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Global Nuclear Fuel
A Joint Venture of GE, Toshiba, & Hitachi
Global Nuclear Fuel – Americas, LLC
Castle Hayne Road, Wilmington, NC 28401

GNF Technology Update
May 1-2, 2007
J Auditorium

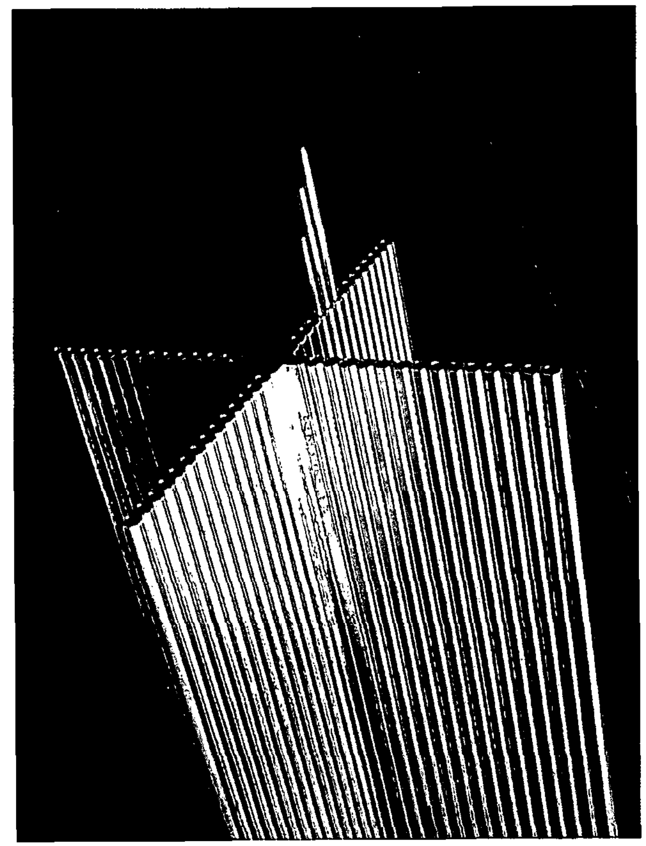
Agenda

Day 1, AM	**Plant Tour**	
8:30	Control Blade Manufacturing	
Day 1, PM	**Technology Update**	
10:00	Welcome	R. Brown, A. Lingenfelter
10:15	Control Blade Performance	S. Nelson
11:15	Stability Update	A. Chung
11:45	Safety Limit Methodology	J. Fawks, M.Thomas
	Lunch	
13:00	LANCER/ AETNA status	S. Palmtag
13:45	TRACG Status	C. Heck, J. Andersen
	Break	
14:15	Methods Improvements: γ-scan, fission gas, void fraction	B. Moore, S. Bowman
15.30	GNF2 Update	R. Fawcett
16:15	GEXL ++	J. Andersen, B Aktas
Day 2	**Technology Update**	
8:00	PRIME: Status, Transient	N. Jahingir
8:45	Channel Bow Update	P. Cantonwine
9:30	Defender Debris Filter	G. Luciano
	Break	
10:45	Ziron Cladding	YP. Lin
11:30	Fuel Reliability and Performance	R. Schneider
	Lunch	
13:00	Defense In Depth	R. Schneider
14:00	Planned NRC submittals	R. Kingston, J. Harrison
15:00	Adjourn	

Marathon-5S
Control Rod Blade

GNF Technology
Update Meeting

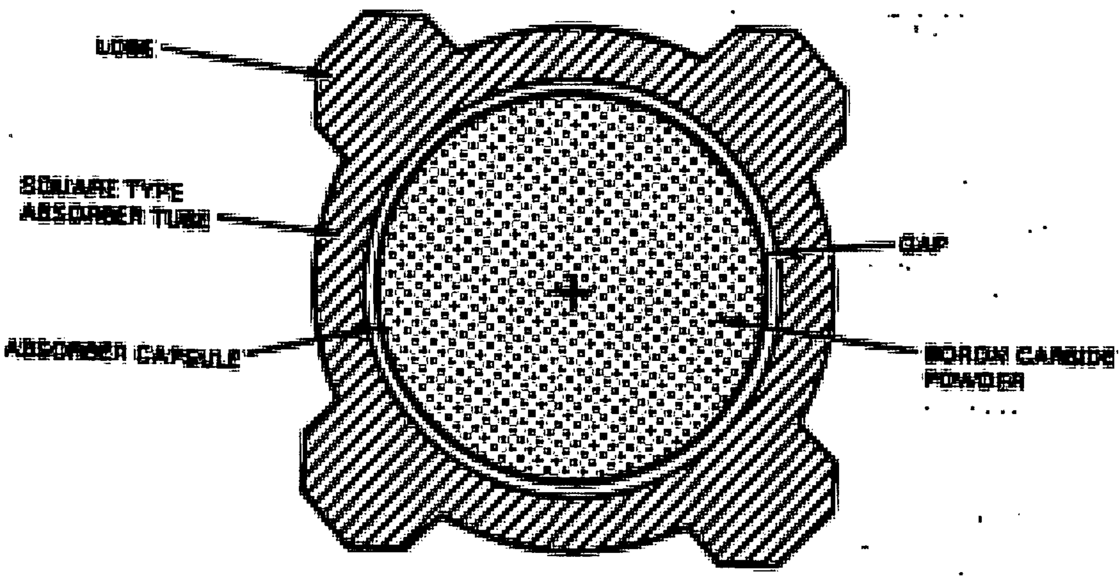
May 1-2, 2007

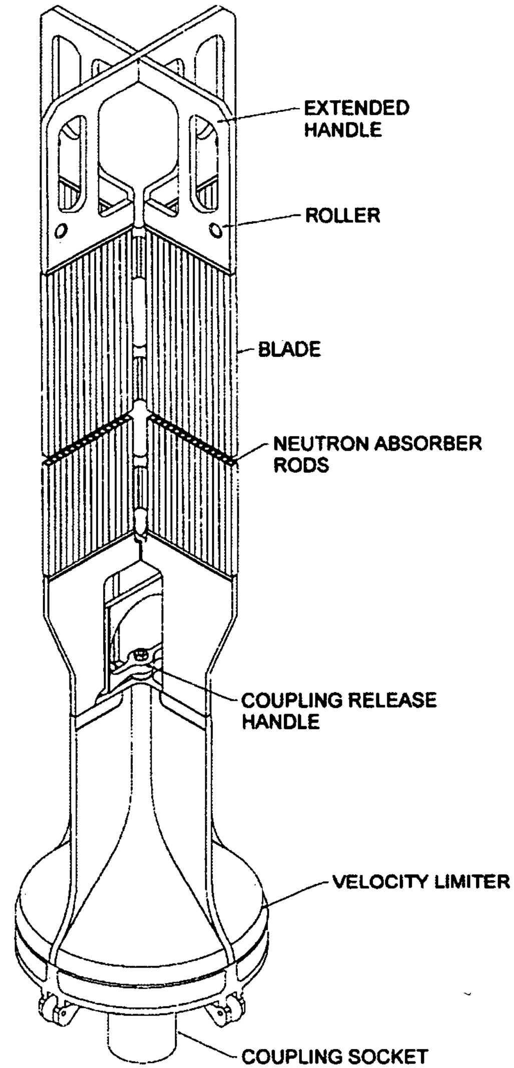


imagination at work

Marathon CRB Description

B4C powder capsule/hafnium rod within a 'square' absorber tube.





Marathon-5S CRB Description

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- Simplified Absorber Tube Geometry
- All B_4C Capsule Design (no hafnium)
- Thicker Wall Capsule Body Tube

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- Full-Length Tie Rod
- Roller-less Handle

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imagination at work

Marathon-5S

M-5S

- Comparison to Marathon-7S
- Same GE proprietary 304S crack-resistant stainless steel
- More conservative design criteria
  - [[

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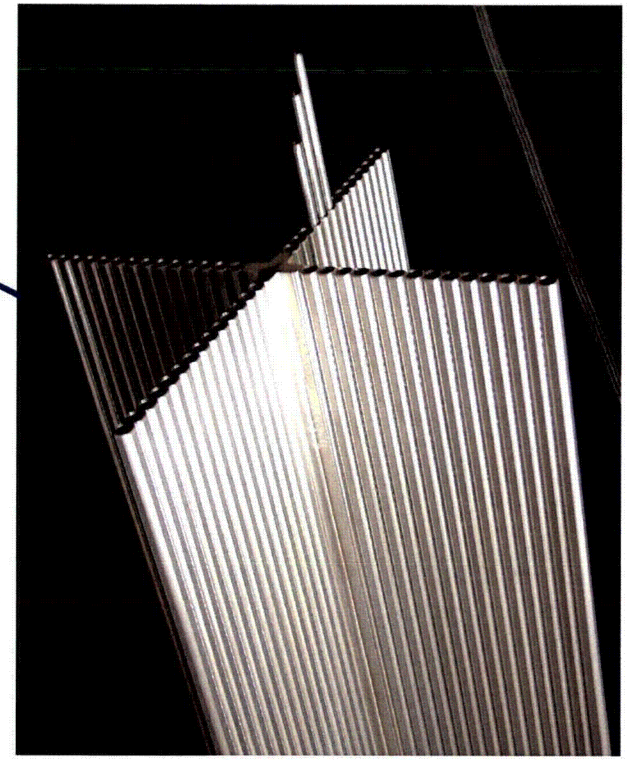
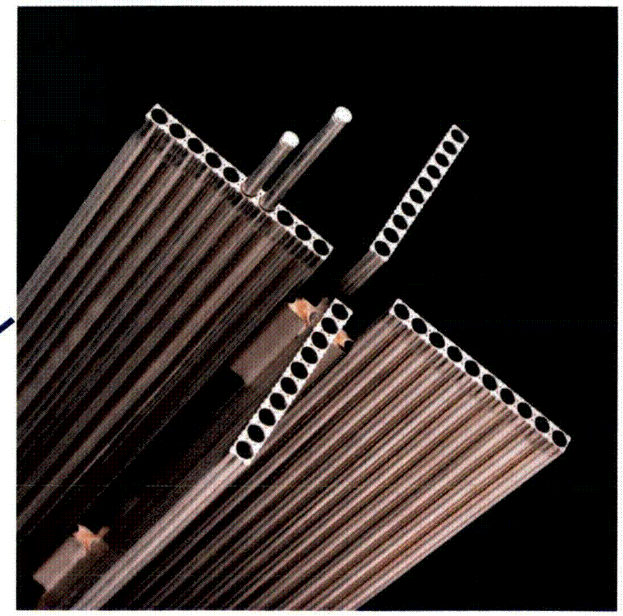
M-7S





imagination at work

Marathon-5S Control Rod

- Licensing Topical Report, NEDE-33284P, currently being reviewed by NRC.
- A domestic BWR/6 plans to install 5 Marathon-5S control rods fall 2007.
- Seismic scram testing successfully completed at the end of 2006.

Marathon-5S Control Rod Nuclear Design Summary

- Matched worth design – initial cold and hot reactivity worths within ±5% of the original equipment.
- Nuclear end-of-life defined to be the ¼ segment depletion at which the cold reactivity worth is equivalent to a 10% reduction in the original equipment's cold reactivity worth.
- The nuclear lifetime is evaluated to be limiting over the mechanical lifetime for all cases.

imagination at work

Marathon-5S Control Rod Mechanical Design Summary

- The control rod is conservatively evaluated for worst case scram, stuck rod compression, handling loads, and loads due to absorber burn-up.
- Seismic and fuel channel bow induced bending, as well as fatigue are also analyzed.
- Maximum stresses and strains for the material, structure and welded connections are found to be acceptable.

Marathon-5S Control Rod – Capsule Swelling

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Marathon Design	Licensing Topical Report(s)	Minimum Diametral Gap Between Capsule and Absorber Tube at Beginning-of-Life (inches)	Local Depletion at Capsule Contact with Absorber Tube Inside Diameter (Nominal)
Marathon – D/S Lattice	NEDE-31758P-A	[[	
Marathon – C Lattice	NEDE-31758P-A		
Marathon-5S – D/S Lattice	NEDE-33284P		
Marathon-5S – C Lattice	NEDE-33284P		]]

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Stability Update

Presentation to NRC

Juswald Vedovi/Alan Chung

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Stability Update

- Brunswick 2 SLO OPRM Scram
- Plant-Specific DSS-CD Update
- Option I-D Plants for M+ Operation
- TRACG Stability LTR

Stability Update

Brunswick 2 SLO OPRM Scram

- Brunswick 2 had an OPRM SLO scram on Christmas last year
- The OPRM system tripped on the defense-in-depth Growth Rate Algorithm
- The GRA is designed for fast growing oscillations that have the characteristics of thermal-hydraulic instability
- The value of the OPRM cell relative signal (P/A) is compared at each hardware time step to a threshold setpoint, S_1 (1.10). If the relative signal exceeds S_1, then the algorithm checks to determine if the relative signal decreases to a second setpoint, S_2 (0.92), within a time period typical of an instability oscillation
- After exceeding S_1 and decreasing below S_2 in the expected time window, a GRA trip is generated if a growth rate (1.30) is exceeded in the expected time window (T_2)

Stability Update
Brunswick 2 SLO OPRM Scram

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Stability Update

Brunswick 2 SLO OPRM Scram

- The OPRM system scrammed as designed
- The mode is core-wide in nature and does not appear to be driven by instability but rather by an external hydraulic excitation noise source.
- The ODYSY code predicted low core decay ratios, indicative of a non-THI condition
- The SLMCPR was protected during the power oscillation event
- The GRA is designed for fast growing oscillations that have the characteristics of thermal-hydraulic instability
- Additional detailed analysis using the TRACG model will be needed to study this power oscillation event

Stability Update

Plant-Specific DSS-CD Update for MELLLA+ Operation

- Generic DSS-CD LTR approved for EPU/MELLLA+
- Generic settings (10 counts and 1.03 amplitude setpoints) might not be adequate to prevent spurious scram during normal plant operation
- One simple change to fix the issue. Two-tiered power/flow-dependent setpoints proposed to fix the spurious scram concern
- The same generic methodology as approved in NEDC-33075 will be applied to setpoint generation for the two power/flow domains
- Browns Ferry Unit 1 will be the lead plant for this modification
- TRACG for DSS-CD LTR will be updated as part of this effort to include TRACG04

Stability Update

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Stability Update

Option I-D Plants for MELLLA+ Operation

- GE will propose Option I-D+ to MELLLA+ operation
- Will retain key elements of Option I-D such as flow-biased APRM flux scram line, dominance of core-wide mode
- APRM flow-biased flux scram line may carve out certain domain on the power/flow map (e.g., upper left corner) to ensure that the Option I-D solution elements are still applicable
- Same solution elements as the current Option I-D
  - Plant- and cycle-specific DIVOM
  - Digital Flow Control Trip Reference cards for multiple slope capbaility for the APRM flow-biased flux-scam lines
  - Exclusion and Buffer Regions
  - Stability online monitor
- GE putting together material for lead Option I-D plants (Vermont Yankee, DAEC)

Stability Update
Option I-D Plants for MELLLA+ Operation

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Stability Update

TRACG Stability LTR

- TRACG02 approved for the DIVOM application per NEDO-32465-A
- Approved SERs for separate ESBWR and DSS-CD applications
- New TRACG Stability LTR will provide the documentation to support the DIVOM application
- Will cover TRACG04 also
- Expected 1Q08

SLMCPR Methodology

MIP Criterion
(MCPR Importance Parameter)

GNF
Jim Fawks
May 2007

MIP Criterion Review Requirement

NRC Letter

Acceptance for referencing of licensing topical reports NEDC-32601P, Methodology and Uncertainties for Safety Limit MCPR Evaluations; NEDC-32694P, Power Distribution Uncertainties for Safety Limit MCPR Evaluation; ...

NRC SER ... actions should be taken as follows:

(3) In view of the importance of MIP criterion and its potential sensitivity to changes in fuel bundle designs, core loading and operating strategies, the MIP criterion should be reviewed periodically as part of the procedural review process to insure that the specified value recommended in NEDC-32601p is applicable to future designs and operating strategies.

Original MIP Criterion Basis

- Indirect technical argument based on CPR
  - Cores not on limits have inherent SLMCPR operating margin
  - Develop MIP criterion to determine SLMCPR conservatism
  - Result is an indirect method showing that the SLMCPR methodology is sufficiently

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NEDC-32601P

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NEDC-32601P

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NEDC-32601P

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New MIP Criterion Basis

- Direct technical argument based on NRSBT
  - –Due to new feature that allows for direct measure of SLMCPR operating margin
  - –Using this new feature results in a direct method showing that the SLMCPR

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Typical SLMCPR Operating Margin (unverified)

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A00+.04 Operating Margin (unverified)

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What Next?

- LTR late 2007 / Approval late 2008

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GNF Technology Update Meeting

LANCER/AETNA Status

Scott Palmtag

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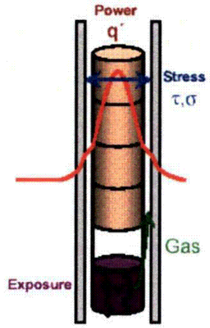
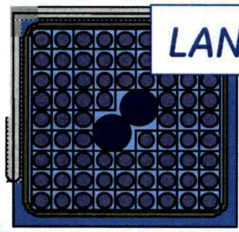
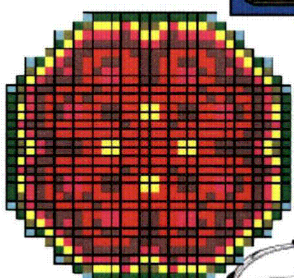
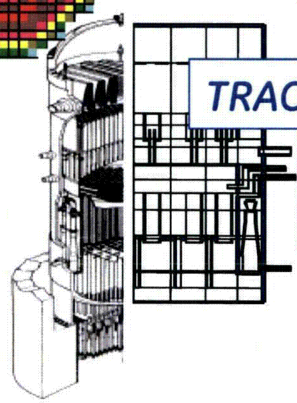
New Methods Code Suite









PRIME

Fuel rod thermal-mechanical
Mechanical behavior of fuel rod.

(Replaces GSTRM)

LANCER

2-D Lattice Physics
Nuclear Behavior of Fuel Rods Within Bundle.

(Replaces TGBLA)

AETNA

3-D Core Simulation
Nuclear + Thermal-Hydraulic Behavior of Bundles in Core

(Replaces PANAC)

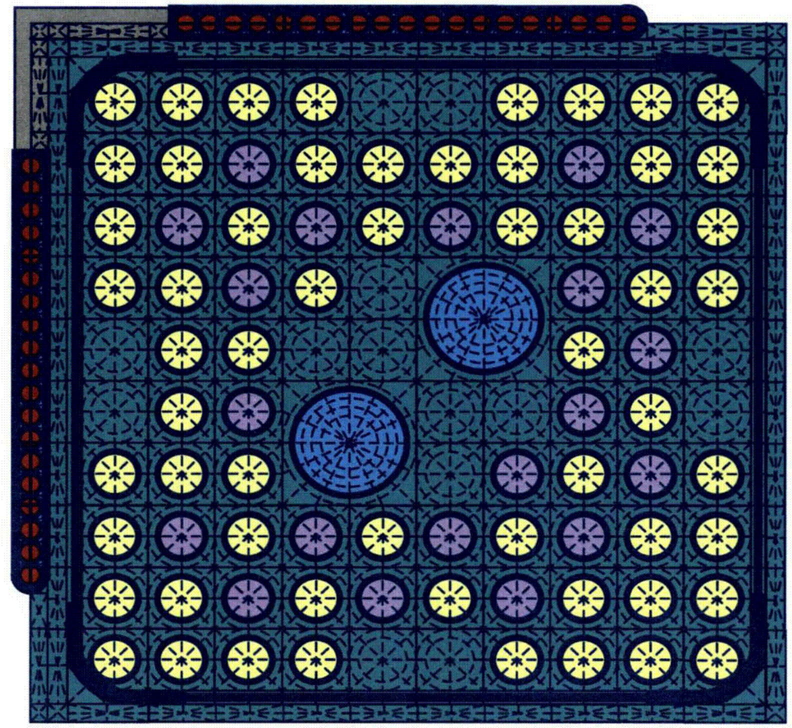
TRACG

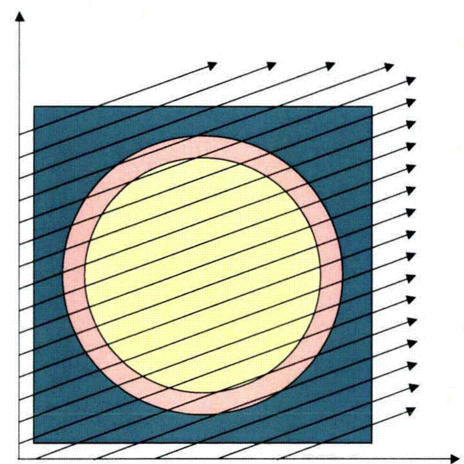
Best Estimate Analysis of Operational Transients

(Replaces ODYN, TASC, SAFER, CORCL)

LANCER Highlights

- Model fuel rods (U+Gad) , water Rods, control blade within lattice
- Complex/exact geometry & material
- 2D fine-mesh spatial resolution (multiple angular + radial discretization)
- Method of Characteristics (MOC) transport solution – neutrons and gammas
- Detailed isotopic tracking
- Detailed neutron energy group structure
- Fine time-step temporal resolution (exposure dependence)
- Fundamental nuclear data from ENDF/B-VII





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LANCER Status

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LANCER Benchmarks

Single assembly benchmarking against MCNP for a wide range of BWR applications

- High enrichment/Low enrichment
- High void/Low void
- High Gd/Low Gd
- Lumped Gd/Evenly distributed Gd
- Controlled/Uncontrolled
- Hot/Cold
- UOX/MOX
- Burnup (compare to MCNP/MOCUP)

Uncontrolled Δk (unverified)

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Controlled Δk (unverified)

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Uncontrolled Pin-wise %rms (unverified)

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Controlled Pin-wise %rms (unverified)

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0% Void Depletion (unverified)

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80% Void Depletion (unverified)

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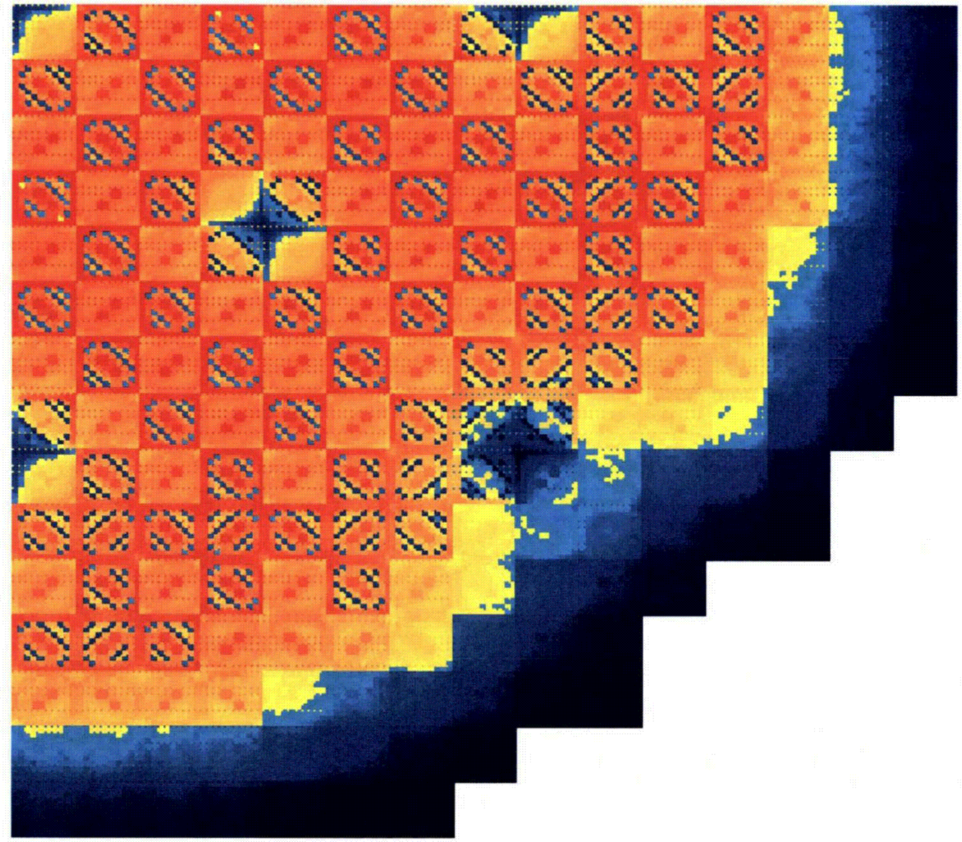
AETNA Highlights

- Model all fuel bundles, control blades, and T/H within core
- Coupled neutronic-T/H feedback
- 3D coarse-mesh spatial resolution
- Few-group energy structure
- Diffusion theory physics (homogeneous solution)
- Pin power reconstruction (heterogeneous solution)
- Detailed nuclear data obtained from LANCER



Improve Current and Future Applications
(e.g. EPU, ESBWR, MOX)

AETNA Feature Detail

Built Upon PANAC11 Software Base

•Retain Functionality, User Interface and Automation Support

Cross Section Model

- Expanded Functional Matrix
  - **100% Void Branch / History**
  - Control Blade History
- Improved Spectral History Models (Void & Control Blade)

T/H Physics

- **All Channels modeled - T/H** (5 Eqn. T/H)
- Multiple Bypass Regions
- Bypass Voiding
- ESBWR Modeling
  - 16 Bundle Chimney
  - Natural Circulation Heat Balance

Nodal Physics Models

- Semi-Analytic Nodal Method
- **3 Energy Groups** (Fast, Epithermal, Thermal)
- Improved Pin Power Reconstruction
- **Isotopic tracking** includes ^{241}Pu-^{241}Am, ^{135}I-^{135}Xe, ^{149}Pm-^{149}Sm, ^{140}Ba
- **Multi control blade modeling**
- Exposure Dependent Fuel Temperatures
- Channel Distortion
- Advanced Detector Models

Target Platform: Windows PC

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AETNA Status

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Cycles 1-8 BWR/6 (unverified)

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Licensing Schedule

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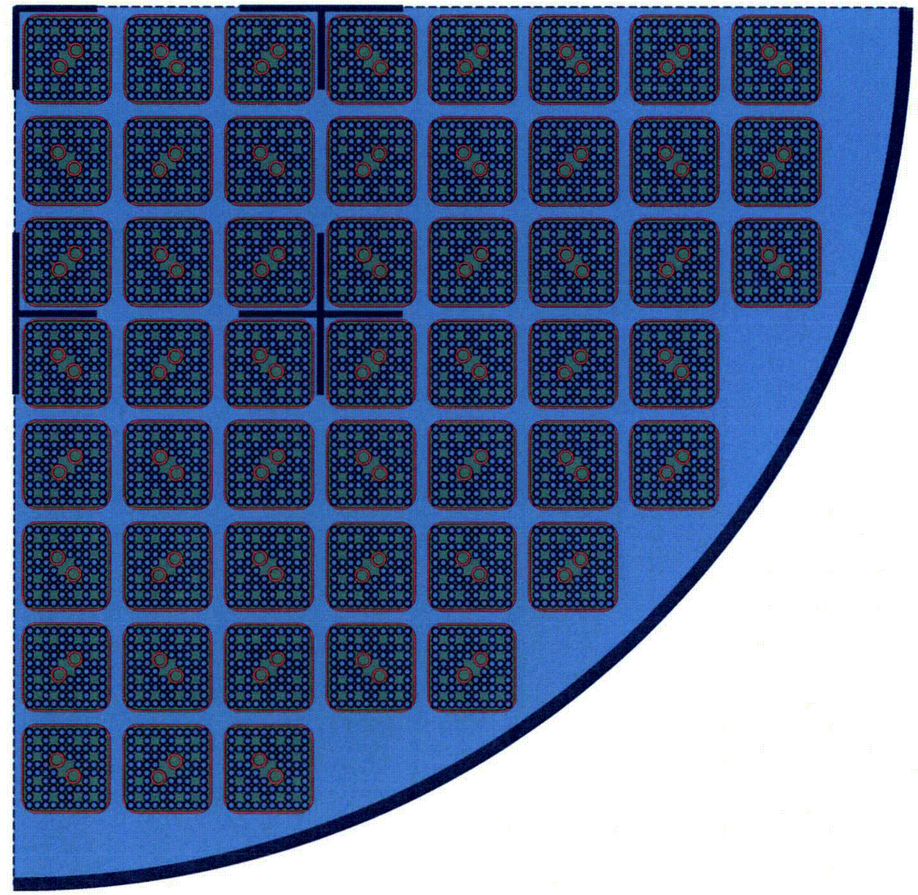
Further Development

GNF is committed to developing and **maintaining** industry leading methods.

Advanced Methods Group created in 2005 to drive development of new methods.

Further Direction

- Integration of AETNA02 models into TRACG06
- Full-core LANCER02 capability
- Advanced subchannel models
- Integration of COBRAG subchannel methods into AETNA02 and/or TRACG06
- 3-D LANCER



Large-scale parallel computation!

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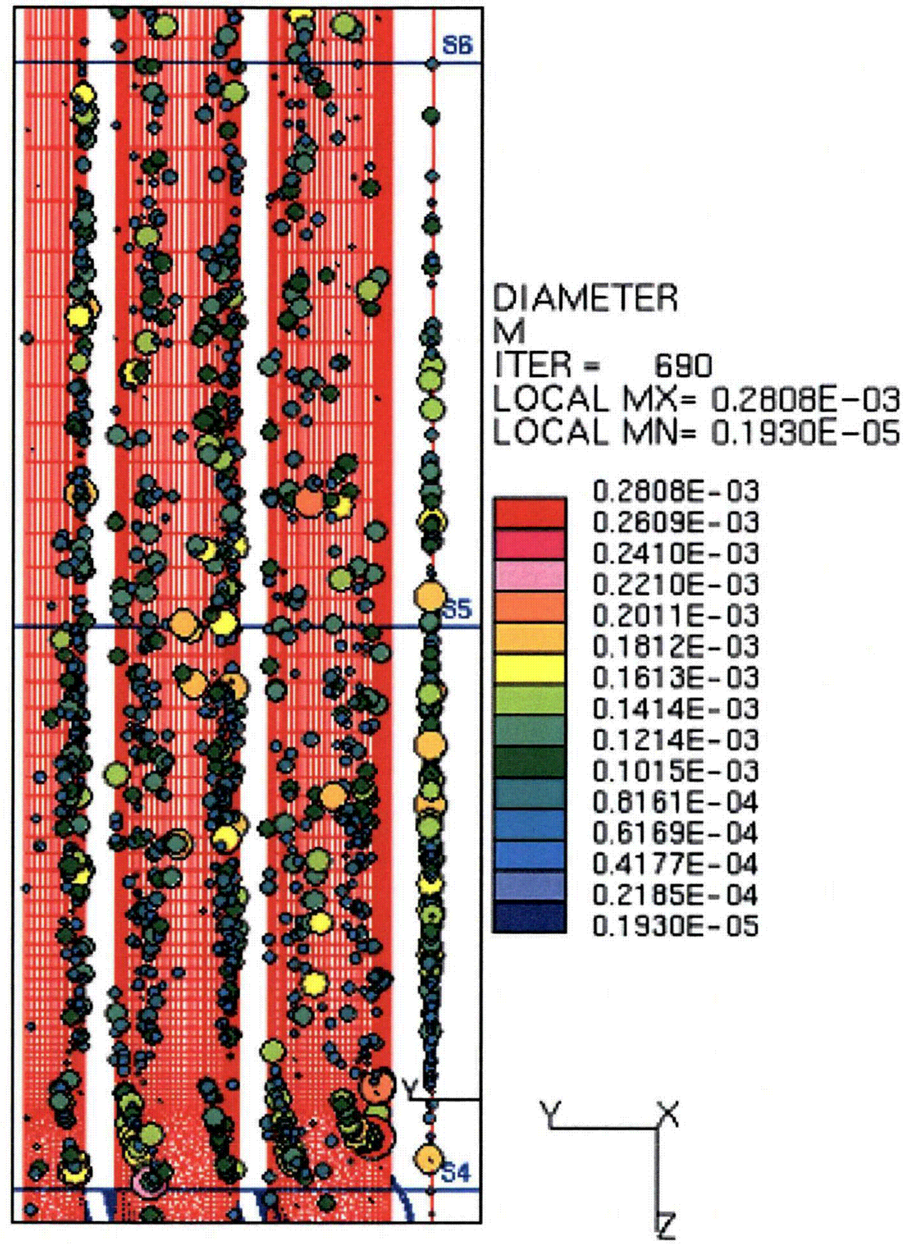
CFD Direction

- Single-phase CFD
- Turbulence Models
- Multi-phase CFD (adiabatic)
- Multi-phase CFD (steam/water)
- Experimental work to validate CFD models
- Working with GRC and Universities



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GNF Technology Update Meeting

TRACG
Code and Application Status

May 1-2, 2007

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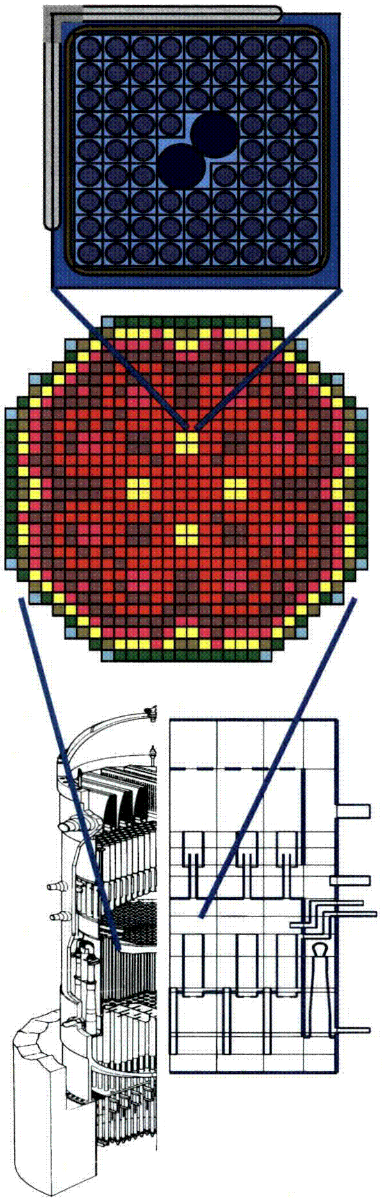
TRACG Benefits

- Improved fidelity:
  - Best Estimate models, 3D Effects, Mixed cores
- Transients:
  - 0.05 – 0.07 OLMCPR Improvement
- LOCA:
  - LHGR improvement for LOCA limited plants
- Stability:
  - Detect and suppress stability solutions
- ATWS:
  - Lower peak pressure and containment loads
- RIA/RDA:
  - Realistic assessment of margins
- ESBWR
  - Design and NRC certification

Relationship Between Codes



TGBLA06 ->LANCER02

2-D Lattice Physics

Nuclear Behavior of Fuel Rods Within Bundle

(LANCER replaces TGBLA)

PANAC11 ->AETNA02

3-D Core Simulation

Nuclear + Thermal-Hydraulic Behavior of Bundles in Core

(AETNA replaces PANAC)

TRACG04 ->TRACG06

Coupled Core and BOP Simulation

Best Estimate Analysis of Operational Transients

(Either TRACG can replace ODYN, TASC, SAFER, CORCL)

GSTRM ->PRIME

Fuel / Clad Thermal-Mechanical Analysis

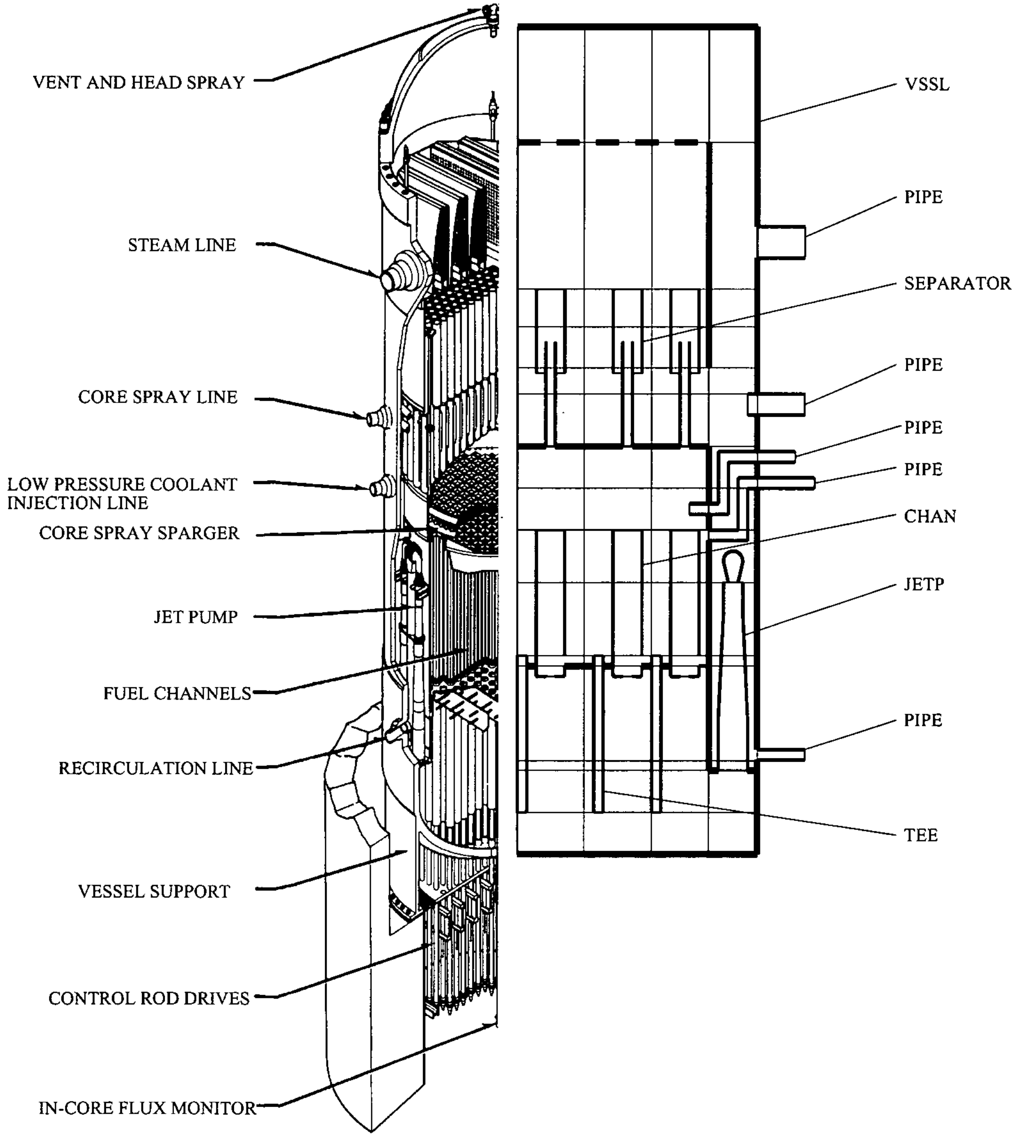
Detailed fuel pellet, fission gas, and fuel-clad interactions

PRIME03 UO2 thermal conductivity model is in TRACG04.
Model interfaces with TRACG via the fuel files.

TRACG

Realistic Code for BWR Transients

- Transients, LOCA, ATWS, Stability, RIA, RIPD
- Multi-dimensional thermal hydraulics
  - Two-fluid hydraulic model: Steam, liquid, boron and non-condensable gases
  - Best estimate basic models for shear and heat transfer
- Proven 3D nuclear kinetics consistent with GE core simulator PANACEA and AETNA
- Flexible modular structure with control system capability
  - Test facilities, BWR/2-6, ABWR and ESBWR
- BWR component models
  - Fuel elements, jet pumps, steam separators
- Extensive qualification
  - Simple separate effects tests
  - Scaled simulation
  - Full scale plant data



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Extensive TRACG Qualification

Separate Effects Test

- Void Fraction: FRIGG OF64, Christensen, Wilson, Bartolomei, EBWR, Ontario Hydro, Toshiba, PSTF
- Heat Transfer: THTF, CSHT
- Counter Current Flow Limitation
- Critical flow: Marviken, PSTF, Edward
- Pressure drop: ATLAS
- Critical Power: ATLAS
- Natural circulation and T/H stability: FRIGG
- Kinetics: SPERT

Component Performance

- Jet pump: INEL 1/6 scale, Cooper, LaSalle
- Steam Separator: 2 and 3-stage full scale
- Upper plenum effects: SSTF
- Passive containment cooling: PANTHERS, PANDA, GIRAFFE

Included for ESBWR qualification

Integral System Effects test

- LOCA Simulation: TLTA, FIST, ROSA-IV, FIX, CSHT
- Multiple channel effects: SSTF
- ESBWR simulation: GIST, GIRAFFE, PANDA
- Containment: PSTF
- Loop oscillation tests: CRIEPI, SIRIUS
- Boron mixing: Vallecitos 1/6 scale tests

Plant Data

- Peach Bottom turbine trip test
- Hatch MSIV closure and pump trip tests
- Nine Mile Point pump upshift test
- Leibstadt loss of feedwater test
- Dodewaard
- LaSalle instability event
- Leibstadt stability test
- Forsmark stability test
- Cofrentes instability event
- Peach Bottom low decay ratio stability test
- Nine Mile Point Instability event
- Perry Instability event

Progression of TRACG Applications

TRACG02A (2000)

- PANAC10/TGBLA04 3D kinetics
- AOO, stability

TRACG04A,P (2006)

- PANAC11/TGBLA06 3D kinetics with improved boron model
- Integrate PRIME03 fuel thermal mechanical models
- BWR/2-6 and ABWR AOO, stability, LOCA and ATWS
- All ESBWR analyses

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TRACG04 Application to ESBWR

- All transient, stability, LOCA and ATWS calculations done with TRACG
  - Current design codes hardwired to the standard BWR geometry
- Additional models for ESBWR applications
  - ESBWR component simulation: Containment, Passive containment cooling system, Gravity driven ECC
- Additional qualification for ESBWR applications
  - Passive containment cooling systems: PANTHERS, PANDA, GIRAFFE
  - Gravity driven cooling systems: GIST, GIRAFFE, PANDA
  - Containment: GIST, GIRAFFE, PANDA, PSTF
  - CRIEPI startup oscillation tests
  - Dodewaard plant data

Planned Code Enhancements

- TRACG04A,P

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TRACG04 Application for RIA/RDA

- Additional models
  - Oxide and hydride correlations
  - Model for assumed fuel dispersal
  - Testing for pressure response from fuel dispersal
- Additional qualification
  - Additional SPERT cases for hot conditions
- Application elements

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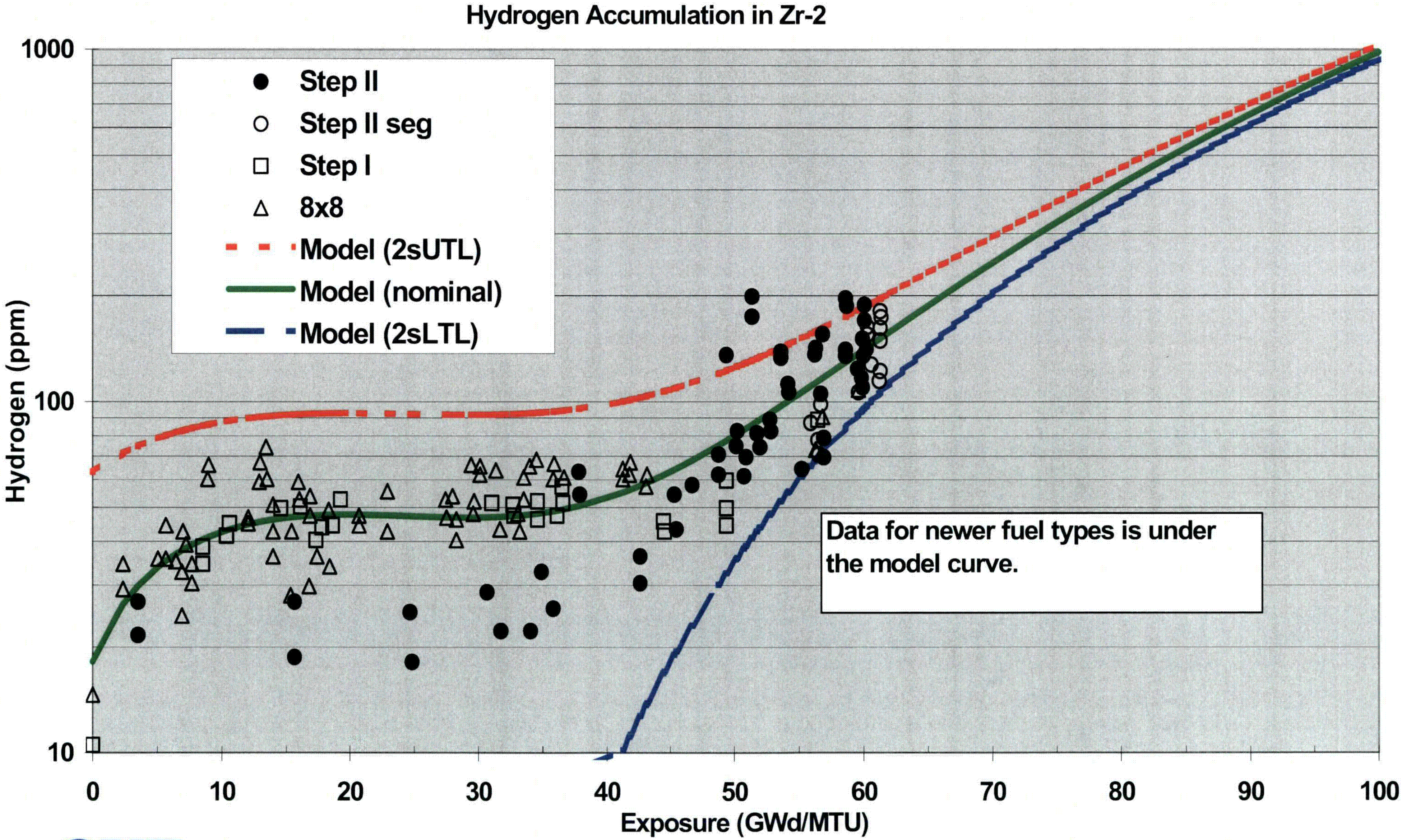
Hydrogen Accumulation in BWR Zr-2 Cladding



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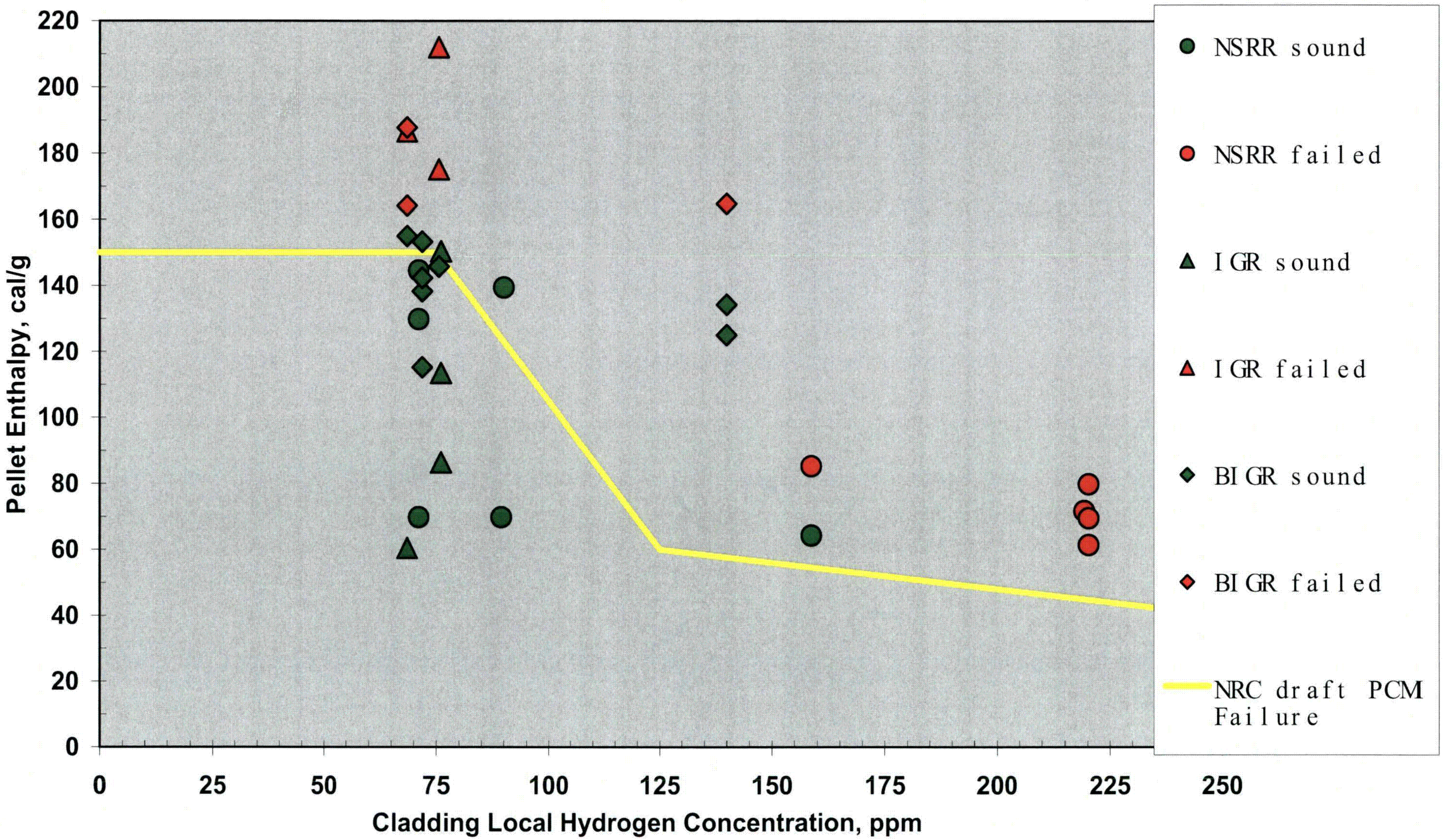
Failure Data Suggest Correlation to H2 Concentration



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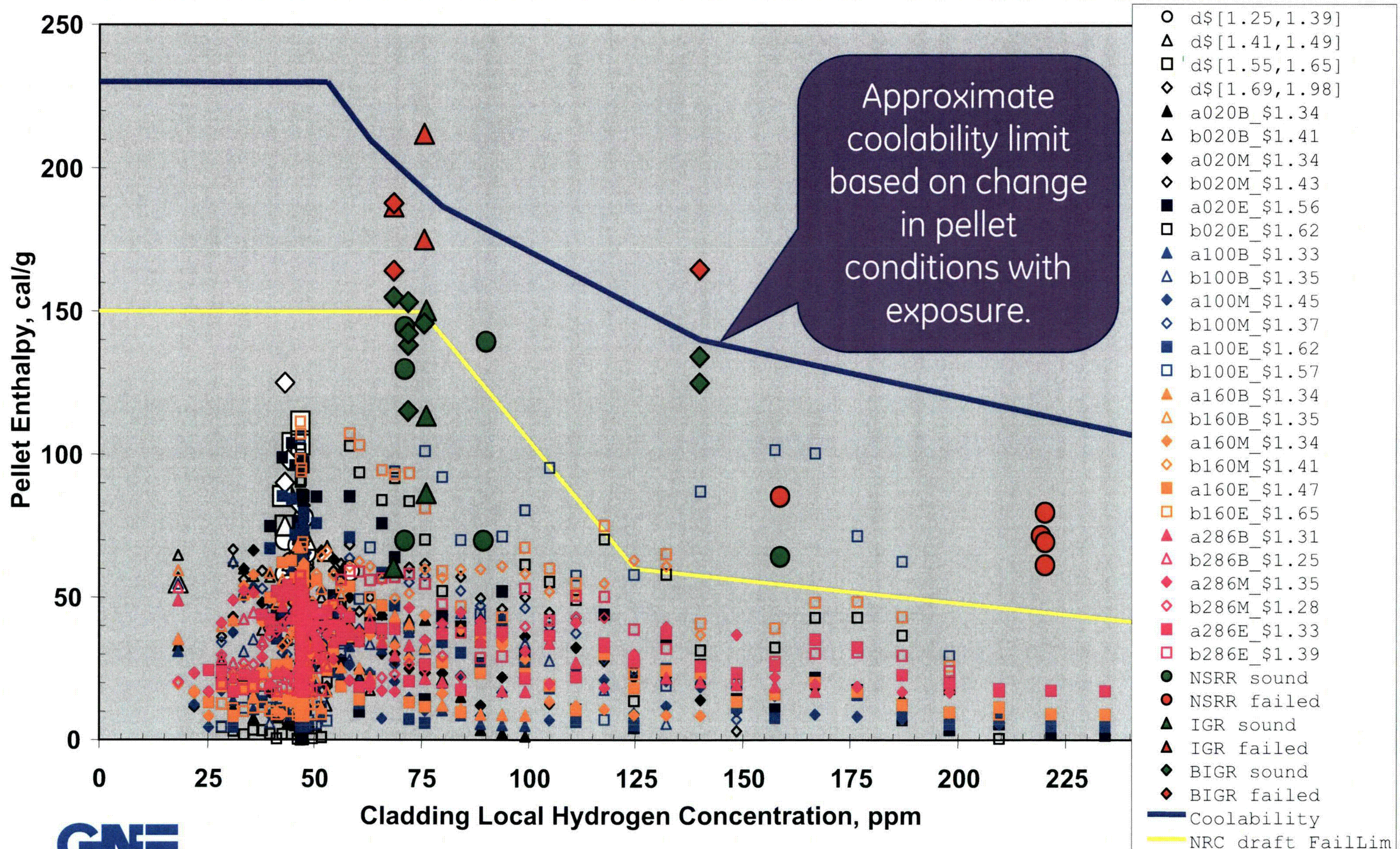
BWR Best-Estimate Calculated CRDA Enthalpies & Interim USNRC Limits vs. Local H2 Concentration



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Anticipated New Qualification

- Additional void fraction separate effects
  - Higher pressure range; high void fractions
- Brunswick scram on OPRM signal
- Leibstadt steam blowdown event
- Updated boron qualification cases for
  - Santa Barbara test
  - Vallecitos test
- Updated ABWR qualification cases

Anticipated TRACG LTRs

- TRACG Qualification LTR, Rev. 3, April 2007
- LOCA (June 2007)
- Generic Stability (April 2008)
- RIA/RDA (1Q 2008)
- ATWS (4Q 2008)

TRACG Benefits

- Improved fidelity:
  - Best Estimate models, 3D Effects, Mixed cores
- Transients:
  - 0.05 – 0.07 OLMCPR Improvement
- LOCA:
  - LHGR improvement for LOCA limited plants
- Stability:
  - Detect and suppress stability solutions
- ATWS:
  - Lower peak pressure and containment loads
- RIA/RDA:
  - Realistic assessment of margins
- ESBWR
  - Design and NRC certification

Method Validation Programs

May 1, 2007

B.R. Moore
J.S. Bowman

imagination at work

Agenda

Nuclear data

- Bundle gamma scans
- Pin gamma scans
- Other

Thermal-hydraulic data

- Pressure drop predictions
- Void fraction uncertainties

Gamma Scan Data

Gamma scans provide confirmation of power predictions

2002 Cofrentes gamma scan data

- GE12 10x10 fuel
- GE11 9x9 fuel
- In pool 4 bundle corner Ba140 at multiple axes & elevation
- Stretch power uprate with MELLLA

Cofrentes Cycle 13 (2002)

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Power & Flow History for Cofrentes

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TIP Comparison Summary (PANAC11)
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imagination at work

EOC Core Average Axial TIP Agreement

PANAC11, 4 days prior to shutdown

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EOC TIP Agreement

PANAC11, 4 days prior to shutdown

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Power Measurements

Preferred

$$_{56}Ba^{140} \rightarrow {}_{57}La^{140} \rightarrow {}_{58}Ce^{140}$$

β- 12.8 d

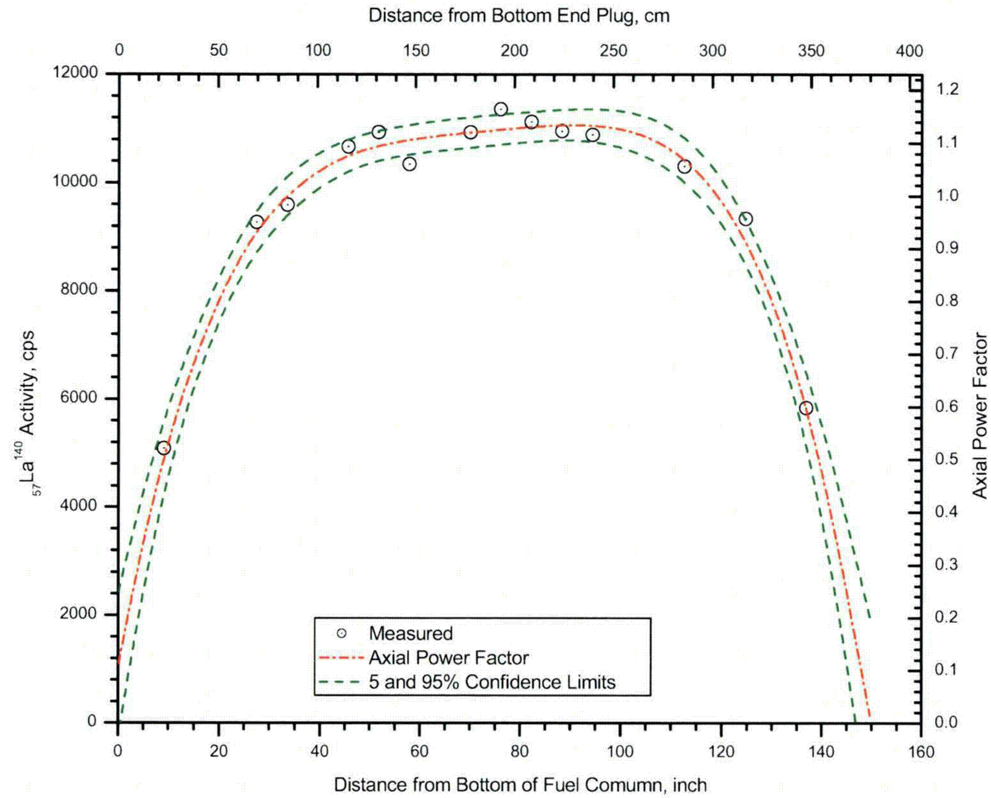
β- 40.2 h 1596 keV

Alternate

$$_{40}Zr^{95} \rightarrow {}_{41}Nb^{95} \rightarrow {}_{42}Mo^{95}$$

β- 65.0 d

β- 35.1 d 765.8 keV



- Ba^{140} inventory varies with power the last 60 days of operation
- The rapid decay of Ba/La^{140} requires measurements in 12 - 36 days after shutdown

Bundle/Nodal Power

Comparison Process

GS data time-corrected to shutdown

Perform 3D core tracking to time of shutdown

Integrate Ba^{140} concentrations

Normalize both measured & predicted Ba^{140}

Statistical comparison (vary subgrouping)

- Core – Region – Type – Bundle – Axial – Nodal

Results reported for PANAC11

A GE12 (10x10) Comparison

(Excerpt from Report)

[[

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imagination at work

Summary Predicted vs. Measured

[[

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Error Versus Bundle Power

[[

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imagination at work

Error versus Axial Position

[[

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Methods Comparison Summary

PANAC11, Monitoring Basis

Last TIP Data

Bundle RMS = [[ ]]

Axial RMS = [[ ]]

Nodal RMS = [[ ]]

Gamma Scan Data

Bundle RMS = [[ ]]

Axial RMS = [[ ]]

Nodal RMS = [[ ]]

Power Allocation (PAL) Uncertainty

Determination Process

Obtain bundle powers around TIP strings

[[ ]]

Compare measured PAL to predicted PAL

Statistical summary

Apply directly in SLMCPR process (σ_{PAL})

imagination at work

NEDE-32694P-A Gamma Scans

[[

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Accumulated Uncertainty Rollup

[[

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Results

Measured vs. predicted power agreement

- 10x10 fuel – well predicted
- Power distribution uncertainties confirmed
- Nodal power agreement excellent
- Data does not indicate any trends with void fraction or bundle power level

Conclusions
Cofrentes Bundle Gamma Scan (2002)

Good comparison between measured and predicted power

- Approved uncertainty confirmed
- Indicates good void prediction
  - Indirect, but VERY relevant confirmation of Findlay-Dix correlation

Power → Neutron Flux → Voids

Cofrentes Cycle 15 (2005)

GNF-A has acquired – In process

[[

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System Deployed at Fitzpatrick

[[

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Rod Power Validation

NEDC-32601P-A, Section 3.1.4

Total rod power is measured

Compare total uncertainty to

[[ ]]

Confirms analytically derived σ is sufficient

imagination at work

GE12/GE14 Product Line Description

[[

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Last Gamma Scan at Duane Arnold in 1984

[[

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FitzPatrick Gamma Scan Statistics JLM420

Preliminary & Unverified

[[

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FitzPatrick Gamma Scan Statistics JLM420
Preliminary & Unverified

[[

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Rod Gamma Scan Preliminary Conclusions

Fitzpatrick Rod Gamma Scan (2006)

10x10 fuel, GE14 lead fuel $\rightarrow$ well predicted

Measurement statistics improved over DA'88

Prediction on modern methods/fuel better

[[ ]]

Post-processing and verification in 2007

Upcoming Gamma Scan Campaigns

More rod scans

Fission gas

Relative burnup

Void Fraction

Void Fraction Comparisons

Thermal-hydraulic experimental data

- 10x10 ΔP measurements
- Uncertainty analysis for α

Full-Scale Tests [[

ATLAS and Stern Labs

- Critical power
- Pressure drop

GNF2 and GE14 tested

]]

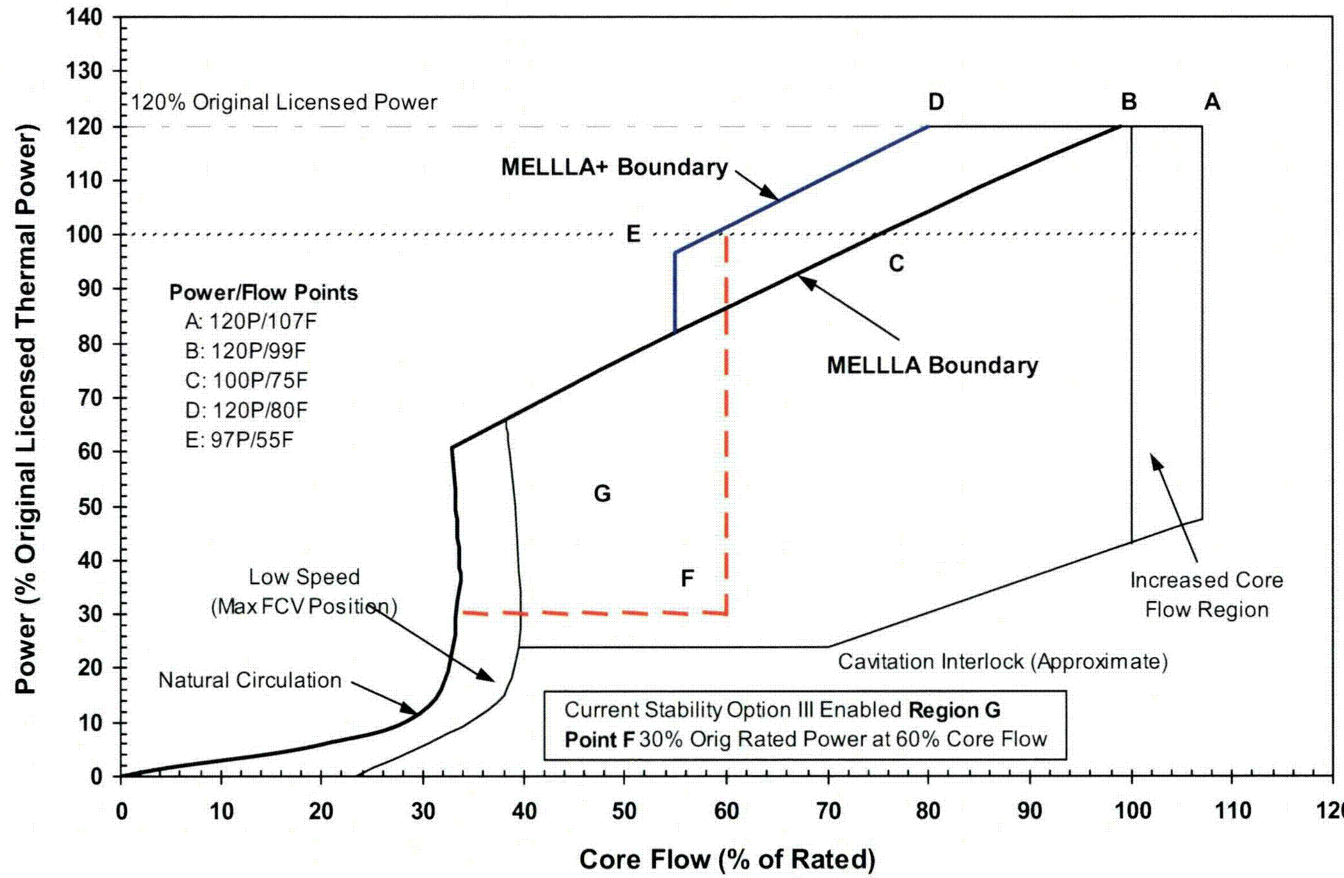
Range of Pressure Drop Tests

Power range: 0 to 8 MWt

- Max approaches critical power

Flow range: 0.1 to 1.5 Mlbm/hr-ft²

- Natural circulation to ICF region



Broad test range to cover the BWR fleet

GE14 and GNF2

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GNF2

GE14

Two geometries for 10x10

10x10 ΔP Test Data Summary

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GE14 ΔP

[[

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GE14 ΔP

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GNF2 ΔP

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GNF2 ΔP

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Pressure Drop Components

ΔP friction

ΔP elevation

ΔP local losses

ΔP acceleration

\+ ΔP expansion/contraction

ΔP total

$$\Delta P_{Elev,Calc} = \frac{\bar{\rho} g \Delta z}{g_c} = \frac{g \Delta z}{g_c}\left[\bar{\alpha}\rho_g + (1-\bar{\alpha})\rho_{liq}\right]$$

Void fraction appears explicitly as a variable

Comparison to Findlay-Dix

[[

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Confirmatory Low Flow Data

[[

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Comparison to Findlay-Dix

Conclusions

- GE14 & GNF2 tests – geometry represents current fuel designs

[[

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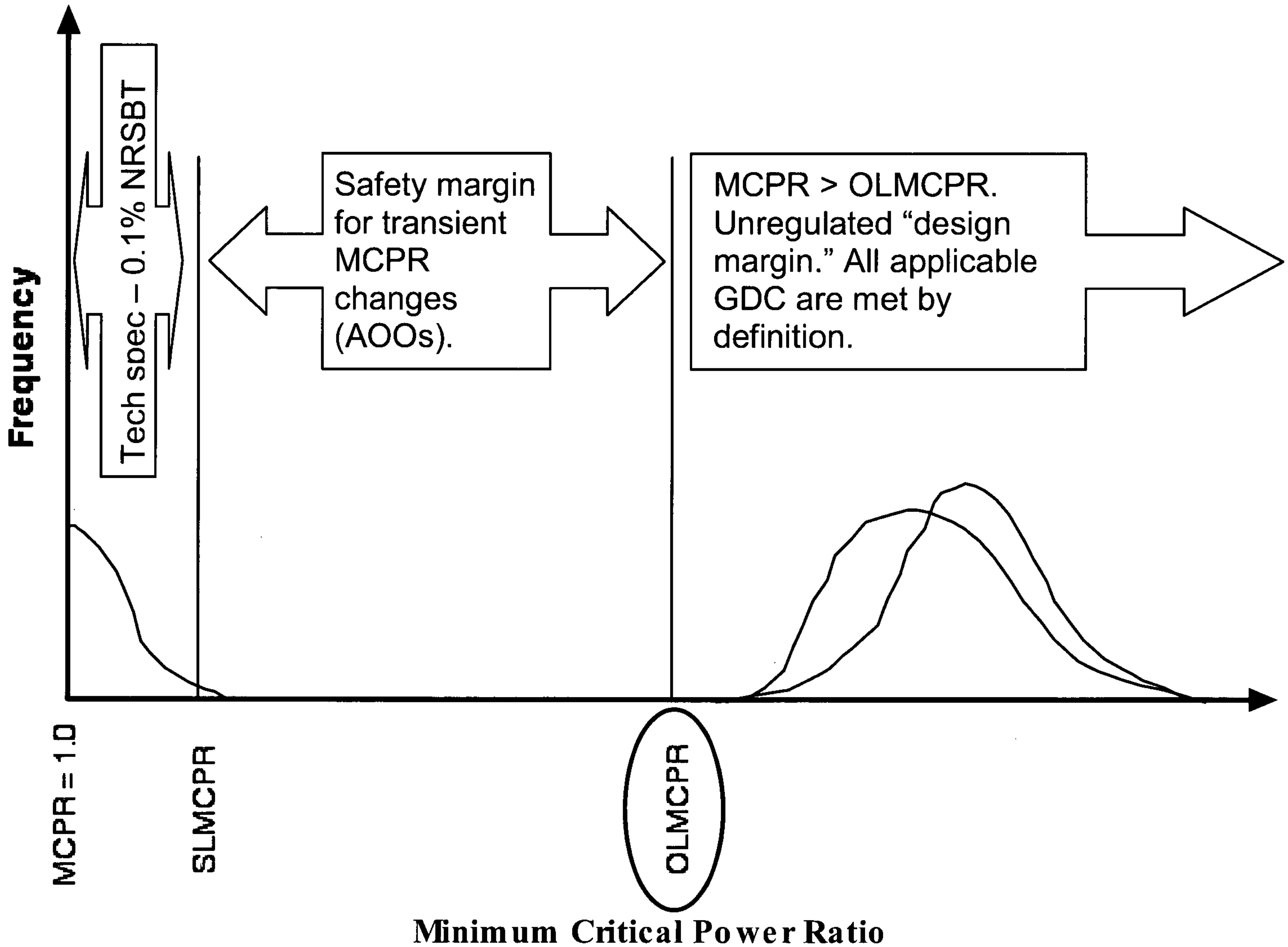
How High Does the Void Fraction Get in the Reactor?

Margins Limit Void Fractions



imagination at work

Sample of BWR Fleet OLMCPRs

OLMCPR caps the max bundle power

$$MCPR = \frac{Critical\ Power}{Power}$$

Informal survey of some 2005 BWR fleet data

[[

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Maximum Expected Values

[[

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Next Steps

COBRAG Licensing Topical Report

- Model description
  - Critical power predictions
  - Void fraction
- Qualification description
  - Subchannel voids (e.g., NUPEC)

END

GNF2 Advantage Description & Licensing

Russ Fawcett
Manager,
Core, Fuel & Advanced Design

GNF2 Design Description

[[

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GNF2 Characteristics

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Margin Characteristics

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GNF2 Licensing Overview

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Generic New Fuel Licensing (A22)

[[

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Generic New Fuel Licensing (A22)

- Thermal-Mechanical
- Nuclear

[[•

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Generic New Fuel Licensing (A22)

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Generic New Fuel Licensing (A22)

- **GEXL**
  > GNF2 specific correlation is GEXL17
  - GEXL form
  - Documented in NEDC-33292P, Revision 0, "GEXL17 Correlation for GNF2 Fuel", November 2006.
  - Provided to USNRC along with 33270P

Generic New Fuel Licensing (A22)

[[

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GNF2 Plant Specific Analyses (NFI)

[[

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GEXL17

Overview

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Database

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Extended Database

[[

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Correlation Performance

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Summary

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GEXL++

Improved GEXL Correlation
GNF Technology Update Meeting
May 1-2, 2007

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Background

- GEXL introduced with GETAB
  - GETAB, NEDO-10958A, 1977
  - $Xc = f(L_B, D_Q, G, P, R)$
  - GEXL01 for 7X7 and 8X8 fuel
- GEXL+ introduced with Amendment 15 to GESTAR II
  - Amendment 15 to GESTAR II, 1986
  - $Xc = f(L_B, D_Q, G, P, R, L_A)$
  - GEXL02 and GEXL05 for 8X8 fuel
  - GEXL07 and GEXL09 for 9X9 fuel
  - GEXL10, GEXL14 and GEXL17 for 10X10 fuel

GESTAR II Requirement GEXL form

1.1.7 Critical Power Correlation

A. The currently approved critical power correlations will be confirmed or a new correlation will be established when there is a change in wetted parameters of the flow geometry; this specifically includes fuel and water rod diameter, channel sizing and spacer design.

B. A new correlation may be established if significant new data exists for a fuel design(s).

C. The criteria for establishing the new correlation are as follows.

i. The new correlation shall be based on full-scale prototypical test assemblies.

ii. Tests shall be performed on assemblies with typical rod-to-rod peaking factors.

iii. The functional form of the currently approved correlations shall be maintained.

iv. Correlation fit to data shall be best fit.

v. One or more additional assemblies will be tested to verify correlation accuracy (i.e., test data not used to determine the new correlation coefficients).

vi. Coefficients in the correlation shall be determined as described in References 1-5 or 1-6.

vii. The uncertainty of the resulting correlation shall be determined by:

$$\sigma^2 = \frac{1}{N-1}\sum_{i=1}^{N}(\mu - ECPR_i)^2$$

where:

σ = standard deviation.

μ = $\frac{1}{N}\sum_{i=1}^{N} ECPR_i$

N = Total number of data in both the data set used to determine the coefficients and the set used for verification.

$ECPR$ = Calculated bundle critical power divided by experimentally determined bundle critical power.

$$X_C = \sum_{I=1}^{18} A(I) \cdot V(I)$$

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Fuel and GEXL Development

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- 7X7 Fuel
  - Egg Crate Spacers
- 8X8 Fuel
  - Egg Crate Spacers
  - Water rods
- 8X8 Fuel
  - Ferrule Spacers
  - Large central water rod
- 9X9 Fuel
  - Ferrule Spacers
  - Large central water rods
  - Part length rods

  [[-]]
- 10X10 Fuel
  - Ferrule and X-750 spacers with flow wings
  - Large central water rods
  - Part length rods

  [[-]]

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GEXL++

[[

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COBRAG Qualification

Existing qualification

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COBRAG Qualification

Additional qualification (unverified)

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Schedule

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PRIME03 Status & PRIME Transient Models Development

Nayem Jahingir & Steve Liu

NRC/GNF Technology Update Meeting
May 1 - 2, 2007
GNF, Wilmington, NC

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Outline

- PRIME03 Development & Status
  - Summary of new models
  - Summary of PRIME03 qualification
  - NRC Submittal & Review
- PRIME Transient Models Development
  - Status and Licensing Approach
- Summary

PRIME03 Thermal/Mechanical Model

A state-of-the-art computer program for fuel rod Thermal/Mechanical licensing and behavior analysis

> Address high exposure mechanisms
  - **Porous pellet rim**

> Address high exposure materials properties measurements
  - **Pellet thermal conductivity**
  - Pellet grain growth
  - Cladding irradiation creep and growth

> Address exposure dependencies of fuel performance models
  - **Fission Gas Release**
  - Pellet relocation
  - Fuel-cladding axial slip
  - Pellet radial power distribution

> Developed to replace GESTR-Mechanical (and GESTR-LOCA)

PRIME03 Thermal/Mechanical Model (cont.)

[[

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PRIME03 Thermal/Mechanical Model (cont.)

- High Burnup structure (rim) Formation at Pellet Periphery
  - Increased porosity
  - Lower fuel density
  - Sub micron grains
  - Decreased thermal conductivity

[[

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PRIME03 Thermal/Mechanical Model (cont.)

- Fuel Thermal Conductivity [[
  - Function of exposure
  - Function of Gadolinia and Additive content
  - Defect recovery due to thermal annealing

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PRIME03 Thermal/Mechanical Model (cont.)

- Fission Gas Release (FGR)
  - Athermal release
    - direct recoil and knock-out
  - Thermal diffusion
  - Increased release at high exposure
  - Threshold is calibrated with high exposure test rods and commercial BWR fuel rods

[[

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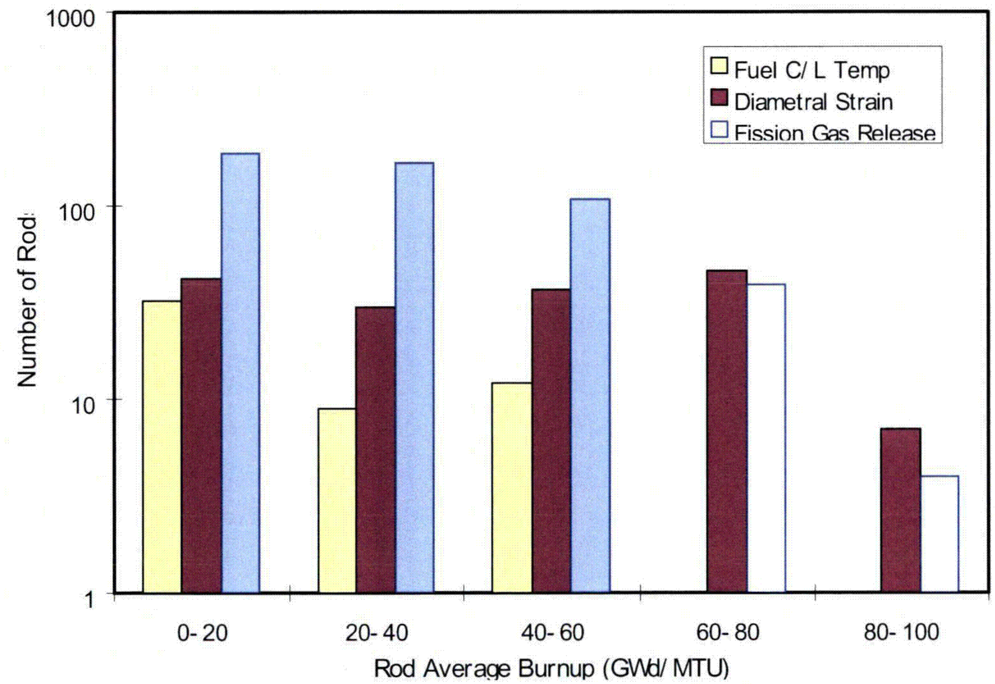
PRIME03 Qualification

- More than 600 rods
  - test and commercial reactors data
  - wide range of manufacturing and operating conditions
  - about 50% of the rod burnup > 40 GWd/MTU

- Fuel Centerline temperature
  - about 50 rods
  - key parameters
    - fuel burnup
    - fuel densification
    - initial gap
    - fill gas composition
    - fuel surface roughness
  - LHGR well beyond the typical of commercial reactor operation
  - extensively qualified at the most limiting burnup



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PRIME03 FGR Qualification

- About 500 rods from test and commercial reactors
- Includes in-pool gamma scan data + Rod puncturing data
- Significant number of high burnup data
  - reliable prediction of EOL rod internal pressure

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PRIME03 Status

- LTRs Submitted to NRC on 02/07
  - PRIME Technical Bases (NEDC-33256P)
  - PRIME Qualification (NEDC-33257P)
  - PRIME Application (NEDC-33258P)
- NRC acceptance review
- SE anticipated ~ 08/08

PRIME Transient Models Developments

- Current analysis approach
  - Separate codes for steady state and transient analysis
  - Substantial effort to interpolate and transfer variables in between codes
  - Additional code maintenance

- PRIME Steady State & Transient Analysis code
  - Seamless transition from steady state to transient analysis domains
  - Compatible numerical structures for steady state and transient regimes
  - Qualified for fast transients like RIA

PRIME Transient Application

- Intended to replace current methods for licensing evaluations for transient events
- PRIME transient application
  - Licensing Calculation
    - No fuel melting
    - 1% plastic strain
  - RIA type of transient
    - Final RIA criteria development

PRIME Transient Licensing Approach

PRIME

PRIME03 Steady State

Model
Qualification
Application

NRC 02/07

SE expected ~ 08/08

PRIME Transient

Model
Qualification
Application

NRC 3Q/07

SE expected ~ 1Q/09

PRIME SS & Tran Code

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Summary

- PRIME03 Steady State Code
  - LTR Submitted 02/07
  - Support [[ ]]
  - Support [[ ]]
  - Replace GESTR-Mechanical and GESTR-LOCA
  - SE expected ~08/08
- PRIME transient Models Development
  - Level II under GE/GNF QA procedure
  - No change in current steady state methods (PRIME03)
  - LTR Submission ~ 3Q/07
- Maintain currently approved "GE/GNF Procedure for Fuel Property and Model Revision" (MFN-170-84)

Channel-Control Blade Interference Update

Presentation to NRC
May 1-2, 2007

Paul Cantonwine
Lead Engineer – Materials Technology & Fuel Reliability
Fuel Engineering

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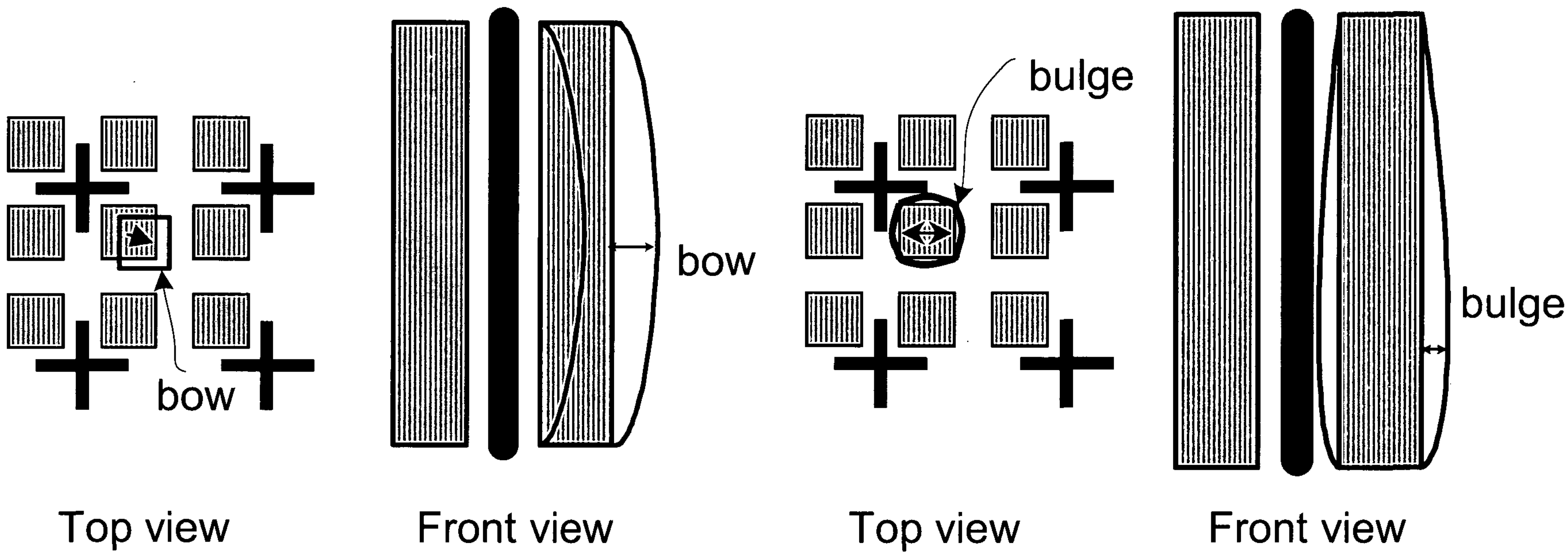
Outline

- Background
  - Channel bow and bulge
  - Observations of interference
  - GNF response to observations
- Mitigation Strategy
  - Cell Friction Methodology
  - Improve Channel Materials
    - Lead Use Channel Plans
- Summary

Deformations and Definition of Terms



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Fluence Gradient Induced Bow

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Shadow Corrosion-Induced Channel Bow

[[

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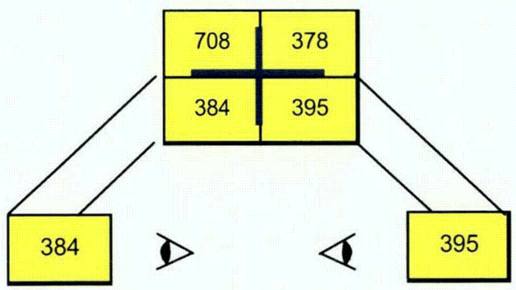
Impact of Channel-Control Blade Interference

- Slow Settle
  - 10 s < Settle Time < 30 s
- No Settle
  - Settle Time > 30 s
- Slow Scram Time
  - Scram time to 90% Insertion < 7.0 sec
- Failed Scram Time Test
  - Scram time to 90% Insertion > 7.0 sec

Background - Observations

- BWR/6 S-Lattice Plants
  - Observed no-settle and slow-to-settle cells in 2000-2001
- BWR/4-5 C-lattice Plants
  - Observed no-settle and slow-to-settle cells in 2003
- BWR/2-4 D-Lattice Plants
  - One no-settle observation in 2007



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Background – GNF Response to Observations

Characterization program initiated

- Poolside channel bow, bulge, length measurements
- Channel coupons retrieved for hotcell examination Safety Information

- 10 CFR Part 21 Communications
  - SC03-04: Notification of Interference Observations - March 3, 2003
    - New bow mechanism identified (shadow-corrosion induced bow)
  - SC03-08 Rev 1: Interim Surveillance Program – April 30, 2003
    - Introduced use of Effective Control Blade Exposure (ECBE; units inch-days) as a correlating parameter for shadow bow
  - SC05-06: Updated Surveillance Program – July 14, 2005
    - Introduced Cell Friction Methodology; a more quantitative tool that could be used to prevent interference in design
  - SC06-12: Updated Surveillance Program – September 26, 2006
    - Clarification of procedure for stall flow measurements and full stroke insertion testing
- Updating Cell Friction Methodology to include shadow effect in D-Lattice Plants (2007)

Mitigation Strategy

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Near Term: Mitigate via Monitoring and Design

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Core Map of Cell Friction Metric Values

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Long Term: Mitigate via New Materials

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Status of In-core Demonstration Programs

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New Material LTA Program: Summary

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Shadow Corrosion Effect Assessment

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Summary

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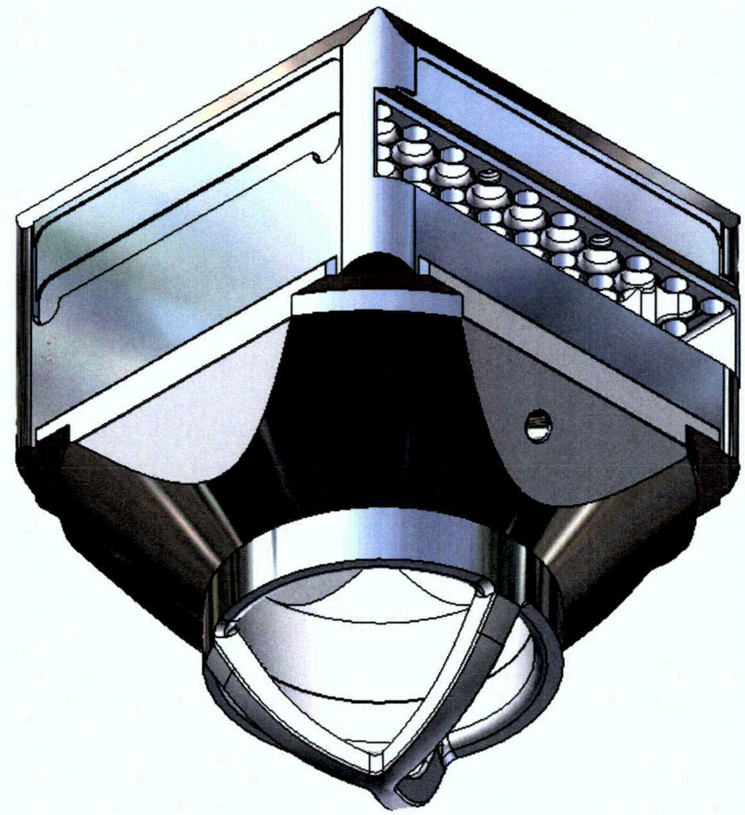
GNF Technology Update Meeting

Defender Lower Tie Plate



May 1-2, 2007

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Agenda

- Defending Against Debris ... Customer Impact
- Debris Filter Evolution ... Three Generations !
- Defender Description
- Significant Testing
- Defender Development
- Defender Product Deployment

Customer Impact (Debris)

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Debris Filter Evolution ... Three Generations !

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Defender Description

- The Defender Bundle
- Capturing The Filter
- The Defender Filter

Defender Bundle – Assembly Description

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Defender – Capturing the Filter

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Defender Filter

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Defender Testing

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Debris Testing – Selecting the Best Filter

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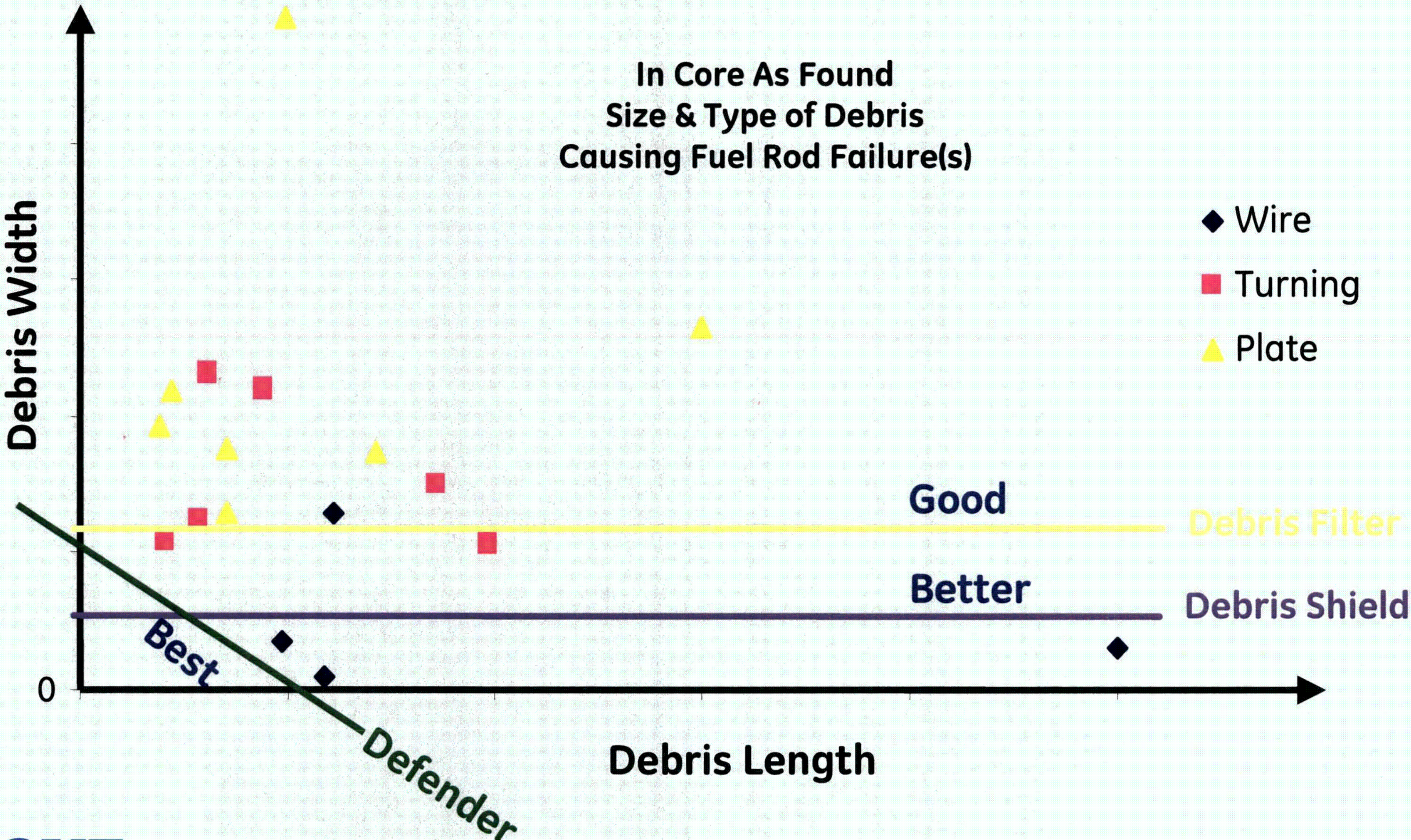
Debris Testing – Selecting the Best Filter



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Single Phase Testing – Tuning Defender

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Endurance Testing

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Defender Development

GNF & Suppliers
Key CTQ – Foreign Material Exclusion

Developing Defender … A Global Effort

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No Single Supplier Could Do It All !

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Foreign Material Exclusion – Setting Expectations

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Defender Deployment

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GNF - Defending The BWR Fleet !

GNF Technology Update Meeting

GNF-Ziron Cladding

Yang-Pi Lin

May 1-2, 2007

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GNF-Ziron Cladding

Program Objective

Introduce [[

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- Introduction/Background
- In-reactor Experience

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Composition Comparison (wt%)

	Zircaloy-2	**GNF-Ziron**
Zirconium	> 97	[[
Tin	1.20 – 1.70	
Iron	0.07 – 0.20 (0.17 – 0.18 typical)	
Chromium	0.05 – 0.15	
Nickel	0.03 – 0.08	]]

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GNF-Ziron Background

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GNF-Ziron Experience

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GNF-Ziron Performance

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Tensile Elongation

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Creep Behavior

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GNF-Ziron – Lead Use Applications

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GNF-Ziron – Lead Use Applications

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Simulated LOCA Oxidation Results

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Simulated LOCA Test Results

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Simulated LOCA Test – additional tests

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GNF-Ziron Licensing Strategy

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GNF Fuel Experience & Reliability

Presentation to NRC
May 2007

Rob Schneider

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Agenda

- Fuel Experience Summary

  Total, current designs

- Reliability Trend

  historical, recent trends

  2006 data

- Details

  GE14 failures

- New Fuel Reload Surveillance Status
- LUA Surveillance Status
- Rod Gap Observations

GNF Fuel Experience (May '74 to Dec '06)

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Fuel Experience Update (through 3/31/07)

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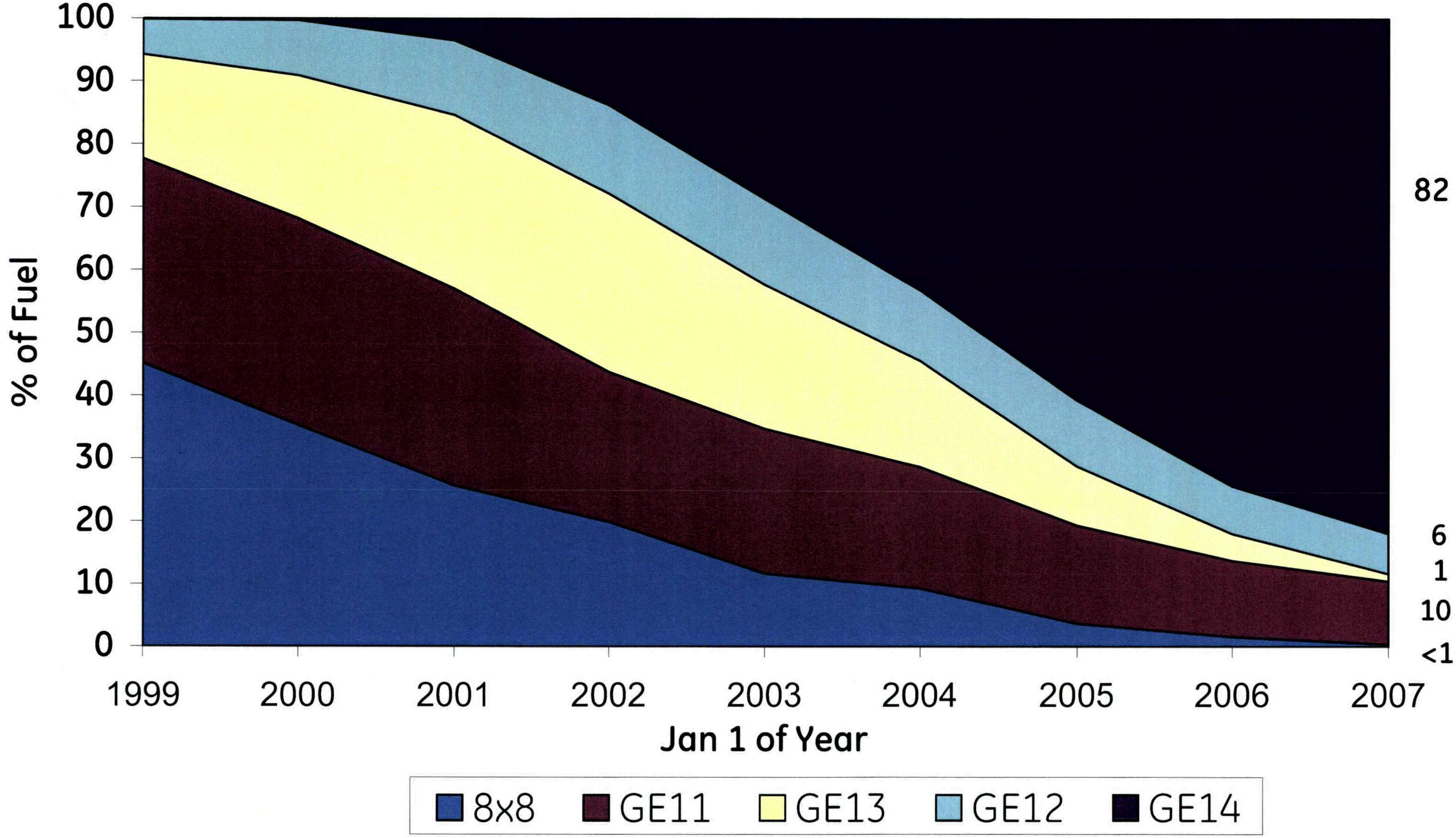
Fuel Experience Update



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Historical Reliability Trends

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GNF Fuel Failures per Year – All designs

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2006 overview

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New Fuel Reload Surveillances

- Completion reported to NRC for designs through GE11
- Inspections partially completed for GE13 and GE12
- GE14 - some reload bundles discharged after three two-year cycles now available for inspection at "end of life"

Fuel Design	1st Year of Introduction	BOL Date Examined Bundles	Total Plants	Total Bundles Examined
GE8B	4/87-3/88	6/87-9/87	3	33
GE9B/GE10	11/89-5/91	6/90-6/91	4	30
GE11	7/92-6/93	7/92-8/93	3	28
GE12	12/96-1/97	12/96-5/98	3	5
	NOTE: also ~73 bundles with BOL 11/97, 5/99 inspected after two cycles at ~40 GWd/MT			
GE13	3/96-4/97	3/96-11/97	6	10
	NOTE: Numerous additional inspections at EOL of more recent bundles and channels			
GE14	2000-2001 in US			
	NOTE: over 70 inspections completed at various exposures (LUAs, failures, and routine surveillances associated w/ chemistry changes, etc.)			

Rod Gap Surveillance

[[

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Lead Use Assembly Surveillances

- GE14 LUA Irradiations complete
- GNF2 LUAs began irradiation in 2005

[[

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GNF2 LUA Inspections Summary

Background

- Completed first annual cycle of operation (Sept 05 to Aug 06)
- 11.5 GWd/MTU bundle average exposure
- Two bundles inspected
  - JLL934 – channel & bundle periphery visuals
  - JLL936 – above inspections, plus detailed component visuals, disassembly for individual rod visuals and COINS (liftoff), fuel deposit sampling, water rod removal (length measurements and inspection)

Liftoff Results

Expected good corrosion performance

- Low Liftoff, within GNF experience base
  - like most US plants, Zn injection and NobleChem™

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all-new Inconel spacer

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Nothing unusual noted; 10 rods removed & returned, no problems

LTP – finger springs eliminated

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Nothing unusual noted; no problems de-channeling, or re-channeling

Channel

[[

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Nothing unusual noted; integral spacer & adapter, 100 mil uniform thick ends, no problems de-channeling, or re-channeling

Partial length rods on periphery

[[

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Nothing unusual noted

Empty cells in upper spacer

Debris Shield

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no clogging or unusual crud deposition

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Fuel rods

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GNF2 LUA Failure Inspection Summary

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One of 3 failures in first ~5-6 mos of cycle, removed at Dec 06 MCO

Replacement rod installed, to be reinserted May 07 RFO

GNF2 LUAs Inspection Summary

No surprises

New features - performance as anticipated

Rods successfully removed/reinstalled

Inspections planned at KKM after every cycle

    Aug 2007 two cycles at ~24 GWd/MTU

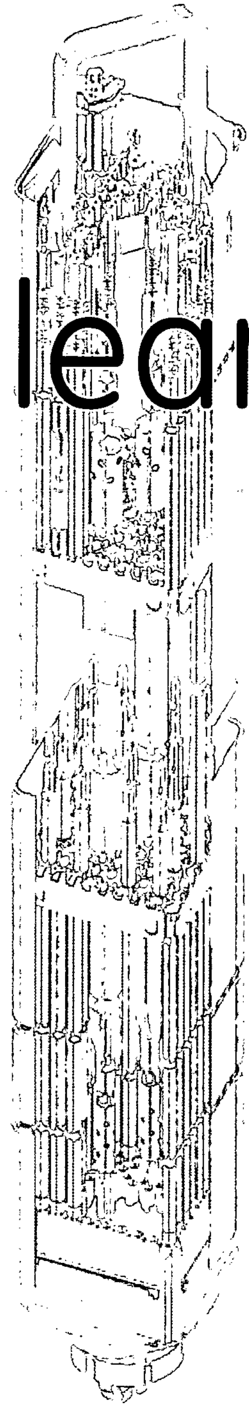
Inspection completed at Forsmark-3 April '07

Inspection at PB3 fall '07

Global Nuclear Fuel

April 2007

Rob Schneider



Topics

Defense in Depth

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Fuel reliability is defined as

"Boring Fuel[1]"

[1] a working definition courtesy of Dr. Schraeder (RWE).

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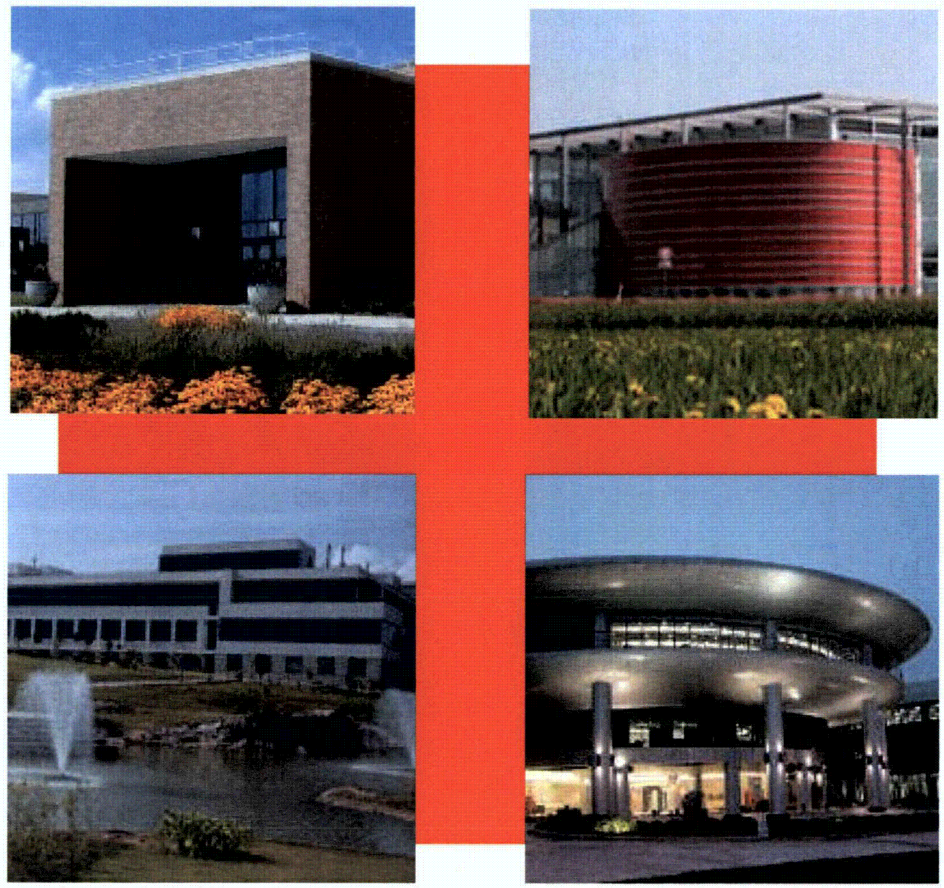
Four GE Global Research Centers

Global Research Center Headquarters

Niskayuna, New York

Global Research—Europe

Munich, Germany



John F. Welch Technology Centre

Bangalore, India

China Technology Center

Shanghai, China

Aided in the development of barrier fuel – now engaged in materials and chemistry defense in depth activities

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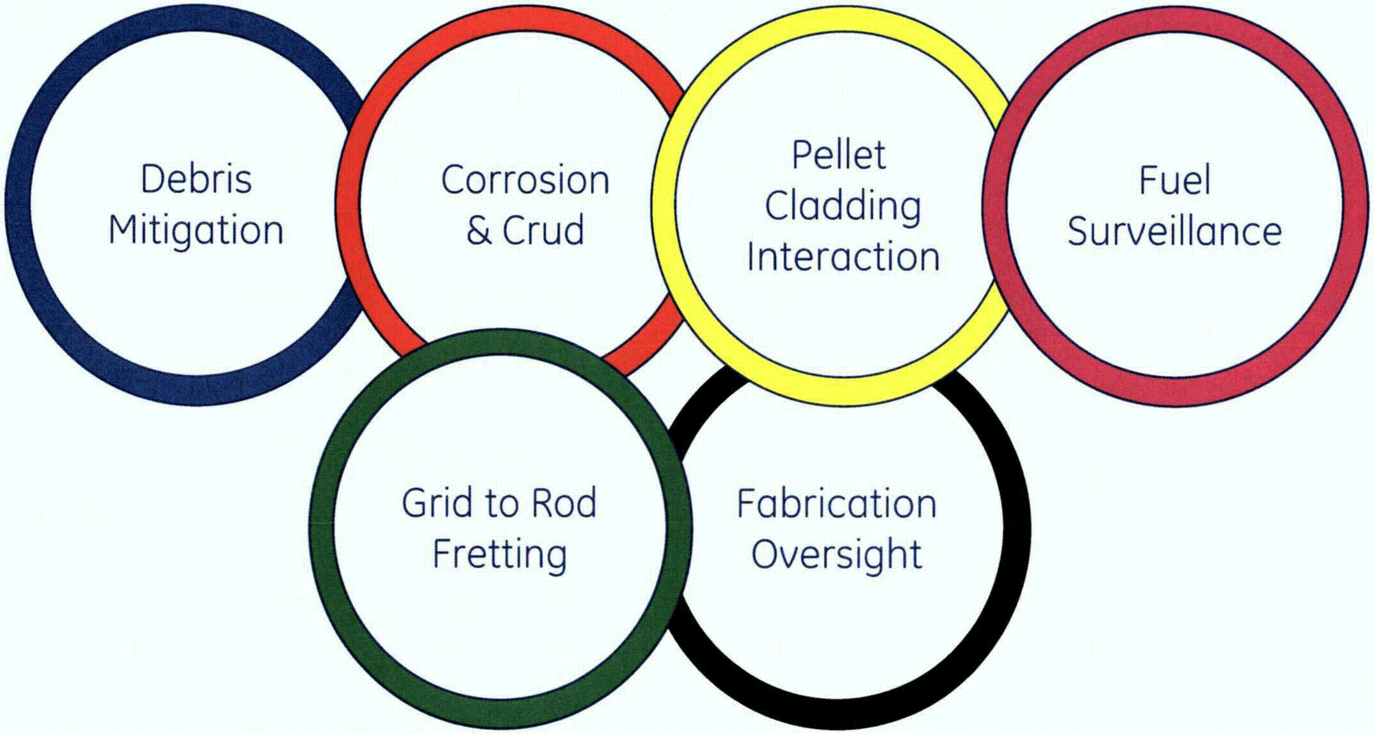
INPO Guidelines: Zero by 2010 Guideline Committees



GNF Team involved in creation of each guideline area except Grid to Rod fretting

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GNF Defense-in-Depth Program Initiated in 2005

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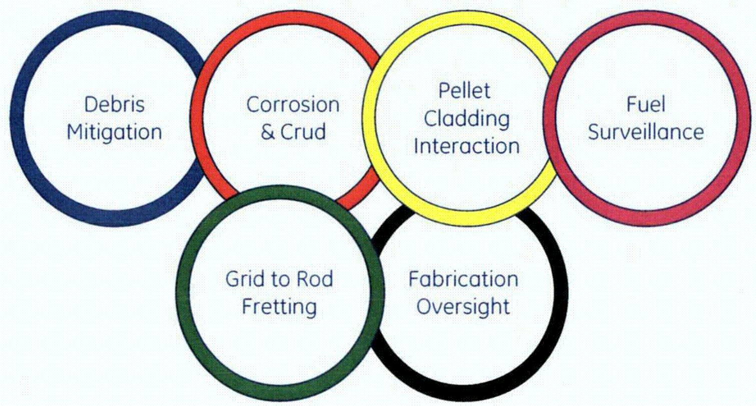
Program scope (target active mechanisms):

- Debris, Corrosion, Duty and Manufacturing

Validated by:

- EPRI (2005) and multiple customers

Well aligned with emergent INPO initiative:



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10x10 Debris Failures Occur at Top of Bundle

Debris Mitigation

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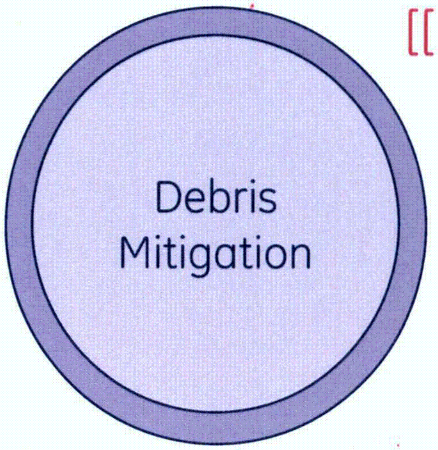
Debris Fretting Velocity Threshold



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GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

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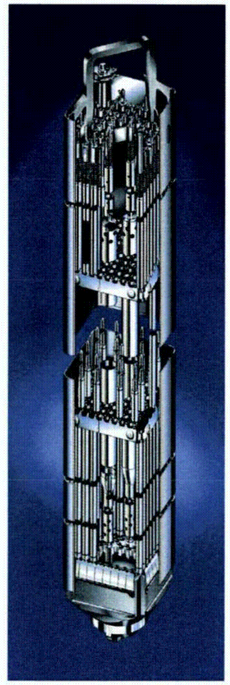
Debris from top and BOP

Debris Mitigation



Clad fretting

Spacer capture

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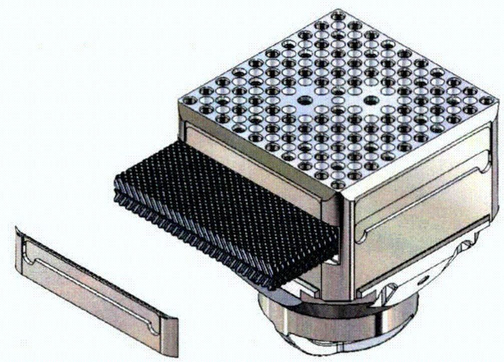

Debris from bottom

Non line of sight filter

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Stern Labs Debris Test Facility

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Debris filter capability evolution

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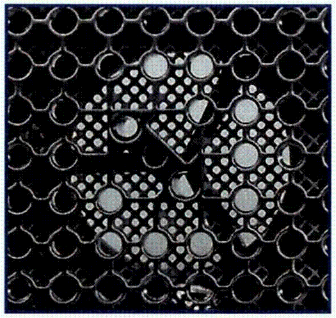

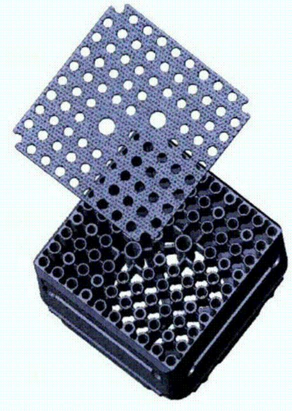

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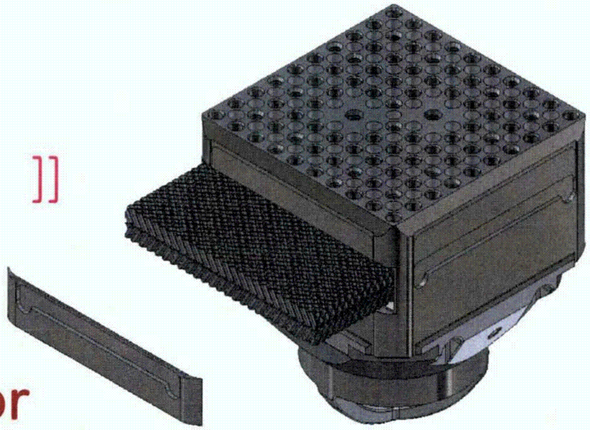

Deployed in three reloads – 50% of reloads for '07, 75% for '08

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Debris filter capability evolution

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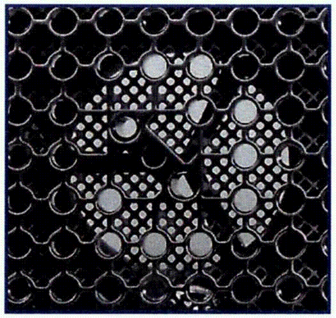

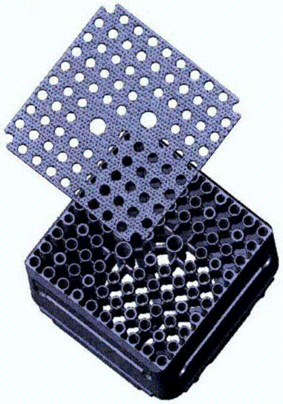

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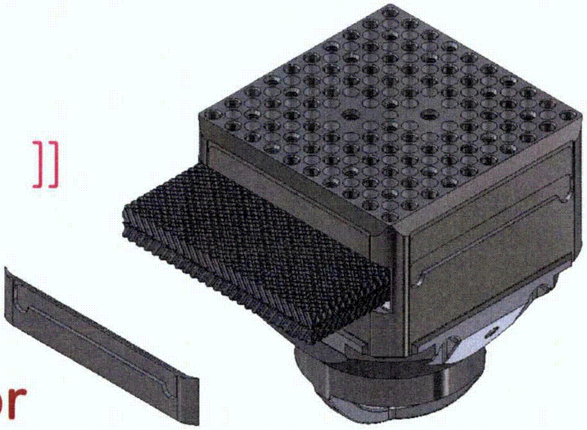

Deployed in three reloads – 50% of reloads for '07 fab, 75% for '08 fab

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GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

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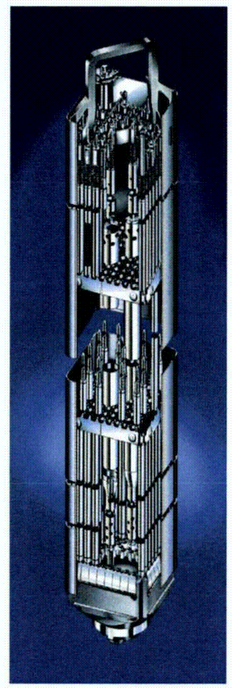
Debris Mitigation

Debris from top and BOP



Clad fretting

Spacer capture

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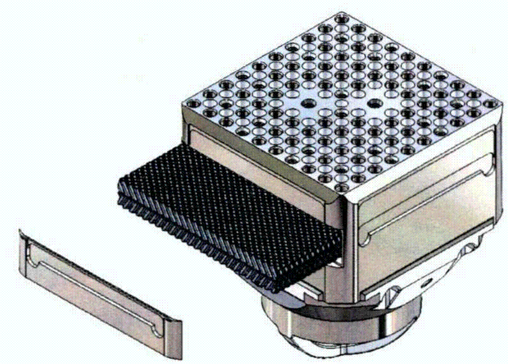

Debris from bottom

Non line of sight filter

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Hitachi 2Φ debris interaction study

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Hitachi results ....spacer capture modes

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Hitachi 2Φ debris interaction study

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GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

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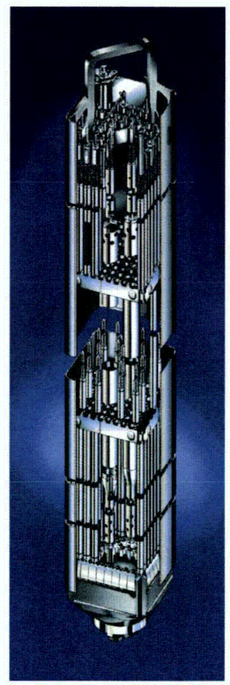
Debris from top and BOP

Debris Mitigation

Clad fretting



Spacer capture

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Debris from bottom

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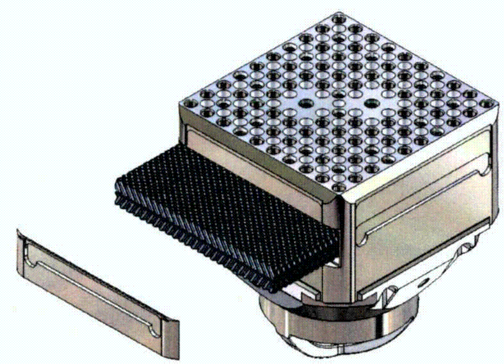

Non line of sight filter

GRC Fretting/Fuel Rod Coating Test

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GRC Fretting Test Comparison to in-reactor

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Depth Wear Rate as a Function of Initial Contact Stress

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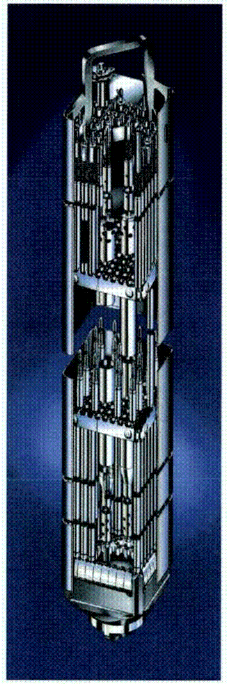
Debris Mitigation

Debris from top and BOP



Clad fretting

Spacer capture

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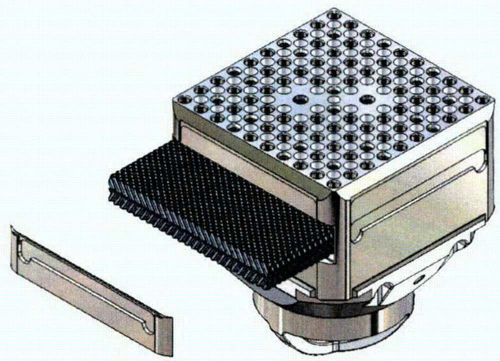

Debris from bottom

Non line of sight filter

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Defender Planned Debris Retention Testing

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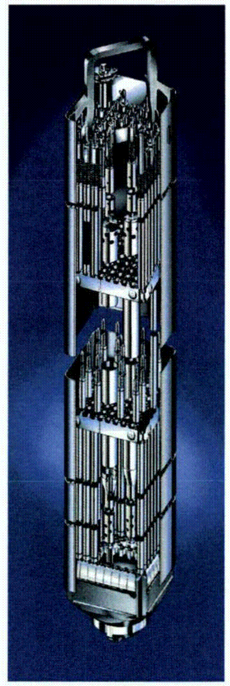
Debris Mitigation

Debris from top and BOP



Clad fretting

Spacer capture

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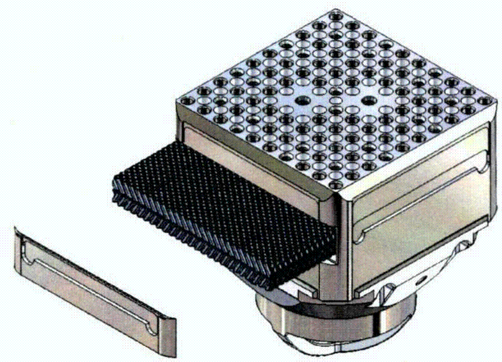
Debris from bottom



Non line of sight filter

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Water*MD* Debris Strainer

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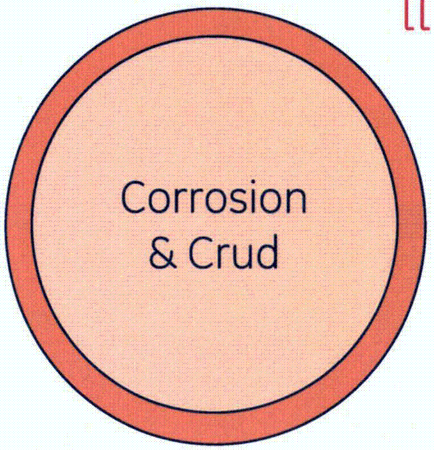

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GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

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Corrosion & Crud

GE Global Research Center work

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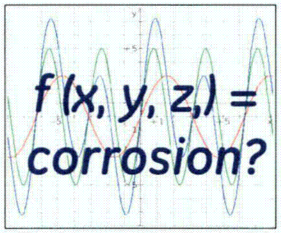
WaterMD – Chemistry M&D Solution

Instrumentation:

- More/better data than ever before. 18 species (Anions, Cations, TMetals, Silica) every 30 min, 100ppt or better.
- Online/Remote Monitoring
- "Hands-free", low-dose operation.
- GE-assured uptime/accuracy.

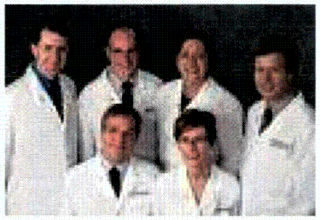
Software:

- Technology to translate species observations to corrosion rates/predictive failure.
- Reduced false alerting. Improved productivity.
- Enhanced capability to associate scenarios to species observations.
- Streamlined setup/configuration.



Consulting:

- GE assembled panel of experts (GE Nuclear Chemistry, Nuclear Fuels, Water & Process Technologies, EPRI) .
- Responsive to real-time alerting of transient conditions.
- Impact forecast + remediation recommendations.
- Shutdown/Outage/Startup Chemistry Optimization.
- Fuel inspection analysis & recommendations.
- Fuel/chemistry expertise augmentation.



Additional Value - **"Better than current capabilities, at less than current costs."**

- Hardware & software significantly discounted (leveraged WaterMD volume).
- What other "incentive" would be attractive to customers?
- EPRI/INPO-endorsed, proactive compliance with 2010 "no fuel failures" initiative.

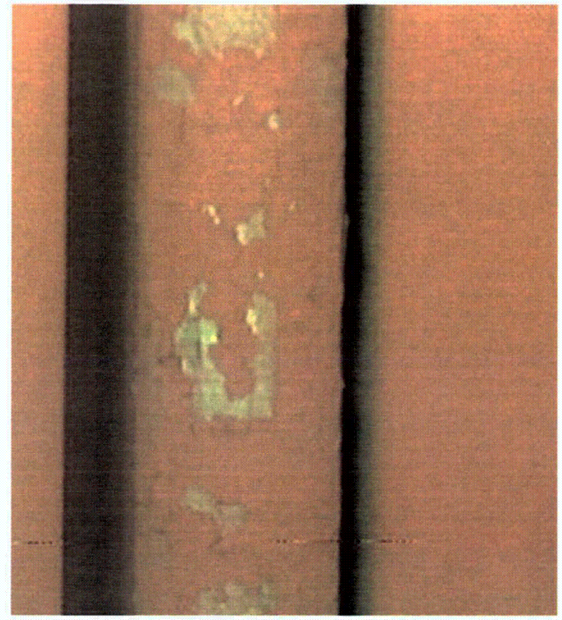
GE holistic solution to BWR customers

GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

Corrosion & Crud

Help from INPO:

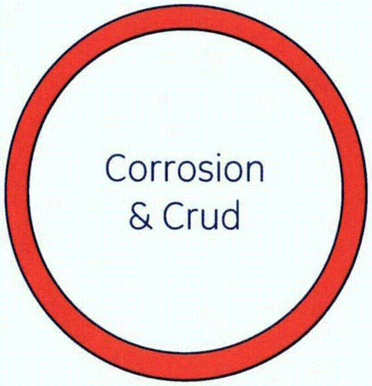
Driving the right behavior to prevent future CILC (Crud Induced Localized Corrosion) failures



Copper Crud layer within oxide

INPO has drafted chemistry excursion index (CEI) which includes copper

Shadow corrosion: Zr-4 Channels as potential long term solution for channel bow.



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Channel materials to eradicate channel shadow bow

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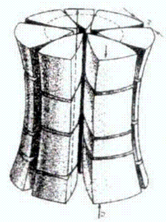
GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

Pellet Cladding Interaction



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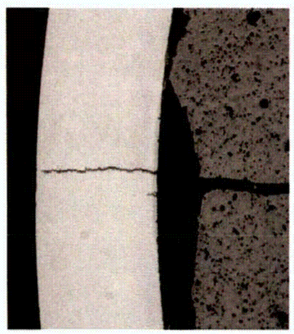

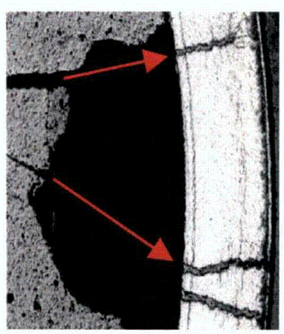

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GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative – Monitoring System Upgrade (3D Monicore)

Pellet Cladding Interaction

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Pellet Cladding Interaction

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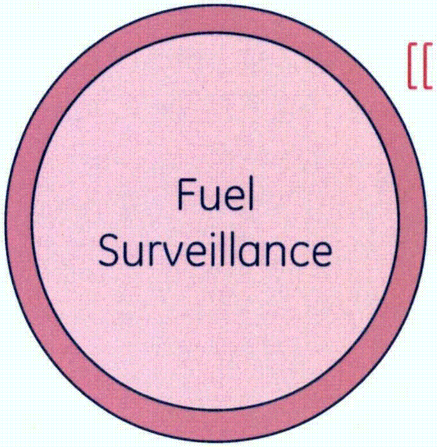

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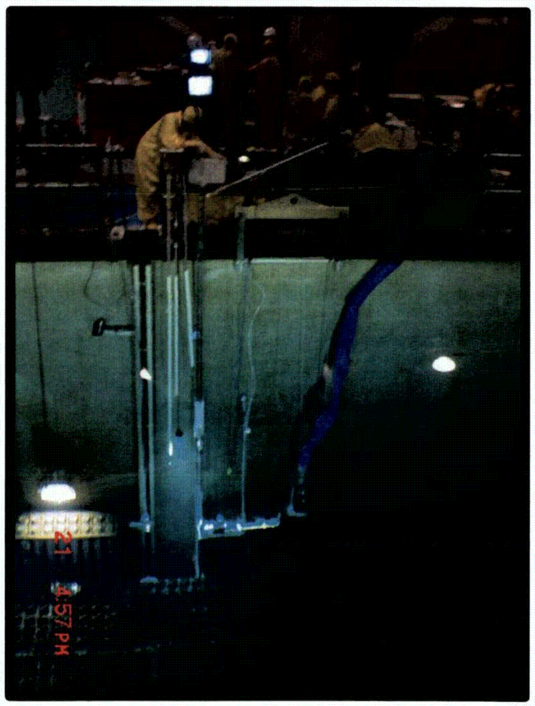
GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

Fuel Surveillance



Cofrentes 2002 Bundle Scan

10x10 fuel, mixed core

- Bundle RMS = [[ ]]
- Axial RMS = [[ ]]
- Nodal RMS = [[ ]]

Cumulative Power Allocation Factor

[[ ]]

Verified

Fitzpatrick Rod Scan

10x10 fuel, GE14 lead fuel

Measurement statistics improved over DA'88

Prediction on modern methods/fuel better

[[ ]]

Preliminary

Vermont Yankee Rod Scans

Mid-May 2007

GNF Defense-in-Depth Program Alignment with INPO 2010 Initiative

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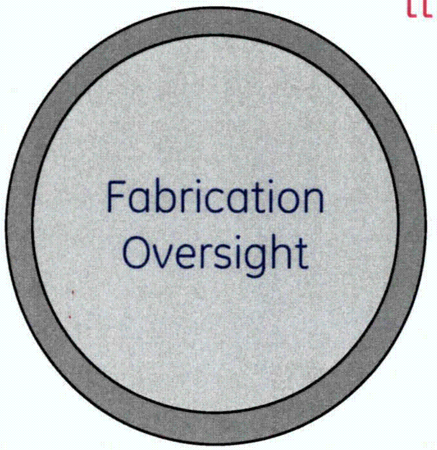

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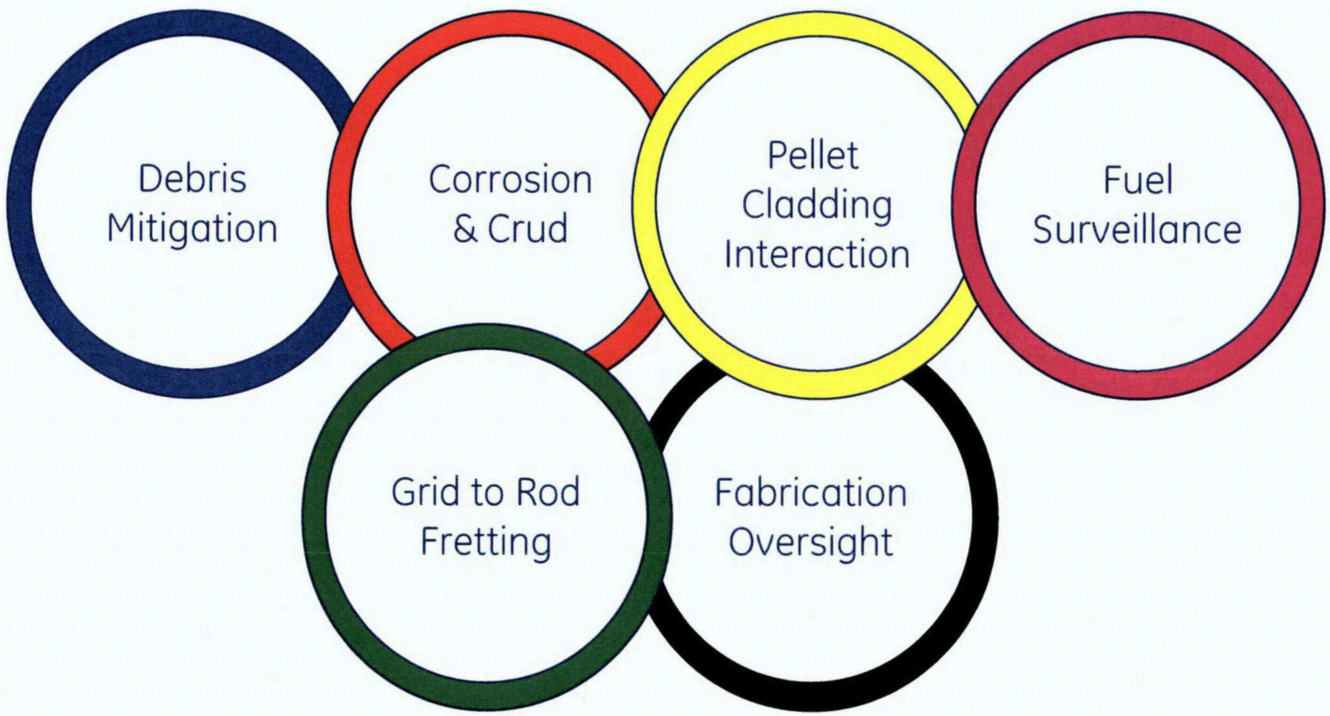
GNF Defense-in-Depth ... Complete BWR alignment with INPO 2010 Initiative



Total GNF/GE engagement

Fuel & Services Engineering & Quality & Manufacturing & GRC

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GNF Information	Planned Submittal	Target Approval
LTRs CLOSING		
NEDC-33173P Applicability of GE Methods to Expanded Operating Domain (Methods LTR - Interim)	Submitted	2007 3Q
NEDE 33006P "GE BWR Maximum Extended Load Line Limit Anlysis Plus" (MELLLA+)	Submitted	2007 3Q
DSS-CD Rev. 5	Final SE	NA
DSS-CD Rev. 6		NA
DSS-CD TRACG02 Application	Awaiting final SE	
GESTAR Rev 16A		
GNF2 GESTAR II Compliance	Submitted	N/A
GNF2 GEXL report	Submitted	N/A
LTRs IN PROCESS		
NEDE-33284P GE Marathon 5S Control Rod Assembly	Submitted	2007 3Q
Prime Thermal Mechanical Model	Submitted	2008 2Q
TRACG Implementation of P11 Kinetics. Supplement to 3 NEDE-32906 (Application Report)	Submitted	2007 4Q
GEXL14 Supplement	Submitted	2007 2Q
FUTURE LTRs		

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GNF Information	Planned Submittal	Target Approval

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