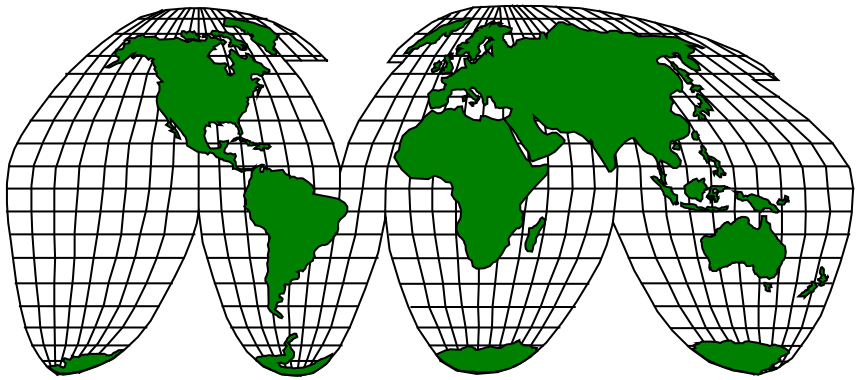
SECRETARIAT

BURNUP CREDIT ACTIVITIES AT OECD/NEA/NSC and IAEA



M.C. Brady Raap, PNNL
Ali Nouri, OECD/NEA
Barry Kaufer, OECD/NEA
Peter Dyck, IAEA

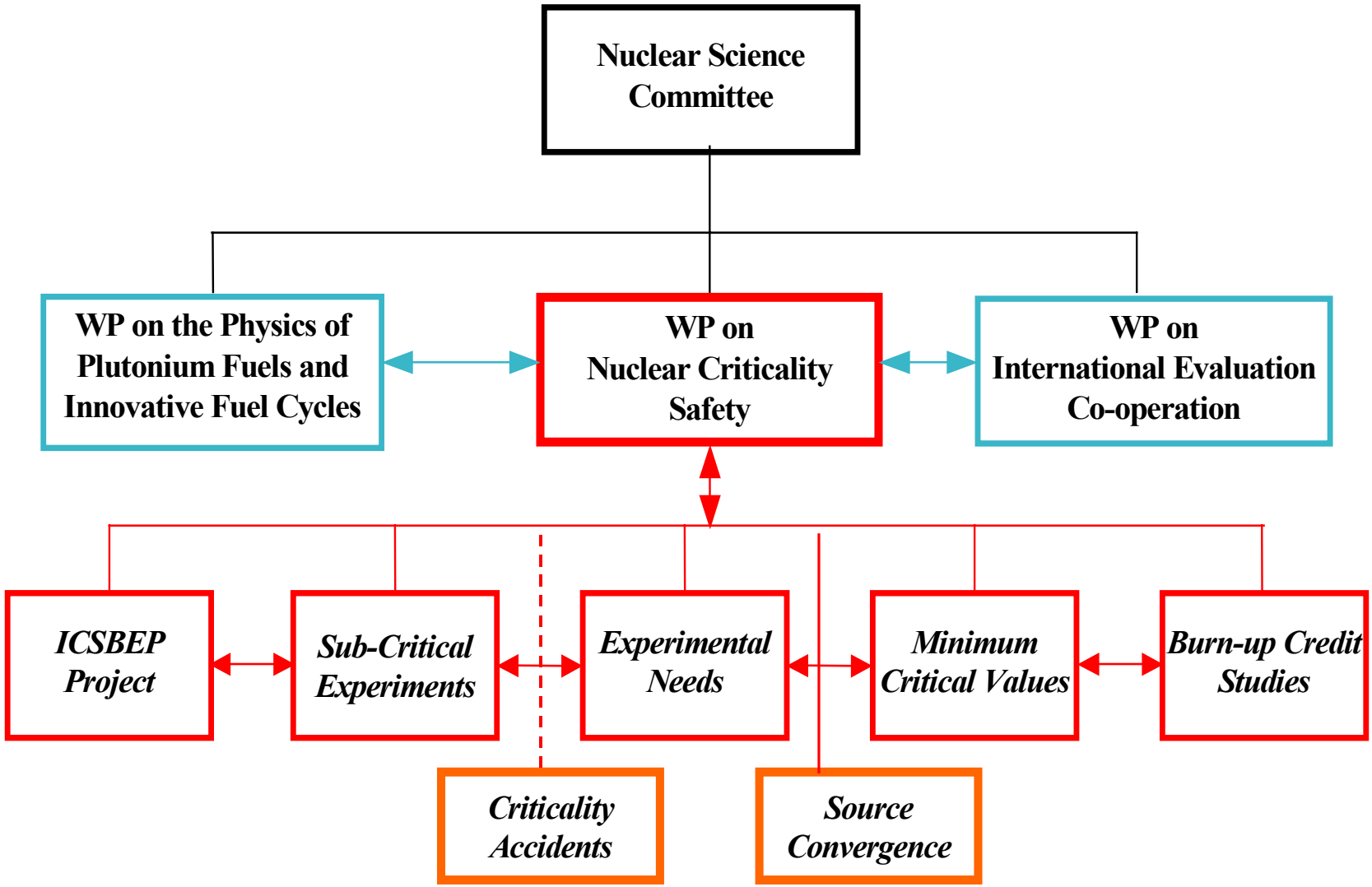
Overview of Burnup Credit Issues and Approaches – Tutorial
2002 ANS Annual Meeting, June 9-13, 2002
Hollywood, Florida USA

NEA
AEN

Working Group Participants

- 17 countries (Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, Japan, South Korea, The Netherlands, Spain, Sweden, Switzerland, United Kingdom and the United States) have participated in various phases of the study
- Have included nuclear data specialists, code specialists, experimentalists, plant operators, reactor physicists, criticality assessors and regulators
- Have provided multiple solutions from independent organisations and/or codes and nuclear data sets.

NEA
AEN



http://www.nea.fr/html/science/wpncs/buc

NEA AEN

Benchmarks

Phase I-A	**PWR: Effects of 7 major actinides and 15 fission products. Vary initial enrichment and burnup, k_∞ pin-cell calculations**
Phase I-B	**PWR: Depletion calculations for PWR pin-cell**
Phase II-A	**PWR: Study axially distributed burn-up, 2-D**
Phase II-B	**PWR: Axially distributed burnup, 3-D**
Phase II-C	**PWR: Sensitivity of Burn-up Profiles**
Phase III-A	**Effect of moderator void distribution, burn-up distribution for array of BWR pins**
Phase III-B	**Depletion calculations for BWR assembly**
Phase IV-A	**Investigate burnup credit for MOX spent fuel**
Phase IV-B	**MOX Super-cell inventories**
Phase V	**VVER burn-up credit**

NEA
AEN

Benchmark Reports Currently Available

I-A	**JAERI-M 94-003, NEA/NSC/DOC(93)22, January 1994**
I-B	**ORNL/TM-6901, NEA/NSC/DOC(96)06, June 1996**
II-A	**JAERI-Research 96-003, NEA/NSC/DOC(96)01, February 1996**
II-B	**IPSN/98-05, NEA/NSC/DOC 1 (1998), May 1998**
III-A	**JAERI-Research 2000-0441, NEA/NSC/DOC 12 (2000), September 2000**
III-C	**JAERI-Research 2002-001, NEA/NSC/DOC(2002)2, February 2002**

http://www.nea.fr/html/science/wpncs/buc

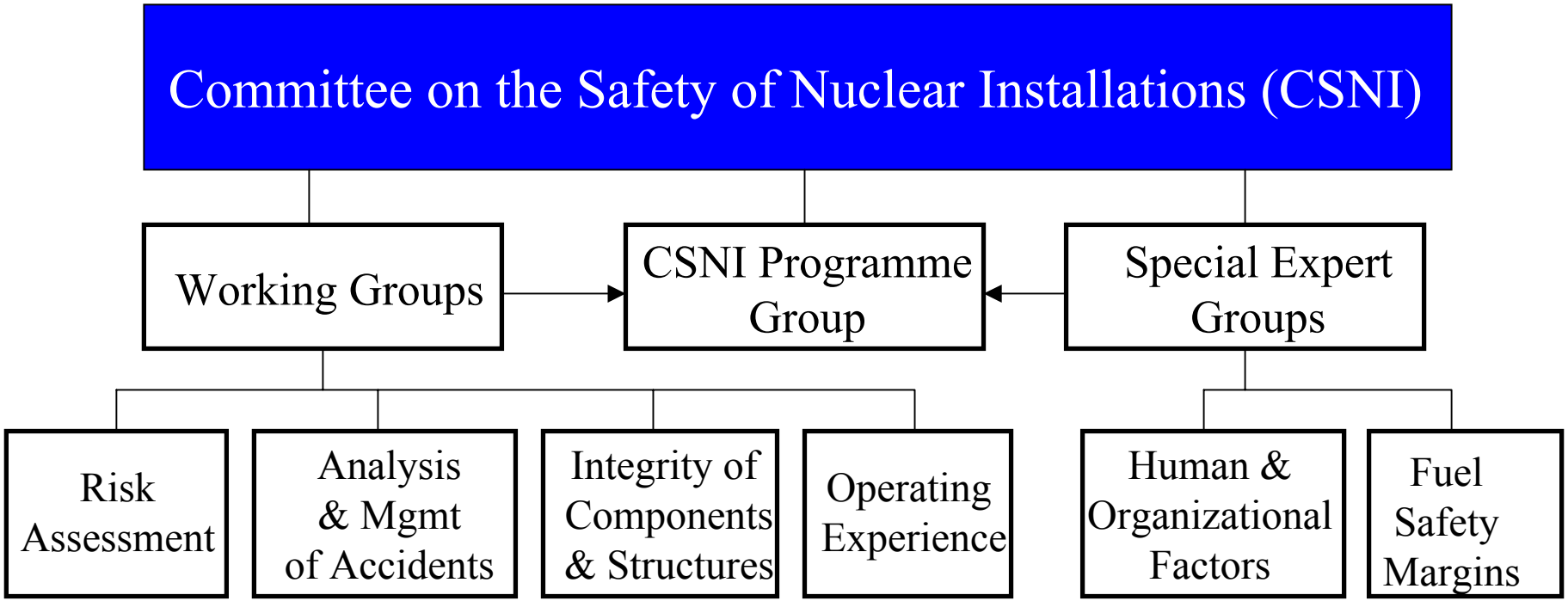
NEA AEN

Codes and Nuclear Data

All major code and nuclear data sets represented, including:

Codes: (k-eff)	APOLLO, BOXER, CASMO/SIMULATE, CGM, KENO, MAIL, MCNP, MONK, MORET, MORSE, PHOENIX, SCALE , TRIMARAN, WIMS
Codes: (depletion)	CCCMO, FISPIN, ORIGEN, SWAT, TGBLA, UNITBURN
Data:	ENDF, JEF, JENDL

NEA
AEN



- Software Reliability
- Human Reliability
- Risk Monitor
- Passive Systems PSA

- Design Basis
- Severe Accidents
- Fission Product Behavior

- Integrity Metal C&S
- Concrete Aging
- Seismic Behavior

- Fuel Cycle Safety
- Databases e.g., FINAS IRS

NEA AEN

WGOE/FCS Questionnaire

1. Facilities where the burn-up credit is adopted.
2. Burn-up data
3. Precision and accuracy of burn-up data
4. Maximum allowable multiplication factor
5. Level of burn-up credit adoption
6. Method to derive multiplication factor from the burn-up data
7. Gadolinium effect for burn-up credit (especially for countries adopting BWR)
8. **Issues to be solved**
9. **Adoption or improvement**
10. R&D
11. Other comments, if any

NEA
AEN

IAEA Burnup Credit Programme

October 1997 - Organized an advisory group meeting (AGM)
Review status of burnup credit for storage, transport, reprocessing, and disposal of PWR, BWR, VVER, RBMK and MOX spent fuel.
IAEA-TECDOC-1013, (April 1998)

Consultancies to monitor the progress in burnup credit implementation
July and December 1998, July 1999, July 2001, tentatively 2004

Organize Technical Coordination Meetings (TCMs) to promote international cooperation in the application of burnup credit

Training courses are held by the Agency for developing countries

Technical Committee Meeting (TCM)
July 2000, Vienna Austria

Purpose

"to survey the progress and status of international activities related to the use of burnup credit for spent fuel applications. "

Conclusions of the TCM (35 experts, 17 countries, 2 international organizations)

Recommended continued acquisition of data to support burnup credit.
Need for additional chemical assay to benchmark calculation methods
Studies of axial effects, and verification methods for fuel burnup values
The value of a co-operative approach was recognized.
Training course for potential users of burnup credit and their respective regulators was a stated goal of the participants.

Proceedings published in the TECDOC-1241, August 2001.

IAEA Burnup Credit Training Course

15 to 26 October 2001
Argonne National Laboratory

Training course on
the implementation of burnup credit in spent fuel management systems

25 experts from 12 different countries participated

Training courses are held by the Agency for developing countries

Technical Committee Meeting (TCM)
April 2002, Madrid, Spain

Purpose

address commercial factors that have influenced decisions on the use of burnup credit. The meeting will examine the technical information that is already available, being developed, and needed for future progress.

Requirements, Practices and Developments in Burnup Credit Applications.

53 persons, 18 countries and 2 international organizations.

Technical Program at the IAEA TCM Madrid, Spain

Technical Topic	Countries Presenting
Experimental validation: Isotopic composition and reactivity calculations; high burnup fuel implications; nuclear data quality	France, Switzerland, Spain, Belgium, United Kingdom, United States
Depletion and Critiality parameters that guarantee a bounding approach. Application dependence of BUC parameter importance.	Hungary, Slovakia, Slovenia, Spain, United States, Germany, Ukraine
Safety margin, bias, uncertainty and statistical confidence.	Germany, United States
Risk perspective and perception, building consensus	United Kingdom, United States
BUC assessment scheme: implementation, fuel and loading verification, review analysis assumptions against fuel parameters	Armenia, Bulgaria, China, Czech Republic, France, Germany, Slovak Republic, Korea, Lithuania, Sweden
BUC application to long term storage and disposal	Germany, United States
BUC for MOX and Advanced fuel designs	France, United Kingdom, United States

Technical Committee Meeting (TCM) Workgroup Topics

Validation of codes and methods

Lessons learned from previous experimental programs

Application of results and experience to multiple fuel types

Increase of initial enrichment and burnup

Key Issues

Depletion parameters

Axial burnup profiles

Variations in plant operations and fuel design.

Variability of parameter importance for different applications

Safety assessment and implementation

Safety criteria

Fuel and loading verification

Risk, its perception and building consensus

Continued validity of the analysis assumptions

Future applications

MOX and advanced fuel designs

High burnup fuel

Long term storage and disposal

Country	PWR	BWR	MOX	VVER	RBMK	Reactor Types
Armenia	na	na	na	APU-0	na	VVER
Belgium	INT	na	na	na	na	PWR
Brazil	Nc	na	na	na	na	PWR
Bulgaria	na	na	na	INT	na	VVER
China	INT	na	na	na	na	PWR
Czech Republic	na	na	na	RR-2	na	VVER
Finland	na	INT	na	INT	na	VVER, BWR
France	APU-1, UD-2	Nc	UD-1,2	na	na	PWR
Germany	APU-1, RR-2	Gd	RR-2	Nc	na	PWR, BWR, VVER
Hungary	na	na	na	INT	na	VVER
Japan	INT	INT	INT	na	na	PWR, BWR
Korea	INT	na	na	na	na	PWR
Lithuania	na	na	na	na	INT	RBMK
Mexico	na	Nc	na	na	na	BWR
Netherlands	APU-1	na	na	na	na	PWR
Russia	na	na	na	APU-1	INT	VVER, RBMK
Slovakia	na	na	na	UD-2	na	VVER
Slovenia	Nc	na	na	na	na	PWR
South Africa	Nc	na	na	na	na	PWR
Spain	INT	INT	na	na	na	PWR, BWR
Sweden	Nc	Nc	na	na	na	PWR, BWR
Switzerland	APU-1	INT	INT	na	na	PWR, BWR
Ukraine	na	na	na	INT[2]	INT[2]	VVER, RBMK
U. K.	RR-1	Nc	Nc	na	na	PWR
USA	APC-1, UD-1,2	INT	INT	na	na	PWR, BWR

Future IAEA Activities

Consultants Meeting is planned for 2003 in conjunction with a symposium on spent fuel storage for power reactors to be held 2 to 6 June 2003 in Vienna with 2 overview presentations on burnup credit

<u>Proposed in the 2004/2005 budget cycle:</u>
new task: "Advances in Applications of Burnup Credit to Reduce the Number of Transports and Increase Storage Capacity"
Consultants Meeting in 2004 to prepare for a Technical Meeting in 2005.

Consultants Meetings in 2004 and 2005 to prepare a technical Document on benchmarking depletion codes for burnup credit using chemical assay data of WWER fuel from a DOE funded programme.

Phase I-A Summary (Infinite Pin-cell, k)

- k-infinity for pincell, isotopics specified for fresh and burnt fuel cases, with and without fission products

- detailed comparisons of neutron spectra, absorption & fission reaction rates, neutrons per fission

- no trends in standard deviation (σ) among participants with burnup or cooling

- largest σ seen for fresh fuel case, and cases with fission products included

- See JAERI-M 94-003, NEA/NSC/DOC(93)22, January 1994

NEA
AEN

Phase I-B Summary (PWR Pin-cell, depletion)

- depletion calculations made for three burnup levels. Power and boron histories specified
- participants calculated concentrations of 12 actinides and 15 fission products
- evidence of significant trend in σ for residual U235 with burnup (trend is small for most isotopes)
- following isotopes identified as warranting further study (observed σ has significant effect on k): ^{239}Pu, ^{155}Gd, ^{235}U, ^{241}Pu, ^{240}Pu, ^{151}Sm)
- See ORNL/TM-6901, NEA/NSC/DOC(96)06, June 1996

Phase II-A Summary (axial profile 2-D)

- fresh and burnt fuel compositions specified for axial average BU and axial BU profile. Profiles were symmetric about mid-plane, represented as 9 different burnup zones
- largest σ seen for fresh fuel cases
- evidence of increase in 'end effect' with burnup
- importance of end regions illustrated: 70% of total fissions occur in upper 40cm of fuel (22% of volume)
- results show that use of axial averaging can be non-conservative at high burnup
- See JAERI-Research 96-003, NEA/NSC/DOC(96)01, February 1996

NEA
AEN

Phase II-B Summary (3-D axial effects)

- 21 PWR fuel assemblies in borated stainless steel transport cask. Average BU and axial BU profiles considered. All material compositions specified.
- generally consistent with Phase II-A results. End effect positive below ~30GWd/t
- good agreement between participants 2σ ~1% in k-effective (better than seen in Phase II-A)
- two additional accident cases highlighted importance of profile if axial heterogeneity present
- See IPSN/98-05, NEA/NSC/DOC 1 (1998), May 1998

NEA
AEN

Phase II-C PWR Axial Effects

Axially distributed burnup is a key parameter in the use of burnup credit.

Early benchmarks assumed symmetric profiles for modeling simplicity

Two primary issues:
(1) Measured axial profile data and detailed power history data
(2) Analysis to determine the sensitivities due to different axial burnup profiles across the full range of burnups

Studies are ongoing

NEA
AEN

Phase III-A Summary (BWR, 2-D calcs k-eff)

- Infinite array of STEP-II-type assemblies, identical fuel rods, isotopics specified for 20, 30 and 40GWd/MTU

- Cases include average and profiled BU, with/without fission products, uniform and profiled moderator void fractions

- Results consistent with PWRs:
  - largest deviations for fresh fuel,
  - deviations higher for distributed burnup vs average
  - deviations higher neglecting fission products
  - deviations larger for 70% uniform void

- See JAERI-Research 2000-0441, NEA/NSC/DOC 12 (2000), September 2000

NEA
AEN

Phase III-B BWR Assembly Depletion

- complex geometry of BWR assembly is represented, fuel pins have five different initial enrichments, with and without Gd
- void fraction is varied - 0, 40% and, 70%
- participants to calculate number densities for 12 actinides, 15 fission products
- burnup for each of 9 pins in 1/8 assembly model to be calculated
- k for 0, 0.2, 10, peak burn-up 20, 30, 40, 50GWd/MTU to be calculated
- final draft approved, to be published 2002

NEA
AEN

Phase IV-A MOX Pincell

- similar to Phase I-A for PWR UO2 fuel
- isotopics for three types of fresh and burnt MOX assembly specified (included Cm isotopes):single cycle Pu, weapons disposition Pu, multi-recycle Pu
- preliminary results from 16 institutions show significantly larger spread than for UO2 cases
- rate of change of k with BU strongly related to initial Pu content
- Cm contributes up to 1.5% to k
- Final draft approved, to be published 2002

NEA
AEN

Phase IV-B MOX Super-cell

- Similar to Phase I-B for PWR UO2 fuel
- Objective to compare computed nuclide concentrations from depletion in a MOX super-cell
- Initial draft in review

NEA
AEN