3-D Rod Ejection Methodology
(Slide Presentation of July 17, 2001)

July 2001

3-D Rod Ejection Methodology

Presentation to the NRC by
Westinghouse Nuclear Fuel
July 17, 2001

Agenda

- Introductions
- Industry perspective
  Proprietary session follows
- 3-D Methodology
- Nuclear model overview
- Thermal / hydraulic models overview
- Conclusions

3-D Rod Ejection Team

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Purpose of Meeting

- Provide an overview of a Westinghouse 3D rod ejection methodology
- Share the schedule need for implementation

Industry Perspective

Industry Perspective

- As you are aware, Reactivity Insertion Accidents (RIA) have been the subject of much discussion since a test revealed that high burnup fuel could have a problem
- Additional tests have been performed, and the industry, through an EPRI working group, is developing proposed revisions to the limits

Industry Perspective - 2

- Additionally, there is an EPRI subgroup that is defining 3-D rod ejection methodology guidelines
- Westinghouse is participating on both of these industry groups
- It is our intent to be consistent with the recommendations of these groups

Purpose of Rod Ejection Analysis

- The reactor must be designed taking into account reactivity insertion events
- Rod ejection is used as the limiting reactivity insertion event

Current 1-D Methodology

- Generate static ejected rod power distributions assuming adiabatic conditions
- Assumes peaking factor ramps up to adiabatic peak and remains there
- Conservative Doppler and moderator feedback
- Minimum trip reactivity versus time
- Documented in WCAP-7588, Revision 1-A

Current Westinghouse Limits

- 200 cal/gm maximum fuel enthalpy
- Less than 10% fuel melt in pellet at the hot spot

Why Is 3-D Methodology Needed?

- Several plants are very close to the current limits with the extremely conservative 1-D methodology
- Some current high energy cores, with 1-D methods, are also pushing the current limits
- Deregulation and energy costs are requiring different operational strategies which further increase the ejected rod worth
- Recent experimental data suggests that a lower fuel failure limit should be used at high burnup

Summary

- Codes and methodologies are consistent with current NRC approved methodologies
- Margin increases in fuel enthalpy and DNBR are obtained primarily from more realistic power distributions and peaking factors

Schedule

- Generic topical report has been prepared summarizing methodology and sensitivity studies, and is ready for submittal
- Plant specific 3-D analysis to be submitted in 1Q02, applicable for reload core starting up in fall 2002
- Independent of revised HZP limits

Conclusions

- Appropriate, conservative 3-D methodology has been defined for HFP and HZP ejected rod analyses
- Sensitivity cases have been run to understand the model
- Uses previously NRC licensed computer codes and hot-rod analysis methods
- Need approval for start-up in fall 2002

Westinghouse Future Usage of 3-D Methodology

3-D Methodology Usage

We intend to selectively use the 3-D methodology in compliance with the current and revised limits

Focus of Topical Report

To license the use of a 3-D methodology for the analysis of ejected rod transients

The topical report would **not** be for:

- Licensing of any new computer codes (codes used already licensed)
- Licensing for a specific plant, or class of plant
- Definition of the new limits to be used

How Do We Gain 3D Margin?

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F_Q Versus Time

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3D Rod Ejection Methodology Overview

Methodology Philosophy

Conservative, bounding approach demonstrating margin to the limits

- [ ]a, c
- [ ]a, c
- [ ]a, c

Planned Usage

- For a specific unit, we would perform reference analyses to serve as the licensing basis using this 3-D methodology
- On a cycle-by-cycle basis, we would confirm, using static analyses, the key parameters as we do now in our Reload Safety Analysis Checklist, RSAC, analysis

Rod Ejection Methodology

- Operational history
- Precondition
- Static analysis
- Transient analysis
- Hot rod analysis
  - Enthalpy
  - DNBR
- RCS overpressure and radiological consequences

Operational History

- Rod ejection is sensitive to the core reactivity distribution
  - BOL cases need to address the impact of the previous cycle burnup window
  - Potential for rod shadowing must be addressed for EOL cases, dependent on anticipated plant operation
    - Bite depletion
    - Equivalent load follow depletion
    - Reduced power operation with rods inserted

Time in Cycle

- HFP ejected rod worth relatively insensitive to burnup
- HZP ejected rod worth significantly worse at end of cycle

Why?

- Ejected rod worth sensitive to axial power profile - worth increases as power moves to the top of the core

Precondition

- Ejected rod worth sensitive to radial and axial power profile
- More power in lead bank assemblies increase ejected rod worth
- Skewing the axial power to the top increases ejected rod worth
- Deeper insertion of the lead bank usually increases ejected rod worth

Static Calculations

- Determine appropriate precondition
  - Time in life
  - Xenon distribution
  - Initial rod position
  - Soluble boron concentration
- Determine location of worst ejected rod
- Compare key parameters to bounding analysis

Key Parameters

- Ejected rod worth (and peaking factor)
- Delayed neutron fraction
  (The worth and beta are combined by evaluating ejected rod worth in dollars of reactivity)
- Doppler temperature coefficient
- Moderator temperature coefficient

Only the ejected rod worth varies much from cycle to cycle (with same fuel type)

Sample Application

- 3 loop core with 8 rod D bank
- VANTAGE 5 fuel

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EOC HZP Static Results Impact of Rod Shadowing

Depletion Model	Ejected Rod Worth		Peaking Factor	
	Worth (pcm)	Diff (%)	F_q	Diff (%)
ARO	[ ]a, c	--	[ ]a, c	--
Bite	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c
Rodded	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c

HZP Static Results
BOC versus EOC

Case, Burnup (MWd/MTU)	Ejected Rod Worth		Peaking Factor	
	Worth (pcm)	Diff (%)	F_q	Diff (%)
HZP, 150	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]
HZP, 21130	[ ][a, c]	--	[ ][a, c]	--

EOC HZP Static Results
Impact of Xenon Distribution

Lead Bank @ HFP	Axial Offset		Ejected Rod Worth		Peaking Factor	
	HFP (%)	HZP (%)	Worth (pcm)	Difference (%)	F_q	Difference (%)
ARO & No Xe	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]
ARO	[ ][a, c]	[ ][a, c]	[ ][a, c]	--	[ ][a, c]	--
Bite	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]
Bite	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]
RIL	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]
RIL	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]
Peak Xe	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]	[ ][a, c]

HFP Static Results
Impact of Rod Insertion

Lead Bank Position (steps)	Ejected Rod Worth		Peaking Factor	
	Worth (pcm)	Diff (%)	F_q	Diff (%)
184	[ ]a, c	--	[ ]a, c	--
161	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c
140	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c

HFP Static Results
Impact of Xenon Distribution

Lead Bank (Steps)	Axial Offset	Ejected Rod Worth		Peaking Factor	
		Worth (pcm)	Diff (%)	F_q	Diff (%)
140	[ ]a, c	[ ]a, c	--	[ ]a, c	--
140	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c
140	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c	[ ]a, c

Typical EOC, HZP Key Parameters

Key Parameter	Conservative Base Value	Bounding Value
Static ejected rod worth (pcm)	[ ]a, c	[ ]a, c
Static adiabatic ejected rod peaking factor (relative)	[ ]a, c	[ ]a, c
Ejected rod location	[ ]a, c	[ ]a, c
Banks D and C initial position (steps)	0, 118 (RIL)	0, 118 (RIL)
Delayed neutron production (fraction)	[ ]a, c	[ ]a, c

3-D Transient

- Start transient from appropriate initial condition
- Define transient drivers
  - Rod ejection in 0.1 sec
  - Control rod trip
    - 3/4 detectors indicating trip
    - 0.5 sec trip delay
    - Conservative trip rod position versus time curve
    - Assume ejected rod and an adjacent rod do not trip

Feedback Conservatisms

- Doppler feedback is primary mechanism to turn pulse around
- Reduce Doppler feedback cross section adjustment
- Event is very rapid with little heat transfer
- Heat transfer to coolant (and direct heating) increases fluid enthalpy
- Increase boron concentration to increase MTC and reduce feedback effect

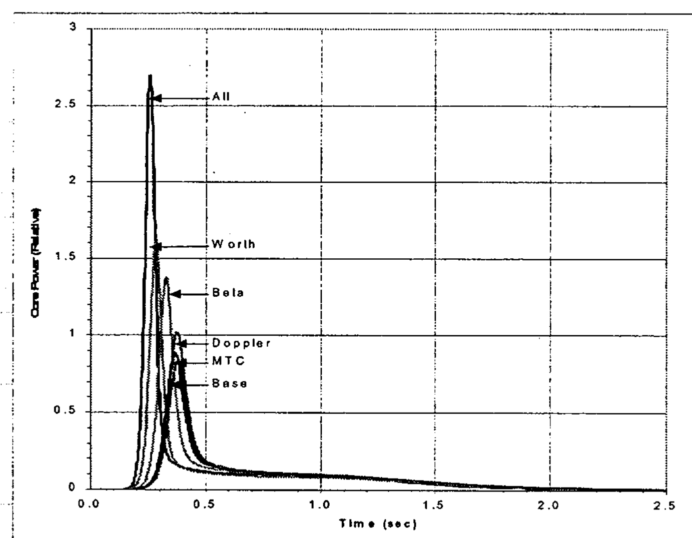
Transient Time Steps

- Time step sizing is important to accurately follow the transient
- Stiffness Confinement method used to reduce sensitivity to time step size
- Small time steps used during the pulse, larger time steps in the rest of the transient

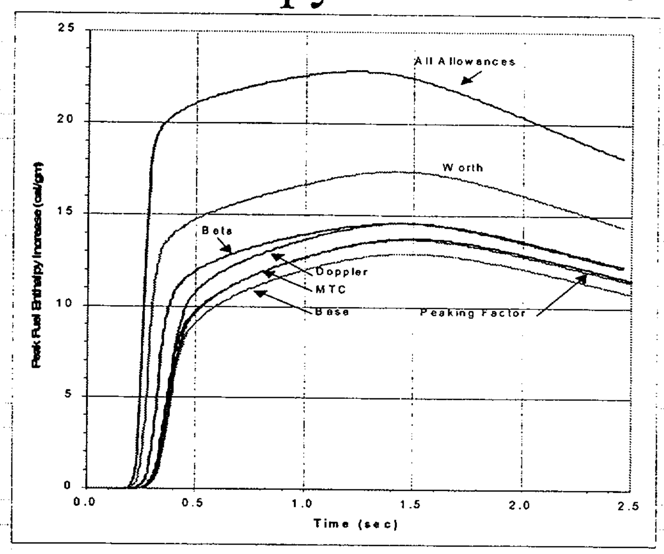
Hot Rod Analysis

- A separate hot rod transient analysis is performed
- Uses the core transient as driver function
- Conservative model consistent with current approved method
- Allows different pessimistic assumptions to be made
- Uncertainties in modeling and input parameters applied to give more limiting results

HZP Power Sensitivities



HZP Enthalpy Sensitivities



HZP Key Parameter Sensitivities

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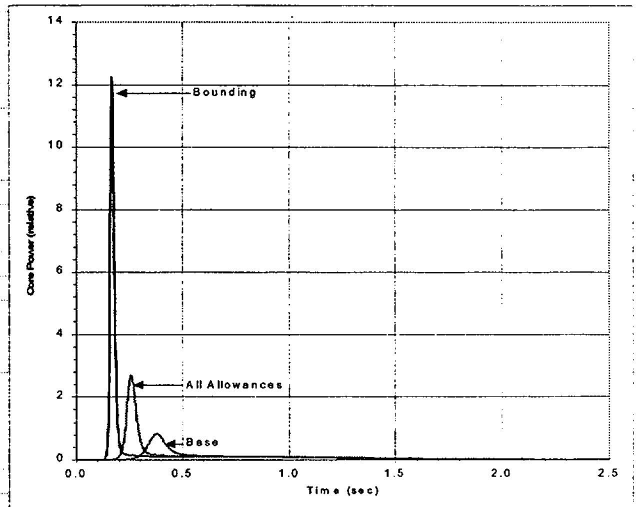
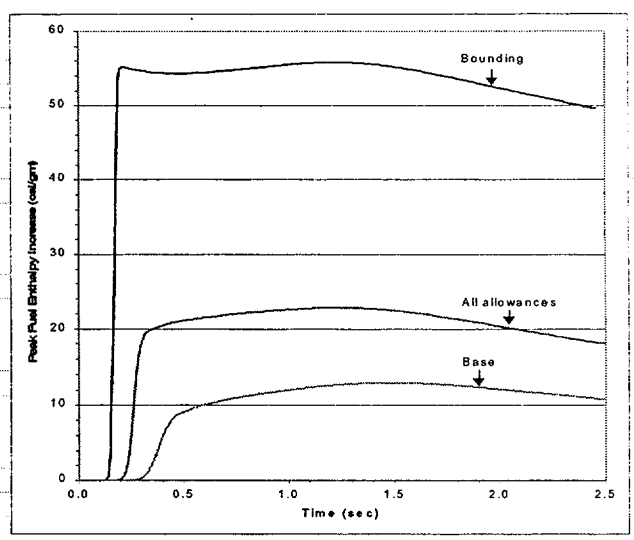
HZP Bounding Analysis



HZP Bounding Enthalpy



EOC, HZP Correlations

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Variable Time Steps

Interval (s)	Step Size (ms)
0.0 - 0.1	20.0
0.1 - 0.4	5.0
0.4 - 1.0	25.0
1.0 - 2.5	100.0

HZP transient, pulse width = 50 ms

Time Step Sensitivity

Time Step	Core Power	Fuel Enthalpy
0.25x	+1.8%	0
0.5x	+0.5%	0
1x	--	--
2x	+14.9%	+2.9%

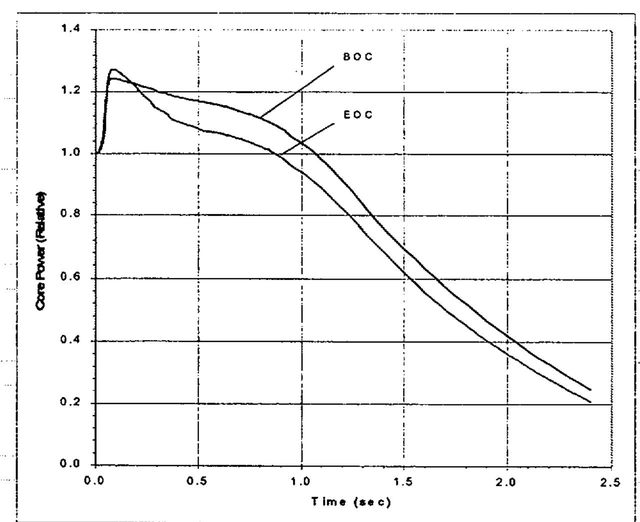
HFP Transient Parameters

Parameter	BOC	EOC
Static ejected rod worth (pcm)	[ ][a, c]	[ ][a, c]
Static adiabatic ejected rod peaking factor (relative)	[ ][a, c]	[ ][a, c]
Ejected rod location	[ ][a, c] (Diagonal – inside)	[ ][a, c] (Axis – outside)
Bank D initial position (steps)	140	140
Delayed neutron production (fraction)	[ ][a, c]	[ ][a, c]

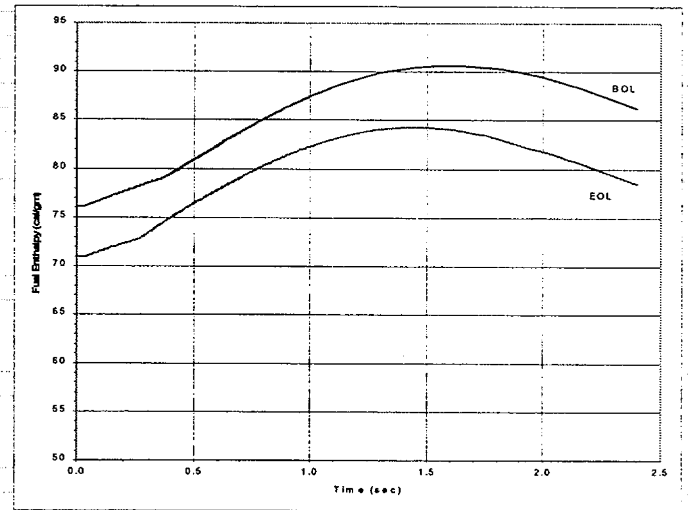
HFP Transient Results

Parameter	BOL	EOL
Maximum Core Power (relative)	[ ]a, c	[ ]a, c
Maximum Fuel Enthalpy (cal/gm)	[ ]a, c	[ ]a, c
Minimum DNBR	[ ]a, c	[ ]a, c

HFP Analyses



HFP Fuel Enthalpy



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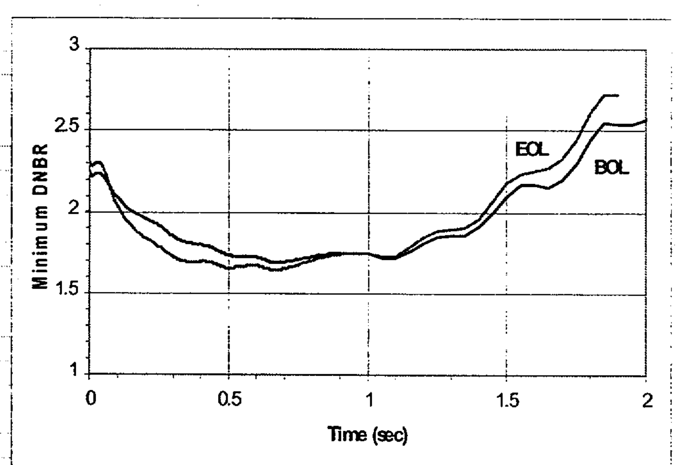
HFP DNBR



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RCS Overpressure

- Determine volumetric surge versus time
- Compare to design pressure relief surge rate
- Current analyses are still limiting

Radiological Consequences

- Based on number of fuel cladding failures predicted
  - Rods in DNB at HFP
  - Fuel enthalpy criteria at HZP
- Also sensitive to amount of fuel melting
  - Not expected in 3D analyses

Summary HZP Methodology

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Summary HFP Methodology

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Reload Safety Evaluation

- Preserve WCAP-9272 bounding analysis methodology
- Compare key limiting parameters in RSAC
  - Ejected rod worth (in $)
  - Ejected rod peaking factor
  - Doppler temperature coefficient
  - Moderator temperature coefficient
- Change in fuel type may also require reevaluation

Summary

Appropriate 3-D methodology has been defined using

- A more realistic, but conservative approach
- Conservative uncertainty allowances
- Key parameters and a bounding approach for cycle specific evaluations

Model Overview

Code Interfaces

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Computer Codes

- Codes approved by NRC
  - SPNOVA (WCAP-12394-P-A)
  - VIPRE-01 (WCAP-14565-P-A)
- Application to 3-D rod ejection is in compliance with SER conditions and limitations
- Coupling using Parallel Virtual Machine
  - Consistent geometric models
  - Data transfer every time step

SPNOVA Model

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Qualification

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VIPRE Transient Core Model

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Hot Rod Model

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Hot Rod Enthalpy

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Hot Rod DNBR

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