UNITED STATES
NUCLEAR REGULATORY COMMISSION
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April 6, 2000

MEMORANDUM TO: Cynthia A. Carpenter, Chief
Generic Issues, Environmental, Financial and Rulemaking Branch
Division of Regulatory Improvement Programs
Office of Nuclear Reactor Regulation

FROM: Peter C. Wen, Project Manager Peter C. Wen
Generic Issues, Environmental, Financial and Rulemaking Branch
Division of Regulatory Improvement Programs
Office of Nuclear Reactor Regulation

SUBJECT: SUMMARY OF MARCH 30, 2000, MEETING WITH THE NUCLEAR ENERGY INSTITUTE AND ELECTRIC POWER RESEARCH INSTITUTE REGARDING HIGH BURNUP FUEL ISSUES

On March 30, 2000, a public meeting was held at the Nuclear Regulatory Commission (NRC) offices in Rockville, Maryland. The participants included members of the NRC staff and representatives from the Nuclear Energy Institute (NEI), the Electric Power Research Institute (EPRI), and fuel vendors. Attachment 1 lists attendees at the meeting, and Attachment 2 contains the meeting agenda.

The meeting was held to discuss issues related to high-burnup fuel, including NEI's petition for rulemaking on revised cladding materials, industry's progress on the development of licensing criteria for fuel burnup extensions, and the status of the staff's ongoing study on possible revisions to required features of 10 CFR Part 50, Appendix K.

Petition for Rulemaking on Revised Cladding Materials

On March 14, 2000, NEI submitted a petition for rulemaking to revise 10 CFR 50.44 and 50.46. The petition requests changes to 10 CFR 50.44 and 50.46 to eliminate the need for licensees to obtain exemptions in order to use advanced fuel cladding materials. These regulations currently specify that fuel pellets used in commercial reactors be contained in cladding material made of zircaloy or ZIRLO. Fuel vendors have developed other materials that have been approved by the NRC by exception to the rule for use in power reactors. NEI is proposing changes that would allow licensees discretion to use other zirconium-based cladding materials.

During the meeting, Dave Modeen of NEI described the petition and provided the rationale for NEI's position. The NEI presentation material is contained in Attachment 3. A major discussion in this area is the replacement language of "zirconium-based alloy" used in NEI's petition. The staff expressed concern that the term may be interpreted to include materials that are beyond current appropriate materials. The staff's concern stems from the cladding performance criteria stated in the current emergency core cooling system regulation. These criteria might not be appropriate for future cladding materials. NEI indicated that it would further evaluate its petition in light of the staff's concern.

After this discussion, David Meyer of the NRC's Office of Administration joined the meeting and presented an overview of the NRC's general handling of rulemaking petitions. The preliminary processing and threshold determination were explained. Further, he explained the concept of "fast-track" processing and the staff's role in determining the petition's eligibility for such processing. He indicated that NEI had requested that NRC proceed by issuing a direct final rule. NEI's petition and its request for NRC to proceed with a direct final rule are currently being reviewed by the NRC's Office of the General Counsel. If the NRC decides not to proceed to a direct final rule, the NRC will draft and publish a notice of receipt in the *Federal Register* and request public comment. This notice of receipt will also be put on NRC's rulemaking Web site (http://ruleforum.llnl.gov).

Licensing Criteria for Fuel Burnup Extensions Beyond 62 GWd/tU

Terry Rieck, Chairman, Robust Fuel Program (RFP) Working Group 2, informed the staff that the industry is proceeding with the high-burnup fuel program. A draft interim report, " Process for Establishment of Licensing Criteria for Fuel Burnup Extensions Beyond 62 GWd/tU," was transmitted to the staff before this meeting by letter dated March 21, 2000. He began the discussion by outlining the industry development of a process for establishing licensing criteria. Robert Montgomery of ANATECH then discussed the four-stage review process and used two examples (rod internal pressure and excessive fuel enthalpy) to demonstrate the review process. Presentation materials used during this discussion are contained in Attachment 4. The staff expressed its general agreement with the industry approach. The staff and RFP representatives agreed that these items will be followed up:

1. The staff will provide feedback by letter on the industry's approach and the interim report within 1 month from this meeting to support the industry's initiative on development of high-burnup fuel licensing criteria.

2. NEI will submit a formal interim report within 3 months after receiving NRC feedback. The staff requested that a discussion of the relevance of this work to the four NRC performance goals to be included in the NEI submittal.

Continued interaction between NEI and the staff on this program is anticipated.

Evaluation of Possible Revisions to Required Features of 10 CFRPart 50, Appendix K

Norman Lauben of the NRC's Office of Nuclear Regulatory Research (RES) presented current RES activities to evaluate the effect of allowing more realistic models for decay heat and metal water reaction in Appendix K analyses. His presentation materials are provided as Attachment 5.

Finally, meeting participants discussed the possibility of exemption from NRC fees for review of the NEI document on high-burnup fuel. On the basis of the preliminary information provided by the NEI, the staff indicated that the review of these documents would be exempt from NRC fees because the NEI effort involves the development of generic guidance for use industry-wide.

Representatives of the NRC and the industry agreed that this meeting had been useful for the exchange of information on high-burnup fuel issues.

Attachments: As stated
cc w/atts: See next page

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NRC/NEI HIGH BURNUP FUEL MEETING
LIST OF ATTENDEES
March 30, 2000

NAME	ORGANIZATION
Timothy Collins	NRR/DSSA
Jared Wermiel	NRR/DSSA/SRXB
Ralph Caruso	NRR/DSSA/SRXB
Muffet Chatterton	NRR/DSSA/SRXB
Edward Kendrick	NRR/DSSA/SRXB
Shih-Liang Wu	NRR/DSSA/SRXB
Jim Davis	NRR/DE/EMCB
Farouk Eltawila	RES/DSARE/SMSAB
Ralph Meyer	RES/DSARE/SMSAB
Norm Lauben	RES/DSARE/SMSAB
Harold Scott	RES/DSARE/SMSAB
Sud Basu	RES/DSARE/SMSAB
Tom Kenyon	NRR/DRIP/RGEB
Raj Auluck	NRR/DRIP/RGEB
Mike Jamgochian	NRR/DRIP/RGEB
Peter Wen	NRR/DRIP/RGEB
David Meyer	ADM/DAS/RDB
Alzonia Shepard	ADM/DAS/RDB
Dave Modeen	NEI
Terrance Rieck	Com Ed
Glen Watford	GNF-A
Jerry Potts	GNF-A
Sumit Ray	Westinghouse
Dan Risher	Westinghouse
Ian Rickard	ABB CENP
Gary Hanson	Framatome Cogema Fuels
Bill Brgnson	FCF
Frank McPhaffer	FCF
Nicolas Waeckel	EPRI
Robert Montgomery	EPRI/Anatech
Rosa Yang	EPRI
Jerry Holm	Siemens
Whee Choe	TXU
Robert Neal	NUSIS
J.V. Ramsdell	PNNL
Elaine Hiruo	Nuclear Fuel

Attachment 1

NRC-INDUSTRY MEETING
HIGH BURNUP FUEL ISSUES

March 30, 2000 9:00 am - 11:40 am
Room O-10B4

Preliminary Agenda

9:00	Introductions and Opening Remarks	Rieck, Com Ed Wermiel, NRC
9:10	Industry Guide for Establishing Criteria for Fuel Burnup Extensions Beyond 62 GWD/MTU • Process/Approach	Montgomery, Anatech
9:30	Demonstration Cases • Design Stress • Rod Internal Pressure • Excessive Fuel Enthalpy • Violent Expulsion of Fuel	Montgomery, Anatech
10:30	NRC Initiatives • Decay Heat Curve • Different Metal-Water Reaction Models	Eltawila, NRC
10:50	Break	
11:00	Cladding Material Petition	Modeen, NEI Brunson, FTI
11:20	Discussion • Feedback/Technical Questions • Proposed Schedule: Future Interactions/Submittals • Review Fee Waiver (burnup extension licensing criteria guide)	All
11:40	Adjourn	

ATTACHMENT 2

Industry Petition to Revise Cladding Materials Referenced in NRC Regulations

Dave Modeen, NEI
Bill Brunson, FCF
March 30, 2000
Rockville, MD

NEI

Meeting Objectives

- Present industry proposal and motivation for petitioning to revise cladding materials referenced in Part 50
- Provide technical basis for the proposed revision
- Obtain preliminary NRC staff feedback on petition content
- Identify next steps for industry and NRC

NEI

Petition to Revise Regulatory Reference to Cladding Materials

- Process
  - Direct final rulemaking
- Desired Outcome
  - Add flexibility to promote innovation in new cladding materials
  - Adopt a more performance-based rule structure
  - Avoid licensee exemption requests

NEI

Referenced Cladding Material Proposed Amendment

- Change wording in §50.44 (a), (b), (c)(1) and §50.46(a)(1)(i)
  - Replace zircaloy or zirlo with ***zirconium-based alloy***
- Recognize need for parallel dialogue with NRC staff on implementing details or guidance
  - Cladding material performance demonstrated by vendor/licensee
- No other changes required

NEI

Performance of Cladding Material Requirements Remain Unchanged

- No change in 10 CFR 50.46(b)
  - Peak cladding temperature < 2200 degrees F
  - Maximum cladding oxidation not to exceed 0.17 times the total cladding thickness before oxidation
  - Maximum hydrogen generation
  - Coolable geometry
  - Long term cooling

NEI

Elimination of Unwarranted Licensee Implementation Costs

- Estimate 30 exemption requests over next eight or nine years.
- Licensee cost per exemption request is approximately $50,000
- Additional benefit of removing impediment to applying technical advancements

NEI

Summary

- Ensures adequate coolability for reactor fuel and no increased risk to public health and safety.
- Provides more of a performance-based approach to regulatory requirements.
- Removes unwarranted licensing burden.

NEI

Licensing Criteria for Fuel Burnup Extensions Beyond 62 GWd/tU

"Industry Guide Development"

Review Process and Demonstration Cases

Working Group 2
Robust Fuel Program

NRR-RFP Meeting
Nuclear Regulatory Commission
March 30, 2000

Background

- NRC Strategic Plan for High Burnup (Nov. 1997)
  - Industry should provide a guide the NRC can review and endorse
    - » Criteria and type of needed data to demonstrate compliance
    - » Non-proprietary
    - » Risk-Informed
    - » Industry-wide
- Industry Guide Development for Burnup Extension
  - Minimize Resources for Industry and NRC
  - Streamline the Licensing Process
  - No surprises

Background (cont^{d})

RFP and NRR Discussions/Meetings

- Indicated interest in burnup extension and outlined the process
  - » April 1998 (NRR and RES attend RFP Meeting)
  - » January 1999 (Executive and Technical)
  - » March 1999 (Technical)
- Interim report submitted on March 23, 2000 for this meeting

Industry Guide for Burnup Extension Beyond 62 GWd/tU

Issues

- What are the licensing criteria to be applied to fuel designs with burnup limits in excess of 62 GWd/tU (peak rod average)?
- What combinations of methods, programs, and data are appropriate to demonstrate that fuel designs meet the licensing criteria?

NRC-RFP Meeting March 30, 2000

- Industry expectation of this meeting
  - Verbal feedback from NRC on the industry approach
  - Written comments from NRR on the industry approach and the interim Industry Guide

Presentation Overview

- Industry Guide Development
  - Review Process
  - Approach Used to Apply the Process
  - Demonstration Cases
    - » Design Stress
    - » Rod Internal Pressure
    - » Excessive Fuel Enthalpy
    - » Violent Expulsion of Fuel
- Interim Report: Process for Establishment of Licensing Criteria for Fuel Burnup Extensions Beyond 62 GWd/tU
  - Submitted to NRC for review and comment March 23, 2000

Four Stage Review Process

(I) **Establish Baseline for Current Fuel System Designs**
(Requirements, Limits, Parameters, Methods, Measures and Data)

↓

(II) **Perform Burnup Effects Screening Evaluation**
(Is there a burnup effect?)

↓

(III) **Perform Comprehensive Burnup Effects Evaluation**
(How to address burnup effects?)

↓

(IV) **Establish New Baseline for Licensing Fuel System Designs for Extended Burnup**
(Requirements, Limits, Parameters, Methods, Measures and Data)

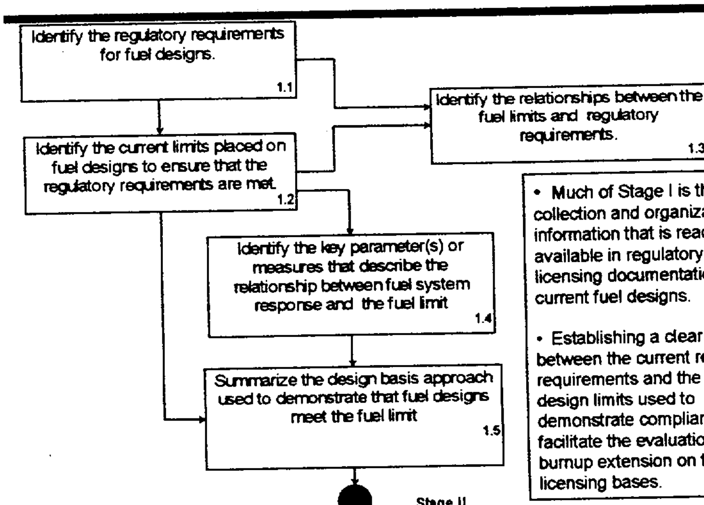
Road Map for the Process

- Stage I - Establish Baseline for Current Fuel System Designs
  1. Application
     » the conditions for which the limit is applied
  2. Standard Review Plan Section 4.2
     » reiteration of the SRP 4.2 requirement
  3. Regulatory Requirement
     » a summary of the regulatory basis for the limit
  4. Design Limit
     » a summary of the basis for the current limit used by licensees in the fuel design process
  5. Design Basis Approach
     » a summary of the analysis methods/processes used to show compliance to the limit

Road Map for the Process

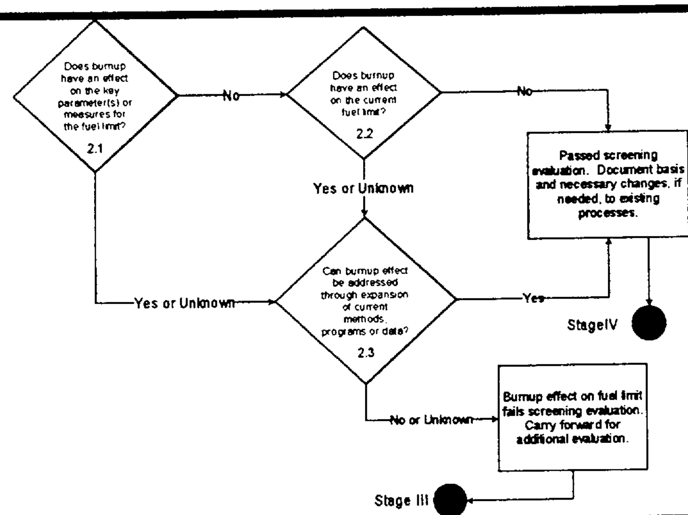
- Stage II - Burnup Effects Screening Evaluation
  6. Does burnup extension impact key parameter(s) or limit?
     » review of burnup effects on the methods/processes used to demonstrate compliance to the limit and the burnup effects on the limit.
- Stage III - Comprehensive Burnup Effects Evaluation
  7. Review of burnup impact on underlying phenomena
     » a detailed assessment of the burnup effect on the design limit and the methods/processes used to demonstrate compliance
     » NRC PIRT Activity used as basis for review
- Stage IV - Establish New Baseline for Extended Burnup
  8. Assessment
     » recommendations/actions to address burnup extension

Stage I
Establish Baseline for Current Fuel System Designs

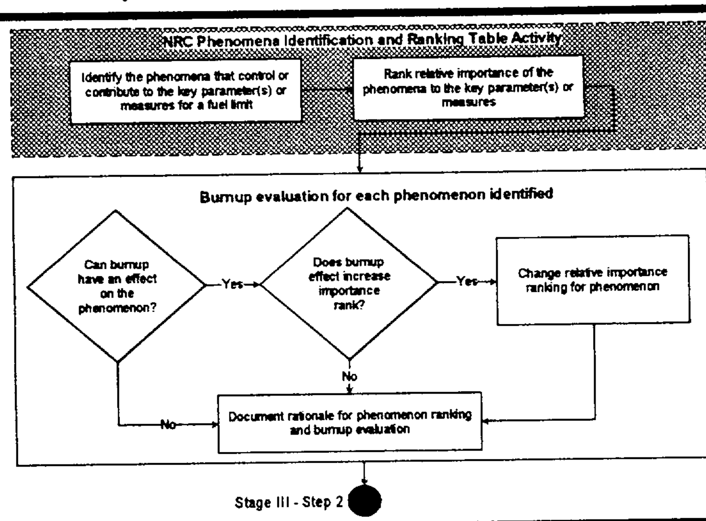


- Much of Stage I is the collection and organization of information that is readily available in regulatory and licensing documentation for current fuel designs.
- Establishing a clear link between the current regulatory requirements and the fuel design limits used to demonstrate compliance will facilitate the evaluation of burnup extension on the fuel licensing bases.

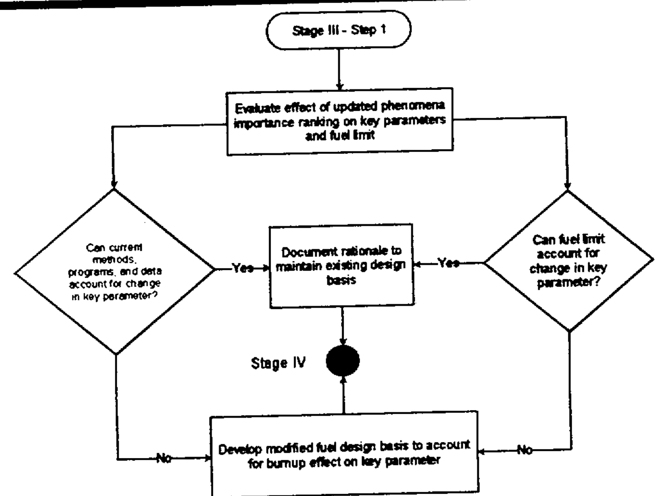
Stage II
Burnup Effects Screening Evaluation



Stage III - Step 1
Comprehensive Burnup Effects Evaluation



Stage III - Step 2
Comprehensive Burnup Effects Evaluation



Stage IV
Establish New Baseline for Burnup Extension

- Rationale to support new baseline for licensing fuel system designs for burnup extension
  - Basis to support each fuel limit
    - » current or revised limit
    - » data to set the limit
  - Basis for approach to demonstrate compliance
    - » Data from poolside or destructive examinations
    - » Analysis methods or programs

Application of the Review Process

- Approach
  - Apply to fuel limits defined in Standard Review Plan Chapter 4.2, Chapter 15, and 10CFR50.46
  - Develop documentation to support recommended design bases for extended burnup
- Exercise the approach
  - Selected four limits defined in SRP 4.2
  - Use to workout the process
  - Solicit comments from NRC
- Focused on Stage I and II
  - preliminary Stage III material prepared
  - Some rationale developed for Stage IV

1. Fuel System Damage	Current Acceptance Criteria	Criteria Change
Design Stress	ASME Section III	No
Design Strain	ASME Section III	
Strain Fatigue	< 2 on Stress; <20 on Cycles	
Fretting Wear	Should be limited (Include in Stress/Strain/Fatigue)	
Oxidation	Should be limited (Include in Stress/Strain/Fatigue)	
Hydriding	Should be limited (Include in Stress/Strain/Fatigue)	
Crud	Should be limited	
Rod Bow	Include in Design Analysis	
Irradiation Growth	Include in Design Analysis	
Internal Gas Pressure	< System Pressure or Justified	No
Hydraulic Lift Loads	< Hold down Force	
2. Fuel Rod Failure		
Internal Hydriding	< 20 micro-gram/gram moisture	
Cladding Collapse	No collapse	
Fretting	Covered in Fuel System Damage	
Overheating of Cladding	DNBR/CPR Limits	
Overheating of Fuel Pellets	No Centerline melting	
Excess Fuel Enthalpy	< 170 cal/gm; DNBR/CPR Limits	Yes
Pellet/Cladding Interaction	Uniform Strain < 1.0% or no fuel melting	
Clad Rupture	Reg. Guide 1.157 or 10CFR50 Appendix K	
Mechanical Fracturing	Applied Stress < 90% irradiated yield stress	
3. Fuel Coolability		
Cladding Embrittlement	2200 F peak clad temp. and 17% oxidation	
Violent Expulsion of Fuel	< 280 cal/gm	Yes
Generalized Clad Melting	Satisfied by Cladding Embrittlement criteria	
Fuel Rod Ballooning	Reg. Guide 1.157 or 10CFR50 Appendix K	
Structural Deformation	SRP Appendix A	

Demonstration of the Process

- Licensing Limits from SRP 4.2
  - Design Stress
    - » least affected by burnup
    - » burnup impact accounted for in design methods
  - Rod Internal Pressure (RIP)
    - » affected by burnup
    - » burnup impact can be accounted for in design methods
  - Excessive Fuel Enthalpy
    - » affected by burnup
    - » requires more detailed review (Stage III)
  - Violent Expulsion of Fuel
    - » affected by burnup
    - » requires more detailed review (Stage III)

Current Design Bases

- Review Material
    - » Nonproprietary generic fuel assembly Topical Reports prepared by SPC, FCF, W, ABB-CE, and GE
    - » Technical Evaluation Reports prepared by PNL on the SPC, W, GE and FCF Topical Reports
    - » Standard Review Plan Section 4.2, 15.4.8/Appendix A, 15.4.9/Appendix A
    - » Regulatory Guide 1.77 "Assumptions Used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors"
    - » 10 CFR 50 Appendix A – "General Design Criteria for Nuclear Power Plants"
    - » 10 CFR 100 Part 11 – "Determination of Exclusion Area, Low Population Zone, and Population Center Distance"
    - » ASME Boiler and Pressure Vessel Code
    - » NRC PWR RIA Phenomena Identification and Ranking Tables

Rod Internal Pressure

- Stage I - Establish Baseline for Current Fuel Designs
  1. Application: fuel system damage during normal operation and AOO's
  2. Standard Review Plan 4.2: Fuel and burnable poison rod internal gas pressures should remain below the nominal system pressure during normal operation unless otherwise justified.
  3. Regulatory Requirement: SAFDL - GDC 10, 12, 17, 20, and 25.
  4. Design Limit:
     - » Most design bases use RIP limit above the coolant pressure
     - » RIP is established below that required to cause;
       - fuel-cladding gap reopening during constant or increasing fuel rod power conditions under normal operation
       - extensive DNB propagation to occur
     - » Based on thermal and mechanical calculations

Rod Internal Pressure

- Stage I - Establish Baseline for Current Fuel Designs (con't)
  5. Design Basis Approach:
     - » Utilize fuel performance codes to calculate the rod internal pressure
     - » RIP analysis includes
       - initial helium pressure/inventory, initial internal void volume, fission gas release, helium release from fuel and burnable poisons , total rod internal volume, and temperature of the different internal void volumes.
     - » Bounding approaches are used to ensure conservatism

Rod Internal Pressure

- Stage II - Burnup Effects Screening Evaluation
  - *Does burnup have an effect on the key parameter(s) or measures identified for the fuel limit?* - **Yes**
    - » Burnup influence constituents that control rod internal pressure
      - fission gas release, helium release from fuel and burnable poisons, fuel pellet swelling, cladding creepdown, fuel rod growth, and fuel pellet thermal conductivity.
  - *Does burnup have an effect on the current fuel limit?* - **No**
    - » The fuel-cladding gap reopening limit is not dependent on burnup

    However,
    - » Burnup influences the mechanisms that control fuel-cladding gap reopening
    - » Increasing the limit will require consideration of burnup effects in the justification

Rod Internal Pressure

- Stage II - Burnup Effects Screening Evaluation (con't)
  - *Can the effect of burnup be addressed by expansion of current methods, programs or data?* - **Yes**
    - » Fuel performance codes should address changes caused by burnup, such as;
      - fuel pellet thermal conductivity effects on temperature
      - void volume changes caused by fuel pellet swelling, fuel rod growth, and cladding creep
      - gas inventory and thermal conductivity changes caused by fission gas and helium release.

Rod Internal Pressure

- Stage IV - Assessment
  - No change in current design basis for extended burnup
  - Industry Recommendation
    - » Design basis calculations must demonstrate conservatism in the rod internal pressure using applicable data for the expected burnup range
    - » Justification of RIP limit for gap reopening should consider effects of fluence, temperature, and stress levels at target burnup level

Excessive Fuel Enthalpy

- Stage I - Establish Baseline for Current Fuel Designs
  1. Application: Fuel rod failure during postulated reactivity initiated accidents including control rod ejection (CREA) or control rod drop (CRDA) accidents.
  2. Standard Review Plan 4.2: For a severe reactivity initiated accident (RIA) in a BWR at zero or low power, fuel failure is assumed to occur if the radially averaged fuel rod enthalpy is greater than 170 cal/g (711 J/g) at any axial location. For full-power RIAs in BWR and all RIAs in a PWR, the thermal margin criteria (DNBR and CPR) are used as fuel failure criteria to meet the guidelines of Regulatory Guide 1.77 as it relates to fuel rod failure. The 170 cal/g (711 J/g) enthalpy criterion is primarily intended to address cladding overheating effects, but it also indirectly addresses pellet/cladding interactions (PCI). Other criteria may be more appropriate for an RIA, but continued approval of this enthalpy criterion and the thermal margin criteria may be given until generic studies yield improvements.

Excessive Fuel Enthalpy

- Stage I - Establish Baseline for Current Fuel Designs (con't)
  3. Regulatory Requirement
     » Reg. Guide 1.77 - the number of fuel rods experiencing clad failure should be calculated to obtain the fission product inventory released to the coolant.
       - Clad failure assumed when DNBR limit exceeded for PWR Control Rod Ejection Accident (CREA) - Reg. Guide 1.77
       - SRP 4.2 and SRP 15.4.9 define 170 cal/g for BWR zero or low power Control Rod Drop Accident (CRDA).

     » 10 CFR 100 Part 11 requires dose for the exclusion area boundary (EAB) and the low population zone (LPZ).
       - SRP 15.4.8/9 Appendix A - 25% of 10 CFR 100.11 limits
       - Reg. Guide 1.77 Appendix B - gap inventory contains 10% of the iodines and 10% of the noble gases.

     » GDC 28 defines pressure boundary integrity and core coolability and is not concerned with fuel rod failure.

Excessive Fuel Enthalpy

- Stage I - Establish Baseline for Current Fuel Designs (con't)
  4. Design Limit
     » Zero-power RIA experiments in SPERT showed fuel rod failure coincident with post-DNB clad temperatures for zero or low burnup fuel.
       - Basis for DNB limit in PWR
       - 170 cal/g used in BWR CRDA as a thermal limit

     » DNB/CHF performance function of fuel assembly and reactor design.
       - Controlling parameters include coolant flowrate, temperature, pressure, and operating power level.
       - Thermal-hydraulics calculations are required to relate DNB and fuel enthalpy

     » DNB is used for RIA events at full-power in both PWRs and BWRs

Excessive Fuel Enthalpy

- Stage I - Establish Baseline for Current Fuel Designs (con't)
  5. Design Basis Approach:
     » Calculate the energy deposition following rapid insertion of reactivity using conservative neutron kinetics methods and assumptions.
       - Conservatism assumptions defined in Reg. Guide 1.77
       - static core depletion calculations used to initialize nuclear parameters and define assembly peaking factors
       - core average power pulse calculated using point, 1-D, 2-D or 3-D spatial kinetics methods.

     » perform a conservative thermal analysis using energy deposition to determine the maximum radially averaged fuel enthalpy.
       - Hot spot power transient calculated using assembly peaking factors based on limiting xenon distribution.
       - Adiabatic pellet heat-up is assumed in the calculation of the fuel enthalpy

Excessive Fuel Enthalpy

- Stage II - Burnup Effects Screening Evaluation
  - *Does burnup have an effect on the key parameter(s) or measures identified for the fuel limit?* - **Yes**
    » Burnup decreases fuel rod reactivity by decreasing fissionable material and introducing fission products.
    » Fuel-cladding gap closure increase amount of heat conduction
    » Burnup influences the fission product release during an RIA.

Excessive Fuel Enthalpy

- Stage II - Burnup Effects Screening Evaluation (con't)
  - *Does burnup have an effect on the current fuel limit?* - **Yes**
    - » Burnup causes changes in fuel rod response to rapid energy deposition
      - high burnup fuel may fail by PCMI stresses
    - » Transition from high temperature (DNB) to PCMI failure is related to cladding ductility
      - PCMI loading increases with burnup due to gap closure, etc.
      - cladding ductility depends on fluence, oxide layer thickness, hydride concentration, and temperature

Excessive Fuel Enthalpy

- Stage II - Burnup Effects Screening Evaluation (con't)
  - *Can the effect of burnup be addressed by expansion of the current methods, programs or data?* - **Yes**
    - » Effects of burnup on nuclear parameters should be considered in the methods used to calculate the fuel enthalpy
      - cross-section data, control rod worth, Doppler coefficient, and delayed neutron fraction.
    - » Consideration should be given to the burnup of individual fuel rods or assemblies.
      - The fuel rod capacity to withstand an RIA varies throughout the core
      - Thermal margin limits are not necessarily applicable to high burnup fuel.

Excessive Fuel Enthalpy

- Stage III - Comprehensive Burnup Effects Evaluation
  - Results of NRC PWR RIA PIRT used as starting point
    - » phenomena list and ranking
  - Phenomena Identification and Assessment
    - » Analysis Methods
      - Energy Deposition
      - Fuel Enthalpy Increase
    - » Licensing Limit
      - Departure from Nucleate Boiling
      - Maximum radially averaged fuel enthalpy >170 cal/gm

Excessive Fuel Enthalpy

- Stage III - Comprehensive Burnup Effects Evaluation
  - Step 1 - Effect of burnup on phenomena ranking
    - » Can burnup have an impact on the phenomenon?
    - » Does burnup increase importance rank?
  - Step 2 - Assessment

Methods {
- » Can current methods, programs, or data account for changes in key parameters caused by burnup effects on ___?
  - Energy Deposition
  - Fuel Enthalpy Increase

Limits {
- » Can the current fuel limit of DNB or 170 cal/gm account for changes in cladding failure at high temperature caused by burnup effects on ________?
- » Can the current fuel limit of DNB or 170 cal/gm account for changes in nominal temperature PCMI cladding failure caused by burnup effects on ________?

Can burnup have an effect?
Analysis Methods

Key Parameter	Phenomena	Ranking	Can burnup have an impact on the phenomenon?	Does burnup effect increase importance ranking?
Energy Deposition	Ejected Rod Worth	High		
	Rate of Reactivity Insertion	Medium		
	Moderator Feedback	Medium		
	Temperature Feedback	High		
	Delayed-neutron fraction	High		
	Fuel Cycle Design	High		
Fuel Enthalpy Increase	Pellet, Gap, and Cladding Heat Resistances	Medium		
	Cladding to Coolant Heat Transfer	Medium		
	Pellet and Cladding Heat Capacities	High		
	Pellet Radial Power Distribution	Medium		
	Pin Peaking Factors	High		

Phenomena list and ranking based on NRC PWR RIA PIRT

Can burnup have an effect?
Licensing Limit

Key Parameter	Phenomena	Ranking	Can burnup have an impact on the phenomenon?	Does burnup effect increase importance ranking?
Cladding Failure at High Temperature	DNB	High		
Cladding Failure by Nominal Temp. PCMI	Fuel-Cladding Gap Size	High		
	Cladding Oxidation	Medium		
	Cladding Oxide Spallation	High		
	Hydrogen Content	Medium		
	Hydrogen Distribution	High		
	Fast Fluence	Low		
	Pellet Rim Size	Medium		
	Fission Gas Induced Pellet Swelling	Medium to High		
	Cladding Temperature	High		

Phenomena list and ranking based on NRC PWR RIA PIRT

Are current Analysis Methods adequate?

Key Parameter	Phenomena	Ranking	Can current methods, programs, or data account for changes in energy deposition caused by burnup effects on___?
Energy Deposition and Pulse Width	Ejected Rod Worth	High	
	Rate of Reactivity Insertion	Medium	
	Moderator Feedback	Medium	
	Temperature Feedback	High	
	Delayed-neutron fraction	High	
	Fuel Cycle Design	High	
Key Parameter	Phenomena	Ranking	Can current methods, programs, or data account for changes in fuel enthalpy increase caused by burnup effects on___?
Fuel Enthalpy Increase	Pellet, Gap, and Cladding Heat Resistances	Medium	
	Cladding to Coolant Heat Transfer	Medium	
	Pellet and Cladding Heat Capacities	High	
	Pellet Radial Power Distribution	Medium	
	Pin Peaking Factors	High	

Phenomena list and ranking based on NRC PWR RIA PIRT

Is current License Limit adequate?

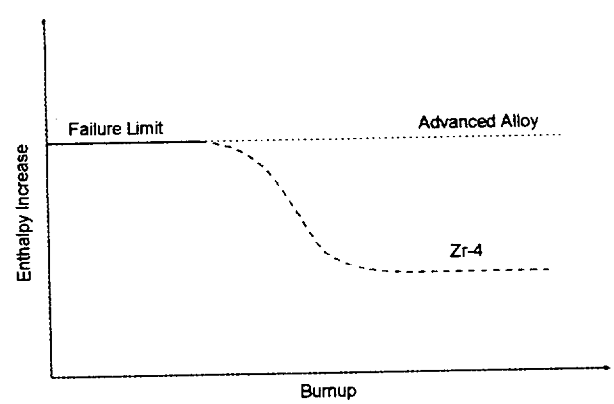
Key Parameter	Phenomena	Ranking	Can current fuel limit of DNB or 170 cal/gm account for changes in cladding failure at high temperature caused by burnup effects on___?
Cladding Failure at High Temperature	DNB	High	
Key Parameter	Phenomena	Ranking	Can current fuel limit of DNB or 170 cal/gm account for changes in nominal temperature cladding failure caused by burnup effects on___?
Cladding Failure by Nominal Temp. PCMI	Fuel-Cladding Gap Size	High	
	Cladding Oxidation	Medium	
	Cladding Oxide Spallation	High	
	Hydrogen Content	Medium	
	Hydrogen Distribution	High	
	Fast Fluence	Low	
	Pellet Rim Size	Medium	
	Fission Gas Induced Pellet Swelling	Medium to High	
	Cladding Temperature	High	

Phenomena list and ranking based on NRC PWR RIA PIRT

Excessive Fuel Enthalpy

- Stage IV - Assessment
  - Burnup independent limit (170 cal/gm or DNBR) is insufficient for zero-power RIA events if PCMI cladding failure is possible
  - Industry Recommendation
    - » Fuel rod failure limit that is a function of irradiation (burnup, oxide layer thickness, etc.)
    - » The limit for burnups up to 75 GWd/tU may involve;
      - Additional RIA tests to address fuel pellet burnup effects
      - Mechanical property tests to demonstrate ductility
      - Limited RIA tests to confirm the additional margins that exists for advanced cladding alloys
    - » Use PRA to define
      - Risk-Informed Part 100 Dose Limits
      - Realistic Neutron Kinetics Methodologies and Assumptions

Schematic of Excessive Fuel Enthalpy Limit



Planned Activities

- Written feedback on Industry Approach and Interim Report
- Revised Interim Report addressing NRC feedback 1 - 3 mons
- Complete review of remaining limits
  - Two Parts
    - » Part A ~50% of the limits Dec. 2000
    - » Part B ~remainder of limits Jun. 2001

EVALUATION OF POSSIBLE REVISIONS TO REQUIRED FEATURES OF 10 CFR 50 APPENDIX K

G. Norman Lauben
Office of Nuclear Regulatory Research
USNRC

NRC-INDUSTRY MEETING ON
HIGH BURNUP FUEL ISSUES

March 30, 2000

Attachment 5

RES EVALUATION PROCESS

- RES is evaluating the effect of allowing more realistic models for decay heat and metal water reaction in Appendix K analyses. In particular:

  1. Would the model changes result in any significant risk changes?

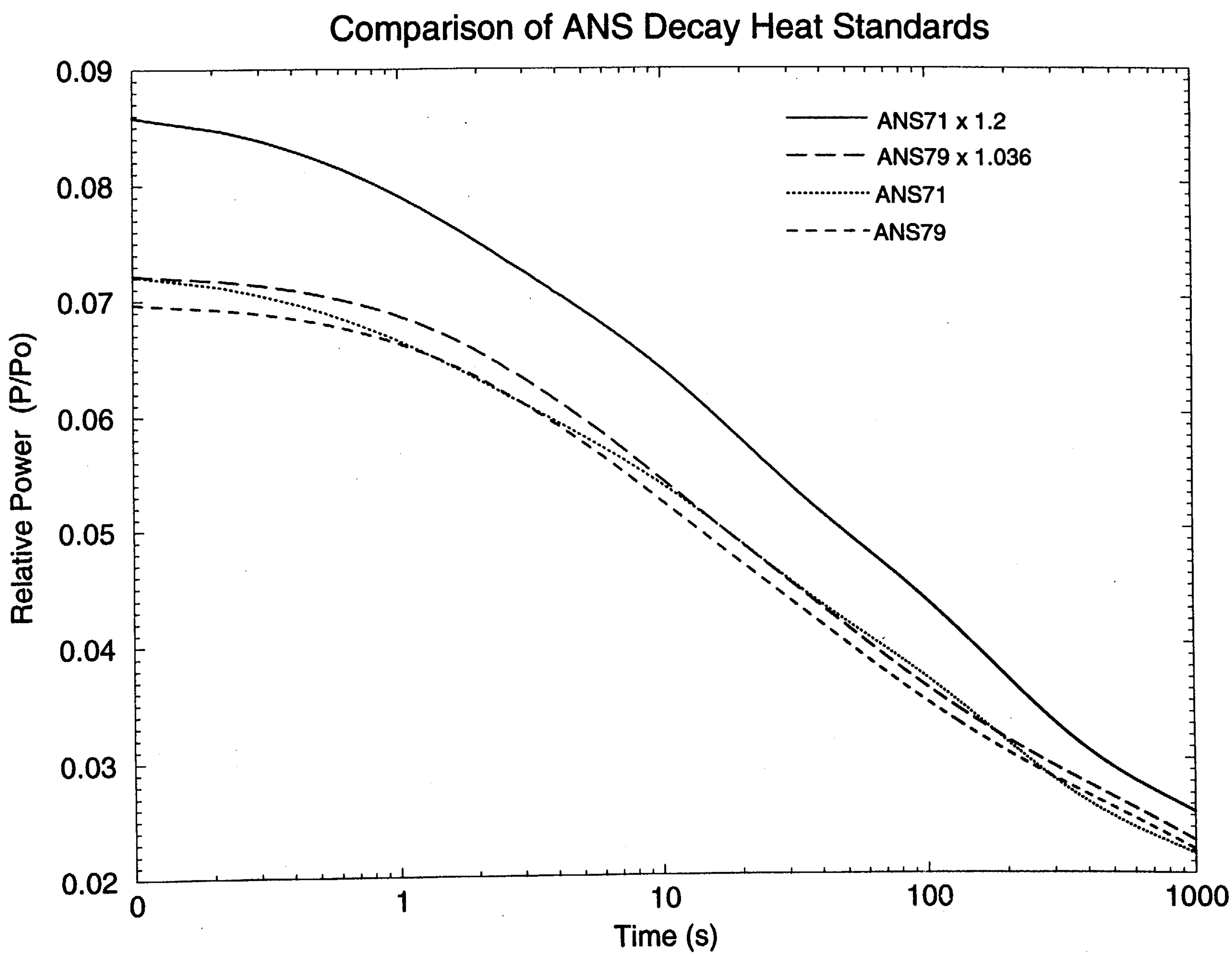
  2. What is the reduction in margin associated with separate or combined model changes?

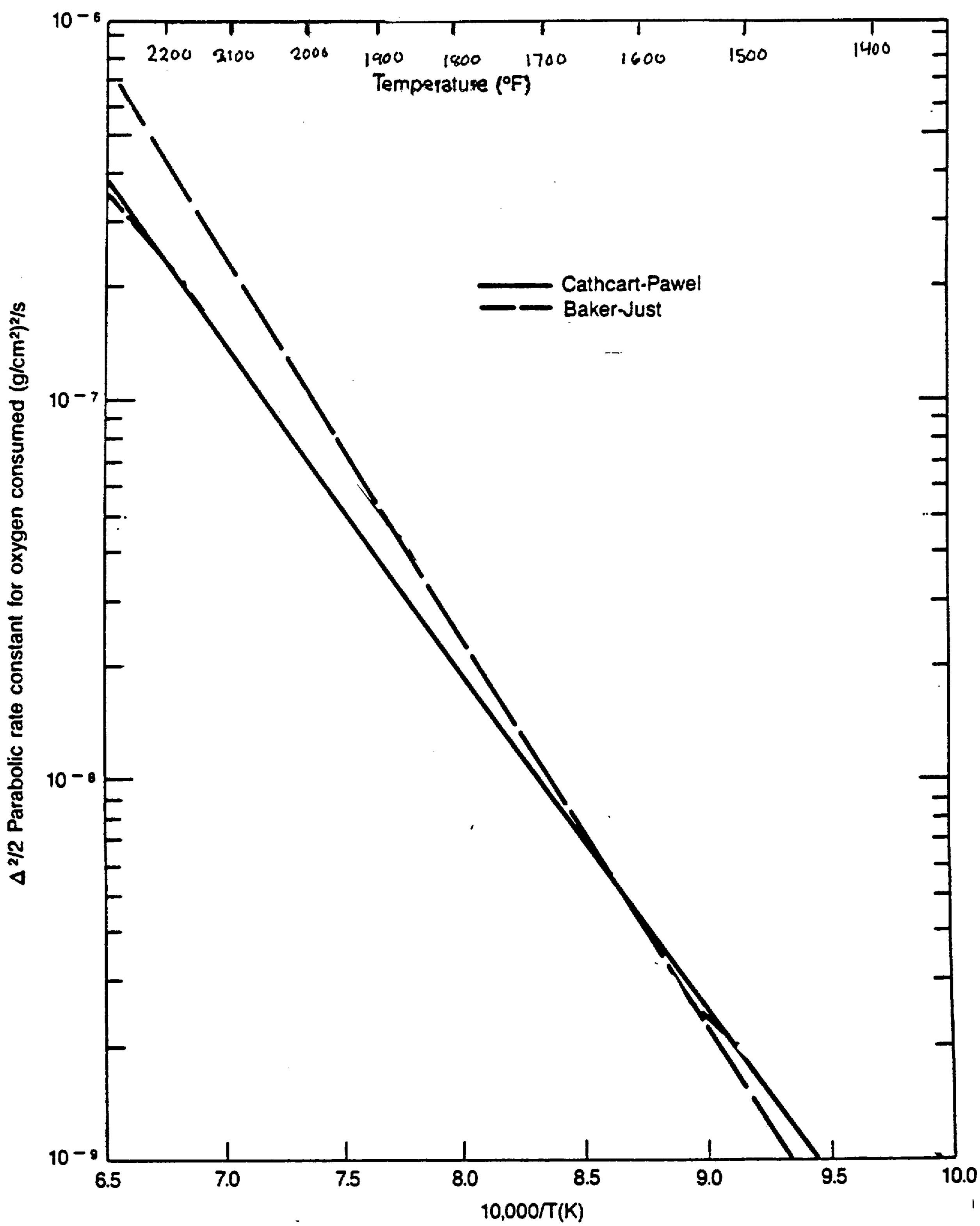
  3. What is the retained conservatism as a result of the changes?

- Any modification to Appendix K would select a simple decay heat and/or metal water reaction model with an appropriate uncertainty for each model.

- NRC has chosen to evaluate the 1979 ANS decay heat standard and the Cathcart-Pawel metal water reaction model, since they are referenced as acceptable models in Reg. Guide 1.157 (Best Estimate Calculations of ECCS Performance,1989).

- Other decay heat and metal water models would be possible candidates, but they are similar in magnitude to the selected models.


Comparison of ANS Decay Heat Standards
ANS71 x 1.2
ANS79 x 1.036
ANS71
ANS79
Relative Power (P/Po)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0
1
10
100
1000
Time (s)



Δ 2/2 Parabolic rate constant for oxygen consumed (g/cm²)²/s
10 − 6
10 − 7
10 − 8
10 − 9
2200
2100
2006
1900
1800
1700
1600
1500
1400
Temperature (°F)
Cathcart-Pawel
Baker-Just
6.5
7.0
7.5
8.0
8.5
9.0
9.5
10.0
10,000/T(K)

MARGIN REDUCTION AND RETAINED COSERVATISM

- In order to evaluate the margin reduction and retained conservatism of using more realistic models, RES will utilize existing information or perform analyses. For a sufficient sampling of plant types the information will include:

  1. A current Appendix K calculation,

  2. One or more Appendix K calculations using the more realistic decay heat and/or metal water models. Those models should include appropriate uncertainties, and

  3. A best estimate calculation that meets the requirements for the realistic option of 50.46.

- The difference in results between 1 and 2 is a measure of margin reduction.

- The difference in results between 2 and 3 is a measure of retained conservatism.

- Some additional analyses will also be performed to estimate the increase in thermal power available by utilizing more realistic decay heat and metal water reaction models.

MARGIN REDUCTION AND RETAINED CONSERVATISM (CONTINUED)

- RES is accumulating as many existing analyses of the three types mentioned above as possible. Where there are gaps we are supplementing the existing information with our own analyses.

- RES would greatly appreciate any information that industry could provide to facilitate this effort.

- Our schedule is to complete this work by August 31, 2000.