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# IAEA ACTIVITIES RELATED TO BURNUP CREDIT

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## ABSTRACT

The most common assumption used in criticality safety analysis of spent nuclear fuel from power reactors is that spent fuel has the same reactivity as unburned fuel. This approach is typically known as the "fresh fuel" assumption and results in significant conservatism in the calculated value of the system reactivity. Current calculation methods have made possible taking credit for the reactivity reduction associated with fuel burnup, hence reducing the analysis conservatism while maintaining an adequate criticality safety margin. Spent fuel management is a common and costly activity for all operators of nuclear power plants. Implementing burnup credit offers the possibility to reduce fuel cycle costs, given the number of Member States dealing with increased spent fuel quantities and extended durations.

In 1997, the IAEA initiated a task to monitor the implementation of burnup credit in spent fuel management systems, to provide a forum to exchange information, to discuss the matter and to gather and disseminate information on the status of national practices of burnup credit (BUC) implementation in Member States. The IAEA started this active program with a meeting in 1997 exploring worldwide interest in using BUC in spent fuel management systems. A second meeting was held in Vienna in 2000 followed by a third meeting in Madrid in 2002 on requirements, practices, and developments in BUC applications. Following recommendations of the Madrid meeting encouraging the IAEA to continue this effort, the Agency held a fourth technical meeting on burnup credit applications in London in 2005.

This paper highlights spent fuel management trends and related IAEA activities as context for focusing on the results of the Agency's meeting held in London in September 2005 to address advances in applications of burnup credit. Sixty participants from 18 countries addressed calculation methodology, validation and criticality safety criteria, procedural compliance with safety criteria, benefits of BUC applications, and regulatory aspects in BUC. This meeting encouraged the Agency to continue its activities on burnup credit, given the number of Member States having to deal with increased spent fuel quantities and extended durations. A fifth major meeting on burnup credit is planned for April 2009.

## INTRODUCTION

The production of nuclear electricity results in the generation of spent fuel that requires safe, secure and efficient management. Appropriate management of the resulting spent fuel is a key issue for the steady and sustainable growth of nuclear energy. There are currently 439 nuclear

power reactors operating in 30 countries worldwide [1], providing over fifteen per cent of the global electricity supply. Over 10,000 metric tons of heavy metal (tHM) are unloaded from these reactors each year, with annual discharges increasing to ~11,500 tHM by 2010. This is the largest continuous source of civil radioactive material generated, and needs to be managed appropriately. Since less than one third is reprocessed as shown in Figure 1 [2], about 8 000 tHM/year on average will need to be placed into interim storage facilities.

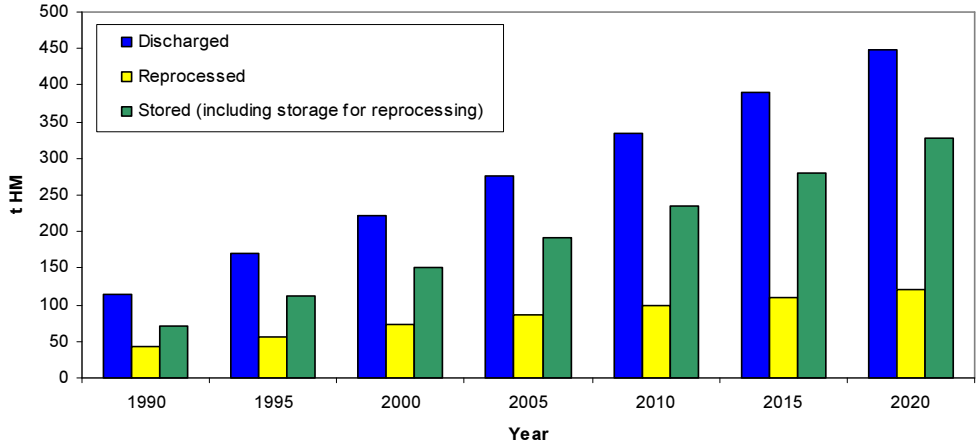


**Figure 1: Historical and projected amounts of spent fuel discharged, reprocessed, stored.**

Global capacity for reprocessing civilian spent fuel is approximately 5000 tHM/year [3].The Rokkasho-mura facility in Japan adds 800 tHM/year of capacity when it begins full operation.

Regarding storage, over 190 000 tHM of spent fuel were estimated to be in storage facilities in early 2005 [3], mostly under water but with an increasing amount in dry storage. The corresponding total amount of spent fuel cumulatively generated worldwide was close to 255 000 tHM. Projections indicate that the cumulative amount generated by the year 2020, the time when most of the presently operated nuclear power reactors will approach the end of their licensed operation life time, the total quantity of spent fuel generated will be approximately 445 000 tHM. Regional projections reported by the IAEA [4] are shown in Figure 2.

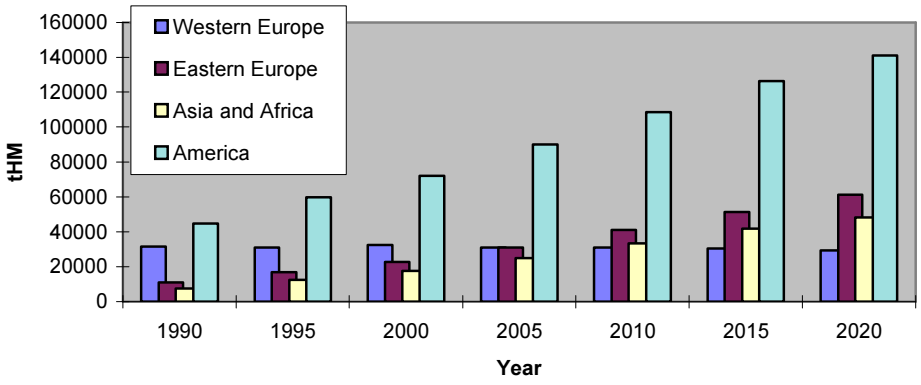


**Figure 2 Spent fuel stored by regions**

As delays are incurred in implementing reprocessing and in plans for geologic repositories, spent fuel storage for extended durations has become a progressive reality. Member States have referred to storage periods of 100 years and even beyond, and as storage quantities and durations extend, new challenges arise in the institutional as well as in the technical area.

This trend of more storage capacity for longer durations is expected to continue. The situation is complicated by trends toward higher initial enrichment, higher fuel burnup, as well as other considerations including the use of evolving fuel designs and mixed oxide (MOX) fuel [4].

The IAEA conference on management of spent fuel from nuclear power reactors in 2006 highlighted the following trends and findings [5]:

- Rising expectations for nuclear energy will continue to motivate new initiatives addressing the backend of the fuel cycle, including recycling options;
- Storage remains an interim solution, and all fuel cycle options require geologic disposal sooner or later;
- Current wet and dry technologies for spent fuel storage are mature and safe, but as storage durations extend and specifications and designs evolve, continued R&D will be needed particularly for behavior of fuels with higher burnups and new cladding materials;
- Further work is required to develop safety standards regarding spent fuel management, including not only storage but also recycling options;
- Further progress on reporting to the Joint Convention relevant to spent fuel was encouraged, both in the number of contracting parties as well as the rigor of the review process;
- Multilateral approaches will continue to be of interest given the potential benefits described by the 2005 DG Expert Group report;
- The evolving international scene has made spent fuel management one of the more important factors influencing the future of nuclear energy.

## OVERVIEW OF IAEA SPENT FUEL MANAGEMENT ACTIVITIES

Given the above trends and the importance of effective spent fuel management to sustainable utilization of nuclear energy, Member States of the IAEA maintain an active interest in related Agency work. Both the Standing Advisory Group for Nuclear Energy and the Technical Working Group responsible for spent fuel management (TWGNFCO) assign high priority to Agency activities in this area. This interest is also evident in participation in IAEA meetings. The 2006 spent fuel conference cited above was attended by 150 participants and observers from 40 countries and international organizations, representing a continuing increase relative to preceding conferences. Sixty participants attending the 2005 IAEA meeting on burnup credit applications represented a continuing increase in participation relative to preceding burnup credit meetings. Approximately 200 representatives from more than fifty Member States participated in a forum on spent fuel management issues in Vienna in late 2004.

The IAEA has been proactively involved in spent fuel management activities for more than 25 years (see http://www.iaea.org/OurWork/ST/NE/NEFW/nfcms_spentfuel.html). The Nuclear Fuel Cycle and Materials Section within the Department of Nuclear Energy organizes various meetings, often focused on producing technical documentation available to all member States on a topic of interest [6]. A list of technical documents related to spent fuel management published by the IAEA since 1990 is accessible at the above web link. Most IAEA technical documents on this topic can be accessed and downloaded free of charge at http://www-

pub.iaea.org/MTCD/publications/tecdocs.asp. In addition to the work on burnup credit described below, Agency activities in spent fuel management also include the following:

• Spent fuel storage technology (particularly dry storage) is undergoing evolution, with modified/new fuel and material designs and increasing target burnup levels. Increased burnup infers higher strains and increased cladding hydriding and oxidation. The coordinated research project on spent fuel performance assessment and research (SPAR-II) builds on over 25 years of related efforts, including the SPAR [7] and BEFAST projects. SPAR-II objectives include surveillance and monitoring programs for spent fuel storage facilities, fuel materials performance evaluation for wet/dry storage, and collection and exchange of spent fuel storage experience. Participants from over a dozen Member States and institutes have developed technical documentation resulting from the first two research coordination meetings held in Karlsruhe in 2005 and Tokyo in 2006 and will finalize this work at a concluding meeting to be held in Budapest in 2008.

• Extended spent fuel storage was explored during a regional workshop organized by the IAEA and held in Ljubljana in late 2004. Senior representatives from regulatory and implementation authorities in Bulgaria, Croatia, the Czech Republic, Hungary, Lithuania, Romania, Slovakia, Slovenia, and the Ukraine focused on the evolution of related national approaches, operational considerations, and cooperative initiatives. Participants concluded that significant progress had been made in these countries over the last few years in making provision for interim spent fuel storage.

• Based on one of the recommendations from the Ljubljana meeting, the IAEA initiated an activity to investigate the handling of damaged spent fuel. A technical meeting on this topic was held in December 2005 in Vienna and attended by 17 participants from 13 countries. Consultants meetings in 2006 and 2007 lead to a technical document addressing identification, detection, and handling of damaged spent fuel, due to be issued in 2008.

• The transfer of nuclear knowledge to Member States through the technical cooperation (TC) program is an important component of the work of the IAEA. In the area of spent fuel management, TC funds have supported participation in international conferences and regional workshops as well dedicated projects. The Agency has provided experts to review designs (e.g. in Pakistan) and address technical issues as well as organized visits to operational storage facilities of interest. As noted below, the IAEA has also assisted China in their request regarding burnup credit applications.

• As noted during the 2006 spent fuel conference, interest has been growing recently in emerging initiatives and technologies for spent fuel reprocessing. The IAEA held a meeting in October 2005 in the Republic of Korea attended by thirty participants from 14 countries to review spent fuel treatment options and applications. The results of this meeting were reviewed in subsequent smaller meetings in 2006 and 2007 to develop a technical document on spent fuel reprocessing options to be issued as a sequel to TECDOC-1467 dated September 2005.

• A particular challenge facing countries with small nuclear programs is to prepare for extended interim storage and then disposal of their spent nuclear fuel. The costs and complications of providing for away-from-reactor storage facilities and/or geological repositories for the relatively small amounts of spent fuel may be prohibitively high, motivating interest in regional solutions. Accordingly, the IAEA organized meetings on technical, economic, and institutional aspects of regional spent fuel storage and determined that technical considerations and economic issues may be less significant than ethical and institutional issues for the development of a multinational project. TECDOC-1482 [8] further informs the dialogue on multinational approaches to spent fuel management.

• An activity on the influence of high burnup and mixed oxide fuel on spent fuel management has involved meetings in 2006 as well as the week before PATRAM 2007 to develop a technical document as a resource to Member States on this topic.
• Economic considerations in spent fuel storage projects grow in importance as spent fuel storage quantities increase. Meetings held to date on this topic have served as key steps toward development of a pending technical report on economics of spent fuel management.
• For further information on these and other activities as well as related technical documents, see http://www.iaea.org/OurWork/ST/NE/NEFW/nfcms_spentfuel.html.

## IAEA BURNUP CREDIT ACTIVITIES

Criticality safety analyses for spent fuel systems traditionally assumed that the fuel was fresh, resulting in significant conservatism. Improved methods (calculations and measurements) for developing solid knowledge of spent nuclear fuel characteristics support efforts to take credit for the reactivity reduction associated with fuel burnup, by reducing this conservatism while maintaining appropriate criticality safety margins. The IAEA started its burnup credit (BUC) program with an advisory meeting in Vienna in 1997 to examine and report on the status of burnup credit for storage, transport, reprocessing, and disposal of PWR, BWR, VVER, RBMK and MOX spent fuel. The proceedings of that meeting (IAEA-TECDOC-1013 issued in 1998 and entitled "Implementation of burnup credit in spent fuel management systems.") noted that economics was a prime motivator for pursing BUC; gathering needed data consumed time and funds; cooperative development and communication would mitigate these needs.

A second major technical meeting in Vienna in 2000 attended by 35 participants from 17 countries and 2 international organizations surveyed the progress and status of international activities related to the use of burnup credit for spent fuel applications. Participants recognized the value of international cooperation on this topic and recommended further studies of axial effects, and verification methods for fuel burnup values, including cooperation in future experimental programs and sharing of available data. As noted by the IAEA at PATRAM 2001, participants also recommended holding a training course for potential users of burnup credit and their respective regulators. The proceedings of the technical meeting in 2000 were published in August 2001 as IAEA-TECDOC-1241, also entitled "Implementation of burnup credit in spent fuel management systems." As recommended in the latter technical meeting, a training course on the implementation of burnup credit in spent fuel management systems was held in the USA at the Argonne National Laboratory in 2001 with 25 course participants from 12 different countries.

In April 2002, the IAEA held its third technical meeting on burnup credit applications in Madrid with participation from 54 experts from 18 countries. Following eight topical sessions, four parallel working groups focused on code validation, key issues, safety assessments, and future applications. The proceedings of this meeting were published in 2004 [9] as TECDOC-1378, entitled "Practices and developments in spent fuel burnup credit applications."

In the area of technical cooperation, the IAEA has coordinated a project with China at their request focused on technology transfer related to burnup credit. Project activities from 2001 to 2005 included scientific visits, expert missions to provide training, equipment procurement, and fellowships. As one indicator of success, China was ably represented at the 2005 IAEA technical meeting on burnup credit by a fellowship recipient trained in 2004.

Pursuant to recommendations from the Madrid meeting, the IAEA held its next technical meeting on burnup credit applications in London 29 August – 2 September 2005. Sixty representatives

from 18 countries attended and participated in active discussions related to 34 plenary presentations in six topical sessions as well as four subsequent parallel working groups. The six topical sessions were entitled:
• Principles of choosing the calculation methodology with respect to the fuel design and the fuel management system;
• Nuclear data and Validation of depletion and reactivity calculations (reactivity worth and chemical assay);
• Criticality safety criteria;
• Procedural compliance with the safety criteria;
• Benefits of BUC applications;
• Regulatory aspects in BUC.

The four working groups focused on (1) Calculation methodology, (2) Validation and criticality safety criteria, (3) Procedural compliance with safety criteria, and (4) Regulatory aspects in BUC. Reports by the Working Group Chairs highlighted the following:
• Working group one (calculation methodology) identified three areas where insufficient guidance is readily available, for example the need to develop guidance as to what constitutes a complete set of documentation for burnup credit implementation.
• Working group two (validation and criticality safety criteria) provided thirteen specific conclusions, for example that experiments should be amenable to calculation without significant modeling approximations or assumptions and should include a thorough assessment of experimental uncertainty.
• Working group three (procedural compliance) provided six specific observations, for example that significant variation exists between standards with respect to whether measurement of burnup is a firm requirement or not.
• Working group four (regulatory aspects) identified six conclusions and four recommendations related to regulatory considerations, for example that the IAEA should assist in efforts to develop internationally accepted regulatory guidance for the implementation of burnup credit.

The leaders of these working group discussions presented their results at the closing plenary session on 2 September and then participated in an integrated panel discussion that preceded the closing summary by the meeting chair. The following conclusions and recommendations derived from deliberations during the 2005 meeting:
• Since BUC methodology is still developing, the international meetings organized by the IAEA play an important role in developing and maintaining technical capability as well as establishing good practice in BUC. The IAEA therefore was urged by the London TM participants to continue its activities in BUC and to organize BUC technical meetings in the future.
• Since the lack of publicly available chemical assay data, particularly for VVER fuel, is a serious obstacle to BUC usage, the international community should assist this effort.
• In addition, the international community should support cooperation in performing new radiochemical assays and critical experiments appropriate to enhance application of BUC.
• The IAEA was urged to assist the development of international standards or guidelines for implementation of BUC in wet and dry storage systems, transport casks, reprocessing facilities, and for final disposal.
• The IAEA was urged to assist in studying application of risk informed methods to BUC criticality safety assessments. It would be beneficial to develop methods of quantifying the risk factors due to the individual steps of BUC implementation and estimating the integral risk due to the use of BUC inclusive of its benefits.

The Meeting Chair concluded that the 2005 meeting represented an encouraging step forward in application of burnup credit among Member States. The proceedings of the 2005 London meeting were issued in 2007 as IAEA-TECDOC-1547 [10].


In addition to the larger technical meetings (TMs) described above, small consultancies have been held over the years both to handle pre- and post-TM actions and to monitor interim progress in burnup credit implementation. For example, the latest consultancy meeting on this topic was held in September 2007 in Vienna to review progress and to prepare for the next major technical meeting to be organized by the IAEA in April 2009. Further context is available at http://www.iaea.org/OurWork/ST/NE/NEFW/nfcms_spentfuel.html.

## CONCLUSIONS AND FUTURE DIRECTIONS

Spent fuel storage has been carried out safely and effectively for decades, and there is high confidence that this will continue to be the case. Yet as storage inventories and durations increase, issues associated with long term storage compel more attention, as witnessed by growing participation of IAEA Member States in Agency meetings (e.g. 2006 spent fuel conference, 2005 burnup credit meeting). Trends toward more storage capacity for longer durations are complicated by trends toward higher initial enrichment, higher fuel burnup, as well as evolving fuel designs. Motivated by these trends, the IAEA will continue to prioritize scrutiny of issues associated with extended spent fuel storage durations and quantities. Recent activities have examined issues associated with materials aging, performance monitoring, economics, maintenance, data requirements, cask loading, spent fuel treatment, regional facilities, and facility selection criteria.

In particular, activities associated with the implementation of burnup credit continue to receive focused attention by the IAEA, given the potential for increased capacities and resultant reduced costs and operational exposure. The Technical Working Group responsible for spent fuel management (TWGNFCO) has identified burnup credit activities as one of the top two priorities in this field. Member States are encouraged to consult the series of proceedings from IAEA technical meetings on burnup credit (for example, TECDOC-1547 issued in 2007) at http://www-pub.iaea.org/MTCD/publications/publications.asp, and to participate in the next

meeting on this topic scheduled for 21-24 April 2009 (details at http://www.iaea.org/OurWork/ST/NE/NEFW/nfcms_b3.html).

## ACKNOWLEDGMENTS

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