OVERVIEW ON THE BURNUP CREDIT ACTIVITIES AT THE IAEA

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Spent fuel management is a necessary and costly activity for all operators of nuclear power plants regardless of the strategy selected for the back-end of the nuclear fuel cycle. As of today, more than 145,000 tHM of the accumulated 230,000 tHM spent fuel from power reactors are stored world-wide in reactor pools and wet and dry away from reactor (AFR) storage facilities.

Generally, there is a desire to reduce the cost of nuclear power production. One approved possibility to achieve a reduction in fuel cycle costs is to implement burnup credit in spent fuel management systems. In fact, in many countries, burnup credit is already applied to transportation systems, dry and wet storage facilities, and components of reprocessing plants. For disposal, spent fuel burnup credit is considered to be a necessity for any viable scheme. Benefits for transport systems are derived for existing casks using higher fuel enrichments, or to increase capacities of new casks, which will maintain or decrease the number of transports.

Because of the worldwide interest and broad applicability of burnup credit for spent fuel management, the International Atomic Energy Agency (IAEA) has taken an active interest in the subject. The IAEA role has been one of an observer and disseminator of appropriate information. The ongoing IAEA program on burnup credit began in 1997.

A Technical Committee Meeting (TCM) on the evaluation and review of the implementation of burnup credit in spent fuel management systems was held in July 2000 in Vienna with 35 experts from 17 countries and 2 international organizations.

The purpose of this TCM was to survey the progress and status of international activities related to the use of burnup credit for spent fuel applications. The scope of the meeting included the use of burnup credit for storage, transportation, reprocessing, and disposal of spent light water reactor (LWR) fuels. The LWR fuel types considered included boiling water reactor (BWR) fuel, pressurized water reactor (PWR) fuel, Mixed Oxide (MOX) fuel, VVER and RBMK fuel.

The main agenda items for the TCM were:

1. International Activities
2. Country Reports
3. Technical and Regulatory Topics
4. Group Discussions

Eleven country reports provided information on planned and current burnup credit activities, and updates of progress made in the reporting countries since 1997. Countries with larger nuclear power generation capabilities and interest in using burnup credit reported new research and development initiatives and advances in seeking regulatory acceptance of burnup credit. Countries with smaller nuclear power programmes noted the challenges of obtaining the data needed to implement burnup credit initiatives.

Several technical and regulatory topics are essential to the applications of burnup credit. Those wishing to use burnup credit for spent fuel applications must acquire an understanding of the regulatory and technical aspects of burnup credit. Although the IAEA is not involved in developing burnup credit technologies, it is involved in bringing pertinent technical and regulatory developments to potential users of burnup credit.

The regulatory and technical topics presented at the TCM were arranged in the following sessions:

1. Regulatory Aspects,
2. Depletion and Criticality Calculation and Code Validation,
3. Parameters Affecting Burnup Credit, and
4. Implementation Issues.

Three papers were presented in the session on Regulatory Aspects of burnup credit. The papers described criticality safety standards used in Germany, regulatory perspectives on criticality safety based on about ten years of using burnup credit for spent fuel storage in Spain, and work being conducted in the USA to support approval of burnup credit for spent fuel transport. Eight papers were presented in two sessions on Depletion and Criticality Calculation and Code Validation. The presentations covered technical development activities conducted by individual countries and countries working co-operatively, and discussions identifying various research needs. Speakers in a session on Parameters Affecting Burnup Credit presented four papers, which included such things as axial effects. The final session addressed Implementation Issues. Seven papers were presented covering such topics as burnup verification and measurement.

The group sessions were convened in a workshop format. Four parallel discussion groups were formed for storage, transportation, reprocessing, and disposal applications. The groups reported their results at a closing session attended by all. The working group activities and reports followed a generally consistent format. The items discussed and reported by each working group included the following:

1. Specific applications of burnup credit in a topic area;
2. Motivation and benefits of using burnup credit;
3. Status of ongoing activities;
4. Future plans;
5. Research and development, and operational needs; and
6. Regulatory considerations.

The main results of the working groups were:

A common theme related to the motivation for seeking burnup credit was economics. For existing systems, changes in reactor operating practices have led to increases in initial enrichments of fissile isotopes (e.g., uranium U^{235}). When systems are designed under the fresh fuel assumption, the higher initial enrichments of these new fuels result in capacity reductions for storage, transport, and disposal systems, and reduced through-put for processing facilities. For existing units, capacities must be down-rated (e.g., reduced cask capacities), or process lines reconfigured (e.g., hold tank diameters limited) to accommodate the more reactive higher initial enrichments. For new designs not using burnup credit, maximum achievable capacities or process rate may be artificially limited by assuming a higher than actual reactivity. This results in more storage and disposal units, more shipments for transport, and in lower process rates.

All four of the working groups cited the need for research and development efforts to acquire additional data for validating calculation methods. A set of actinides and fission products has been identified as being applicable to burnup credit assessments. For validation of depletion calculations, Post Irradiation Examination (PIE) data giving the concentrations of these isotopes in spent fuel is used. For the criticality codes, "reactivity worth" measurements or critical experiments, using appropriate fuel samples, are applied.

As a means of broadening and improving the experimental data set, it was suggested that support and participation in various ongoing international co-operative efforts would be beneficial. Although some data of this type is available for BWR and PWR systems, the scarcity of such data for VVER systems was noted. This observation led to a recommendation to seek support for PIE data for spent VVER fuel.

The reactivity effects of axial burnup distributions (end-effects) were identified by the groups as a significant issue needing further study, because an assumption of uniform average burnup may be non conservative.

Verification of fuel loading is an important factor when implementing burnup credit. All the groups found that for their specific application of burnup credit some form of verifying that the fuel loaded or processed was compliant is needed. Verification methods range from use of reactor records to measurements of fuel before loading. The property of interest is the burnup (e.g., assembly average, local), where the local burnup infers the axial distribution.

Results from the Group Discussion

Wet and dry storage systems:

BUC for wet and dry storage systems is needed and already applied in many of the member countries to allow for increased fuel initial enrichment, and to increase the storage capacity. If dry storage takes place in casks, BUC is needed to demonstrate a sufficient criticality safety margin for both the cask loading/unloading process and for the accidental flooding case. The same is true for dry transport.

The current BUC applications status is shown in Table I. The BUC level implemented in each application is given in Table II.

As can be seen in Tables I and II, the actinide and fission product BUC level is applied to PWR wet storage systems in Brazil, Germany, Korea, South Africa, Spain and the United States. In the case of Germany, a very low minimum burnup is required at the present time (5 GWd/tU at 4.4 wt.% enrichment). In addition to this level of BUC implementation, partial boron credit is allowed in South Africa, Spain and the United States. In other countries, either actinide only BUC level is used, or no decision has been made at the present time.

For wet storage of BWR fuel, burnable absorber BUC level is taken in Germany, Spain, Sweden, Switzerland and the United States.

The participants of the working group recommend participation in the international experimental programmes (like REBUS, PROTEUS, and further programmes) to improve and broaden the database for burnup credit validation of depletion and criticality codes.

TABLE I. WORLDWIDE USES OF BURNUP CREDIT: NATIONAL PRACTICES AND STATUS IN WET AND DRY STORAGE

COUNTRIES	WET STORAGE					DRY STORAGE				
	PWR	BWR	RBMK	MOX	WWER	PWR	BWR	RBMK	MOX	WWER
BELGIUM	AP [1]	-	-	-	-	-	-	-	-	-
BRAZIL	AP	-	-	-	-	-	-	-	-	-
BULGARIA	-	-	-	-	IC	-	-	-	-	IC
CHINA P. REP.	IC/UD	-	-	-	-	IC	-	-	-	-
CZECH REP.	-	-	-	-	IC	-	-	-	-	UD
FRANCE	AP	IC	-	UD	-	-	IC	-	IC	-
GERMANY	AP	AP [2]	-	IC	NO	RR	RR	-	IC	IC
HUNGARY	-	-	-	-	IC	-	-	-	-	IC
JAPAN	IC	IC	-	UD	-	IC	IC	-	UD	-
KOREA, REP.	AP	-	-	-	-	IC	-	-	-	-
LITHUANIA	-	-	AP [3]	-	-	-	-	IC	-	-
RUSSIAN FED.	-	-	AP [4]	-	IC	-	-	-	-	IC
SLOVAKIA	-	-	-	-	IC	-	-	-	-	IC
SOUTH AFRICA	AP	-	-	-	-	-	-	-	-	-
SPAIN	AP	AP [2]	-	-	-	IC	IC	-	-	-
SWEDEN	-	AP [2]	-	IC	-	-	-	-	-	-
SWITZERLAND	NO	AP [2]	-	NO	-	IC	IC	-	IC	-
UKRAINE	-	-	-	-	IC	-	-	-	-	IC
UK	RR	UD	-	UD	-	IC	IC	-	IC	IC
USA	AP	AP [2]	-	-	-	RR [5]	IC	-	-	-

Note: The table contains information from countries participating in IAEA meetings on burnup credit implementation and from personal communications.

AP = Approved.
UD = Under Development.
NO = Applicable but not intended.
IC = Interest/Considering, or Applicable.
RR = Regulatory Review.
- = Not Applicable.

[1] Burnup credit has been approved on a case-by-case basis using actinides only, no fission products
[2] Credit for the presence of integral burnable absorbers.
[3] For Ignalina.
[4] For Smolenskaja.
[5] Use of burnup credit for loading single purpose PWR casks is implemented.

TABLE II. WORLDWIDE USES OF BURNUP CREDIT: BUC LEVEL ALLOWED IN WET AND DRY STORAGE

COUNTRIES	WET STORAGE					DRY STORAGE				
	PWR	BWR	RBMK	MOX	WWER	PWR	BWR	RBMK	MOX	WWER
BELGIUM	A	-	-	-	-	-	-	-	-	-
BRAZIL	FP	-	-	-	-	-	-	-	-	-
BULGARIA	-	-	-	-	ND	-	-	-	-	ND
CHINA P. REP.	FP	-	-	-	-	FP	-	-	-	-
CZECH REP.	-	-	-	-	ND	-	-	-	-	ND
FRANCE	A	-	-	-	-	-	-	-	-	-
GERMANY	FP	BA	-	ND	-	A	A	-	ND	ND
HUNGARY	-	-	-	-	A	-	-	-	-	A
JAPAN	ND	ND	-	ND	-	-	-	-	-	-
KOREA, REP.	FP	-	-	-	-	-	-	-	-	-
LITHUANIA	-	-	A	-	-	-	-	A	-	-
RUSSIAN FED.	-	-	A	-	-	-	-	-	-	-
SLOVAKIA	-	-	-	-	-	-	-	-	-	-
SOUTH AFRICA	FP	-	-	-	-	-	-	-	-	-
SPAIN	FP	BA	-	-	-	ND	ND	-	-	-
SWEDEN	-	BA	-	ND	-	-	-	-	-	-
SWITZERLAND	-	BA	-	-	-	-	-	-	-	-
UKRAINE	-	-	-	-	ND	-	-	-	-	ND
UK	ND	ND	-	ND	-	-	-	-	-	-
USA	FP	BA	-	-	-	ND	ND	-	-	-

Note: The Table contains information from countries participating in IAEA meetings on burnup credit implementation and from personal communications.

A = Reduction of the actinides concentration only considered
FP = Reduction of actinides and build-up of fission products considered
BA = Credit for the presence of integral burnable absorbers
ND = Not decided

Transportation:

The use of burnup credit in the criticality safety analysis of transportation and loading/unloading operations is based on representing the composition of burned fuel (depletion analyses) and the effect of that composition on the effective multiplication factor (criticality analysis). The key issues include the combination of fuel type and physical characteristics of the transportation cask/flask as well as consideration of operator mistakes and incidents.

Recertifying existing cask designs with burnup credit may permit the transport of higher enriched fuel, so that current casks can continue to be used at design capacities. In the case of small casks burnup credit may be needed to permit continued shipment of higher enriched fuel. New cask designs using burnup credit could have larger capacities, requiring fewer casks to be manufactured and reducing the number of shipments.

TABLE III. WORLDWIDE USES OF BURNUP CREDIT FOR SPENT FUEL TRANSPORTATION: NATIONAL PRACTICES AND STATUS

COUNTRIES	TRANSPORTATION[1]							
	WET				DRY			
	PWR	BWR	MOX	WWER	PWR	BWR	MOX	WWER
BELGIUM	AP[2]							
BULGARIA	-	-	-	IC	-	-	-	IC
CZECH REP.	-	-	-	-	-	-	-	IC
FRANCE	AP	IC	IC	IC	AP	IC	IC	IC
GERMANY	-	-	-	-	AP	RR	IC	IC
HUNGARY	-	-	-	-	-	-	-	IC
JAPAN	UD	UD	-	-	-	-	-	-
KOREA, REP. Of	IC	-	-	-	IC	-	-	-
LITHUANIA	-	-	-	-	-	-	-	-
RUSSIAN FED.	-	-	-	AP[3]	-	-	-	IC
SLOVAKIA	-	-	-	IC	-	-	-	IC
SPAIN	-	-	-	-	IC	IC	-	-
SWEDEN	-	-	-	-	IC	IC	-	-
SWITZERLAND	-	-	-	-	AP[4]	IC	IC	-
UK	RR	UD	UD	-	IC	IC	IC	IC
USA	-	-	-	-	RR	IC	-	-

Note: The table contains information from countries participating in IAEA meetings on burnup credit implementation and from personal communications.

AP=Approved. IC=Interest/Considering, or Applicable. NO=Applicable but not intended.

RR = Regulatory Review. UD = Under Development. - = Not Applicable.

[1] Wet/Dry refers to the assumed condition of the package as transported. Regulatory assumptions for the safety analysis are typically performed wet.

[2] Burnup credit has been approved on a case-by-case basis using actinides only, no fission products.

[3] For Kola.

[4] Approved for one case in connection with reprocessing in foreign plants.

Table IV, which is based on the work performed in July 2000, summarises the needs and issues requiring additional investigation.

Regulatory considerations:

The regulator looks for confidence in the analysis, assessment and implementation of BUC. The importance of adoption and training in best practice, such as ST-2, was recognised. A conservative approach to setting safety margins is required. Unnecessary conservatism may be removed as knowledge and experience is increased with relation to effects such as horizontal/axial BU effects, accident effects to intact fuel, and off-normal conditions.

The use of measurement as a means of demonstrating that the fuel is compliant with the limits derived in the safety assessment was considered as necessary.

TABLE IV. SUMMARY OF TOPICS DISCUSSED AS R&D AND OPERATION NEEDS

Depletion Analyses	**k_{eff} Calculations**	**Cask Operations**
Validation: - PIE data - proprietary data - use of reactor criticals ***Modelling:*** - use of solid absorbers - control rods - depletion parameters - improved geometrical modelling, particularly for BWR (2D vs. 1D depletion methods) - adequacy of point depletion being studied, e.g., Japan, MCNP-BURN (integrates depletion and criticality in one calculation). - temperature distribution ***Modelling parameters***: - specific power - operating history - fuel temperature distribution - moderator temperature distribution - changes in soluble boron (e.g., boron letdown) - location of burnable poison rods - integral burnable poisons - history of control rod movement - void history and distribution - fuel geometry (design) - axial blankets - assembly geometry - initial enrichment - burnup	***Validation:*** - spent fuel critical experiments (overall validation needs based on degree of BUC sought) - re-evaluation of existing experiments - proprietary data - reactor criticals - reactivity worth of BUC nuclides and spent fuel samples[1] ***Modelling:*** - axial distribution of burnup - source convergence - absorber materials (particle heterogeneity, not really a BUC issue) - absorber distribution in basket/cask - improved modelling for BUC needs (add end fittings to model, etc.) - confirm (qualify or quantify) representativity of benchmarks - confirm adequacy of modelling assumptions	- co-ordination between international regulators - shipment specific analyses - multiple loading curves (one for each set of parameters) ***Measurement:*** - verification requirement - "measurement" needs to be defined - Japan suggests that reactor records are sufficient for some parameters ***Reactor Records:*** - validate reactor records - Japan considers that reactor records are measurements for some parameters

[1] Validation of integral cross section data

Reprocessing:

The use of burnup credit as applied to reprocessing operations, can be of great benefit in storage, dissolution, and tank design. Wet storage at reprocessing facilities may attract the same benefits as discussed earlier. The reasons for using BUC include the extension of the range of permitted fuel assembly characteristics, and optimisation of the design of new facilities, thus reducing costs. For example, BUC may extend the upper mass limit in the dissolver, or avoid the use of neutron absorbers, such as gadolinium.

Disposal Issues:

For pre-closure applications, burnup credit for disposal of irradiated commercial fuel provides design flexibility that may provide economic and ALARA/ALARP benefits. Burnup credit facilitates increased assembly loading in waste packages, which leads to reduced cumulative radiological risks and associated cost savings. The use of burnup credit in post-closure disposal applications has the additional value that over the long time period considered for disposal, active criticality control features such as moderator exclusion barriers, neutron absorbing (poison) plates, and geometry features (e.g., flux-traps) are expected to degrade and change. The reduced reactivity associated with the presence of actinide and fission product absorbers in irradiated fuel is likely to be a sufficiently long-lasting feature.

TABLE V. DISPOSAL BURNUP CREDIT: NATIONAL PRACTICES AND STATUS

Country	PWR	BWR	MOX	WWER
Czech Republic	-	-	-	ID
Germany	UD	IC	UD	IC
Slovakia	-	-	-	IC
Sweden	UD	UD	-	-
USA	AC/UD	AC/UD	IC	-

IC = Interest/Considering, or Applicable
ID = Initial Development
UD = Under Development
AC = Accepted – basic concepts described in DOE Topical Report

Conclusions

During the closing session of the TCM, it was concluded that the use of burnup credit for spent fuel management continues to progress. The TCM recommended continued acquisition of data to support burnup credit. In particular the need for additional chemical assay and criticality data to benchmark calculation methods was identified. Further studies of axial effects, and verification methods for fuel burnup values were recommended. The value of a co-operative approach was recognised. Thus co-operation in future experimental programmes and sharing of available data was recommended by the TCM. Implementation of a training course for potential users of burnup credit and their respective regulators was a stated goal of the participants.

The proposed training course will take place 15 to 26 October 2001 at Argonne National Laboratory with the support of their Division of Educational Programs.