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DATE OF MEETING
06/28/2002

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Docket Number(s)	N/A
Plant/Facility Name	N/A
TAC Number(s) (if available)	
Reference Meeting Notice	ML021690520
Purpose of Meeting (copy from meeting notice)	NOTICE OF PUBLIC MEETING WITH INTERESTED STAKEHOLD REGARDING POTENTIAL CHANGES TO 10 CFR 50.46 AND OTHER ML021720744 pkg # for Research Information Letter

NAME OF PERSON WHO ISSUED MEETING NOTICE	TITLE
Ralph Meyer	Sr Tech Advisor

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DF03

Meeting with Stakeholders Regarding Potential Changes to 50.46 Criteria and Evaluation Model Requirements

June 28, 2002
Two White Flint T-7 A1

AGENDA

9:00 Meeting Opening and Introduction (S. Bajorek)

9:15 10 CFR 50.46 Acceptance Criteria (R. Meyer)

9:40 Use of the 1994 Decay Heat Model (N. Lauben)

10:00 Evaluation Model Requirements (S. Bajorek)

10:30 Public Comment & Discussion

12:00 Adjourn

ATTENDANCE SHEET

Subject: Potential Changes to 10 CFR 50.46/Appendix K

Location: Rockville, MD

Date: June 28, 2002

Name (print)	Title (print)	Telephone	Organization Affiliation (print)
Alan Kuritzky	Sr. Rel. and Risk Eng.	(301) 415-6255	NRC/RES/DRAA/PRAB
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Norm Lauben	Sr. Nuclear Eng.	301 415-6762	NRC/RES/SMSAB
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Deann Raleigh	LIS Client Mgr	240 626 1556	LIS, Scientech
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Samuel Lee	Proj. Mgr.	301 415-1061	NRR/RPRP
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Ralph Meyer	Sr Tech. Advisor	301-415-6789	NRC/RES
Jack Rosenthal	Branch Chief, RES	301 415 7497	RES/DSARE/SMSAB
Tony Pietrangelo	Dir, Nuc Gen	202 739 8081	NEI
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Mahmoud MASSOUD	Consulting Engineer	410-495-6522	Calvert Cliff NPP
Adrian Heymer	Project Mgr	202-739-8094	NEI
Elaine Hiruo	MEDIA	202-383-2163	Platts nuclear pubs.
Whee Choe	Safety Analysis Mgr.	214-812-4371	TXU Energy
Chris Grimes	Program Director	301-415-1184	NRC/NRR

Name (print)	Title (print)	Telephone	Organization Affiliation (print)
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Gregg Max	Senior Engineer	(860) 731 6453	Westinghouse/CEOG
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James F. Mallay	Dir., Reg. Affairs	434-832-2981	FRAMATOME ANP

Risk-Informed Revision of 10 CFR 50.46 Acceptance Criteria and ECCS Evaluation Model Requirements (Appendix K)

Public Meeting with Stakeholders

June 28, 2002

Stephen M. Bajorek, G. Norman Lauben, Ralph O. Meyer
Safety Margins and Systems Analysis Branch
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

OBJECTIVES

1. Summarize findings in Research Information Letter 0202.

2. Obtain comment & feedback from stakeholders.

BACKGROUND

SECY-01-133 states:

"The staff recommends that rulemaking should be undertaken to change the current 50.46. ....

....

..... In the near term, this revision would involve an update of Appendix K requirements based on more current and realistic information. ....

As part of this update, the staff will also consider the recognized non-conservatisms and model limitations to insure that proper safety focus is incorporated in any new rule.

.......; in summary, the staff will undertake work to:

support removal of unnecessary conservatisms from Appendix K."

The principal focus of this effort has been on:

1. Replacement of the Appendix K requirement to use 1.2 X 1971 ANS decay heat standard with a requirement based on the 1994 ANS decay heat standard.

2. Determining the impact of decay heat & metal-water reaction rate models and effect of accounting for non-conservatisms in existing Appendix K evaluation models.

- **Staff efforts have been in three areas:**

  - **Reviewing basis of exising 10 CFR 50.46 acceptance criteria for:**

    Peak Cladding Temperature (< 2200 ^{o}F),
    Maximum Cladding Oxidation (< 17% of total cladding thickness before oxidation)

  - **Reviewing 1994 Decay Heat Standard for incorporation into Appendix K, and feasibility of revising criteria related to Metal-Water Reaction, Steam Cooling, and Return to Nucleate Boiling During Blowdown**

  - **Evaluating known conservatisms and non-conservatisms in Appendix K EMs**

Outline: Recommendations to be Presented

1. Revise the 10 CFR 50.46 acceptance criteria for PCT and ECR to be "performance-based".

2. Replace 1971 ANS Decay Heat Standard with 1994 Standard

3. Replace the Baker-Just correlation with Cathcart-Pawel for metal-water reaction heat release.

4. Delete the requirement for steam cooling only at reflood rates below 1 inch/sec.

5. Retain the prohibition on assuming a return to nucleate boiling during blowdown.

6. Require that the new Evaluation Models to demonstrate sufficient overall conservatism and that they account for several identified non-conservatisms.

United States Nuclear Regulatory Commission

ACCEPTANCE CRITERIA
AND
METAL-WATER REACTION CORRELATIONS

Ralph Meyer
Office of Nuclear Regulatory Research

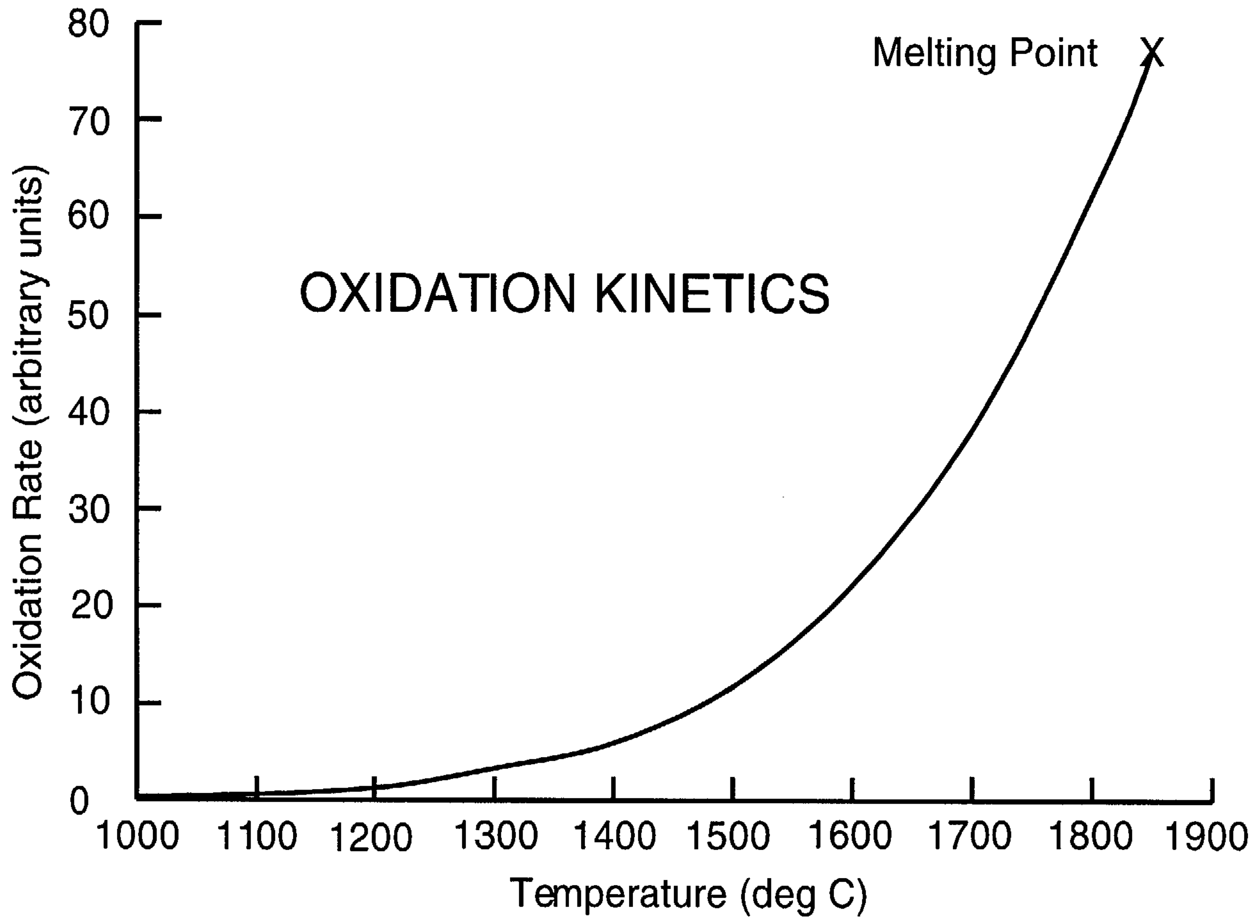
Public Meeting
June 28, 2002

ORIGIN OF PEAK CLADDING TEMPERATURE LIMIT

- Comes from temperature at which 17% ECR limit breaks down
- There was a second consideration related to runaway temperature escalation

STATEMENT ON TEMPERATURE LIMITS FROM 1973 HEARING

Westinghouse proposed a maximum calculated temperature limit of at least 2700°F; Combustion Engineering and the Utility Group agreed on 2500°F as the peak allowable calculated temperature on the basis that much of the data on oxidation and its effects stops at 2500°F. Babcock and Wilcox suggested a more conservative 2400°F as the peak calculated temperature to be allowed, presumably because "significant eutectic reaction and an excessive metal-to-water reaction rate would be precluded below 2400°F." General Electric argued strongly that the limit should not be reduced to 2200°F; that 2700°F is really all right as far as embrittlement is concerned, but that the Interim Acceptance Criterion value of 2300°F should be retained. In addition to being consistent with their expressed desire not to change any of the criteria, the GE recommendation of retaining the 2300°F limit is intended to ensure that the core never "gets into regions where the metal-water reaction becomes a serious concern." (Ref. 1, p. 1097)


OXIDATION KINETICS
Melting Point X
Oxidation Rate (arbitrary units)
0
10
20
30
40
50
60
70
80
1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
Temperature (deg C)

HEAT GENERATION RATE

- When reaction heat becomes a significant part of total, positive feedback may cause runaway

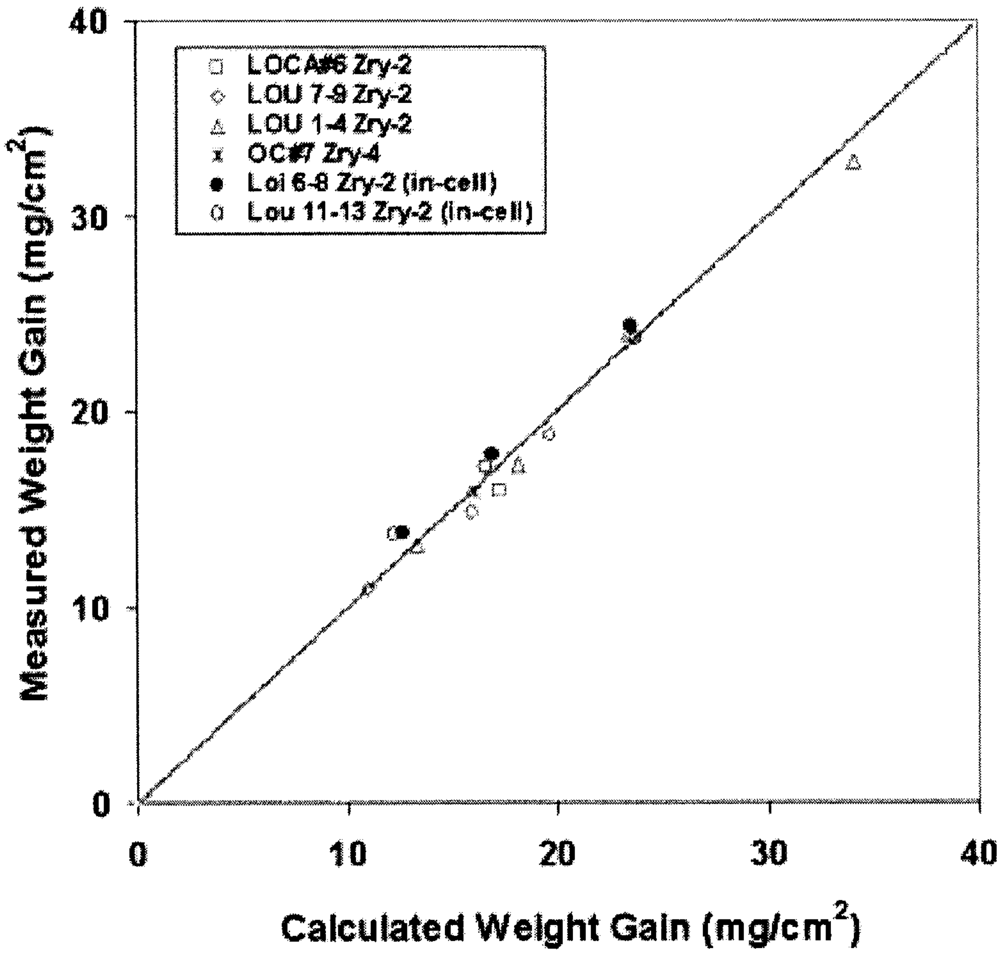
$$\text{Heat Rate}_{B\text{-}J}(2200°F) = \text{Heat Rate}_{C\text{-}P}(2307°F)$$

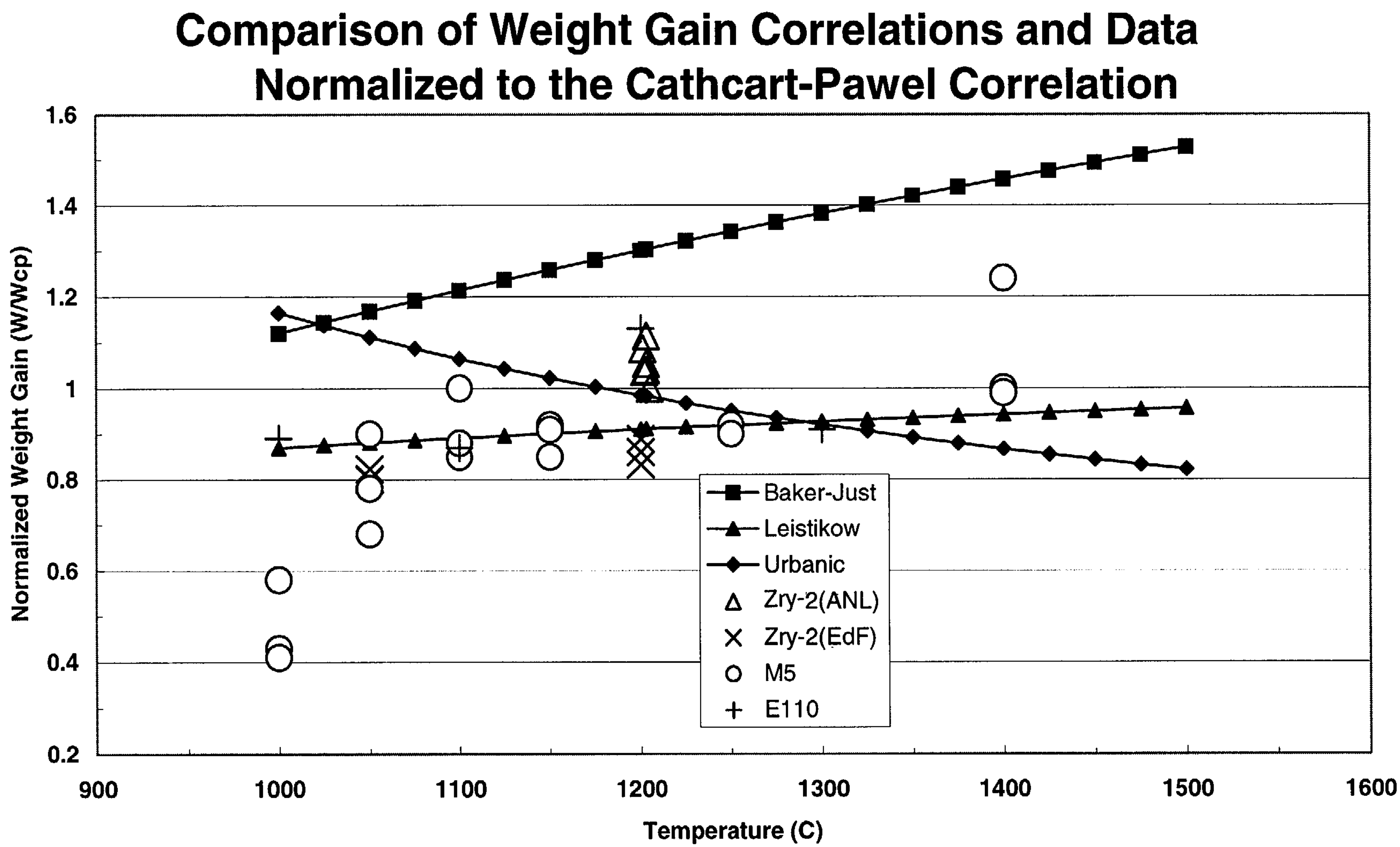
- Because Cathcart-Pawel is accurate, PCT could be increased to 2300°F with same margin to runaway as perceived in 1973

HIGH-TEMPERATURE OXIDATION MEASUREMENTS
(Approximately the same rate around 2200°F)

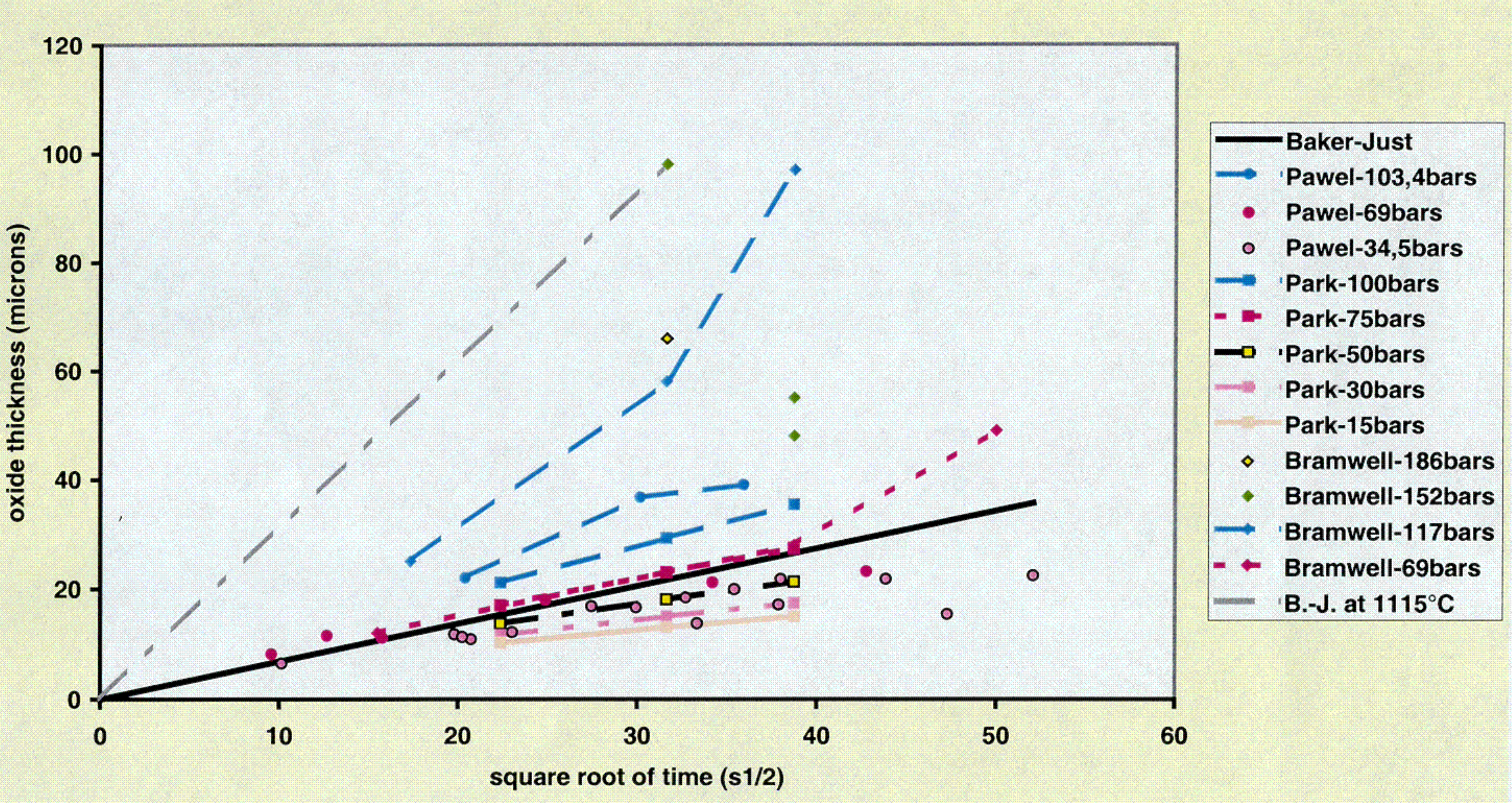
Investigators	Metal
Baker and Just	Zr
Lemmon	Zr
White	Valoy (Zr-1.3Cr-0.1Fe)
Urbanic	Zircaloy-2, Zircaloy-4, Zr-2.5Nb
Cathcart et al.	Zircaloy-4
Chung and Kassner	Zircaloy-4
Grandjean et al.	Zircaloy-4
Yan et al.	Zircaloy-2
Waeckel and Jacques	Zircaloy-2
Le Bourhis	M5
Leech	ZIRLO
Yegorova et al.	E110 (Zr-1Nb)

Cathcart-Pawel model predictions vs. weight gain data for unirradiated Zry-2 and Zry-4 and high-burnup Zry-2 (Loi 6-8) exposed to steam for 5-40 min. at ≈1200°C




Comparison of Weight Gain Correlations and Data
Normalized to the Cathcart-Pawel Correlation
Normalized Weight Gain (W/Wcp)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
900
1000
1100
1200
1300
1400
1500
1600
Temperature (C)
Baker-Just
Leistikow
Urbanic
Zry-2(ANL)
Zry-2(EdF)
M5
E110

Zry - oxide thickness at 900°C as a function of square root of time and steam pressure

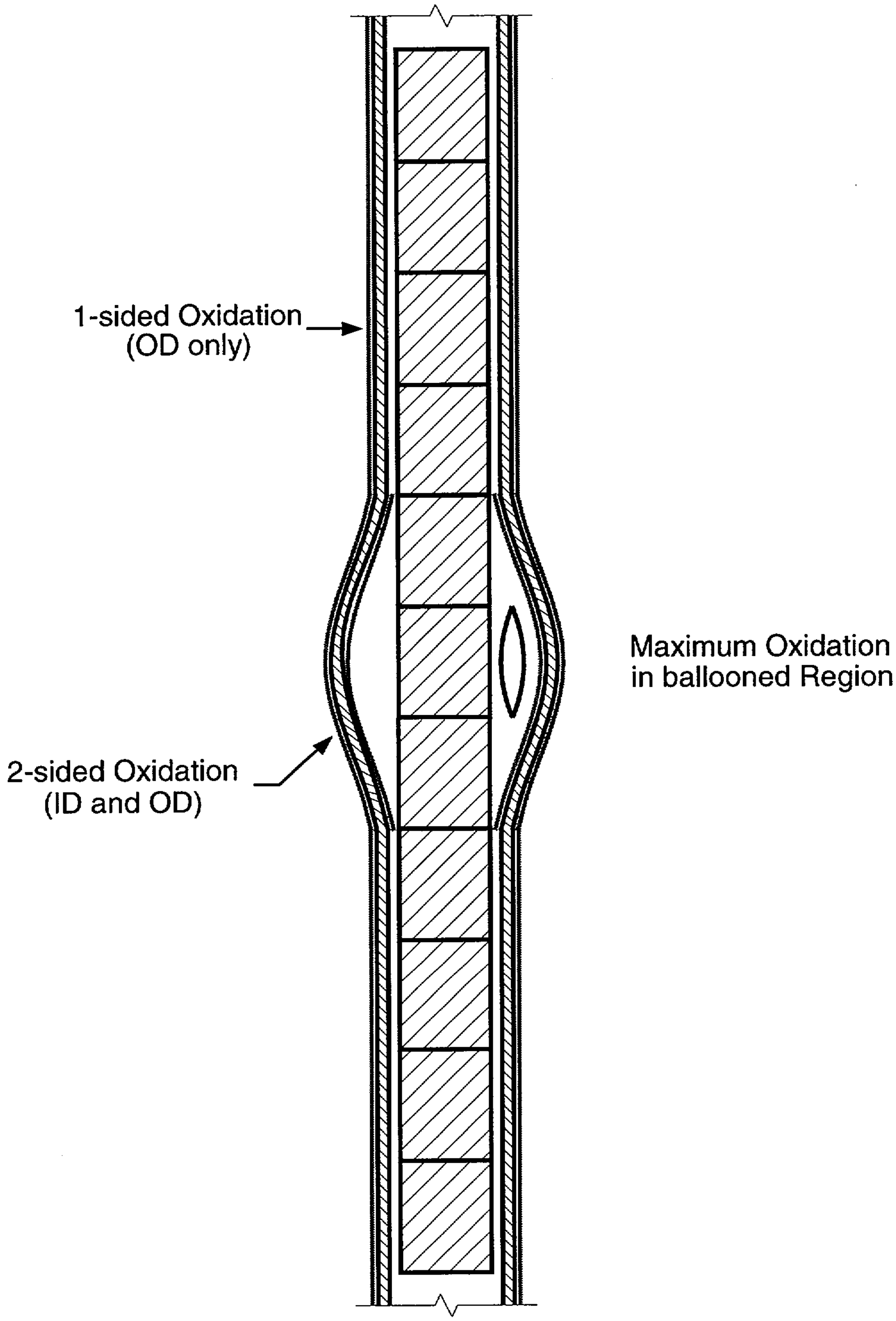


C01

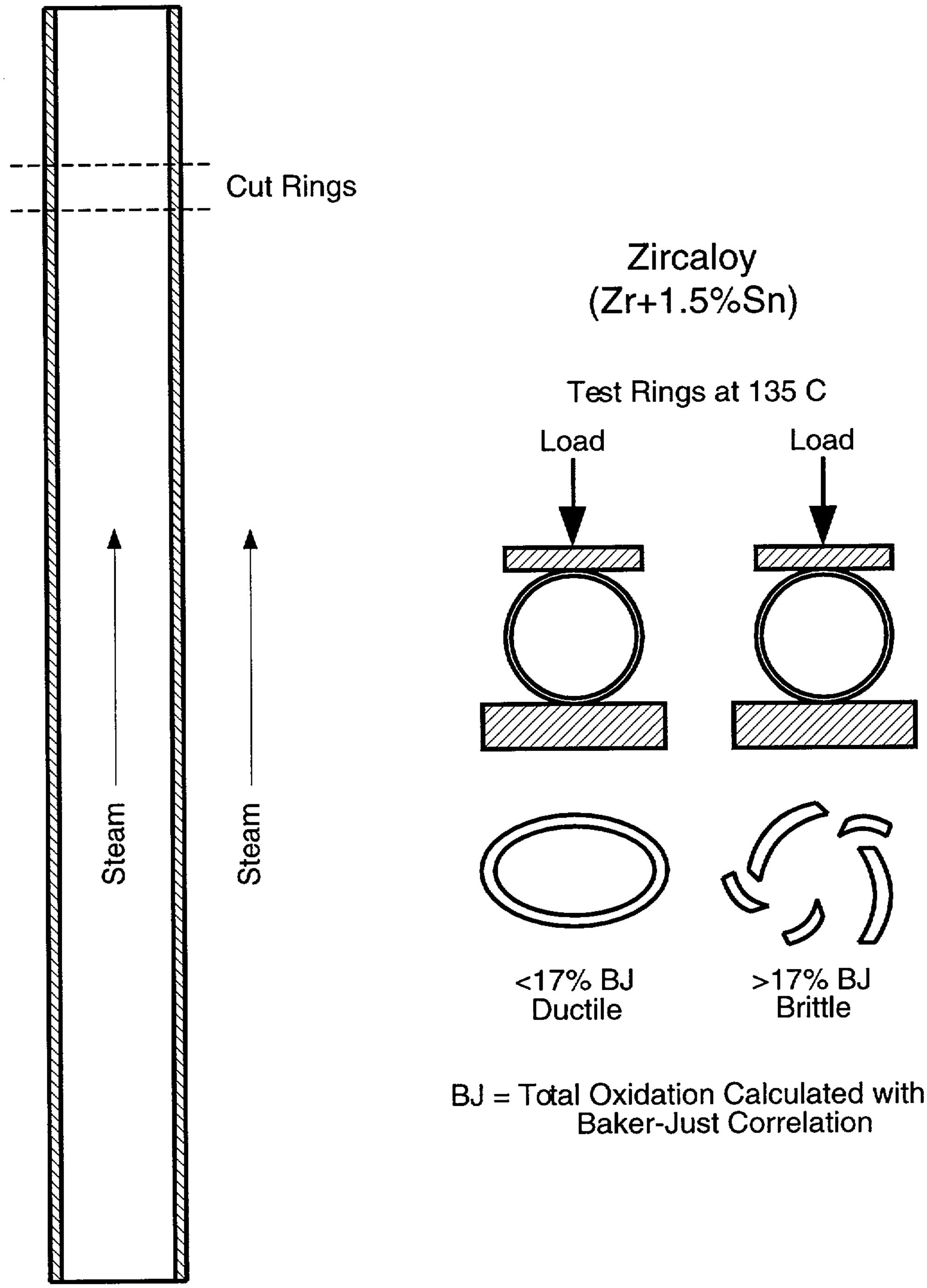
THERMAL SHOCK TESTS

Not adequate according to U.S. AEC Commissioners in 1973

"Our selection of the 2200°F limit results primarily from our belief that retention of ductility in the zircaloy is the best guarantee of its remaining intact during the hypothetical LOCA. The stress calculations, the measurements of strength and flexibility of oxidized rods, and the thermal shock tests all are reassuring, but their use for licensing purposes would involve an assumption of knowledge of the detailed process taking place in the core during a LOCA that we do not believe is justified."

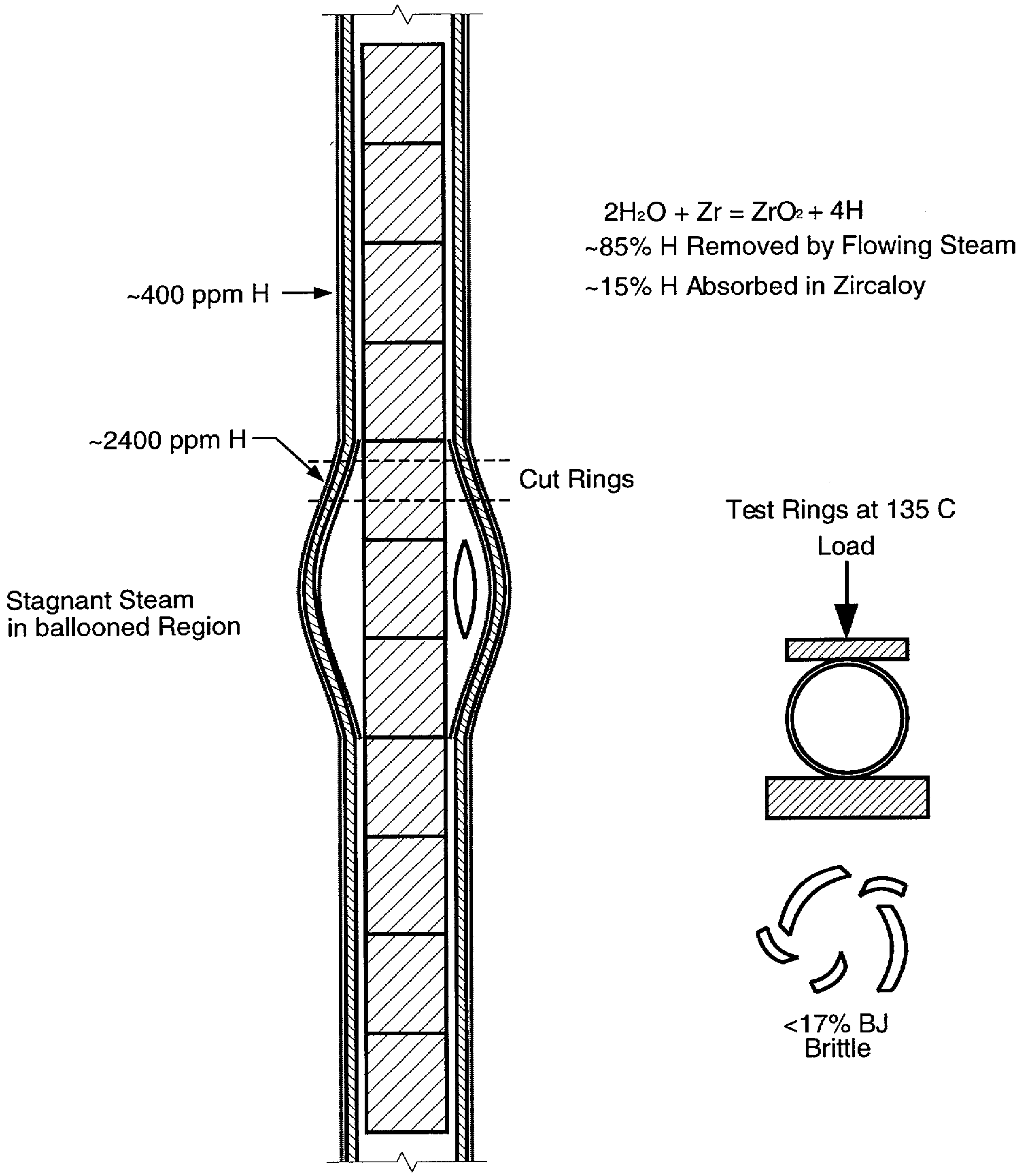


Significant Oxidation 1000 - 1200 C
(2200 F = 1204 C)

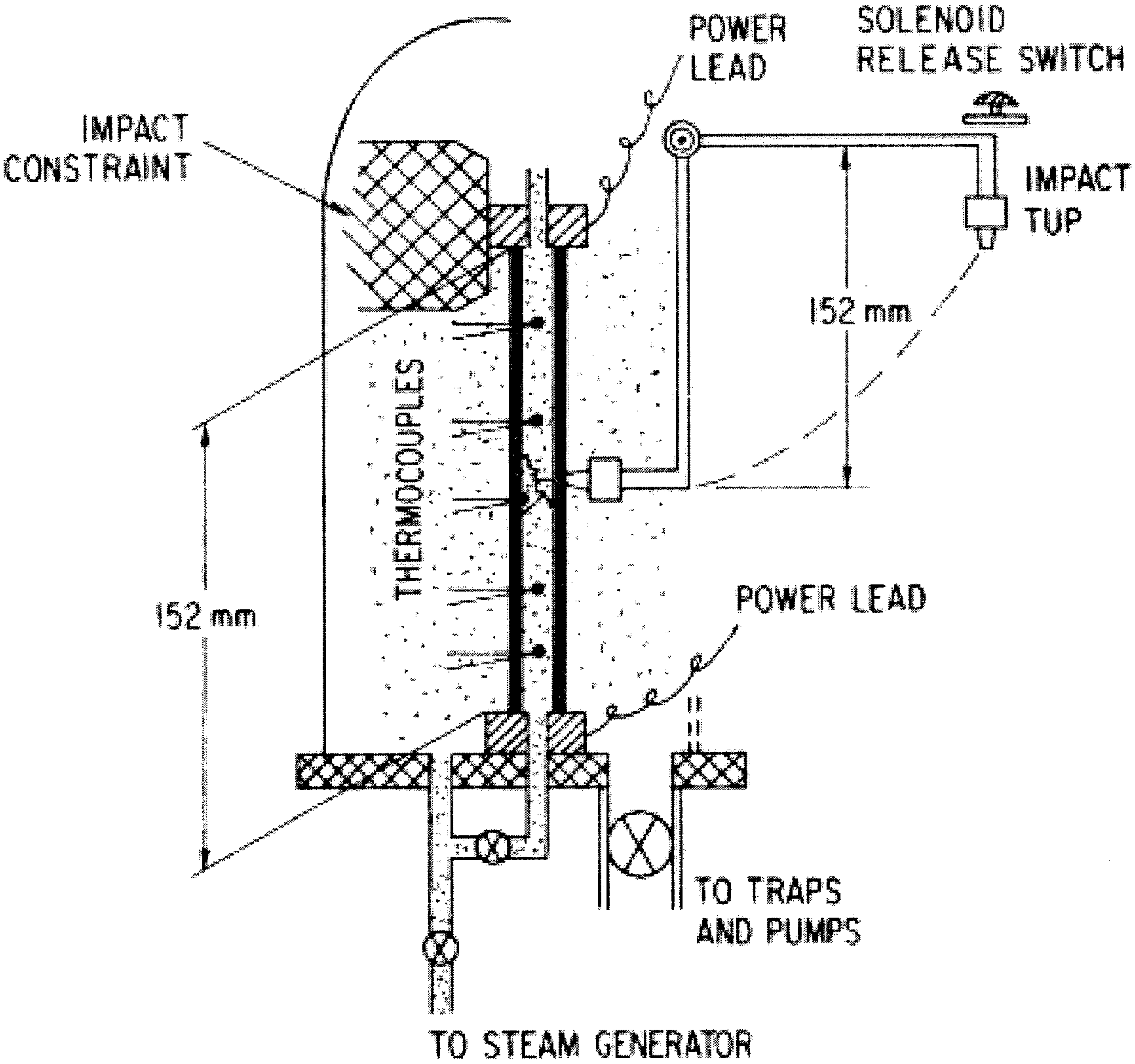


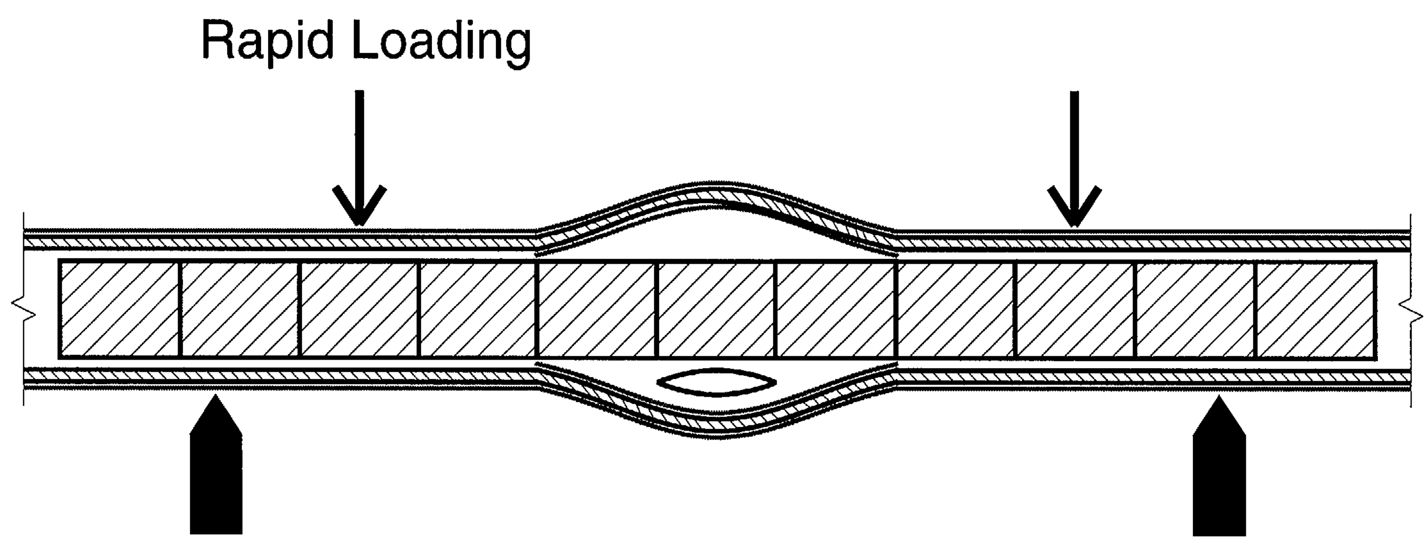
Oxidize at 1000 - 1200 C

BJ = Total Oxidation Calculated with
Baker-Just Correlation



Hydrogen Effect Discovered ~1980


POWER LEAD
SOLENOID RELEASE SWITCH
IMPACT CONSTRAINT
IMPACT TUP
152 mm
THERMOCOUPLES
152 mm
POWER LEAD
TO TRAPS AND PUMPS
TO STEAM GENERATOR



4-Point Bend Test

CONCLUSIONS

- New PCT and ECR limits can be derived from mechanical property tests for all burnups and different alloys
- Simple ductility test (ring compression) may be adequate, as shown for unirradiated Zircaloy
- Confirmation of ductility test to be investigated with 4-point bend test
- PCT should not exceed 2300°F to retain margin to avoid runaway temperatures
- Cathcart-Pawel may work adequately for all alloys and burnups (TBD) provided pressure enhancement is added for SBLOCA analysis

Decay Heat Changes to 50.46 and Appendix K

Meeting with Stakeholders Regarding Potential Changes to 50.46 Criteria and Evaluation Model Requirements

June 28, 2002

G. Norman Lauben
Safety Margins and Systems Analysis Branch
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

THE 1994 ANS DECAY HEAT STANDARD

- The decay heat requirements in Appendix K and the best estimate guidance in Regulatory Guide 1.157 could be replaced with requirements and guidance based on the 1994 ANS decay heat standard.

- The Appendix K option in 50.46 currently requires fission product decay heat be modeled using the draft 1971 ANS standard with a multiplier of 1.2 and the assumption of infinite irradiation. A separate paragraph in Appendix K requires consideration of Actinide decay heat.

  - An alternative would permit the use of the 1994 ANS decay heat standard, which involves more sophisticated uncertainty methods and a greater number of options left to the user.

  - The 1994 ANS standard considers more recent available data and methods.

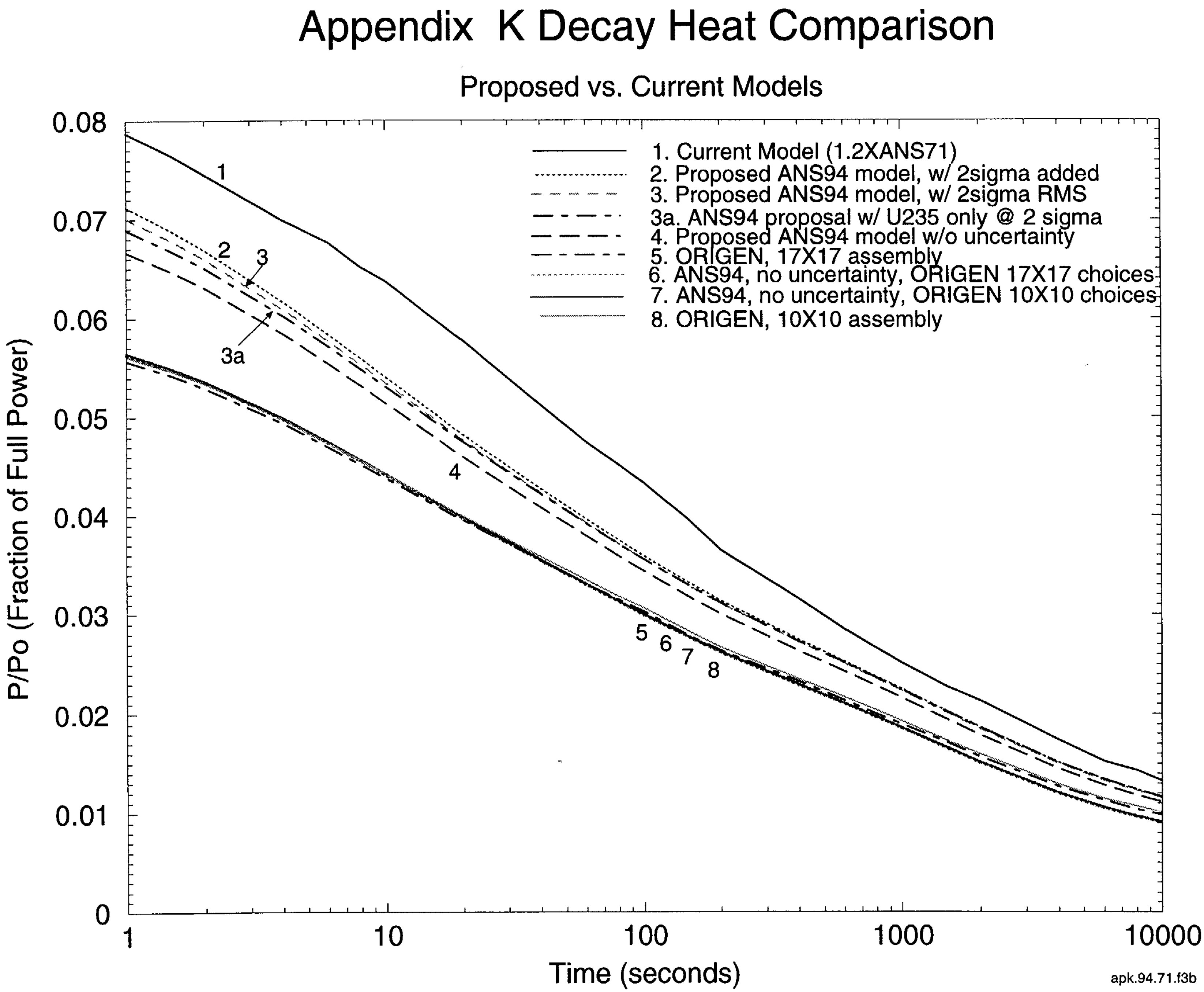
  - Model options in the 1994 standard have been identified and studied.

- The performance based realistic evaluation model option in 50.46 would allow use of the 1994 standard today. Specification of the 1994 standard as an acceptable method in Regulatory Guide 1.157 would facilitate its use.

ASSUMPTIONS FOR NINE DIFFERENT DECAY HEAT CALCULATIONS

Case No.	Model	Multiplier	Operating Time	Fiss. Fractions	Capture Time (Sec.)	Ψ	Fission Energy MeV/f.	Actinide Yield	Isotope Tables	Isotopic Uncertainties
				Current Appendix K						
1	ANS73	1.2	∞	100% ^{235}U	N/A	N/A	N/A	0.7	N/A	N/A
				Appendix K Proposals						
2	ANS94	2σ,add	∞	Note 3	2.e8	1.0	200	0.7	Note 7	Note 8
3	ANS94	2σ,RMS	∞	Note 3	2.e8	1.0	200	0.7	Note 7	Note 8
3a	ANS94	2σ	∞	100% ^{235}U	2.e8	1.0	200	0.7	Note 7	Note 9
4	ANS94	mean	∞	Note 3	2.e8	1.0	200	0.7	Note 7	N/A
				Best Estimate						
5	ORIGEN[1]	mean	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	N/A
6	ANS94	mean	ORIGEN[5]	Note 4	1.2e8[5]	1.0	ORIGEN[5]	.514[5]	Note 7	N/A
7	ANS94	mean	ORIGEN[6]	Note 4	1.2e8[6]	1.0	ORIGEN[6]	.508[6]	Note 7	N/A
8	ORIGEN[2]	mean	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	Calc.	N/A

Note 1 17X17 PWR assembly
Note 2 10X10 BWR assembly
Note 3 Assumes fissioning fractions are 90% ^{235}U and 10% ^{238}U
Note 4 Cycle average values from ORIGEN calculations for four isotopes
Note 5 From 17X17 PWR ORIGEN calculation
Note 6 From 10X10 BWR ORIGEN calculation
Note 7 23 decay group exponential fits for F(t,∞) in ANS94 standard
Note 8 Used curve fits from Figures 1 and 2
Note 9 Used curve fit from Figure 1


Appendix K Decay Heat Comparison
Proposed vs. Current Models
1. Current Model (1.2XANS71)
2. Proposed ANS94 model, w/ 2sigma added
3. Proposed ANS94 model, w/ 2sigma RMS
3a. ANS94 proposal w/ U235 only @ 2 sigma
4. Proposed ANS94 model w/o uncertainty
5. ORIGEN, 17X17 assembly
6. ANS94, no uncertainty, ORIGEN 17X17 choices
7. ANS94, no uncertainty, ORIGEN 10X10 choices
8. ORIGEN, 10X10 assembly
P/Po (Fraction of Full Power)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
10
100
1000
10000
Time (seconds)
1
2
3
3a
4
5
6
7
8
apk.94.71.f3b

ANS94 DECAY HEAT FEATURES & COMPARISONS

1. Standard fission product decay heat tables and individual uncertainties are OK-

   A. Requires lattice physics calculation to determine time and space dependent fissioning istopic fractions. *ORIGEN values vs. 100% ^{235}U ≅ 6% effect*

   B. Operating time *ORIGEN 3 cycle assumption vs. ∞ ≅ 2% effect*

2. Recoverable fission energy, Q_i *ORIGEN values vs. 200 MeV/fission ≅ 4% effect*
   (ANS94 future recommendation - Specify Q_i)

3. Uncertainty *ORIGEN (none) vs. 2σ for 100% ^{235}U ≅ 4% effect*

4. Fission product neutron capture - Standard uses 25 year old "correlation". May be non-conservative between 4000 and 10,000 seconds. Becomes conservative using tabular "G" values after that. (ANS94 future recommendation - Improve Specification)

5. Actinides -

   A. ^{239}U & ^{239}Np decay - ^{239}U production/fission
      ORIGEN value vs. 0.7 ≅ 3% effect

   B. Actinides that are not explicitly considered in ANS standard
      ORIGEN calculation vs. no consideration

Shutdown time(sec)	*220*	*1800*	*6000*
Effect	*-2%*	*-3%*	*-4%*

   (ANS94 future recommendation - Include other actinides)

6. Increment from NRC Appendix K ANS94 recommendations to 1.2XANS71 ≅ 10-20%

SUGGESTIONS/RECOMMENDATIONS

- "Grandfather" the current Appendix K decay heat requirements.

- Add an Appendix K option to use the 1994 ANS standard with pre-selected "choices" (probably in a regulatory guide.)

- Choices which are equivalent to Case 3a are:

  1. Assume ^{235}U is the only fissioning isotope.
  2. Assume infinite operating time.
  3. Assume 200 MEV/fission recoverable energy.
  4. Use Equation 11 in the standard for neutron capture effect for shutdown times less than 10^4 seconds. Use 2.e8 seconds operating time for this equation. Use 1.0 as the value for Ψ.
  5. Use Table 13 in the standard for neutron capture for shutdown times greater than or equal to 10^4 seconds.
  6. Apply Section 4 in the standard for the decay heat contribution for ^{239}U and ^{239}Pu. Use a value of 0.7 for R.
  7. Use a 2σ value of uncertainty for ^{235}U. Along with options 1 and 2, this obviates the need to consider methods to combine uncertainties.

- Use of the new Appendix K option would be subject to a model review as required in 50.46. A model review is prudent to assure retention of sufficient remaining conservatism in any revised Appendix K model in which a substantial amount of conservatism has been removed. This subject is discussed in more detail by Steve Bajorek.

- Allow use of the 1994 ANS standard in best estimate Reg. Guide 1.157

Risk-Informed Revision of ECCS Evaluation Model Requirements (Appendix K)

Public Meeting with Stakeholders

June 28, 2002

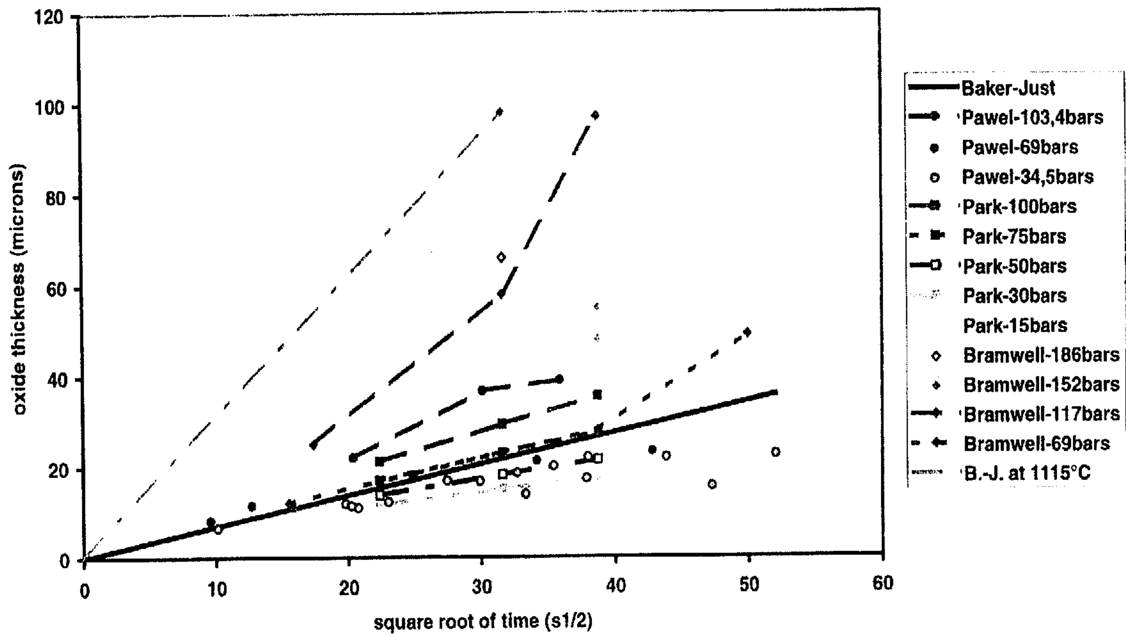
Stephen M. Bajorek
Safety Margins and Systems Analysis Branch
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research

Appendix K Modeling Requirements
Metal-Reaction Heat Release

- Original rulemaking assumed Baker-Just was conservative at 2000 ^{0}F, but was approximately correct at 2200 ^{0}F.
- Baker-Just equation based on pure Zr data - not alloys. Review of more recent data covering several different Zr based alloys shows low experimental data scatter and good agreement with Cathcart-Pawel.
- All Zr-based alloys exhibit about the same oxidation kinetics. Reason: Dominant rate-controlling step at high temperatures is diffusion of oxygen through ZrO_2 surface layer.

Recommendation:

The Baker-Just correlation for exothermic heat release can be replaced with the Cathcart-Pawel correlation or suitable realistic correlation shown applicable to a specific alloy. An adjustment to Cathcart-Pawel or other correlation is necessary if used at high pressure.



- Experimental data however, exhibits enhanced oxidation rates at high pressure. Cathcart-Pawel correlation is non-conservative for heat release at high pressure.

Appendix K Modeling Requirements
Steam Cooling Below 1 inch/sec

- Paragraph I.D.5.b. of Appendix K states that:

"During refill and during reflood when reflood rates are less than one inch per second, heat transfer calculations shall be based on the assumption that cooling is only by steam, ...

- Experimental data from FLECHT series of tests demonstrated high rates of entrainment & carryover, even for VIN < 1 ips.

Recommendation:

Delete the requirement for steam cooling only at reflood rates below 1 inch/sec.

Appendix K Modeling Requirements
Return to Nucleate Boiling During Blowdown

- Paragraph I.C.4.e. in Appendix K prohibits the return to nucleate boiling heat transfer even if the fluid and surface conditions apparently justify the return.

- Rewet during blowdown supported by LOFT experiments. However, overall database demonstrating blowdown rewet is sparse for Zr cladding and Tmin can be predicted only with very high uncertainty.

Recommendation:

Retain the prohibition on assuming a return to nucleate boiling during blowdown.

Appendix K "Non-Conservatisms"

Sources of potential non-conservatism:

1. Thermal-hydraulic processes and fuel behavior that have been observed in experimental programs since 1973, but are not specifically addressed by Appendix K .

2. Large calculational uncertainties that are on the order of the overall conservatism of the EM. This was a main concern of SECY-86-318, ("Revision of the ECCS Rule Contained in Appendix K and Section 50.46 of 10 CFR Part 50) which recommended that the Appendix K decay heat guidelines <u>not</u> be revised unless model uncertainties were accounted for.

Non-Conservative Processes Identified:

- ◆ Downcomer Boiling
- ◆ Reflood ECC (Downcomer) Bypass
- ◆ Fuel Relocation

◆ Downcomer Boiling

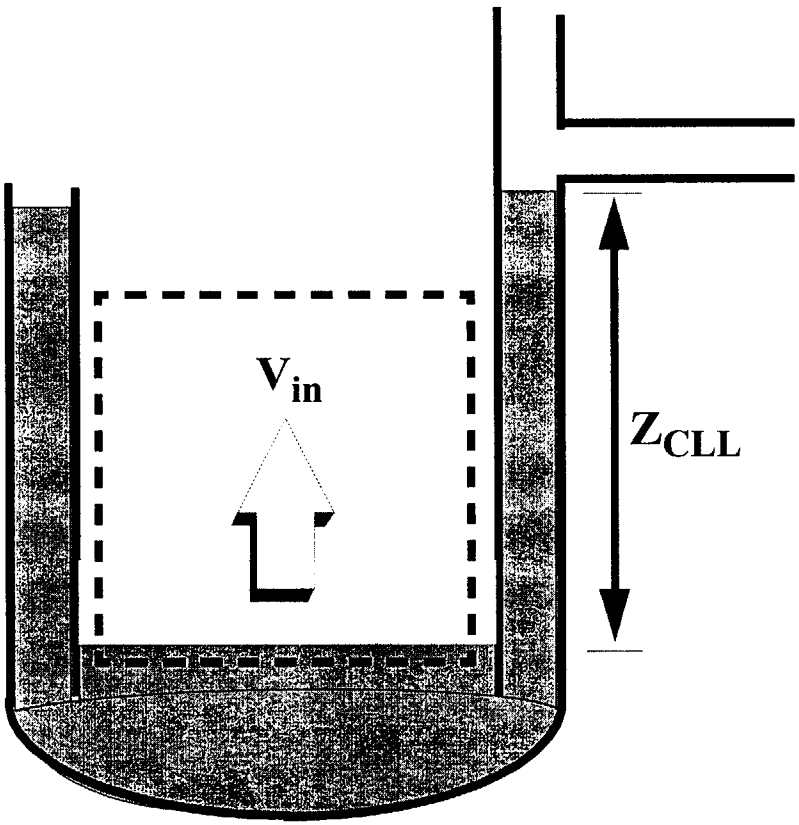
- Experimental data from several facilities, and simulations using "Best Estimate" thermal-hydraulic codes show that stored heat in vessel walls, core barrel and lower plenum structures can cause coolant in the downcomer to boil during reflood.

- Voiding in the downcomer can result in a significant reduction in downcomer head. This reduces the flooding rate and increases the PCT.

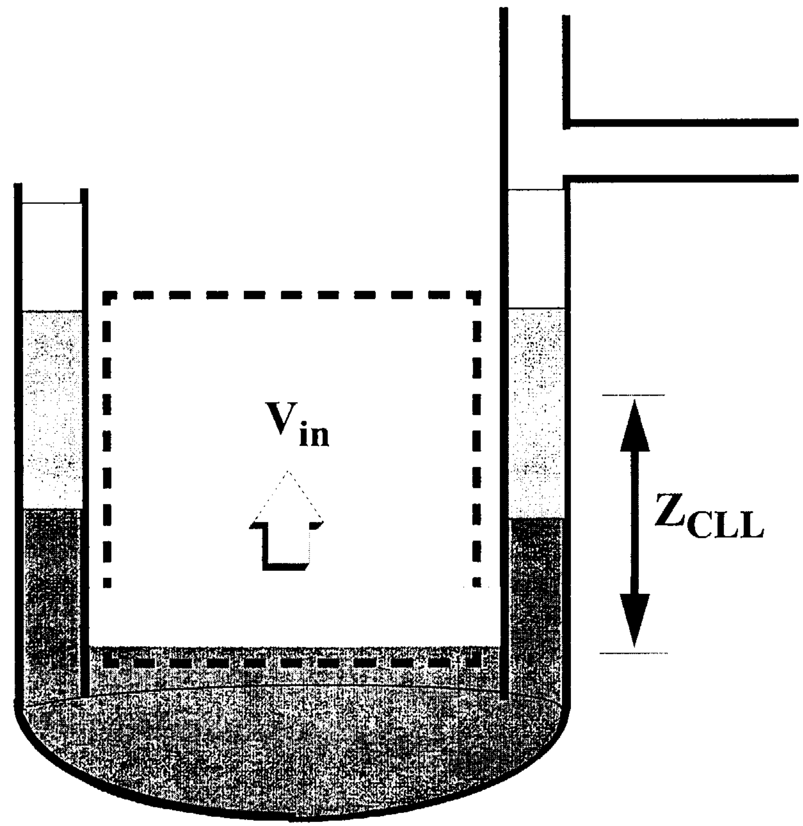
- PWR Appendix K reflood models do not model downcomer boiling. Yet, for at least some plants in all three PWR vendor designs, the existence of downcomer boiling has at least been acknowledged.

DOWNCOMER BOILING

Early in Reflood:
DC Fluid Subcooled

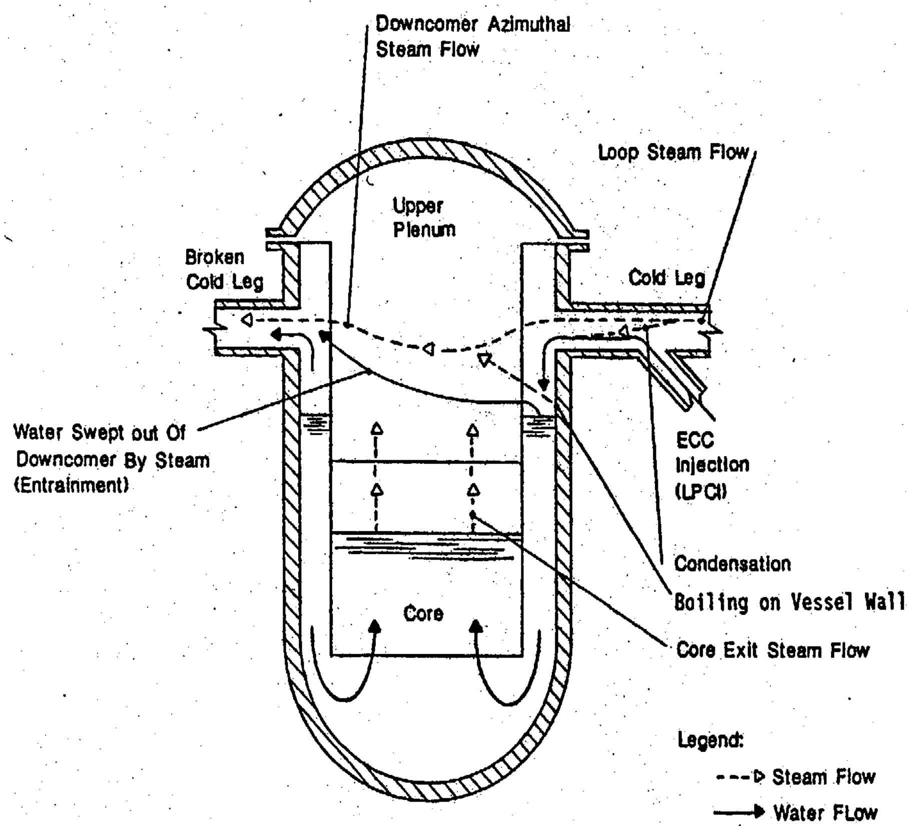


Late in Reflood:
Downcomer Boiling



Downcomer Boiling: Causes Net Loss of Driving Head & Reduces Reflood Rate

◆ Reflood ECC (Downcomer) Bypass



- Experimental tests in the full scale UPTF facility showed that steam from intact loops could entrain significant amounts of water from the downcomer during reflood.

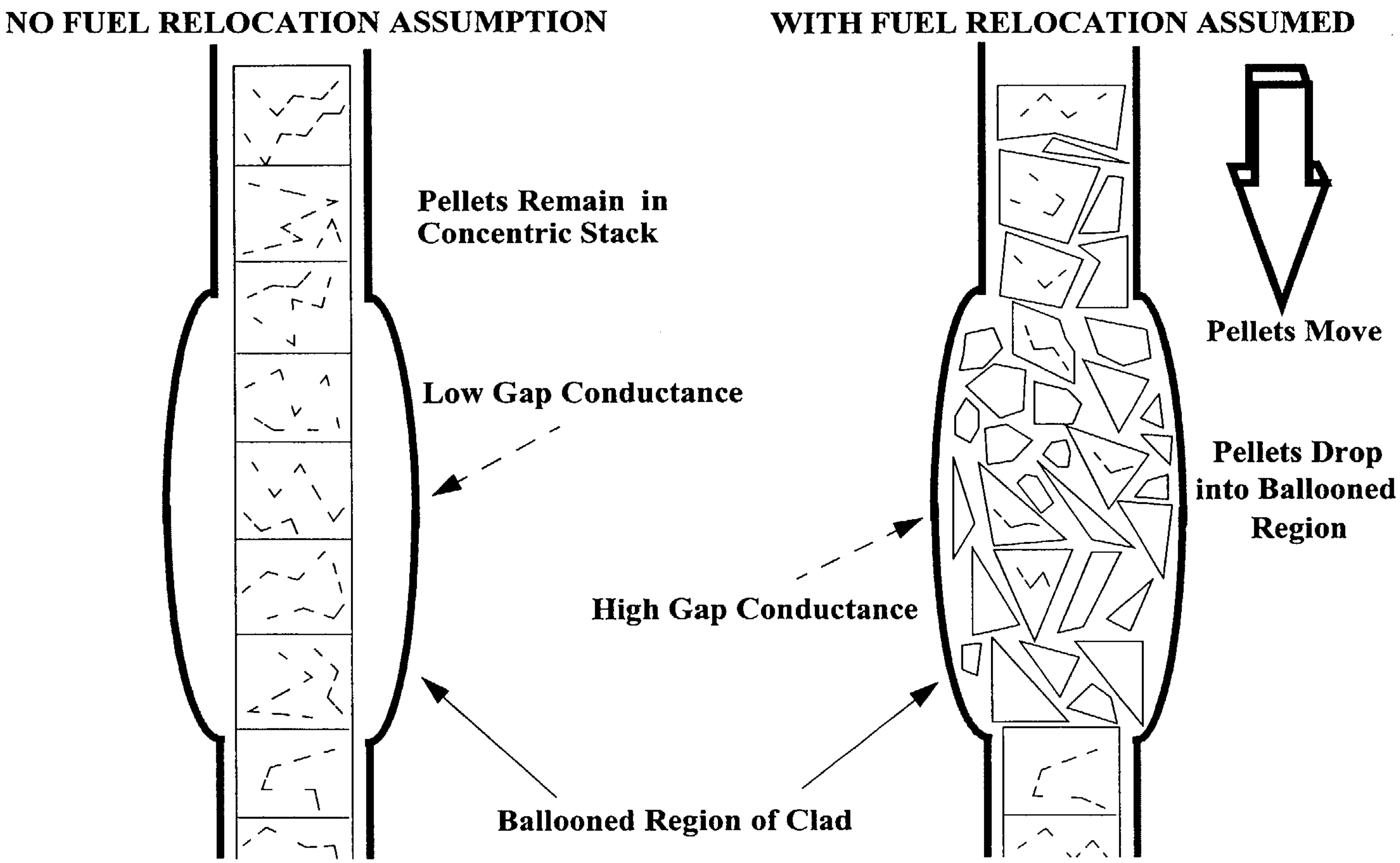
- High entrainment and carryover to the break reduced the downcomer water level and can result in a reduction in downcomer head. This reduces the flooding rate and increases the PCT.

- Process is a strong function of the downcomer water level and oscillations.

◆ Fuel Relocation

- Experiments in PBF-LOC, FR2 (Germany) and FLASH5 (France) showed significant fuel movement in regions where clad has ballooned.

- Relocation of additional fuel into ballooned region increases local power and increases conductance between pellets and clad.



Appendix K "Non-Conservatisms"

Recommendations:

A. Evaluation Models making use of a new, optional Appendix K should account for the non-conservatisms of downcomer boiling, downcomer ECC bypass, and fuel relocation.

B. These new Evaluation Models must demonstrate sufficient overall conservatism in their results.

Conclusions & Recommendations

1. Revise the 10 CFR 50.46 acceptance criteria for PCT and ECR to be "performance-based".
2. Replace 1971 ANS Decay Heat Standard with 1993 Standard
3. Replace the Baker-Just correlation with Cathcart-Pawel for metal-water reaction heat release.
4. Delete the requirement for steam cooling only at reflood rates below 1 inch/sec.
5. Retain the prohibition on assuming a return to nucleate boiling during blowdown.
6. Require that the new Evaluation Models to demonstrate sufficient overall conservatism and that they account for several identified non-conservatisms.