REPORT OF EXPERT PANEL ON BURNUP CREDIT

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by

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BACKGROUND

- U.S. NRC (Office of Regulatory Research for Spent Fuel Project Office) initiated a research program to:
  - Clarify guidance on acceptable approaches to burnup credit
  - Develop approaches for expanding the range of burnup credit
  - Address regulatory needs for safe, simple, and cost-effective implementation of burnup credit
- Expert panel was seen as an effective process to advance these aims
- Panel was to do its work using the PIRT methodology
  - PIRT = Phenomena Identification and Ranking Table

MEMBERS OF THE PANEL

George H. Bidinger	Private consultant
Richard J. Cacciapouti	Duke Engineering & Services
Jose M. Conde	Consejo de Seguridad Nuclear
Patrick Cousinou	Institut de Protection et de Sfreté Nucléaire
Thomas Doering	Electric Power Research Institute
Peter Grimm	Paul Scherrer Institut
Hae-Ryong Hwang	Korea Power Engineering Company, Inc.
Willington J. Lee	NAC International
Daniel Marloye	Belgonucleaire
Raymond L. Murray	North Carolina State University
Jens-Christian Neuber	Siemens AG
Michaele B. Raap	Battelle Pacific Northwest National Laboratory
Joseph Sapyta	Framatome ANP
Daniel A. Thomas	Framatome ANP
Stanley Turner	Holtec International
Robert E. Wilson	U.S. Department of Energy

SUPPORT TO THE PANEL

- Technical Support
  - Cecil V. Parks
  - John Wagner
  - Mark DeHart
- Facilitators
  - Brent Boyack
  - David Diamond
- NRC Staff
  - Farouk Eltawila
  - Richard Lee
  - David Ebert
  - Don Carlson
  - Et al.

THEORETICAL PIRT PROCESS

- Define the problem
- Define PIRT objectives
- Define hardware and scenario
- Define evaluation criteria
- Identify, obtain, review database
- Identify phenomena (processes, parameters, etc)
- Rank importance and provide rationales
- Assess uncertainty
- Document results

APPLICATION OF THE PIRT PROCESS

- Define the problem: licensing of casks for transport and storage
- Define PIRT objectives
  - Identify and rank important phenomena relative to criticality of a flooded cask
  - Help guide future NRC efforts in support of licensing taking into account BUC
- Define hardware and scenario
  - Intact PWR UO_2 fuel initial enrichment <5 w/o; cooled >1 yr, <200 yr
  - Generic cask design (32 fuel assemblies)
- Define evaluation criteria
  - Figure of Merit (FOM) #1: The actual neutron multiplication factor (k_{eff}) for irradiated nuclear fuel in transport and storage configuration.

APPLICATION OF THE PIRT PROCESS

- Identify, obtain, and review database
  - Panel was provided information
- Identify phenomena (and define them)
- Rank importance and provide rationales
  - High – phenomenon has dominant impact on FOM#1 e.g., reactivity effect >2%; implies the need to explicitly and accurately model and to be considered in any expt'l program
  - Medium – moderate impact on FOM e.g., 2%>D>0.5%; should be well modeled but accuracy may be somewhat comprised in codes; should be considered in expts.
  - Low – small impact, e.g., D<0.5%; should be represented but model not so important; should be considered in expts. to the extent possible

APPLICATION OF THE PIRT PROCESS

- Assess uncertainty (knowledge scale)
  - "known" - approximately 75-100% of full knowledge and understanding of the phenomenon
  - "partially known" - approximately 25-75% of full knowledge and understanding of the phenomenon
  - "unknown" - 0-25% of full knowledge and understanding of the phenomenon
- Document results
  - NUREG/CR –6764, "Burnup Credit PIRT Report"

PHENOMENA/PARAMETERS THAT INFLUENCE FOM#1

- Spent fuel assembly materials
  - Worth of actinides in SNF
  - Worth of fission products in SNF
  - Worth of oxygen
  - Worth of residual absorber materials
  - Worth of non-fuel component compositions

- Depletion parameters/conditions
  - Fuel temperature
  - Moderator temperature/density
  - Soluble boron
  - Specific power
  - Specific power history
  - Burnable poison rods
  - Integral burnable poisons
  - Control rods

PHENOMENA/PARAMETERS THAT INFLUENCE FOM#1

- Cooling time
- Burnup
  - Axial burnup
  - Horizontal burnup
  - Burnup distribution across pin
- Fuel characteristics
  - Assembly geometry
  - Cladding hydriding
  - Changes in water/fuel ration due to clad creepdown, gap flooding,etc.
  - Rod bowing
- Initial (fresh) fuel enrichment
  - Radial-average initial enrichment
  - Radial variation (pin to pin)
  - Axial variation (including blankets)

PHENOMENA/PARAMETERS THAT INFLUENCE FOM#1

- Cask Characteristics
  - Cask geometry
  - Cask materials
  - Water in the cask
- Nuclear Data
  - Cross sections
  - Decay data
  - Fission product yields
- Temperature effects in cask (decay heat)
  - Effect on moderator density
  - Effect on fuel

IMPORTANCE AND UNCERTAINTY OF PARAMETERS INFLUENCING K-EFF

Category	Parameter/Phenomenon	Importance			Knowledge		
		H	M	L	K	PK	UK
Spent Fuel Assembly Materials							
	Reactivity worth of actinides in SNF	11	0	0	11	0	0
	Reactivity worth of fission products in SNF	11	0	0	5	6	0
	Reactivity worth of oxygen	9	0	0	10	0	0
	Reactivity worth of residual absorber materials	0	9	1	8	1	0
	Reactivity worth of non-fuel component compositions	8	1	0	10	0	0
Initial (Fresh) Fuel Enrichment							
	Radial-average initial fuel enrichment	9	0	0	9	0	0
	Radial variations of initial enrichment (pin-to-pin variations)	0	7	2	8	1	0
	Axial variations of initial enrichment (axial	9	0	0	6	0	0

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IMPORTANCE RANKING RATIONALE

Category	Parameter/Phenomenon	Importance Ranking Rationale
Spent Fuel Assembly Materials		
	Reactivity worth of actinides in SNF	H: The real essence is that if you were to regard actinides as unimportant, you would have no basis for burnup credit. M: No votes. L: No votes.
	Reactivity worth of fission products in SNF	H: The reactivity decrease in SNF due to fission products, relative to fresh-fuel, is approximately 15-20% in a cask configuration. M: No votes. L: No votes.
	Reactivity worth of oxygen	H: The presence of the oxygen in the fuel has an effect greater than 0.02 delta-k. M: No votes L: No votes
	Reactivity worth of residual absorber materials	H: No votes M: It was originally placed in the fuel and as the fuel burns to a target discharge burnup, the residual remains and is less than 0.01 delta-k for current PWR fuel assemblies. L: Current absorber loadings indicate that the effect is less than 0.005 delta-k.

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CONCLUSIONS FROM FOM#1

- Subcategories judged of high importance AND relatively low knowledge (high uncertainty
  - Reactivity worth of the spent fuel fission products (includes fp that are soluble or volatile
  - Axial burnup distribution
  - Cross sections
- Other subcategories of less interest

"FIGURE OF MERIT #2"

- Assessment of the worth of experimental facility types for validation of methods wrt phenomena/processes/parameters previously identified
- Methodology refers to both input data and computer code models used to obtain burnup of spent fuel in cask and then k_{eff} of flooded cask
- Two tables developed
  - Value, or importance, of different measureemtns
  - Importance of measurements for application to burnup credit
    - Actinides only
    - Actinides plus fission products
- Need for additional measurements addressed

MEASUREMENT TYPES CONSIDERED

- Fresh fuel criticals
- Reactivity worth (oscillation)
- Reactivity worth (direct)
- Subcritical measurements
- Reactor critical measurements
- Radiochemical assays

VALUE OF MEASUREMENT TYPE FOR VALIDATING METHODS RE PARAMETER/PHENOMENON

	Validation Needed?		Fresh Fuel Criticals			Reactivity Worth (Oscillation)			Reactivity Worth (Direct)			Subcritical Measurements		
Parameter/Phenomenon	**Y**	**N**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**	**H**	**M**	**L**
SNF Nuclide Cross-Sections														
- Actinides	10 [1]		4 [2]	5 [3]		2 [4]	5 [5]	2 [6]	2 [7]	8 [8]		1 [9]	5 [10]	4 [11]
- Fission Products	10 [12]				10 [13]	5 [14]	3 [20]	2 [21]	3 [22]	6 [23]	1 [24]	1 [25]	6 [26]	3 [27]
Temperature Effects on Cross-Sections (in Cask)		9 [32]												
SNF Compositions (Concentrations)														
- Actinides	9 [33]				9 [34]		3 [35]	6 [36]		3 [37]	6 [38]		2 [39]	7 [40]
- Fission Products	9 [46]				9 [47]		3 [48]	6 [49]		2 [50]	7 [51]		1 [52]	8 [53]
Effect of BPR on SNF Compositions	3 [60]	6 [61]			9 [62]			9 [63]			9 [64]			9 [65]

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RESULTS OF PIRT ON MEASUREMENTS

- Fresh fuel criticals of value for validating calculation of cask structural and absorber materials as well as the cask reflector
  - Validates actinide cross sections to some extent
- Reactivity worth experiments and subcritical expts. not very valuable
- Reactor critical measurements somewhat valuable for validating actinide cross sections
- Radiochemical assays valuable for validating the calculation of both actinide and fission product concentrations

EVALUATION OF EXPTS/MEAS FOR CODE/DATA VALIDATION

	Actinides Only						"Full" Burnup Credit (Actinides + Fission Products)					
	Importance for Burnup Credit			Need for Additional Experiments			Importance for Burnup Credit			Need for Additional Experiments		
Experiment Type	H	M	L	H	M	L	H	M	L	H	M	L
Fresh Fuel Criticals	4 [1]	4 [2]	1 [3]	3 [4]	3 [5]	3 [6]	4 [7]	3 [8]	2 [9]	4 [10]	1 [11]	4 [12]
Reactivity Worth Measurements												
- Oscillation type (small worth)	2 [13]	4 [14]	3 [15]	0	4 [16]	4 [17]	1 [18]	6 [19]	2 [20]	1 [21]	8 [22]	0
- Direct measurement (large worth)	1 [23]	7 [24]	1 [25]	0	5 [26]	2 [27]	2 [28]	6 [29]	0	2 [30]	6 [31]	0
- Individual Fission Products							6 [32]	2 [33]	1 [34]	6 [35]	2 [36]	1 [37]
- Integral Fission Products							5 [38]	4 [39]	0	3 [40]	6 [41]	0
Subcritical Experiments	1 [42]	4 [43]	4 [44]	1 [45]	2 [46]	6 [47]	1 [48]	2 [49]	6 [50]	1 [51]	2 [52]	6 [53]
Reactor Criticals												
- Measurements	5 [54]	3 [55]	1 [56]	0	2 [57]	7 [58]	4 [59]	5 [60]	0	0	2 [61]	7 [62]
- Documentation				6 [63]	2 [64]	0				7 [65]	1 [66]	0
Radiochemical Assays	4 [67]	5 [68]	0	6 [69]	3 [70]	0	6 [71]	3 [72]	0	7 [73]	2 [74]	0

RESULTS OF PIRT ON MEASUREMENTS

- For actinide-only burnup credit little value/need for all categories of measurements except reactor critical measurements and radiochemical assays
- For reactor criticals no need for additional expts.—many already exist
  - Strong need for additional documentation to be made available to the computational community
- More radiochemical assays needed
- Results for full burnup credit similar to above
  - Reactor criticals and chemical assays important
- Reactivity worth measurements of value for fission product
  - Need for additional expts; in particular for individual fission products