STATUS REPORT ON PREPARATION OF IAEA GUIDELINES FOR QUALIFICATION OF RESEARCH REACTOR FUELS*

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Abstract

The International Atomic Energy Agency, through a consultancy, is preparing a document describing good practices for the qualification of research reactor fuel. The rationale for the preparation of the document and the document's organization and content are discussed. It is anticipated that the consultants will present a final draft to the IAEA by mid-December for editing and publication in 2008.

1. INTRODUCTION

Increasingly critical non-proliferation concerns resulting from the use of high-enriched uranium (HEU) fuels in training, research, test, and isotope-production reactors† have resulted in a number of national and international fuel development and qualification programmes aimed at allowing these reactors to fully achieve their missions while using low-enriched uranium (LEU) fuels‡ and isotope-production targets. One result of international collaboration in fuel development and qualification has been the realization that participants from different countries do not always understand the terminology in the same way; for example, the term 'qualification' is currently interpreted differently in different countries. Consequently, an internationally accepted definition of fuel 'qualification' is needed.

Also, it is expected that the high level of fuel development and qualification activity around the world will lead to a high level of demand for the qualified fuels for conversion of existing, and use in new, research reactors. Such demand will mean that fuel-supply arrangements must be made with research reactor fuel manufacturers and that regulatory bodies will be faced with the need to judge the suitability of the newly developed fuels in the research reactors that they oversee.

The International Atomic Energy Agency (IAEA), recognizing the need for a universal understanding of what is required to qualify a new fuel and what information a potential user of the fuel or a regulatory body should expect the fuel developer to provide, convened a consultancy in Vienna during March 2005 to discuss the issue and recommend further activities to meet the

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† Hereinafter in this paper, the term "research reactor" is used to refer to training, research, test, and isotope-production reactors unless explicitly stated otherwise.

‡ Hereinafter in this paper, the term "fuel" will be assumed to refer only to LEU research-reactor fuel unless explicitly stated otherwise.

need. The consultants[*], representing a broad cross section of experts active in the international fuel development community, determined that preparation of a document providing a common definition of qualification and outlining good practices in developing and qualifying new research reactor fuels would provide valuable information for fuel developers and qualifiers, fuel manufacturers, fuel users, and regulatory bodies. Subcommittees of the consultants were established to prepare drafts of specific parts of the document.

Owing to the many duties of the consultants, virtually no work was accomplished for a year. However, for the past year and a half, the consultants have met on a regular basis to discuss the content of the document: in Sophia (April 2006), in Cape Town (November 2006), in Lyon (March 2007), and finally in Prague (September 2007). At the Prague meeting, a relatively complete draft of the document was reviewed. The document is now undergoing further revision, based on the consultants' comments, and will be reviewed again at the beginning of December 2007. By the middle of December, the consultants expect to present their final draft to the IAEA for editing and publication in 2008.

This paper presents a summary of the contents of the Good Practices Document[†].

2. Structure and Content of the Good Practices Document

2.1. Guiding principle of fuel development

Developing fuel, fuel elements, and fuel assemblies that will operate safely under the specified operating conditions is the ultimate goal of any fuel developer and reactor core designer. In the context of fuel development, operating conditions are normally considered to include both normal operating conditions and at least some incident conditions. The guiding principles are that (a) a heat transfer path from the fuel meat to the cladding must be maintained, (b) the fuel element must maintain its integrity to prevent fission products from entering the coolant, and (c) the fuel meat swelling must remain stable to beyond the highest fission density that could be achieved during irradiation.

2.2. Basic document structure

The chapters of the Good Practices Document are listed in Table 1.

Table 1. Titles of Good Practices Document chapters

Chapter Number	Chapter Title
1	Introduction
2	Scope
3	Definitions

[*] The initial group of consultants included: M. Salvatore – INVAP, H. Taboada – CNEA (Argentina); D. Sears – AECL (Canada); J.-P. Durand – Areva-CERCA, P. Lemoine – CEA (France); C.K. Kim – KAERI (Republic of Korea); A. Enin – NCCP (Russia); G. Gale – BWXT, M. Meyer – INL, J. Snelgrove – ANL (United States of America); and P. Adelfang-IAEA. In 2006, M. Salvatore resigned; C. Jarousse replaced J.-P. Durand; N. Arkhangelskiy – Rosatom (Russia) was added; M. Nilles replaced G. Gale, and T. Totev – ANL (USA) was added. In 2007, D. Wachs replaced M. Meyer, and D. Keiser – INL was added.

[†] The suggested title of the draft document is 'GOOD PRACTICES FOR QUALIFICATION OF RESEARCH REACTOR FUELS.' Hereinafter it will be referred to as the 'Good Practices Document.'

Chapter Number	Chapter Title
4	Information supplied by the fuel developer for fuel qualification
5	Overview of the fuel development and qualification process
Appendix	Supplement to Chapter 4 containing additional detailed information

2.3. Definitions

As indicated in the introduction, the terminology of fuel development and qualification currently is not used in a consistent manner by all those involved in this work. Therefore, after the introduction and scope, precise definitions are given of a number of terms specifically used in fuel development and qualification. For example, the definition of 'qualification' agreed upon by the consultants is:

> A process carried out by (1) a Fuel Developer to provide sufficient information about a new fuel type or about a new use for an existing fuel for a regulatory body to license that fuel type for use under a set of bounding geometric configurations and irradiation conditions and (2) a Fuel Manufacturer to demonstrate to a regulatory body and a customer that Fuel Elements and Fuel Assemblies of the new fuel type can be reliably and consistently manufactured to the required specifications.

Under this definition, the process clearly involves both the fuel developer and the fuel manufacturer, and both the regulatory body and the customer are involved in determining if a fuel is qualified.

2.4. Information that should be provided by the fuel developer

Following Chapter 3's definitions of critical terms, Chapter 4 provides a discussion of the information that should be provided by the fuel developer and the justification for each item; additional detailed information and discussion are provided in the Appendix. This information is summarized in Table 2.

Table 2. Information that should be provided by the fuel developer

Information	Rationale for Providing this Information
Basic Fuel Properties	
Fuel chemical and phase composition	Provides basis for the acceptable composition and metallurgical condition of the fuel material
Density	Needed to determine the volume fractions of fuel meat constituents, and, hence, the fuel meat uranium density
Heat Capacity	Needed to calculate the fuel meat temperature in nonequilibrium situations and needed for measurement of fuel meat thermal conductivity by the laser-flash method

Information	Rationale for Providing this Information
Thermal Expansion Coefficient	Needed to determine the thermal expansion coefficient of monolithic fuel meat and, perhaps, of high-density dispersion fuel meat
Method used to produce fuel powder for dispersion fuels	Describes acceptable methods to manufacture fuel powder having the required properties
Particle size distribution (for dispersion fuels)	Influences fuel meat and/or fuel element fabricability and fuel performance
Fuel foil properties (for monolithic fuel)	Influence fuel meat swelling and fuel element areal heat flux and mechanical strength
As-Manufactured Fuel Meat and Fuel Element Properties	
Volume and constituent volume fractions	Needed to determine fuel meat swelling
Heat capacity	Needed to calculate the fuel meat temperature in nonequilibrium situations and needed for measurement of fuel meat thermal conductivity by the laser-flash method
Thermal conductivity	Needed to calculate fuel meat temperature during irradiation and during post-irradiation cooling
Thermal expansion coefficient	Needed to evaluate stress resulting from differential thermal expansion during design of fuel element
Exothermic energy release	Needed to evaluate fuel temperatures during slow transients or loss-of-coolant situations
Mechanical properties	Needed during design of the fuel element and fuel assembly
Fuel Meat and Fuel Element Irradiation Properties	
Fission density distribution	Needed itself and needed to estimate the time history of fuel fission rates, both of which are required to interpret data from post-irradiation examinations
Fuel element and fuel meat swelling	Needed to determine if fuel is behaving in a stable manner and to estimate the narrowing of coolant channels between fuel elements
Fuel meat and fuel particle microstructures	Needed to accurately characterize the nature of fuel/matrix or fuel/cladding interaction and the nature of fuel material and fuel meat swelling
Mechanical integrity	Needed to assure that an adequate heat transfer path and containment of fission products is maintained

Information	Rationale for Providing this Information
Blister threshold temperature	Provides a figure of merit of the fuel element’s ability to withstand high temperatures during incidents
Cladding corrosion behaviour	Needed to assure integrity against the release of fission products and to estimate the thermal history of the fuel element
Fission product release	Needed to estimate the radiological source term in accident situations
Fuel Assembly Properties	
Hydraulic and mechanical properties	Needed to calculate coolant flow rates and to assure that the fuel assembly can withstand hydraulic and thermal stresses during irradiation
Irradiation behaviour	Needed to demonstrate that fuel assemblies will perform under irradiation as expected, based on all of the properties listed above in this table.

2.5. Generic approach to fuel development and qualification

A generic approach for developing and qualifying of a new fuel is described in the first three sections of Chapter 5. Then the variations in the process needed when qualifying an already-qualified fuel type for use under the existing qualification limits (that is, when a potential user of a previously qualified fuel wants to use that fuel in a fuel element or fuel assembly with a different design than the one in which the fuel was originally qualified) and for use outside the existing qualification limits are described. The approach described is a consistent and integrated approach based on the experience of organizations previously involved in LEU fuel development and on international best practices. The fuel development and qualification process that is described focuses on the tasks to be accomplished and the logical sequence of events. It neither describes the tasks in detail nor prescribes the way in which the tasks should be accomplished, because such details depend on the policies, practices, methodologies, and standards of the particular country and organizations involved.

A phased approach is recommended for LEU fuel development and qualification, with the first phase focused on research work and development/testing activities leading to the selection of a preferred fuel type, the second phase focused on fuel performance qualification to demonstrate that the selected fuel meets specified performance requirements, and the third phase focused on qualification of the fuel manufacturer. The recommended activities are summarized in Table 3.

Table 3. Steps in generic approach to fuel development and qualification

Activity	Results of Activity
Phase 1: Research and Development	
Fuel conceptual design	Rationale for developing a new fuel
	Choice of design concept for the fuel element and fuel assembly
	Initial selection of candidate fuel and cladding materials
	Initial selection of candidate manufacturing technologies
Fuel manufacturing development	Fissile material (meat) manufacturing process
	Cladding manufacturing process
	Fuel element (plates, rods, tubes) manufacturing process
Out-of-pile testing	Basic fuel properties (before and after manufacturing)
	Compatibility of fuel meat components or fuel and cladding (before and after manufacturing)
	Integrity of the fuel meat/cladding bond
	Resistance of the fuel to corrosion in the presence of the coolant (after manufacturing)
Irradiation testing and post-irradiation examination	Determination of required materials properties and performance levels
	Selection of irradiation devices and facilities
	Preparation of safety report
	Performance of in-pile measurements
	Performance of PIE
	Preparation of final PIE report
Decision point	Proceed to the final design and qualification phase or continue the development phase
Phase 2: Fuel Performance Qualification	
Detailed design	Design requirements
	Design description
Technical specification	Technical specification for qualification fuel elements and fuel assembly
Prototype manufacturing assessment and development	Fuel material (powder or monolithic) process
	Fuel element process
	Fuel assembly process
Prototypic fuel element and fuel assembly manufacturing	Full-size fuel assemblies for irradiation tests

Activity	Results of Activity
Qualification test planning	Qualification irradiation test plan
Prototype full-size fuel assembly irradiation testing, including post-irradiation examinations	Demonstration that the behaviour of fuel elements and fuel assembly is satisfactory and consistent with results from Phase 1
Fuel qualification report	Report demonstrating that the newly developed fuel can be safely used in its intended applications
Fuel licensing	Approval by a regulatory body for use of the newly developed fuel in a licensed reactor
Manufacturer qualification	
Subcomponent manufacturing qualification	Manufacturing of statistically significant quantities of subcomponents to required specifications
Full-size fuel element and assembly manufacturing qualification	Manufacturing of prototype or lead test assemblies to customer specifications for irradiation to compare behaviour with that of qualified reference fuel
Requalification (if needed)	Demonstration that manufacturing quality is under control
	Demonstration that the workers are still trained
	Demonstration that the inspection equipment is still able to perform properly
	Demonstration that special process qualifications (welding, heat-treatment, etc) are still valid
	Demonstration that previous or new subcontractors and/or material/component suppliers are either still qualified or have been requalified

Chapter 6 discusses qualification processes used in a number of countries engaged in fuel development and qualification, with examples of the qualification of specific fuels. The discussions of Chapter 6 both demonstrate that actual qualification programs are consistent with the generic approach described in Chapter 5 and provide additional detail to emphasize the good practices recommended in Chapter 5. The examples describe the qualification of (a) U_3Si_2-Al dispersion fuel through an international collaboration during the 1980s led by the US Reduced Enrichment for Research and Test Reactor (RERTR) programme, (b) U_3Si_2-Al dispersion fuel by the French CEA for the enhanced conditions required for use in the OSIRIS reactor and in the Jules Horowitz reactor currently being designed, (c) U_3Si-Al dispersion fuel for use in AECL's NRU and Maple-type research reactors, (d) high-density TRIGA® fuel, and (e) high-density UO_2-Al dispersion fuel (IRT-4M) fuel assemblies in Russia for use in several reactors outside Russia.

3. Conclusion

As a result of an IAEA initiative, a draft document on 'GOOD PRACTICES FOR QUALIFICATION OF RESEARCH REACTOR FUELS' is nearing completion. The consultants preparing the document expect to present its final draft to the IAEA in mid-December 2007 for editing and publication in 2008. In addition to recommending good practices to any organization undertaking a fuel development programme in the future, this document will bring research reactor fuel manufacturers, fuel users, and regulatory bodies up to date on the information expected to be available to support licensing of newly developed fuels for conversion of research reactors from the use of HEU fuels to the use of LEU fuels and for use in new reactors.

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