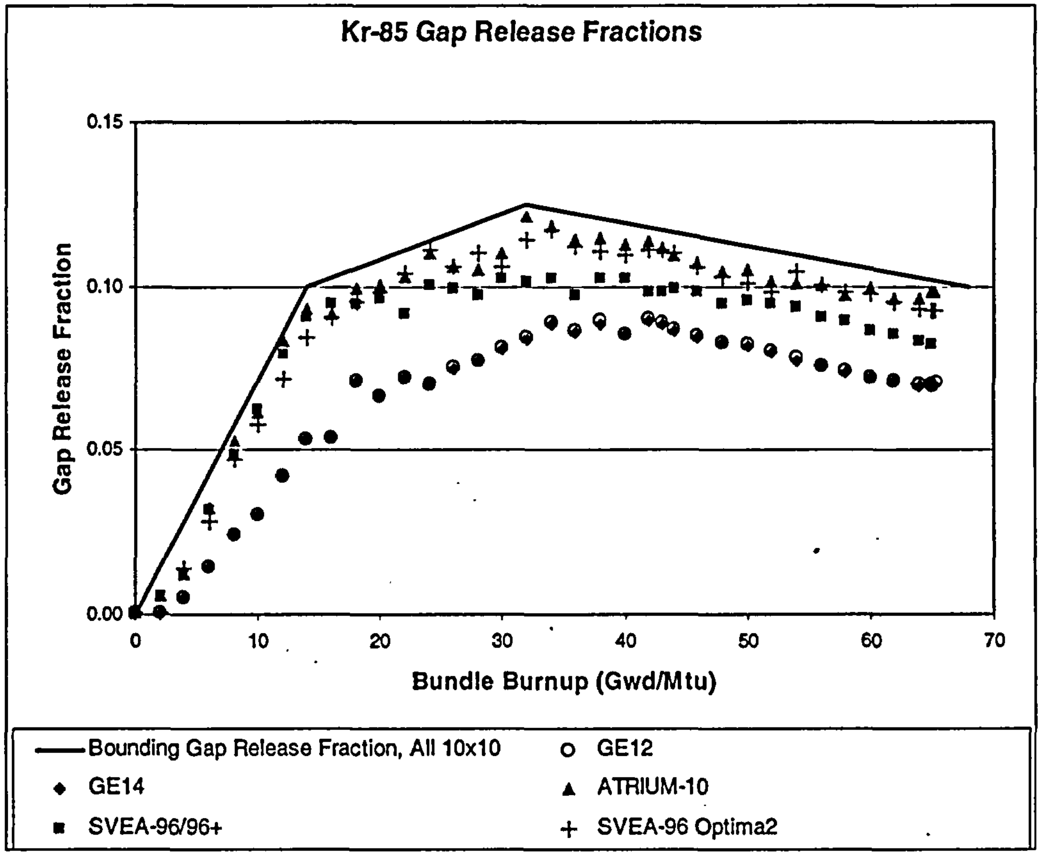
Gap Release Fraction Results for 10x10 Fuel



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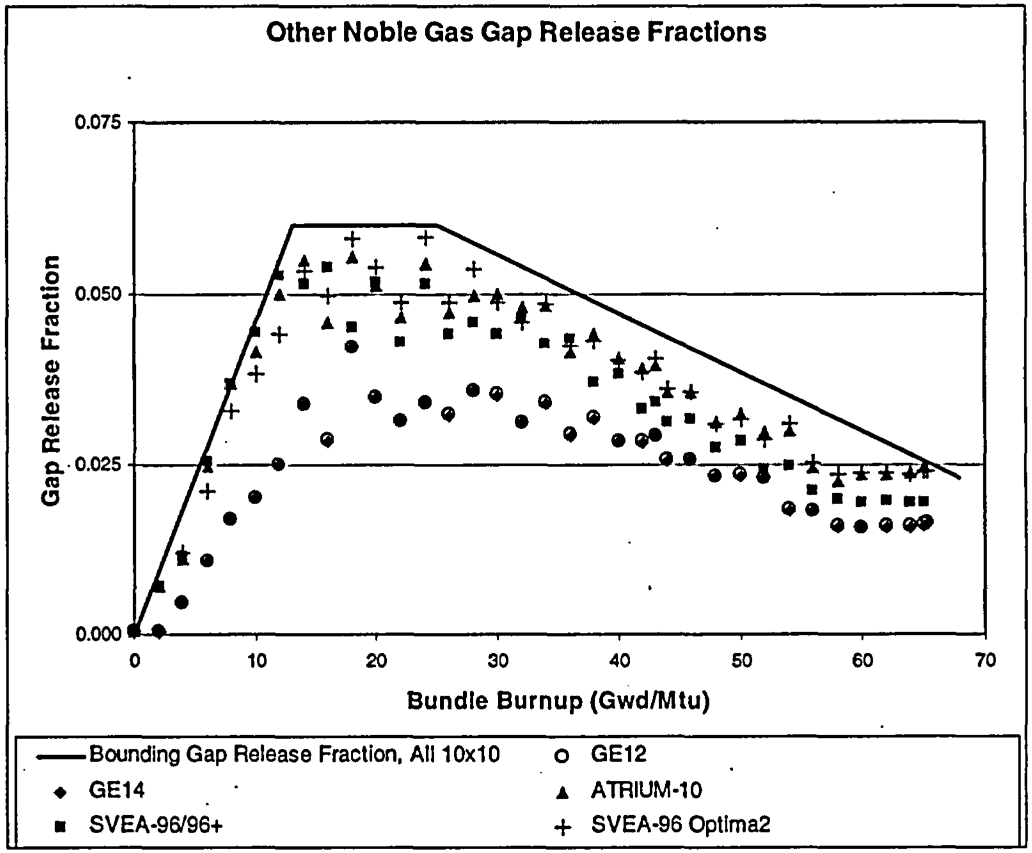
Gap Release Fraction Results for 10x10 Fuel



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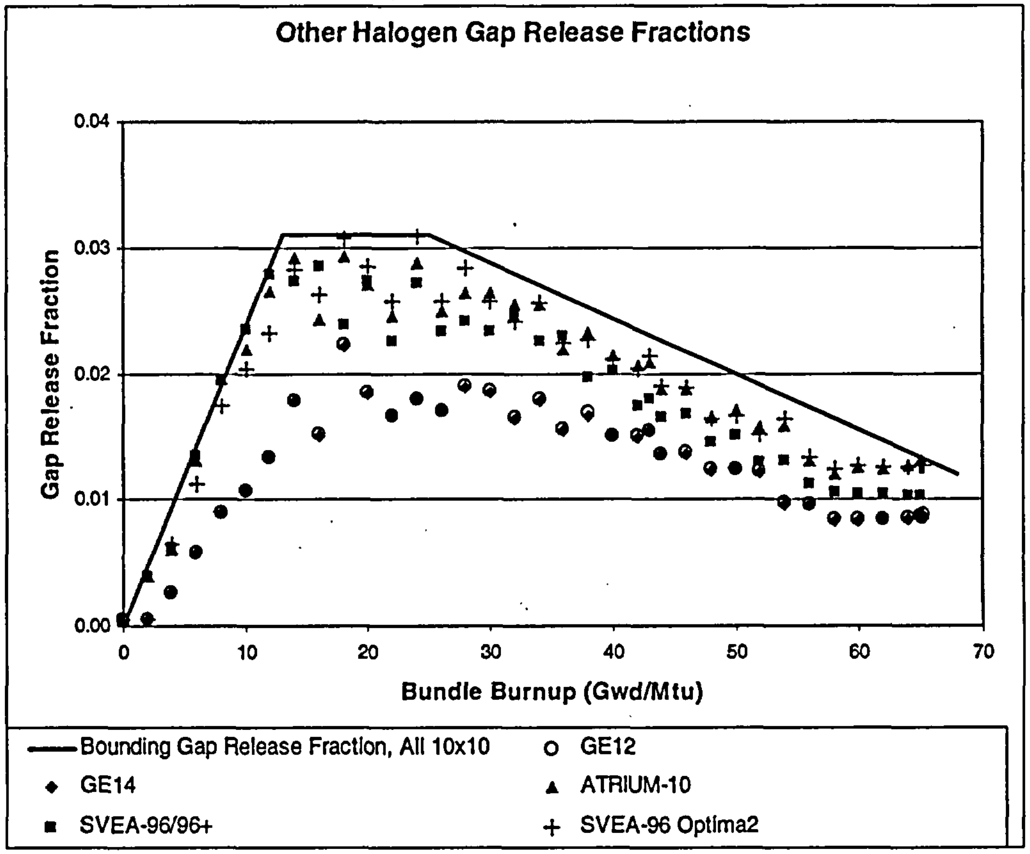
Gap Release Fraction Results for 10x10 Fuel



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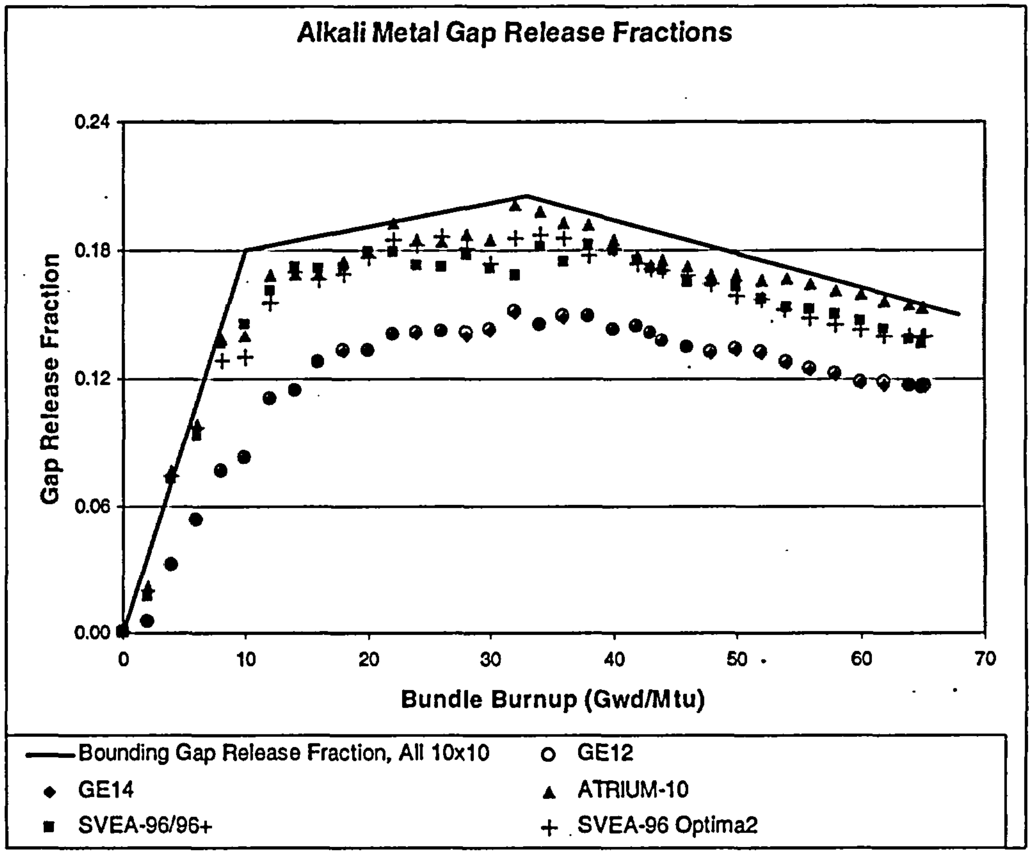

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Gap Release Fraction Results

- Typical behavior as a function of burnup consistent with the gas diffusion constant used in the gas release models

$$D \propto 100^{Bu_{local}/Bu_{const}} e^{-Q/RT}$$

D: diffusion constant

Bu_{local}: local burnup

Bu_{const}: model constant

Q: activation energy

R: gas constant

T: absolute temperature

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Gap Release Fraction Results (cont'd)

- Low burnup: rod powers and fuel temperatures approximately constant, gap release fractions increase with increasing burnup
- Moderate burnups: rod powers and fuel temperatures decrease, compensating for increasing burnup, and gap release fractions plateau and then decrease
- High burnups: peak local burnups exceed the maximum value for the LHGR limits, local powers and fuel temperatures are approximately constant, and gap release fractions plateau or increase

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Peak Gap Release Fractions, All Rod Designs

Fuel Design	Gap Release Fractions				
	I-131	Kr-85	Other Nobles	Other Halogens	Alkali Metals
GE 8x8	0.100	0.173	0.097	0.051	0.217
GE11 9x9	0.092	0.167	0.081	0.043	0.217
GE13 9x9	0.093	0.167	0.081	0.043	0.218
ATRIUM-9	0.106	0.146	0.076	0.040	0.220
GE12 10x10	0.062	0.090	0.042	0.022	0.152
GE14 10x10	0.062	0.090	0.042	0.022	0.151
ATRIUM-10	0.083	0.121	0.055	0.029	0.201
SVEA-96/96+	0.080	0.103	0.054	0.029	0.183
SVEA-96 Optima 2	0.086	0.117	0.058	0.031	0.187
RG 1.183, Table 3	**0.08**	**0.10**	**0.05**	**0.05**	**0.12**

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Changes from Reg. Guide 1.183

- **Inclusion of precursor effects effectively doubles the Other Noble Gases gap release fractions**
  - **After accounting for precursor effects, gap release fractions for the short-lived isotopes (I-131, Other Noble Gases and Other Halogens) are comparable**
- **Increased gap release fractions for the long-lived isotopes (Kr-85 and Alkali Metals) reflect the use of more aggressive power histories**
- **Comparable gap release fractions for the short-lived isotopes reflect the corrections to the FRAPCON-3 implementation of the ANS-5.4 model**

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Shutdown Pressures

- Calculated at a coolant temperature of 200 °F, reactor coolant pressure of 35 psia and decay heat after 24 hours of cooldown = 0.6% of rod power at operating conditions
- End-of-Life rod pressures at shutdown conditions are less than 905 psig
- Bounding value for all earlier times in life

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Conservatisms in This Analysis

- Primary conservatism is the assumption that the lead fuel operates at the bounding rod average and local powers throughout life
  - Gap release fraction results are very sensitive to fuel temperatures
  - Typically, cores are designed with ~10% margin to the LHGR limits to preclude Licensee Event Reports due to small power transients or small differences between predicted and actual core performance
- 10% reduction in local power limits gives a 40-50% reduction in the peak gap release fractions

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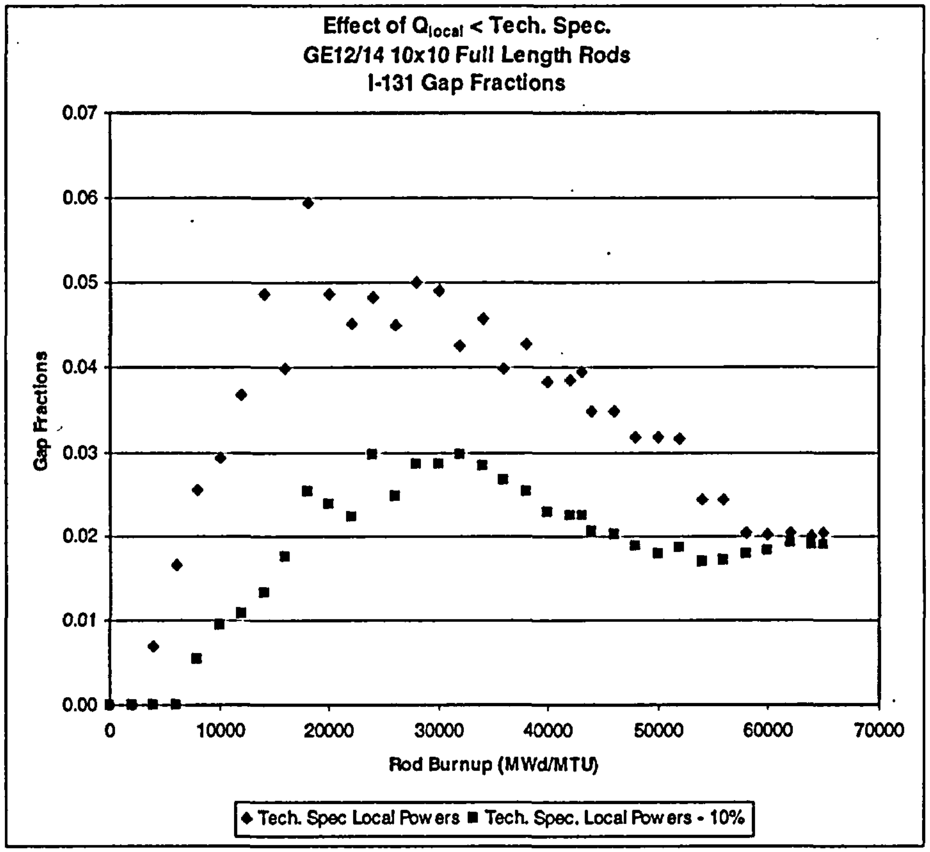
Conservatisms in This Analysis



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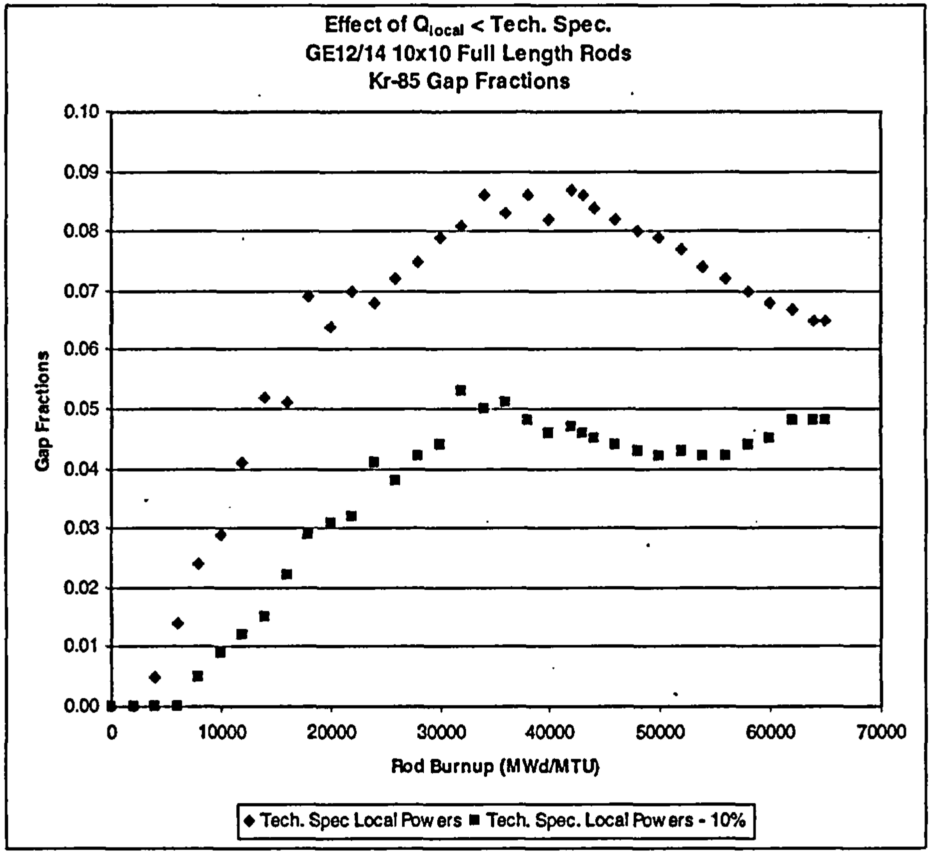
Conservatisms in This Analysis



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Additional Conservatisms

- All rods in the bundle are assumed to operate at the bounding rod average and local power limits
  - Typically, peak rod-to-bundle peaking factors are more than 10% at the peak gap fraction burnup
- No credit is taken for the reduced gap release fractions of the gadolinia rods
- Recent evaluations indicate that the ANS-5.4 model over-predicts I-131 gap release fractions by as much as a factor of 10
  - Scaling by the ratio of the Massih to ANS-5.4 stable gas release values only partially compensates for this conservatism of the ANS-5.4 model

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Additional Conservatisms

- 10x10 analyses use a conservative application of the bounding rod average and local power limit curves
  - Due to the axial burnup distribution in the rod, at high burnups the bounding rod average power is greater than that allowed by the local power limit
  - At these burnups, the gap release fraction analysis used the rod average power and an unrealistic, but conservative, flat axial power shape

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- BWROG intends to request:
  - Extension of current RG 1.183 gap fractions to higher BWR burnups and more aggressive power histories
  - Approval of this methodology for use with new fuel designs and/or revised design inputs
- Benefits:
  - Validation of existing RG 1.183 gap fractions
  - No requirements for re-analysis
  - No increased consequences under 50.59
    - No new submittals

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- Current bounding analyses predict slightly higher gap fractions than RG 1.183 Table 3
- However, conservatisms in the calculations (previously described) more than bound these small increases based:

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- **Iodine-131**
  - 8% per Table 3 of RG 1.183
  - 6.2-10% per BWROG analysis
- **Disposition**
  - 8x8 and ATRIUM-9 fuel are no longer being reloaded and are well past the exposure of peak gap fraction
  - Remaining 9x9 and 10x10 designs are no more than 1% greater than the 8% RG value
    - More than bounded by the conservatisms in the analysis
      - ~40 – 50% margin with 10% lower peak LHGR
      - Another ~40% margin considering rod-to-bundle peaking of 10% or more

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- Other Halogens
  - 5% per Table 3 of RG 1.183
  - 2.2-5.1% per BWROG analysis
- Disposition
  - BWROG analysis calculates the same 5% fraction or less

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- Kr-85
  - 10% per RG 1.183
  - 9-17% per BWROG analysis
- Disposition
  - FHA analysis is insensitive to this isotope
    - Kr-85 contrib. to GGNS FHA Control Dose = 5E-4%
  - Larger BWROG results are offset by the conservatisms in the analysis
    - ~40 – 50% margin with 10% lower peak LHGR
    - Another ~40% margin considering rod-to-bundle peaking of 10% or more

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- Other Noble Gases
  - 5% per RG 1.183
  - 4.2-9.7% per BWROG analysis
- Disposition
  - FHA analysis is insensitive to these isotopes
    - noble gas contrib. to GGNS FHA Control Dose = <2%
  - Larger BWROG results are offset by the conservatisms in the analysis
    - ~40 – 50% margin with 10% lower peak LHGR
    - Another ~40% margin considering rod-to-bundle peaking of 10% or more

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- **Alkali Metals**
  - 12% per RG 1.183
  - 15.1-21.7% per BWROG analysis
- **Disposition**
  - **FHA analysis is completely insensitive to particulate isotopes since they are completely scrubbed by the fuel pool water**
    - **infinite decontamination factor per RG 1.183, App. B, Section 3**

SUMMARY

- The BWROG has/is assisting BWR licensees with AST applications.
- RG 1.183 is currently limiting for high burnup fuel.
- Currently-planned LTR will request NRC review and approval (SER) for extension of current values in Table 3 of RG 1.183 to more aggressive power histories and burnups
- To address future fuel types, LTR will request NRC approval of defined methodology for developing non-LOCA fuel isotopic inventories.