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Report on the Survey of the Design Review of New Reactor Applications

Volume 3: Reactor

Working Group on the Regulation of New Reactors

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NUCLEAR ENERGY AGENCY
COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

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Working Group on the Regulation of New Reactors

Report on the Survey of the Design Review of New Reactor Applications
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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 34 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation’s statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 31 countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, the Russian Federation, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission also takes part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information.

The NEA Data Bank provides nuclear data and computer program services for participating countries. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON NUCLEAR REGULATORY ACTIVITIES

The Committee on Nuclear Regulatory Activities (CNRA) shall be responsible for the programme of the Agency concerning the regulation, licencing and inspection of nuclear installations with regard to safety. The Committee shall constitute a forum for the effective exchange of safety-relevant information and experience among regulatory organisations. To the extent appropriate, the Committee shall review developments which could affect regulatory requirements with the objective of providing members with an understanding of the motivation for new regulatory requirements under consideration and an opportunity to offer suggestions that might improve them and assist in the development of a common understanding among member countries. In particular it shall review current management strategies and safety management practices and operating experiences at nuclear facilities with a view to disseminating lessons learnt. In accordance with the NEA Strategic Plan for 2011-2016 and the Joint CSNI/CNRA Strategic Plan and Mandates for 2011-2016, the Committee shall promote co-operation among member countries to use the feedback from experience to develop measures to ensure high standards of safety, to further enhance efficiency and effectiveness in the regulatory process and to maintain adequate infrastructure and competence in the nuclear safety field.

The Committee shall promote transparency of nuclear safety work and open public communication. The Committee shall maintain an oversight of all NEA work that may impinge on the development of effective and efficient regulation.

The Committee shall focus primarily on the regulatory aspects of existing power reactors, other nuclear installations and the construction of new power reactors; it may also consider the regulatory implications of new designs of power reactors and other types of nuclear installations. Furthermore it shall examine any other matters referred to it by the Steering Committee. The Committee shall collaborate with, and assist, as appropriate, other international organisations for co-operation among regulators and consider, upon request, issues raised by these organisations. The Committee shall organise its own activities. It may sponsor specialist meetings and working groups to further its objectives.

In implementing its programme the Committee shall establish co-operative mechanisms with the Committee on the Safety of Nuclear Installations in order to work with that Committee on matters of common interest, avoiding unnecessary duplications. The Committee shall also co-operate with the Committee on Radiation Protection and Public Health and the Radioactive Waste Management Committee on matters of common interest.

FOREWORD

The Committee on Nuclear Regulatory Activities (CNRA) of the Nuclear Energy Agency (NEA) is an international committee composed primarily of senior nuclear regulators. It was set up in 1989 as a forum for the exchange of information and experience among regulatory organizations and for the review of developments which could affect regulatory requirements. The Committee is responsible for the NEA program concerning the regulation, licencing and inspection of nuclear installations. In particular, the Committee reviews current practices and operating experience.

The CNRA created the Working Group on the Regulation of New Reactors (WGRNR) at the Bureau meeting of December 2007. Its Mandate was to "be responsible for the programme of work in the CNRA dealing with regulatory activities in the primary program areas of siting, licencing and oversight for new commercial nuclear power reactors (Generation III+ and Generation IV)".

At its second meeting in 2008, the Working Group agreed on the development of a report based on recent regulatory experiences describing; 1) the licencing structures, 2) the number of regulatory personnel and the skill sets needed to perform reviews, assessments and construction oversight, and 3) types of training needed for these activities. Also the Working Group agreed on the development of a comparison report on the licensing processes for each member country. Following a discussion at its third meeting in March 2009, the Working Group agreed on combining the reports into one, and developing a survey where each member would provide their input to the completion of the report.

During the fourth meeting of the WGRNR in September 2009, the Working Group discussed a draft survey containing an extensive variety of questions related to the member countries' licensing processes, design reviews and regulatory structures. At that time, it was decided to divide the workload into four phases; General, Siting, Design and Construction. The General section of the survey was sent to the group at the end of the meeting with a request to the member countries to provide their response by the next meeting. The *Report of the Survey on the Review of New Reactor Applications* NEA/CNRA/R(2011)13[1] which covers the members' responses to the General section of the survey was issued in March 2012.

At the tenth meeting of the WGRNR in March 2013, the members agreed that the report on responses to the Design section of the survey should be presented as a multi-volume text. As such, each volume will focus on one of the eleven general technical categories covered in the survey. It was also agreed that only those countries with design review experience related to the technical category being reported are expected to respond to that section of the survey. Since the March 2013 meeting, the following reports have been published:

- Report on the Design Review of New Reactor Applications – Volume 1: Instrumentation and Control, NEA/CNRA/R(2014)7[2], June 2014
- Report on the Design Review of New Reactor Applications – Volume 2: Civil Engineering Works and Structures, NEA/CNRA/R(2015)5[3], December 2015.

[1] To download the report, see: www.oecd-nea.org/nsd/docs/2011/cnra-r2011-13.pdf
[2] To download the report, see: www.oecd-nea.org/nsd/docs/2014/cnra-r2014-7.pdf

In addition to the design phase reports, the working group also issued a report that will deal with a survey on the review of new reactor applications focusing on questions related to the construction stage. The *Report on the Construction Oversight Survey* NEA/CNRA/R(2015)3[4] was issued in September 2015.

The reports of the survey on the design review of new reactor applications are to serve as guides for regulatory bodies to understand how technical design reviews are performed by member countries. It therefore follows that the audience for these reports are primarily nuclear regulatory organisations, although the information and ideas may also be of interest to other nuclear industry organizations and interested members of the public.

[3] To download the report, see: www.oecd-nea.org/nsd/docs/2015/cnra-r2015-5.pdf
[4] To download the report, see: www.oecd-nea.org/nsd/docs/2015/cnra-r2015-3.pdf

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This report, prepared by Dr Steven Downey (NRC, United States), is based on discussions and input provided by members of the CNRA's Working Group on the Regulations of New Reactors or staff at the regulatory body, listed below. Mr Janne Nevalainen (STUK, Finland) and Ms Aurélie Lorin (NEA Secretariat) chaired the meetings and supervised the work carried out by the group.

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EXECUTIVE SUMMARY

At the tenth meeting of the CNRA Working Group on the Regulation of New Reactors (WGRNR) in March 2013, the Working Group agreed to present the responses to the Second Phase, or Design Phase, of the Licensing Process Survey as a multi-volume text. As such, each report will focus on one of the eleven general technical categories covered in the survey. The general technical categories were selected to conform to the topics covered in the International Atomic Energy Agency (IAEA) Safety Guide GS-G-4.1. This document, which is the third report on the results of the Design Phase Survey, focuses on the Reactor.

The Reactor category includes the following technical topics: fuel system design, reactor internals and core support, nuclear design and core nuclear performance, thermal and hydraulic design, reactor materials, and functional design of reactivity control system. For each technical topic, the member countries described the information provided by the applicant, the scope and level of detail of the technical review, the technical basis for granting regulatory authorisation, the skill sets required and the level of effort needed to perform the review. Based on a comparison of the information provided by the member countries in response to the survey, the following observations were made:

- Although the description of the information provided by the applicant differs in scope and level of detail among the member countries that provided responses, there are similarities in the information that is required.
- All of the technical topics covered in the survey are reviewed in some manner by all of the regulatory authorities that provided responses.
- Design review strategies most commonly used to confirm that the regulatory requirements have been met include document review and independent verification of calculations, computer codes, or models used to describe the design and performance of the core and the fuel.
- It is common to consider operating experience and lessons learned from the current fleet during the review process.
- In addition to the country-specific regulations and guidance documents, member countries commonly refer to internationally recognised consensus standards to provide the technical basis of regulatory authorisation.
- The most commonly and consistently identified technical expertise needed to perform design reviews related to this category are nuclear engineering, materials engineering and mechanical engineering.

The complete survey inputs are available in the appendices.

INTRODUCTION

During the five decades of commercial nuclear power operation, nuclear programmes in NEA countries have grown significantly. Over the years, communication among member countries has been a major reason for the steady improvements to nuclear plant safety and performance around the world. Member countries continue to learn from each other, incorporating past experience, and lessons learned in their regulatory programmes. They consult each other when reviewing applications and maintain bilateral agreements to keep the communication channels open. This has been vital and will continue to be extremely important to the success of the new fleet of reactors being built.

The Design Phase Survey Reports continue along these lines by providing detailed information on the design-related technical topics that are reviewed by the regulatory organisation as part of the regulatory authorisation process. This document, which is the third report on the results of the Design Phase Survey, focuses on the Reactor.

SURVEY

The Second Phase, or Design Phase, of the licencing process survey conducted by the CNRA Working Group on the Regulation of New Reactors (WGRNR) covers eleven general technical categories that are based on IAEA Safety Guide GS-G-4.1. Under these eleven general categories, there are a total of 69 specific technical topics to be addressed. For each topic, a member country is asked to answer seven survey questions. At the March 2013 meeting, the Working Group agreed that the report of the responses to the Design section of the survey should be presented as a multi-volume text. As such, each volume will focus on one of the eleven general technical categories covered in the survey. This volume, which focuses on the Reactor, is the third of several reports that will present the results of the Design Phase Survey.

The following pages present high level summaries provided by the members and a discussion of the survey results. Complete survey responses are presented in the appendices.

HIGH LEVEL SUMMARIES

Canada

The Canadian Nuclear Safety Commission (CNSC) offers an optional Pre-Licensing Vendor Design Review service. This is an assessment of the design of a nuclear power plant based on the vendor's reactor technology. The words "pre-licensing" indicate that the design review is undertaken prior to the submission of a licence application to the CNSC by an applicant seeking to build and operate a new nuclear power plant and the word 'optional' indicates that it is not required as part of the licensing process.

The design does not certify that the nuclear power plant design is licensable in Canada, nor does it lead to the issuance of a licence under the *Nuclear Safety and Control Act*. The conclusions of the review do not bind or otherwise influence decisions made by the Commission (being the Tribunal portion of the CNSC); rather they indicate the opinion of the staff of the CNSC.

The objective of a review is to verify, at a high level, the acceptability of a nuclear power plant design against Canadian nuclear regulatory requirements and expectations, as well as against Canadian nuclear codes and standards. The review also identifies any fundamental barriers to licensing the design in Canada and derives a resolution path for any design issues identified in the review. The review considers the areas of design that relate to reactor safety, security or safeguards and has three phases:

Phase 1: Assessment of Compliance with Regulatory Requirements: This phase involves an overall assessment of the vendor's nuclear power plant design against the most recent CNSC design requirements for new nuclear power plants in Canada as indicated in REGDOC 2.5.2, Design Of Reactor Facilities: Nuclear Power Plants as applicable.

Phase 2: Assessment for Any Potential Fundamental Barriers to Licensing: This phase goes into further details with a view to identifying any potential fundamental barriers to licensing the vendor's nuclear power plant design in Canada. The result of Phase 2 will be taken into account when reviewing the Construction Licence Application and is likely to result in increased efficiencies of technical reviews.
Phase 3 Follow-up: This phase allows the vendor to follow-up on certain aspects of Phase 2 findings by seeking more information from the CNSC and/or asking the CNSC to review activities taken by the vendor towards improving the reactor's design readiness

For more information on the CNSC's Pre-licensing Vendor Design Review, please refer to GD-385, Pre-licensing Review of a Vendor's Reactor Design.

The reactor design is reviewed as part of this Pre-Licensing Vendor Design Review, against the requirements and expectations contained in Regulatory Document REGDOC-2.5.2, *Design of Reactor Facilities: Nuclear Power Plants, which* sets out the CNSC's requirements and guidance for the design of new water-cooled NPPs.

REGDOC-2.5.2 was drafted following the identification of the need to update existing regulatory document RD-337, *Design of New Nuclear Power Plants,* which the CNSC published in 2008. The amendments to RD-337 ensure alignment with current national and international codes and practices, most notably the principles set forth in the International Atomic Energy Agency (IAEA) document SSR-2/1, *Safety of Nuclear Power Plants: Design*, and the adaptation of these principles to Canadian practices.

The revised requirements and new guidance also take into account findings from a benchmarking study, which compared RD-337 against the design requirements of the United States, the United Kingdom, France, Finland and the Western European Regulators Association to identify differences in objective, scope and level of detail. In addition, REGDOC-2.5.2 implements recommendations from the CNSC's *Fukushima Task Force Report*. That report identified improvements to the CNSC's regulatory framework to strengthen the oversight of existing programs, including those for the design of new NPPs.

In addition, when applying for a license to construct an NPP, design information, as specified in sections 5(a), 5(b), 5(d), 5(e) and 5(g) of the Class I Nuclear Facilities Regulations, must also be submitted.

Finland

The information provided in this report is based on the review of the Construction License Application (CLA) Preliminary Safety Assessment Report (PSAR) and associated topical reports for the EPR type Nuclear Power Plant, Olkiluoto 3 (OL3). The review is based on Finnish Safety Regulations and STUK YVL Guidance. Chapter 4 of the OL3 PSAR provided a description of the physical and thermal-hydraulic properties of the reactor. In the regulatory review of the reactor the following areas of reactor design were reviewed; fuel behaviour calculations for cycles 1-4 with PCI limits; mechanical design of the fuel assembly including Geometric compatibility and fuel rod and assembly; loads in normal operation and accidents as well as operation experience.

For the regulatory review, STUK (Radiation and Nuclear Safety Authority) carried out fuel behaviour analyses for the first cycles of normal operation as well as fuel behaviour analyses in transients and accidents analyses
STUK utilised experts mainly from its own staff for the CLA review. The staff involved in the review have training and experience in fuel behaviour, structural mechanics and thermal-hydraulics.

France

In France, most of the design information provided by the applicant is in the safety analysis report. In particular, the following information is systematically included: safety requirements, functional and design requirements, design basis, tests results (if any) and experience feedback (if any). More detailed information is usually provided in specific documents on systems, fuel, safety studies, in order to ease the examination of the case.

The technical analysis of the file submitted by the applicant is performed by IRSN (Institute of Radiation Protection and Nuclear Safety), ASN (Nuclear Safety Authority)’s TSO. This analysis is fed by detailed exchanges with the applicant under the form of questionnaires sent by IRSN and answers transmitted by the applicant. This process is supported by technical meetings between IRSN, the applicant and ASN. IRSN also carries out research work on various subjects related to safety like fuel behaviour, severe accidents, structural mechanics, etc. and it contributes to the development of several computing codes used in accident simulation. Confirmatory analyses are performed only in cases of particular difficulties encountered or doubts raised in reviewing the applicant’s file. They are mostly run in thermal-hydraulics, neutronics and structural mechanics.

Reactor materials are subject to specific regulation on nuclear pressure equipment. According to this regulation, an evaluation of the design is performed by ASN on the basis of the information provided by the manufacturer in order to assess the conformity that leads to a certification.

The technical bases include regulatory requirements, technical codes as for example RCCs (Design and Construction Rules) edited by AFCEN (Association Française pour les règles de Conception, de construction et de surveillance en exploitation des matériels des Chaudières Electro Nucléaires - French association for design and manufacturing rules of PWR and FBR), standards and several ASN guides. It is complemented by specific chapters of the safety analysis report. An analysis of all safety studies is systematically performed and this is considered as a good practice.

As regards the level of effort, the amount needed to review a new design strongly depends on the degree of novelty of the design. It can take from a few weeks for a limited evolution to several years for a major evolution in design or demonstration.

Japan

The information provided is based on the new regulatory requirements for commercial nuclear power plants that got into force on July 8, 2013. In the sense of "Back-fit", the new regulations are applied to the existing nuclear power plants. After the TEPCO's Fukushima Daiichi NPS accident, all nuclear power plants were stopped. Only nuclear power plant that conforms to the new regulatory requirements could restart. The Nuclear Regulation Authority (NRA) that was established to improve its nuclear safety management and regulation in 2012 reviews application to restart.

The new regulatory requirements significantly enhance design basis and strengthen protective measures against natural phenomena which may lead to common cause failure, for example strict evaluation of earthquakes, tsunamis, volcanic eruptions, tornadoes and forest fires, and countermeasures against tsunami inundation. They also enhance countermeasures against events other than natural phenomena that may trigger common cause failures, for example strict and thorough measures for fire protection, countermeasures against internal flooding.

The new regulatory requirements newly require preventing core damage under postulated severe accident conditions, such as establishing SSCs, procedures etc. which make a reactor sub-critical and maintain the integrity of the reactor coolant pressure boundary and the containment. They also require preventing containment vessel failure under postulated severe core damage. Moreover they require countermeasures against loss of large area of NPP due to extreme natural hazards or terrorisms. Applicants should provide information including PRA report and safety analysis reports.

The NRA has issued lots of requirements, standards, and guidelines on the above since its establishment. The NRA staff reviews accident progression, reactor design, in terms of design-basis events and severe accident conditions.

Korea

Safety reviews of the license application documents submitted by the applicant are performed by the Korea Institute of Nuclear Safety (KINS) at the request of the Nuclear Safety and Security Commission (NSSC). The review process is started only after the docket review is confirmed as satisfactory in accordance with the laws and regulations. The safety reviews are conducted twice; for the purpose of issuing a construction permit and for the purpose of issuing an operating license purpose. The review plan is made to allow a more strict review to be conducted on the important items relating to: 1) operating experience (i.e., incidents and failures, etc.) at nuclear power plants of the same design that are already in operation; 2) design changes compared to the previous plants; 3) application of the latest technical criteria, 4) first of a kind design issues, 5) issues of significant public concern, and so on. For certain aspects, the key review items are selected and their adequacy verified through confirmatory audit calculations. With respect to the items already approved, or those which were reviewed in connection with the nuclear power plants of the same design that are already in operation, a more simplified review and assessment is performed. A topical report that will address methodologies, relevant computer codes, and matters related to safety that may be generically applied to several reactors, is reviewed independently from the review process of the license application documents.

The principal criteria for review and assessment with respect to safety of nuclear reactor facilities are presented in the Regulation on Technical Standards for Nuclear Reactor Facilities, etc. This Regulation prescribes the specific requirements for acceptance criteria stipulated in Articles 11 (Standards for Construction Permits) and 21 (Standards for Operating Licenses) of the Nuclear Safety Act. NSSC Notices prescribe the specific requirements for nuclear reactor facilities. The Korea Electric Power Industry Codes (KEPIC) and standards endorsed through NSSC Notices can be used as specific requirements for the detailed component design, manufacturing, testing, and so on. The review guidelines developed by KINS also provide guidance on safety aspects, and as such are used as an important reference for review and assessment. KINS Regulatory Criteria, Regulatory Standards, and Standard Review Guides (SRG) are used. KINS/GE-N005 (Technical Guidelines for Safety Analysis Computer Codes and Methodology for Nuclear Reactor Facilities) stipulates that a verification & validation (V&V) for the computer codes be performed as part of the safety analysis of nuclear power plants. Especially in connection with validation, KINS requires that the licensees prove their capability by comparing with 'separate effect test' and 'integral effect test' data for specific phenomena and calculation purposes.

In order to maintain the quality of review and assessment activities, KINS ensures that the regulatory review activities should be performed only by those who have more than 2 years of practical experience in nuclear safety regulation organizations or nuclear industries as per the Rules for Entrusted Regulatory Activities (Specific Rules on Safety Review for Nuclear Reactor and Related Facilities). Those in charge of review activities are required to take continuing education following a training schedule established annually, in order to enhance their technical expertise. Each technical staff member takes at least 40 hours of training a year, which helps to ensure technical competence of the staff engaged in regulatory activities.

Russia

A licensee (or an applicant) in Russia shall carry out researches, experiments and calculations, and develop safety cases for nuclear facilities in compliance with the federal regulations in the field of atomic energy use. In accordance with the requirements established for the licensing procedure, the licensee shall develop and submit to Rostechnadzor a package of documents substantiating safety of a nuclear facility (including a safety analysis report, a probabilistic safety analysis report and others) to obtain licenses for siting, construction and operation of a NPP unit. The applicant should submit all the necessary justifications (including references to calculations and experimental re-searches, if necessary) required by regulations in the field of atomic energy use, and demonstrate the compliance of the taken solutions with the state-of-the-art science and technology.

The regulatory body evaluates the safety substantiations by expert review of the documents submitted by the applicant with involvement of the technical support organisations (TSOs) that have specialists of the adequate competence. Usually, such a safety review includes independent neutronic, thermal-hydraulic calculations, as well as calculations of other types.

Slovak Republic

The information provided is based on Slovak legal framework which accommodates Western European Nuclear Regulators' Association (WENRA) reference levels and IAEA standards. The fulfilment of these requirements is reported via safety analysis report, technical and quality documentation.

Applicant has to demonstrate that the reactor is designed so, that during normal operation, during abnormal operation and during design basis accidents, the robustness, lifetime and functional reliability of its parts and equipment are ensured with a sufficient margin of error. Further must demonstrate that undue coolant leaks will not occur and materials used for their manufacture are selected for their minimum activation during normal operation. The main goal of all submitted documentation is to ensure that all legislative requirements are fulfil and that a nuclear facility will be operated safely and the public will be protected against undesirable effects of nuclear facility.

Review of applicants´ submitted documentation is usually performed by regulatory body employees and also with TSO. In case of using support services from TSO there is a condition of TSO independence. This condition resulting from fact, that the Slovak Republic is small and there is no a lot of organisation with relevant skills in this field. So we have to prevent of possibility, that the same organization will support services for nuclear facility and also for regulatory body.

Slovenia

The information provided is based on the review of a licensing process for reactor core and reactor systems design approval. The fundamental purpose is for the applicant to demonstrate that the facility and equipment, the operating procedures, the processes to be performed and other technical requirements described in the Safety Analysis Report offer reasonable assurance that the plant will comply with the regulations. The most extensive review is performed at the design certification stage. During the operation stage, in case of the systems changes for example, the licensing system is carried out in the same way, only less intensive.

The basic nuclear power plant design bases are set in Rules on Radiation and Nuclear Safety Factors. They based on WENRA reference levels. The requirements for technical acceptance, safety functions, safety analyses, reactor trip systems, residual heat removal, protection systems and instrumentation and control are set in Rules. Technical acceptance includes the fuel cladding protection criteria and criteria for primary coolant system pressure boundary protection.

The information provided by applicant is based on detail system description with drawings, material properties and design basis. The safety analyses are normal part of applications. The uncertainties of results and sensitivity analyses together with the information of code (verification, validation, licence) shall be provided. For the nuclear design is important to provide physical parameters like as power distribution, peaking factors and criticality calculations results (shutdown margin, reactivity). Thermal and hydraulic design information is important for reactor design approval. From the reactivity point of view the information of reactivity control system is needed.

Additionally, the Slovenian Nuclear Safety Administration (SNSA) during the licensing process evaluate that the applicant has provided complete information to demonstrate that the design, materials, fabrication methods, inspection techniques used conform to all applicable regulations, industrial codes and standards. The review of the results of testing, inspection and surveillance is also performed.

It is necessary that during the license process confirm the core design calculations and some thermo-hydraulic calculations.

Nuclear engineer and reactor physicist are the primary expertise needed to successfully perform reactor related core design review and assessment of fuel performance. Nuclear engineers are also needed to evaluate fuel and reactor performance during design basis accidents. In some areas, mechanical engineers (structural integrity of reactor internals and core support structures, thermal-hydraulic and reactivity control system design) and material engineers (material properties, aging) are also needed to completely review the technical topic.

United Kingdom

The information provided here is relevant to the technical review of a Pre-Construction Safety Report (PCSR) and its supporting documentation. Prior to an application for a site licence to construct a nuclear power plant in the United Kingdom (UK), it is now common for the reactor vendor to request that the reactor design be subject to Generic Design Assessment (GDA) with the aim to obtain a UK Design Acceptance Confirmation (DAC). Initially the reactor vendor provides a preliminary safety case for GDA, then develops the safety case documentation needed for the PCSR (taking into consideration advice from the Office for Nuclear Regulation - ONR).

At the end of GDA, a reasonably complete generic PCSR is expected, with no outstanding issues that would be sufficiently serious to prevent the reactor to be constructed and operated safely, and thus, to be used in the UK. However, there may be findings which are carried forward for resolution by the future licensee (e.g. during plant procurement and construction phases). The PCSR will also need to be modified and expand, as appropriate, at a later date, to capture the actual characteristics, and meet the specific requirements, of a particular site and a specific operating organisation. A site-specific PCSR, accepted by ONR, is required prior to start of nuclear island safety-related construction.

The purpose of the PCSR is to document the design and to demonstrate that the detailed design proposal will meet the safety objectives before construction or installation commences, and that sufficient analysis and engineering substantiation has been performed to prove that the plant will be safe. This includes explaining how the decisions regarding the achievement of safety functions ensure that the overall risk to workers and public will be reduced as low as reasonably practicable.

Design information provided by the applicant should establish the capability of the reactor to perform its safety functions throughout its design lifetime under all normal operational modes and anticipated accident conditions (the design basis). It is also a requirement to consider measures necessary to provide defence in depth; including measures to mitigate potential accidents beyond the design basis and severe accidents.

To accomplish these objectives, the applicant is expected to: define the safety functions required of systems and components; identify the potential degradation mechanisms which could impair these safety functions; and set limits and conditions of operation with sufficient margin to plant damage conditions. The adequacy of the safety limits is expected to be demonstrated by pessimistic deterministic studies and by probabilistic risk assessment. Safety significant equipment needs to be designed, manufactured and maintained in accordance with requirements appropriate to its safety classification.

Ultimately, the licensee is responsible for ensuring that the plant has been designed and manufactured in accordance with appropriate standards. However, ONR have developed high-level Safety Assessment Principles (SAP) and more detailed Technical Assessment Guides (TAG) which provide guidance on topics to consider in assessing compliance with regulatory requirements. Office for Nuclear Inspectorate (ONR)'s SAPs and TAGs are regularly reviewed and are publically available.

The ONR approach to regulation is to perform a targeted sample of the safety arguments and evidence presented in the safety case and, where necessary, to carry out confirmatory analysis on issues identified as uncertain or important to the safety arguments being made.

The expertise required for assessment of the reactor is broadly aligned into topics. These include for example: structural integrity, fuel performance, fault studies, PSA and radiological protection. Other topic areas are involved in the assessment of specific issues. To undertake this assessment, ONR deploys experienced nuclear engineers in accordance to their technical expertise, seeking specialist advice from external experts when required.

United States

The information provided is based on the technical review of a new reactor design certification application, but is also applicable to the review of applications for new reactor design approvals and combined licenses issued under 10 CFR Part 52. Typically, the most extensive review of the reactor design is performed at the design certification stage. New reactor combined license (COL) applicants prefer to incorporate most, if not all, of the information related to the reactor by reference to a certified standard plant design. COL applicants also conduct site-specific analyses associated with certain design parameters to confirm that the standard plant design is suitable for the proposed plant site. If the COL applicant identifies parameters that are not bounded by the standard design, additional analyses are performed to demonstrate that the structures, systems, and components (SSCs) are able to perform their safety related function. Otherwise, the COL applicant may propose a departure from the standard design in order to provide an alternative. In addition to departures, a COL application may also include site-specific SSCs that are not part of the standard design. As such, the staff's review of this technical category at the COL application stage would focus on site specific information and departures from the standard plant design.

Regardless of the type of application, the fundamental purpose is for the applicant to demonstrate that the facility and equipment, the operating procedures, the processes to be performed, and other technical requirements described in the safety analysis report (SAR) offer reasonable assurance that the plant will comply with the regulations and that public health and safety will be protected. Design information provided by the applicant in this technical category should establish the capability of the reactor to perform its safety functions throughout its design lifetime under all normal operational modes, including transient, steady-state, and accident conditions. To accomplish this, the applicant should provide a complete description and analysis of the mechanical, nuclear, and thermal-hydraulic design of the various reactor components including the fuel, reactor vessel internals, and reactivity control systems. This description should indicate the independent and interrelated performance and safety functions of each component. The applicant should also include the design and performance characteristics of each component, analysis techniques used, and load conditions considered.

The regulations related to this technical category require that the reactor core and associated coolant, control, and protection systems be designed with appropriate margins to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences. Several regulatory guides have been developed to provide guidance to applicants and licenses on acceptable approaches to meet the regulatory requirements.

Once an application has been formally accepted, the nuclear regulatory commission (NRC) staff reviews the information provided for compliance with the regulatory requirements and performs confirmatory analyses, as necessary, to make a reasonable assurance finding. The scope and level of detail of the staff's safety review of reactor design is based on the guidance provided in the applicable sections of The standard review plan (SRP), NUREG-0800. As part of the review, the staff also considers emerging issues, operating experience, and lessons learned from the current fleet.

Reactor systems engineering and nuclear engineering are the primary expertise needed to successfully perform reviews of the reactor design. Reactor systems engineering evaluate systems and system interactions to ensure their safety function is accomplished. Often, reactor systems engineers evaluate the thermal-hydraulic performance of safety related systems. Nuclear engineers evaluate reactor and fuel performance including the inputs used to evaluate fuel and reactor performance during anticipated operational occurrences (AOOs) and postulated accidents. Materials and mechanical engineers are also needed to review certain technical topics including reactor fuel, reactor internals, core supports, and reactor materials.

DISCUSSION

Under the category of Reactor, there were five technical topics to be addressed in the survey. These topics were selected to conform to the topics covered in IAEA Safety Guide No. GS-G-4.1. For each of the five technical topics under this category, the member countries were asked seven questions in order to gather some insights on the level of detail needed for regulatory authorisation. In responding to these questions, each member country described the following:

- the design information provided by the applicant;
- the analysis, reviews, and/or research performed by the regulatory authority's reviewer(s) and the scope of the review;
- the types of confirmatory analyses performed (if any) by the regulatory authority;
- the technical basis (standards, codes, acceptance criteria) for regulatory authorisation;
- the skill sets required to perform the review;
- the specialised training, experience, education, and/or tools needed to perform the regulatory review;
- the level of effort needed for the regulatory authority to perform the review.

Design information provided by the applicant.

Among the regulatory organizations that responded to the survey, there are similarities in the information provided by an applicant. In the area of fuel system design, all countries responded that the applicant provides a description of the design and design basis of the fuel system. An aspect of the fuel system design identified in several responses was the mechanical design of the fuel assembly, including geometric data and loadings. It is also common for the applicant to describe the performance of the fuel under normal operation and accident conditions as well as the calculations, methods, or computer codes used to assess the fuel performance. In addition, a description the plans for, or results of, testing, inspection, and surveillance are also commonly provided by the applicant. Lastly, in several countries, the applicant provides a description of operating experience with fuel systems of the same or similar design.

In the area of reactor internals and core supports, most countries responded that the applicant provides a description of the design of the reactor internals and core supports. Design information commonly identified in the survey responses include the materials of construction, fabrication and processing, mechanical aspects, and thermal-hydraulic characteristics. Some countries also responded that the applicant describes the effects of service on the reactor internals. In addition, some countries responded that the applicant describes any plans for inspection, surveillance, or testing.

In the area of nuclear design and core nuclear performance, all countries responded that the applicant provides a description of the nuclear design of the reactor and the design basis. Aspects of the core design and performance that were commonly identified in the survey responses include properties and burn-up of the fuel, power distributions, peaking factors, shutdown margins, control rod patterns, reactivity parameters and coefficients, information on neutron absorbers or poisons, and reactor core stability. It is noted that the applicant provides supporting calculations or computer codes for most, if not all, of the commonly identified aspects of the core design. Some countries responded that the applicant also provides an analysis of the uncertainties associated with the nuclear parameters. In addition, some countries also responded that the applicant provides the requirements for instrumentation, including calibration and calculations involved in their use.

In the area of thermal and hydraulic design, all countries responded that the applicant provides a description of the thermal-hydraulic design of the reactor and the design basis. Details of the thermal and hydraulic design that were commonly identified in the survey responses include the critical heat flux, parameters characterizing the distribution of flow, pressure, temperature, and voids in the reactor, and the hydraulic loads on the core and reactor coolant system components. In addition, most countries responded that the applicant describes the analytical tools, methods, or computer codes used to calculate thermal and hydraulic parameters.

In the area of reactor materials, most countries responded that the applicant provides a description of the material used in the reactor. Material specifications that were commonly identified in the survey responses include the chemical, physical, and mechanical properties of the materials as well as irradiation effects. Some countries responded that the applicant provides information regarding the fabrication and processing of the materials. Another common response was that the applicant provides details to justify the use of new or novel materials. Lastly, it is common for the applicant to describe the programs used to address or manage degradation of the components during service.

In the area of function design of reactivity control systems, all countries responded that the applicant provides a description of the reactivity control systems, their design, and/or design bases. In addition to the design description, members also responded that the applicant provides a description of the functional requirements, operating conditions and limits, and provisions for functional testing and qualification of each reactivity control system.

Analysis, reviews and/or research performed.

All of the technical topics covered in the survey are reviewed by all of the regulatory organizations that provided responses. While the responses show that most regulatory organisations have the framework in place to perform separate design reviews related to each survey topic, the responses also indicates that some survey topics may be reviewed concurrently. This is expected given that the technical topics in this category are all related to the design of the reactor core. All countries review the information provided by the applicant for compliance with the applicable regulatory requirements and guidelines. In addition to document reviews, several regulatory organizations responded that design reviews related to this technical category require them to verify the acceptability of calculations, computer codes, or models used to describe the design and performance of the core and the fuel. Confirmatory analyses or independent verification of information provided by the applicant are commonly mentioned as part of the design reviews related to this technical category.

Technical basis.

In all cases, the technical basis for regulatory authorisation is provided by a combination of regulations and regulatory guidance. In addition to the regulations and guidance documents, member countries also make use of internationally recognized consensus standards related to the reactor. For example, IAEA standards were identified as part of the technical basis for granting regulatory authorization in Canada, Slovakia, and Slovenia. Slovenia identified IAEA standards as part of the technical basis for all six technical topics, while Canada identified the IAEA standards as part of the technical basis for fuel system design, nuclear design and core nuclear performance, thermal and hydraulic design, and functional design of reactivity control system. Slovakia also identified the IAEA standard as part of the technical basis for the review of fuel system design.

American society of mechanical engineers (ASME) Codes were identified as part of the technical basis for regulatory authorization in three technical topics. For example, Canada and the United States identified ASME Boiler and Pressure Vessel (B&PV) Code, Section III, “Rules for Construction of Nuclear Facility Components” as part of the technical basis for granting regulatory authorization for reactor internals and core support and reactor materials. Other commonly identified ASME standards that were identified include ASME Code, Section II, *Materials*, Section V, *Nondestructive Examination*, and Section IX, *Welding and Brazing Qualifications*. It is noted that although Korea did not list the ASME Code in the technical basis, experience with ASME Code was identified as a skill required for reviewing of two technical topics (reactor materials, functional design of the reactivity control system).

Finland, France, and the United Kingdom refer to AFCEN standards as part of the technical basis for regulatory authorization. Finland identified the AFCEN RCC-M Code, entitled *Design and Conception Rules for Mechanical Components of PWR Nuclear Islands*, as part of the technical basis for reactor internals and core supports and reactor materials. France and The United Kingdom identified the AFCEN RCC-C Code, entitled *Design and Construction Rules for Civil Nuclear Fuel*, as part of the technical basis for the fuel system design.

Skill sets required to perform review.

The most consistently identified technical expertise needed to review the fuel system design, nuclear design, and thermal and hydraulic design is nuclear engineering. In responses where a specific skill set was not provided, countries identified the need for training and experience in fuel behaviour, structural mechanics, reactor physics, and thermal-hydraulics. Other technical disciplines that were identified on a less consistent basis include reactor physicists and mechanical engineers.

Materials engineers were the most consistently identified technical expertise needed to review the technical topics of reactor materials and reactor internals and core support. Other technical disciplines mentioned on a less consistent basis include mechanical engineers and nuclear engineers.

Mechanical engineers were the most commonly identified technical expertise needed to review the functional design of the reactivity control system. Other technical disciplines mentioned on a less consistent basis include nuclear engineers, materials engineers, reactor systems engineers, and risk assessment engineers.

Specialised training.

Although the specific training requirements may vary, all countries have indicated that experience related to the technical review topic is important. A common emphasis made throughout this technical category was the importance of extensive training or experience related to fuel design, fuel behaviour, structural mechanics, reactor physics, and thermal-hydraulics.

Level of effort.

The total level of effort required for each member country to review the Reactor category is provided in the table below. It is noted that in France, Japan, and Russia, resources (hours) are not set up for each individual review area. Also, in Slovakia, the level of effort allotted for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.

Country	Total level of effort for Reactor	Basis for Estimate
Canada	4 280 hours.	Pre-licensing vendor design review.
Finland	25 280 hours.	Review of a construction license application (CLA) Preliminary safety assessment report (PSAR).
France	_	Resources (hours) are not set up for each individual review area.
Japan	_	Resources (hours) are not set up for each individual review area.
Korea	8 260 hours.	Safety review of licence application documents.
Russia	3 240 hours.	Resources (man-hours) are not set up for each individual review area, but a best estimate was provided.
Slovakia	_	Level of effort defined by regulation and dependent upon the activity to be approved.
Slovenia	3 400 hours.	The level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.
United Kingdom	4 000 hours.	Technical review of a pre-construction safety report.
United States	8 550 hours.	Standard design certification review.

Table 1: Total level of effort for the Reactor category

Note:

The total level of effort is only listed for those countries that provided hours for all technical topics. The level of effort and associated notes for each technical topic are located in the summary table of the corresponding appendix.

CONCLUSION

This report focused on the results of the design survey related to the Reactor. Based on a comparison of the information provided in response to the survey, the following observations were made:

- Although the description of the information provided by the applicant differs in scope and level of detail among the member countries that provided responses, there are similarities in the information that is required.
- All of the technical topics covered in the survey are reviewed in some manner by all of the regulatory authorities that provided responses.
- Design review strategies most commonly used to confirm that the regulatory requirements have been met include document review and independent verification of calculations, computer codes, or models used to describe the design and performance of the core and the fuel.
- It is common to consider operating experience and lessons learned from the current fleet during the review process.
- In addition to the country-specific regulations and guidance documents, member countries commonly refer to internationally recognised consensus standards to provide the technical basis of regulatory authorization.
- The most commonly and consistently identified technical expertise needed to perform design reviews related to this category are nuclear engineering, materials engineering, and mechanical engineering.

Additional reports will be issued by the working group in order to discuss the results of the design phase survey in other technical areas.

APPENDIX A
FUEL SYSTEM DESIGN

Summary table

Country	Is this area reviewed?	Are confirmatory analyses performed?	Expertise of reviewers	Level of effort
Canada	Yes.	Yes.		6 months[1] (960 hours).
Finland	Yes.	Yes.	No formal requirements. The review utilised experts having training and experience in fuel behaviour, structural mechanics, and thermal-hydraulics.	130 working days. (1 040 hours).
France	Yes	Yes.	No formal requirements. TSO staff typically have long experience (more than 10 years) on the topic.	—[2]
Japan	Yes.	Yes.	Civil, structural and mechanical engineers. Generally, staff who have more than 10-year experience are taken on the task.	—[3]
Korea	Yes.	Yes.	Nuclear and mechanical engineers.	300 working days. (2 400 hours).
Russia	Yes.	Yes.	Nuclear and mechanical engineers.	100 man days - (800 hours)[3].
Slovakia	Yes.	Yes.	Nuclear engineer.	—[4]
Slovenia	Yes.	No.	Nuclear engineer, reactor physicist.	600 hours[5].

United Kingdom	Yes.	Yes.	No formal requirements. Experts having training and experience in fuel behaviour and modeling, fault analysis, reactor physics, structural mechanics, thermal-hydraulics.	300 working days. (2 400 hours).
United States	Yes.	Yes.	Nuclear and mechanical engineers.	2 400 hours.

Notes:

1. The review time may be shorter for an existing fuel design.
2. In France, the amount of effort needed to review a new design depends on the degree of novelty in the design
3. In Japan and Russia, resources (hours) are not set up for each individual review area.
4. In Slovakia, the standard level of effort for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.

   In Slovenia, the level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.

Fuel System Design	Canada CNSC
Design information provided by applicant.	Section 6.4.1, design of the fuel system, of the CNSC licence application guide RD/GD-369, "licence to construct a nuclear power plant" specifies information to be provided by applicant for the plant's fuel system design: – description of the main elements of the fuel system, including the fuel design drawings; – design basis requirements, including identification of all fuel damage mechanisms, a description of the design limits, and the characterization of fuel performance under conditions of normal operation, anticipated operational occurrences, and design basis accidents; – results of out- and in-reactor tests, operational experience in other reactors, and the results of analytical assessments to demonstrate that the fuel design meets its design requirements and design limits; – description of the methods and computer codes used to assess the fuel performance under normal and accident conditions, including the knowledge base of phenomena governing the fuel's response to various service challenges., and a justification of the safety limits set to prevent fuel damage from exceeding acceptable levels; – programme to be followed to monitor and evaluate fuel performance; – description of the fuel manufacturing process dictated by design specifications and drawings and how this ensures that the fuel will fulfill its design basis requirements.
Analysis, reviews and/or research performed by the reviewer and scope of review.	CNSC work instruction document, WI-2.01-CON-11NNNN-006.4.1, Design of Fuel System provides guidance on assessment of fuel system design**.** Specific areas of review include, but are not limited to the following topics: – fuel design bases on fuel system damage, fuel rod failure and fuel coolability; – fuel design requirements, description, drawings, and specifications, including other design considerations; – fuel design evaluation on operating experience, in- and out-of-reactor prototype tests, and analytical predictions; – fuel testing, inspection and post-irradiation surveillance pans, including online fuel system monitoring; – fuel manufacturing process and specification to determine whether all design bases are met. this includes an evaluation of "new fuel manufacturing processes", "limits and tolerances", and "introduction of new manufacturing method and/or equipment to the fabrication of the fuel system or component(s).

What type of confirmatory analysis (if any) is performed?	The requirements and expectations found in the following CNSC documents should be met: – RD-337, Design of New Nuclear Power Plants §8.1.1; – RD-310, Safety Analysis for Nuclear Power Plants §5.3, §5.4.5, and §5.5; – WI-2.01-CON-11NNNN-006.4.1. This includes confirmatory analysis to show that the following fuel safety review objectives are met: – the fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs); – Canada deuterium uranium (CANDU) reactor fuel system damage during design basis accidents (DBAs) is not severe enough to prevent the maintenance of the reactor fuel channel integrity; light water reactor (LWR) fuel system damage is never so severe as to prevent control rod insertion when it is required; – the coolability is always maintained; – the number of fuel rod failures is not underestimated for postulated accidents.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	Review Criteria are based on meeting applicable regulatory requirements and expectations given in the following documents: – RD/GD-369, Licence Application Guide: Licence to Construction a Nuclear Power Plants, §6.4.1; – RD-337, Design of New Nuclear Power Plant, §8.1.1; – RD-310, Safety Analysis for Nuclear Power Plants, §5.3, §5.4.5, and §5.5; – GD-310, Guidance on Safety Analysis for Nuclear Power Plants, §5.3, §5.4.5 and §5.5; – G-144, Trip Parameter Acceptance Criteria for the Safety Analysis of CANDU Nuclear Power Plants; – WI-2.01-CON-11NNNN-006.4.1, Design of Fuel System; – Canadian Standards Association (CSA) N286.7-99, Quality Assurance of Analytical, Scientific, and Design Computer Programs for Nuclear Power Plants; – CSA N286-05, Management System Requirements for Nuclear Power Plants. The international standards and guides on nuclear fuel elements and assemblies used as guidance in reviewing the submission include, but are not limited to: – US Nuclear Regulatory Commission NUREG-0800, Standard Review Plan, §4.2 Fuel System Design; – American National Standards Institute/American Nuclear Society ANSI/ANS-57.5-1996, Light Water Reactor Fuel Assembly Mechanical Design and Evaluation; – International Atomic Energy Agency (IAEA) Safety Standards Series No. NS-R-1, Safety of Nuclear Power Plants: Design Safety Requirements, 2000, §6; – American Society of Mechanical Engineers (ASME) Section III, Rules for Construction of Nuclear Power Plant Components of the Boiler and Pressure *Vessel Code*.

Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	The following skills are required to perform the review, but are not limited to: – extensive knowledge of nuclear standards, regulatory documents guidelines particularly those pertaining to the fuel systems and the fuel interface systems; – experience in the design, design and safety analysis, qualification analyses and tests of fuel system used in nuclear facilities; – design/analysis knowledge of fuel thermal-mechanics, thermal-hydraulics, nuclear physics, and safety; – knowledge of fuel interface systems and requirements imposed on the fuel system and components, including nuclear reactor and fuel safety principles.
Specialized training, experience and/or education needed for the review of this topic.	The following training, experience and/or education are needed for the review, but are not limited to: – a university degree in science or engineering (masters or higher level degree would be an asset); – extensive experience in the principles of fuel design, qualification/safety assessment and tests, manufacturing, operations for nuclear power plants.
Level of effort in each review area.	Senior staff: 6 month review period for Construction Licence Application review (time maybe shorter for existing fuel design).

Fuel System Design	Finland STUK

Design information provided by applicant.	Documentation describing:
	– fuel behaviour calculations for cycles 1-4;
	– PCI limits;
	– mechanical design of the fuel assembly:
	  - geometric compatibility;
	  - fuel rod and assembly loads in normal operation and accidents.
	– operation experience.

Analysis, reviews and/or research performed by the reviewer and scope of review.	Review that the documentation provided included all information required in the YVL Guides (1.0, 2.2, 6.2, 6.3) and that the acceptance criteria given in the YVL guides are met. Confirmatory analyses for fuel normal operation.
What type of confirmatory analysis (if any) is performed?	Fuel behaviour analyses for the first cycles of normal operation. Fuel behaviour analyses in transients and accidents analyses are described in Part assessment and verification of safety.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– YVL Guide 1.0: safety criteria for design of nuclear power plants. – YVL Guide 2.2: transient and accident analyses for justification of technical solutions at nuclear power plants. – YVL Guide 6.2: design bases and general design criteria for nuclear fuel. – YVL Guide 6.3: regulatory control of nuclear fuel and control rods.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.

Specialized training, experience and/or education needed for the review of this topic.	– basic knowledge in nuclear power plants and systems;
	– the review utilised experts having training and experience in:
	  - fuel behaviour;
	  - structural mechanics;
	  - thermal-hydraulics.

Level of effort in each review area.	– Regulatory review: 65 working days; – TSO: 65 working days.

Fuel System Design	France ASN
Design information provided by applicant.	The applicant provides the following information in the safety analysis report: – used safety requirements; – functional and design requirements; – design basis; – description of the fuel element; – tests performed; – feedback from experience; – safety analysis.
Analysis, reviews and/or research performed by the reviewer and scope of review.	A comprehensive review of the safety file (Safety Analysis Report + supporting documents) provided by the applicant is performed by the TSO. The following items are reviewed in detail: definition of the safety criteria (temperature limits, critical heat flux ratio, oxidation thickness, etc.), compliance with the safety criteria, characterization tests, feedback form experience gained with the fuel (in laboratories, testing loops, research reactors and power reactors), thermal-hydraulic and mechanical design. IRSN, ASN's TSO, carries out specific research programs on fuel behaviour under accidental conditions.
What type of confirmatory analysis (if any) is performed?	Confirmatory analyses are performed only if particular problems are encountered when reviewing the applicant's safety file, for instance doubts on the capabilities of computational codes to model the relevant phenomena and to predict the values used in the safety criteria. They are generally not performed for issues regarding fuel design.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	The applicant usually makes use of the RCC-C code (edited by AFCEN), which addresses material procurement, fuel design, fabrication and control, but the use of that code is not mandatory. Acceptance criteria are defined by the applicant. There is at present no regulatory guidance on them. A draft guide on PWR design, prepared by ASN and IRSN, will give some guidance on the safety requirements, but acceptance criteria will remain in the hands of the applicant.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	There is no specific requirement on skills applicable to the fuel design. The practice is to assign the juniors on the less difficult files (e.g.: minor modifications of the fuel element).
Specialized training, experience and/or education needed for the review of this topic.	The staff performing the technical review at IRSN has a long experience (more than 10 years) of this topic.
Level of effort in each review area.	The amount of effort needed to review a new fuel design strongly depends on the degree of novelty of this design. It can take from a few weeks for a limited evolution of the clad material to a full year for a completely new design. Usually, the operator introduces fuels with a new design progressively, beginning with 4 to 8 fuel assemblies in a reactor before applying for a full reload

<table>
<tr><th>Fuel System Design</th><th>Japan
NRA</th></tr>
<tr><td>Design information provided by applicant.</td><td>In the establishment permit application stage, the following information is provided in the application:
– fuel material type;
– cladding material type;
– fuel element structure;
– fuel assembly structure;
– maximum burn-up.
The following information is provided in the description in the fuel assembly design approval phase:
– type, initial concentration, and combustion efficiency of nuclear fuel material;
– type, configuration, and organization of fuel material and cladding material as well as type and configuration of components other than fuel material and cladding material;
– structure and weight of a fuel assembly;
– the name and the address of the factory or location at which nuclear power reactors using fuel assemblies are installed;
– the outline of a nuclear power reactor facility relating to nuclear power reactors that use fuel assemblies.
Documents explaining the following matters shall be attached:
– explanation regarding resistance to heat, radiation and corrosion and other performances of the fuel assembly;
– mechanical strength calculation of the fuel assembly;
– structural drawing of the assembly;
– flow-sheet of fabrication;
– explanation regarding quality assurance.</td></tr>
<tr><td>Analysis, reviews and/or research performed by the reviewer and scope of review.</td><td>These activities are to conform to the requirements, standards, criteria, and the like described below.</td></tr>
<tr><td>What type of confirmatory analysis (if any) is performed?</td><td>In the establishment permit stage, adequacy of an applicant's analytic method and the analysis results are verified.
Independent evaluation is also performed to comprehend the uncertainties of the analytic method, if needed..</td></tr>
<tr><td>Technical basis:
• Standards;
• Codes;
• Acceptance criteria.
(e.g, can come from Accident analysis, regulatory guidance).</td><td>The following regulatory requirements and guides are applicable to this technical area:
– the NRA Ordinance Concerning the Installation and Operation of Commercial Power Reactors (S53 #77);
– the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (H25 #5);
– the Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (#1306193);
– the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (H25 #6);</td></tr>
</table>

	– the Regulatory Guide of the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (#1306194); – the NRA Ordinance on Technical Standards for Nuclear Fuel Material Being Used as a Fuel in Commercial Power Reactors (H25 #7); – guide for Evaluation of Effectiveness of Preventive Measures Against Core Damage and Containment Vessel Failure of Commercial Power Reactors (#13061915); – guide for Establish Permit Application of Commercial Power Reactors (#13061919).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: manager and engineer; – Junior: engineer; – TSO: researcher. Generally the staff who have more than 10-year experience are taken on the task.
Specialized training, experience and/or education needed for the review of this topic.	– basic training for the examiner for nuclear safety; – practical application training for the examiner for nuclear safety.
Level of effort in each review area.	Resources (hours) is not set up for the individual review area. Regarding the standard processing duration, 2 years is set up for the basic design of an entire plant, and 3 months per one application is set up for construction work approval. Divided application is granted for construction work approval.

Fuel System Design	Korea KINS
Design information provided by applicant.	The following information is provided in the application: – fuel system description and design drawings; – design bases for the safety analysis address fuel system damage mechanisms and provide limiting values for important parameters to prevent damage from exceeding acceptable levels; – testing, inspection, and surveillance plans.
Analysis, reviews and/or research performed by the reviewer and scope of review.	In a review of a construction permit application for a new nuclear power plant, the regulatory body verifies whether the nuclear power plant will sufficiently meet the related legislation and technical standards by looking into the application documents submitted by applicants, such as the preliminary safety analysis report, radiation environmental report, quality assurance programme for construction, and so on. in a review for an operating license of a new nuclear power plant, the regulatory body reviews the application document such as the final safety analysis report, technical specifications for operation, quality assurance programme for operation, and so on. Scope of Review: 1. KINS SRG Section 4.3: fuel assemblies, control systems, and reactor core; 2. KINS SRG Section 4.4: thermal margins, the effects of corrosion products (crud), and the acceptability of hydraulic loads; 3. KINS SRG Section 6.3: emergency core cooling system (ECCS); 4. KINS SRG 15: postulated fuel failures resulting from overheating of cladding, overheating of fuel pellets, excessive fuel enthalpy, pellet/cladding interaction (PCI), and bursting; 5. KINS SRG 3.9.5: control rod drive mechanism, reactor internals design; 6. KINS SRG 15: radiological dose consequences.
What type of confirmatory analysis (if any) is performed?	FRAPCON-3 was used as an audit code to evaluate rod performance of high burn-up fuel.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	1. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 17, Reactor Design; 2. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 28, Reactivity Control System; 3. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 30, Emergency Core Cooling System; 4. NSSC Notice No.2012-02 (reactor.03) Standard Format and Content of Technical Specifications for Operation; 5. NSSC Notice No.2012-15 (reactor.24) Standards for Performance of Emergency Core Cooling System of Pressurized Light Water Reactor 6. KINS Regulatory Criteria Chapter 5.2: Fuel System Design; 7. KINS Regulatory Standards Chapter 5.1: An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification; 8. KINS Safety Review Guideline 4.2: Fuel System Design.

Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Nuclear engineers, mechanical engineers.
Specialized training, experience and/or education needed for the review of this topic.	– 2 years of practical experience in nuclear safety regulation organisations; – Each technical staff member takes at least 40 hours of training a year. The following specialised training, experience and/or education are needed for the review, but are not limited to: – experience in fuel design; – fuel rod performance code review, confirmatory analysis capability and is familiar with experimental tests.
Level of effort in each review area.	300 working days (2 400 hours).

Fuel System Design	Russia SEC NRS
Design information provided by applicant.	Safety analysis report (chapters 4, 9, 15) describing: – fuel properties, materials etc.; – neutronic properties of reactor core; – thermal-hydraulic properties of reactor core; – mechanical design of the fuel assemblies; – approbation of fuel design. Also all materials referenced in the mentioned above chapters of SAR have to be submitted to Regulatory Body.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– review that the documentation provided included all information required in the federal norms and regulations and that the acceptance criteria given in either federal norms and regulations or in plant design are met; – confirmatory analyses for fuel normal operation and accident conditions behaviour (optional).
What type of confirmatory analysis (if any) is performed?	Observance of fuel design criteria in steady state conditions, and in course of transients and accidents.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– OPB-88/97, General provision on ensuring NPP safety; – NP-006-98, Requirements for Content of Safety Analysis Report for NPP with reactor of VVER-type; – NP-082-07, Nuclear safety rules for reactor installations of nuclear power plants; – NP-061-05, Safety rules for storage and transportation of nuclear fuel at nuclear facilities; – new regulatory draft, Basic requirements for strength analysis and thermomechanical behavior of fuel rods and assemblies, is just published for public comments.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	– basic knowledge in nuclear power plants and systems; – the review utilised experts having training and experience in: - fuel behaviour; - structural mechanics; - thermal-hydraulics; - transient and accident analysis.
Level of effort in each review area.	In Russia men-hours are not set up for each individual review area. Expert judgement of efforts review is appr. 100 man-days.

Fuel System Design	Slovakia UJD
Design information provided by applicant.	– description and design basis of fuel assembly; – analysis of fuel behaviour during normal, transient and abnormal operation; – analysis of fuel behaviour during accident condition; – review and testing plan; – safety criteria (critical heat flux, maximum fuel pin power); – independent design evaluation.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of the submitted documentation, if it conforms to atomic act and regulations. Evaluate if the fuel system is in compliance with all requirements arising from applicable regulations, codes and standards. Confirm that fuel system design is equivalent to or is justified extrapolation from proven design.
What type of confirmatory analysis (if any) is performed?	Independent design review.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	– IAEA safety standards, regulatory guide; – BNS I.6.2/2013 – Requirements for a description of the reactor and its design in the SAR; – BNS II.3.3/2011 – Metallurgical products and spare parts for nuclear facilities.- requirements; – BNS II.5.6/2009 – Rules for the design, manufacture, construction, maintenance and repairs of the machinery and technological components of nuclear power plant equipment of the VVER 440 type; – The requirements from regional and international standards are covered in these documentations.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: nuclear engineer; – Junior: nuclear engineer; – TSO: nuclear engineer.
Specialized training, experience and/or education needed for the review of this topic.	– Experience with fuel design evaluation.

Level of effort in each review area.	Review of the submitted design information is a part of approval process which is performed as an administrative procedure based on administrative proceeding code. Based on this act we have 60 days for approval of the submitted documentation. In case that we need more time (for example if we need review from TSO or the other support organization) we can ask our chairperson about extending the period for approval. In some cases, which are strictly defined in the atomic act the time period for reviewing is longer. These cases are as follows: – four months if siting of nuclear installation, except repository is concerned; – six months if nuclear installation commissioning or decommissioning stage is concerned; – one year if building authorisation, siting and closure of repository or repeated authorisation for operation of a nuclear installation are concerned.

Fuel System Design	Slovenia SNSA
Design information provided by applicant.	– Description and design bases for fuel system; – fuel-cladding protection criteria; – criteria for primary coolant system pressure-boundary protection; – safety analysis related with fuel behaviour under normal and accident conditions; – analysis computer code information (validation and verification results, uncertainties). Testing, inspection and surveillance plans.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Scope of review: – evaluate that the applicant has provided complete information as required by applicable guides and standards; – review the results of testing, inspection and surveillance; – review of final independent evaluation report. Ensure that the fuel system has been designed so that: – the fuel system will not be damaged as a result of normal operation and anticipated operational occurrences; – fuel damage during postulated accidents will not be severe enough to prevent control rod insertion when it is required; Core coolability will always be maintained, even after severe postulated accidents.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	Regulatory guidance: Rules on Radiation and Nuclear Safety Factors IAEA safety standards.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: nuclear engineer, reactor physicist; – Junior: nuclear engineer; – TSO: nuclear engineer, reactor physicist.
Specialized training, experience and/or education needed for the review of this topic.	– special knowledge (experience) of fuel design and fabrication; – experience (knowledge) from the area of fuel damage.
Level of effort in each review area.	– Regulator: 200 hours; – TSO' review time: 400 hours.

<table>
<tr><th>Fuel System Design</th><th>United Kingdom
ONR</th></tr>
<tr><td>Design information provided by applicant.</td><td>Documentation describing:
– design bases for fuel system;
– fuel behaviour calculations for normal operation and faults;
– safety analysis bounding limits for fuel performance:
  - PCI limits;
– mechanical design of the fuel assembly;
  - geometric data and design code;
  - expected levels of fuel assembly distortion, bow and growth;
  - fuel rod and assembly loads in normal operation and accidents;
– measures to mitigate risks of adverse crud formation;
– detailed technical justification of design criteria and limits of operation;
– operation experience;
– testing, inspection and surveillance plans.</td></tr>
<tr><td>Analysis, reviews and/or research performed by the reviewer and scope of review.</td><td>Review of:
– qualification of codes and methods employed in analysis;
– review of the substantiation of limits in normal operation and faults.
Research or review of the state of the art on:
– effect of fuel assembly distortion and growth on down-stream flow field;
– effect of crud distribution and mitigation of crud risk;
– metallographic changes in spent fuel;
– the performance of high-burnup fuel.
Scope of review:
Ensure that the fuel system has been designed so that:
– the fuel system will not be damaged as a result of normal operation and anticipated operational occurrences;
– fuel damage during postulated accidents will not be severe enough to prevent control rod insertion when it is required and core coolability will always be maintained after postulated accidents;
– consequences of fuel failures will be tolerable and as low as reasonably practical.</td></tr>
<tr><td>What type of confirmatory analysis (if any) is performed?</td><td>– Fuel performance in fault transients;
– Fuel assembly flow CFD.</td></tr>
<tr><td>Technical basis:
• Standards;
• Codes;
• Acceptance criteria.
(e.g, can come from Accident analysis, regulatory guidance).</td><td>Safety Assessment Principles for Nuclear Facilities. 2006 Edition, Revision 1, HSE, January 2008.
Design and Construction Rules for Fuel Assemblies of PWR Nuclear Power Plants, RCC-C, AFCEN 103 2005.</td></tr>
</table>

Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Completion of regulatory training and assessment. No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Basic knowledge in nuclear power plants and systems. Experts having training and experience in: – fuel behaviour and modelling; – fault analysis; – reactor physics; – structural mechanics; – thermal-hydraulics.
Level of effort in each review area.	– Regulatory review: 100 working days; – TSO: 200 working days.

<table>
<tr><th>Fuel System Design</th><th>United States
NRC</th></tr>
<tr><td>Design information provided by applicant.</td><td>As part of the SAR, the applicant should describe the following:
– design bases for the mechanical, chemical, and thermal designs of the fuel system;
– description and design drawings of fuel rod components, burnable poison rods, fuel assemblies, and reactivity control assemblies;
– evaluation of the fuel system design for physically feasible combinations of chemical, thermal, irradiation, mechanical, and hydraulic interactions;
– testing, inspection, and surveillance plans.</td></tr>
<tr><td>Analysis, reviews and/or research performed by the reviewer and scope of review.</td><td>The Nuclear Regulatory Commission (NRC) staff (1) reviews the information provided in the SAR for compliance with the regulations, (2) issues requests for additional information (RAIs) as necessary, (3) reviews RAI responses, (4) resolves technical issues with applicants or licensees, and (5) produces a safety evaluation report (SER) documenting its findings. The scope and level of detail of the staff's safety review is based on the guidance of NUREG-0800, Standard Review Plan (SRP). The sections of the SRP that are applicable to this area are as follows:
– SRP 4.2, Fuel System Design.
The staff also considers emerging technical and construction issues, operating experience, and lessons learned related to this category.</td></tr>
<tr><td>What type of confirmatory analysis (if any) is performed?</td><td>A fuel rod performance code is typically run.</td></tr>
<tr><td>Technical basis:
• Standards;
• Codes;
• Acceptance criteria.
(e.g, can come from Accident analysis, regulatory guidance).</td><td>The applicable NRC Regulatory Requirements are listed below:
1. 10 CFR Part 50, Appendix A, GDC 2, Design Basis for Protection Against Natural Phenomena;
2. 10 CFR Part 50, Appendix A, GDC 10, Reactor Design;
1. 10 CFR Part 50, Appendix A, GDC 27, Combined Reactivity Control Systems Capability;
2. 10 CFR Part 50, Appendix A, GDC 35, Emergency Core Cooling Systems Capability;
3. 10 CFR 50.34, Content of Applications; Technical Information;
4. 10 CFR 50.46, Acceptance Criteria for Emergency Core Cooling Systems for Light Water Nuclear Power Reactors;
5. 10 CFR 50.67, Accident Source Term;
6. 10 CFR 100, Reactor Site Criteria;
7. 10 CFR Part 50, Appendix S, Earthquake Engineering Criteria for Nuclear Power Plants.
The NRC guidance documents that provide an acceptable approach for satisfying the applicable regulatory requirements are listed as follows:
1. Regulatory Guide (RG) 1.3, Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors;
2. RG 1.4, Assumptions Used for Evaluating the Potential Radiological</td></tr>
</table>

	Consequences of a Loss of Coolant Accident for Pressurized Water Reactors; 3. RG 1.25, Assumptions Used for Evaluating the potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors; 4. RG 1.60, Design Response Spectra for Seismic Design of Nuclear Power Plants; 5. RG 1.77, Assumptions Used for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors; 6. RG 1.126, An Acceptable Model and Related Statistical Methods for the Analysis of Fuel Densification; 7. RG 1.183, Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors; 8. RG 1.195, Methods and Assumptions for Evaluating Radiological Consequences of design Basis Accidents at Light-Water Nuclear Power Reactors; 9. RG 1.196, Control Room Habitability at Light Water Nuclear Power Reactors.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Nuclear and mechanical engineers**.**
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to complete a formal training and qualification programme prior to performing safety reviews independently. Other specialised training, experience, and education that is needed to successfully perform reviews in this technical area include: – experience in fuel design; – fuel rod performance code review, confirmatory analysis capability and is familiar with experimental tests; – mechanical engineer familiar with fuel assembly response to seismic inputs.
Level of effort in each review area.	2 400 hours. Explanation: – fuel rod performance is usually a topical report that supports chapter 4.2. total review hours for such a topical report is approximately 1 000 hours; – a technical report which demonstrates how non-fuel rod related criteria are met usually supports the chapter 4.2 review. the review time associated with that report is usually approximately 200 hours; – a topical or technical report which describes fuel seismic response addressing srp 4.2, appendix a is usually submitted to support the chapter 4.2 review. review of this report can range from 800-1 200 hours; – DCD Chapter 4.2 review is approximately 100 hours.

APPENDIX B
REACTOR INTERNALS AND CORE SUPPORT

Summary table

Country	Is this area reviewed?	Are confirmatory analyses performed?	Expertise of reviewers	Level of effort
Canada	Yes.	Yes.	Engineer with expertise in design and analysis of reactor internals.	3 months. (480 hours).
Finland	Yes.	No.	No formal requirements. Materials Scientist/Engineer.	140 working days. (1 120 hours).
France	Yes	Yes	No formal requirements. TSO staff typically have long experience (more than 10 years) on the topic.	—[1]
Japan	Yes.	Yes.	Civil, structural and mechanical engineers. Generally, staff who have more than 10-year experience are taken on the task.	—[2]
Korea	Yes.	No.	Materials engineer, mechanical engineer	480 hours.
Russia	Yes.	No.	Mechanical engineer, nuclear engineers	75 man days - (600 hours)[2].
Slovakia	Yes.	No.	Technical engineer	—[3]
Slovenia	Yes.	No.	Materials engineer, mechanical engineer, nuclear engineer	600 hours[4].
United Kingdom	Yes.	Yes.	Chartered engineer Status required for the Regulator in a discipline related to the topic under consideration. No formal requirement for the TSO.	30 working days. (240 hours).
United States	Yes.	No.	Materials engineer, mechanical engineer	600 hours.

Notes:

1. In France, such reviews are very rarely performed and depend on the problem encountered. Therefore, no typical level of effort is provided.

2. In Japan and Russia, resources (hours) are not set up for each individual review area.
3. In Slovakia, the standard level of effort for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.
4. In Slovenia, the level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.

Reactor Internals and Core Support	Canada CNSC
Design information provided by applicant.	Section 6.4.2, design of reactor internals, of the CNSC licence application guide RD/GD-369, “licence to construct a nuclear power plant” specifies that the applicant should provide a description of the reactor internals and their design basis requirements, including: – general external details of the fuel; – structures into which the fuel has been assembled (e.g., the fuel assembly or fuel bundle); – related components required for fuel positioning; – all supporting elements internal to the reactor, including any separate provisions for moderation and fuel location.
Analysis, reviews and/or research performed by the reviewer and scope of review.	CNSC work instruction document, WI-2.01-CON-11NNNN-006.4.2, design of reactor internals provides guidance on assessment of reactor internals design. Reactor internals should be designed such that: – quality standards are commensurate with the importance of the safety functions performed; – the internals can withstand the effects of natural phenomena such as earthquakes without loss of capability to perform safety functions; – the internals can accommodate the effects of, and to be compatible with the environmental conditions associated with normal operations, maintenance, testing, and postulated pipe ruptures, including Loss of Coolant Accidents (LOCAs); – there is appropriate margin to assure that specified acceptable fuel limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.
What type of confirmatory analysis (if any) is performed?	CNSC staff will perform reviews to ensure that: – the reactor internals components designated as ASME Code, Section III, core support structures are designed, fabricated, and examined in accordance with the provisions of Subsection NG of Section III of the ASME Code [7], Core Support Structures; – those reactor internals components not designated as ASME Code, Section III, core support structures are designated as internal structures in accordance with ASME Code, Section III, Subsection NG-1122. The design criteria, loading conditions, and analyses that provide the bases for the design of reactor internals other than the core support structures should meet the guidelines of ASME Code, Section III, Subsection NG-3000 and constructed not to affect the integrity of the core support structures adversely. If other guidelines (e.g., manufacturer standards or empirical methods based on field experience and testing) are the bases for the stress, deformation, and fatigue criteria, those guidelines should be identified and their use justified in the application; – for non-ASME code structures and components, design margins presented for allowable stress, deformation, and fatigue should be equal to or greater than margins for other plants of similar design with successful operating experience. Any decreases in design margins should be justified in the application; – those specific reactor internals components designated as Class 1, Class 2, and Class 3 are designed, fabricated, and examined in

	accordance with the provisions of Codes & Standards accepted by the CNSC; – the design and service loading combinations, including system operating transients, and the associated design and service stress limits considered for each component should be sufficiently defined to provide the basis for design of reactor internals for all loads, including assembly and disassembly loads; – codes and standards used to determine the acceptability of loading combinations that are applicable to the design of reactor internals should be provided. In instances where no codes and standards exist, the design is considered acceptable if the structural integrity of the component can be demonstrated such that no safety related functions will be impaired; – deformation limits for reactor internals, particularly of PWR type, should be provided in the application and presented in the Preliminary Safety Analysis Report (PSAR). The basis for these limits should be included. The stresses of these displacements should not exceed the specified limits. Dynamic responses of structural components within the reactor internals should follow the guidance described in United States Nuclear Regulatory Commission (USNRC) Standard Review Plan § 3.9.2 and, Regulatory Guide (RG) 1.20 or Canadian Standards Association (CSA) N289; – reactor internals, if they are located within the vessel, should be designed to accommodate blowdown loads or show that damage does not impair safety functions from postulated pipe ruptures. Dynamic effects of the postulated pipe ruptures may be excluded from the design basis when analyses, which are approved by CNSC, demonstrate that the probability of fluid system piping rupture is extremely low under conditions consistent with the design basis for the piping; – flow-induced vibration and acoustic resonance testing of reactor internals should follow the guidance described in USNRC Standard review plan § 3.9.5, appendix a or equivalent; – the reactor internals should be designed to consider ageing effects including the analysis of Anticipated Operational Occurrences (AOOs) and Design Basis Accidents (DBAs). The application should provide evidence that ageing effects (end-of-life material properties, deformation, and conditions) were calculated and were used in the design analysis. Some surveillance coupons for reactor internal materials should be considered for periodic testing in design process.

Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	The requirements and expectations found in the following documents should be met: – CNSC RD-337, Design of New Nuclear Power Plants §4, 5, 6, 7, 8, 11; – CNSC RD-310, Safety Analysis for Nuclear Power Plants §5; – CNSC WI-2.01-CON-11NNNN-006.4.2. Applicable sections of the following codes and standards may also be used in the review: – CSA-N285.0, General Requirements for Pressure-Retaining Systems and Components in CANDU Nuclear Power Plants; – CSA-N285.4, Periodic Inspection of CANDU Nuclear Power Plant Components; – CSA-N285.5, Periodic Inspection of CANDU Nuclear Power Plant Containment Components; – CSA-N285.6, Material Standards for Reactor Components for CANDU Nuclear Power Plants; – CSA-N286-05, Management System Requirements for Nuclear Power Plants; – CSA N286.7, Quality Assurance of Analytical, Scientific and Design Computer Programs for Nuclear Power Plants; – CSA-N289.1, General Requirements for Seismic Qualification of CANDU Nuclear Power Plants; – CSA-N289.3, Design Procedures for Seismic Qualification of CANDU Nuclear Power Plants; – ASME Section III, Nuclear Power Plant Components.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Engineer with expertise in design and analysis of reactor internals.
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to have sufficient knowledge and experience in the review area such as the regulatory requirements, codes and standards.
Level of effort in each review area.	Senior staff: 3 month review period for Construction Licence Application review.

Reactor Internals and Core Support	Finland STUK
Design information provided by applicant.	– PSAR and TR; – the specification for design; – preliminary loading specification (pressure and temperature); – dimensioning; – preliminary stress analyses reports; – material data file; – description of manufacturing.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– STUK's inspectors inspect all documents by themselves. The inspection is performed by specialist from different branch of technology (process, component, strength, manufacturing, quality, NDT, QA); – simplified analysis by STUK if needed; – more detailed analysis by TSO if needed.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	RCCM
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– No formal requirements: - Senior: o M.Sc/engineer; o working experience of sector. - Junior: o M.Sc/engineer; - TSO: o Specialist of sector; o Competence of TSO shall be evaluated by audit.
Specialized training, experience and/or education needed for the review of this topic.	– introduction course; – YK Basic professional training course on nuclear safety Finland; – training for standard; – YTD/SAHA archives tools: - diary tools.
Level of effort in each review area.	Regulatory review: 140 working days.

Reactor Internals and Core Support	France ASN
Design information provided by applicant.	The applicant provides the following information in the Safety Analysis Report : – safety requirements, functional and design requirements; – design principles; – description of the reactor internals and core support; – operating conditions; – mechanical design; – thermal-hydraulic design; – safety assessment; – fabrication and procurement.
Analysis, reviews and/or research performed by the reviewer and scope of review.	A review of the safety file (safety analysis report + supporting documents) provided by the applicant is performed by ASN with the support of IRSN, ASN's TSO. The following items are reviewed: definition of the design basis and criteria, compliance with the design criteria, feedback from operating experience. Note that these reviews are performed when an applicant submits an application file for a new reactor or in case of a component modification. Since these components are very rarely modified or repaired, such reviews are not regularly carried out.
What type of confirmatory analysis (if any) is performed?	Confirmatory analysis could be performed in case of serious doubts or difficulties.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	Acceptance criteria are defined by the applicant. There is at present no regulatory guidance on them. A draft guide on PWR design, prepared by ASN and IRSN, will give some guidance on the safety requirements, but acceptance criteria will remain in the hands of the applicant.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	There is no specific requirement on skills applicable to the reactor internal and core support. The practice is to assign the juniors on the less difficult files (e.g.: minor modifications of the fuel element).
Specialized training, experience and/or education needed for the review of this topic.	The staff performing the technical review at IRSN has a long experience (more than 10 years) in structural analysis.
Level of effort in each review area.	Since such reviews are very rarely performed and depend entirely on the problem encountered, no typical level of effort can be indicated.

Reactor Internals and Core Support	Japan NRA
Design information provided by applicant.	In the establishment permit application stage, the following information is provided in the application: – structure (support structures of fuel assembly and reflector, lattice shape of core and main dimensions, etc.); – maximum insertion amount of fuel assemblies; – main nuclear and thermal limiting values; – moderator and reflector types; – structure of reactor container; – maximum operating pressure and temperature of reactor container; – radiation shielding body structure. In addition, in construction work approval application stage, the following information is provided: – reactor types, rated thermal output, excess reactivity and reactivity coefficient (moderator temperature coefficient, Doppler coefficient (PWRs only), void coefficient (PWRs only), pressure coefficient (PWRs only), fuel rod temperature coefficient (BWRs only), moderator void coefficient (BWRs only), and power reactivity coefficient (BWRs only)),as well as moderator material names, types, and composition; – shape of reactor core, the number of fuel assemblies, effective core height, and equivalent core diameter, etc.; – the names, types, compositions, main dimensions (PWRs only), materials (PWRs only), and number (PWRs only) of reflectors; – the names, types, main dimensions, materials, and number of thermal shields (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials and number of reactor vessel bodies, and the types and the number at initial loading of monitoring specimens, as well as the places where they are attached, etc. (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials and number of reactor pressure vessel bodies, and the types and the number at initial loading of monitoring specimens, as well as the places where they are attached, etc. (BWRs only); – the basic design policy and the related applied standards for the reactor body; – the quality control methods for the design and the construction.
Analysis, reviews and/or research performed by the reviewer and scope of review.	These activities are to conform to the standards, criteria, and the like described below.
What type of confirmatory analysis (if any) is performed?	In the establishment permit application stage, adequacy of an applicant's analytic method and the analysis results are verified. Independent evaluation is also performed to comprehend the uncertainties of the analytic method, if needed.

Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The following regulatory requirements and guides are applicable to this technical area: – the NRA Ordinance Concerning the Installation and Operation of Commercial Power Reactors (S53 #77); – the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (H25 #5); – the Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (#1306193); – the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (H25 #6); – the Regulatory Guide of the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (#1306194); – the NRA Ordinance on Technical Standards for Nuclear Fuel Material Being Used as a Fuel in Commercial Power Reactors (H25 #7); – guide for Evaluation of Effectiveness of Preventive Measures Against Core Damage and Containment Vessel Failure of Commercial Power Reactors (#13061915); – guide for Establish Permit Application of Commercial Power Reactors (#13061919); – the Standard Review Plan on Technical Capability of Severe Accident Management of Commercial NPPs (#1306197); – guide for Procedure of Construction Work Approval (#13061920).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: manager and engineer; – Junior: engineer; – TSO: researcher. Generally the staff who have more than 10-year experience are taken on the task.
Specialized training, experience and/or education needed for the review of this topic.	– basic training for the examiner for nuclear safety; – practical application training for the examiner for nuclear safety.
Level of effort in each review area.	Resources (hours) is not set up for the individual review area. Regarding the standard processing duration, 2 years is set up for the basic design of an entire plant, and 3 months per one application is set up for construction work approval. Divided application is granted for construction work approval.

Reactor Internals and Core Support	Korea KINS
Design information provided by applicant.	The following information is provided in the application: – the physical or design arrangements of all reactor internals structures, components, assemblies, and systems; – specific design codes, load combinations, allowable stress and deformation limits, and other criteria used in designing the reactor internals; – cleaning and cleanliness control; – fabrication and processing of austenitic stainless steel components; – non-destructive examination methods; – controls on welding.
Analysis, reviews and/or research performed by the reviewer and scope of review.	In a review of a construction permit application for a new nuclear power plant, the regulatory body verifies whether the nuclear power plant will sufficiently meet the related legislation and technical standards by looking into the application documents submitted by applicants, such as the preliminary safety analysis report, radiation environmental report, quality assurance programme for construction, and so on. In a review for an operating license of a new nuclear power plant, the regulatory body reviews the application document such as the final safety analysis report, technical specifications for operation, quality assurance programme for operation, and so on. Scope of review: 1. KINS SRG Section 3.6.2: The break and crack location criteria and methods of analysis for evaluating the dynamic effects; 2. KINS SRG Section 3.9.1~4: Reactor Pressure Vessel Internals; 3. KINS SRG Section 4.2: Review of the mechanical design, thermal performance, and chemical compatibility of the reactivity control elements; 4. KINS SRG Section 4.5.2: Reactor Internal and Core Support Structure Materials; 5. KINS SRG Section 3.13: Testing of its threaded fasteners (i.e., threaded bolts, studs, etc.); 6. KINS SRG Sections 3.6.3: Leak-before-break (LBB) analysis.
What type of confirmatory analysis (if any) is performed?	None.

Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	1. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 12, Safety Classes and Standards; 2. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 13, External Events Design Bases; 3. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 15, Environmental Effects Design Bases, etc.; 4. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 17, Reactor Design; 5. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 21, Reactor Coolant Pressure Boundary; 6. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 28, Reactivity Control System; 7. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 36, "Reactivity Control Material Drive Mechanism 8. Korea Electric Power Industry Codes MNG, Reactor internals structures; 9. NSSC Notice No.2012-13 (reactor.21), Guidelines for Application of Korea Electric Power Industry Code (KEPIC) as Technical Standards of Nuclear Reactor Facilities; 10. KINS Regulatory Criteria Chapter 5.6, Reactor Pressure Vessel Internals; 11. KINS Regulatory Standards Chapter 4.3, Components and Component supports, and Core support structures under specified service loading combinations; 12. KINS Safety Review Guideline 3.9.5, Reactor Pressure Vessel Internals.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Material or mechanical engineers.
Specialized training, experience and/or education needed for the review of this topic.	– 2 years of practical experience in nuclear safety regulation organisations; – each technical staff member takes at least 40 hours of training a year. The following specialized training, experience and/or education are needed for the review, but are not limited to: – knowledge of the codes and standards for material selection; – knowledge of or experience with welding and NDE.
Level of effort in each review area.	480 hours.

Reactor Internals and Core Support	Russia SEC NRS
Design information provided by applicant.	Safety analysis report (chapter 4 which includes description of reactor internals). Also all materials referenced in the mentioned above SAR chapter have to be submitted to Regulatory Body.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review that the documentation provided included all information required in the federal norms and regulations and that the acceptance criteria given in either federal norms and regulations or in plant design are met.
What type of confirmatory analysis (if any) is performed?	None.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	– OPB-88/97 general provision on ensuring NPP safety; – NP-006-98 requirements for content of safety analysis report for NPP with reactor of VVER-type; – NP-082-07 nuclear safety rules for reactor installations of nuclear power plants.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	The review utilised experts having training and experience in: – reactor construction; – nuclear materials (structural mechanics); – strength theory.
Level of effort in each review area.	In Russia, men-hours are not set up for each individual review area. Expert judgement of efforts review is appr. 75 man-days.

Reactor Internals and Core Support	Slovakia UJD
Design information provided by applicant.	– description and design basis; – review and testing plan; – independent design evaluation; – requirements to reactor internals; – technical report about fulfilment quality requirements; – calculations and calculation results to prove the resistance to environmental influences during all; – test, operation and emergency conditions considered in their design; – safety classification.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of the submitted documentation, if it conforms to atomic act and regulations. Evaluate if the reactor internals and core support are in compliance with all requirements arising from applicable regulations, codes and standards. Confirm that the reactor internals and core support: – are able to manage their roles in the condition of working environment; – that the facilities have been properly classified to identify their importance to safety.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	BNS II.3.3/2011 - Metallurgical products and spare parts for nuclear facilities.- requirements. BNS II.5.6/2009 – Rules for the design, manufacture, construction, maintenance and repairs of the machinery and technological components of nuclear power plant equipment of the VVER 440 type. The requirements from regional and international standards are covered in these documentations.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: technical engineer; – Junior: technical engineer; – TSO: technical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– experience with similar reviews; – detailed knowledge of reactor and reactor design.

Level of effort in each review area.	Review of the submitted design information is a part of approval process which is performed as an administrative procedure based on administrative proceeding code. Based on this act we have 60 days for approval of the submitted documentation. In case that we need more time (for example if we need review from TSO or the other support organisation) we can ask our chairperson about extending the period for approval. In some cases, which are strictly defined in the atomic act the time period for reviewing is longer. These cases are as follows: – four months if siting of nuclear installation, except repository is concerned; – six months if nuclear installation commissioning or decommissioning stage is concerned; – one year if building authorisation, siting and closure of repository or repeated authorisation for operation of a nuclear installation are concerned.

Reactor Internals and Core Support	Slovenia SNSA
Design information provided by applicant.	– the design information of reactor internals and core support systems; – reactor internals and core support materials specifications; – thermo-hydraulic, structural and mechanical properties; – reactor internals response to static and dynamic mechanical loads; – reactor internals integrity analysis; – reactor internals analysis; – a consideration of the effects of service on the performance of safety functions; – surveillance and inspection programme for reactor internals; – the programme to monitor the behaviour and performance of the core.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Scope of review: – evaluate that the applicant has provided complete information as required by applicable guides and standards; – review the results of testing, inspections; – review of final independent evaluation report. Ensure that the reactor internals and core support have been designed so that: – maintain fuel alignment, limit fuel assembly movement, maintain alignment between fuel assemblies and control rod drive mechanisms; – direct coolant flow past the fuel elements and to the pressure vessel head; – provide gamma and neutron shielding; – provide guides for the incore instrumentation.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	Regulatory guidance: Rules on Radiation and Nuclear Safety Factors. IAEA safety standards.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: materials engineer, mechanical engineer, nuclear engineer; – Junior: mechanical engineer, nuclear engineer; – TSO: materials engineer, nuclear engineer, mechanical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– knowledge of the codes and standards for material selection; – knowledge of static and dynamic mechanical loads calculations; – dose calculations.
Level of effort in each review area.	– Regulator: 200 hours; – TSO' review time: 400 hours.

Reactor Internals and Core Support	United Kingdom ONR
Design information provided by applicant.	Fuel: – design information of reactor internals and core support systems; – design drawings; – the physical and chemical properties of the components; – the material properties; – thermo-hydraulic, structural and mechanical aspects; – the expected response to static and dynamic mechanical loads; – a consideration of the effects of service on the performance of safety function; – surveillance and inspection programme for reactor internals; – programme to monitor the behaviour and performance of the core. SI: Pre-Construction Safety Report describing all the claims, arguments and evidence provided in respect of the Reactor Internals and Core Support.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Qualification of reactor physics codes and methods supporting the structural analysis. SI Specific Review: – establish the integrity claim being placed on the reactor internals, and whether evidence can be provided to support the claim that the design is tolerant to gross failure of the lower reactor internals; – see SI step 4 report section 4.12**.**
What type of confirmatory analysis (if any) is performed?	Analysis of the detailed power distribution for the proposed core designs None.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	– ONR Safety Assessment Principles; – Integrity of Metal Components and Structures - EMC.1 to EMC.34, with EMC.1 to EMC.3 specifically applicable to the highest reliability components.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Chartered Engineer Status required for the Regulator in a discipline related to the topic under consideration, with no differentiation in requirement for the Senior or Junior regulator. TSO expertise required in relation to the topic under consideration, but no specific level required.
Specialized training, experience and/or education needed for the review of this topic.	– Expertise in Reactor Physic; – Understanding of the structural integrity safety principles.
Level of effort in each review area.	– Regulatory review: 10 working days; – TSO: 20 working days; – No TSO support required.

Reactor Internals and Core Support	United States NRC
Design information provided by applicant.	As part of the SAR, the applicant should describe the following: – specific design codes, load combinations, allowable stress and deformation limits, and other criteria used in designing the reactor internals; – physical or design arrangements of all reactor internals; – all base and weld materials specifications; – controls on welding; – non-destructive examination methods; – fabrication and processing of austenitic stainless steel components.
Analysis, reviews and/or research performed by the reviewer and scope of review.	The nuclear regulatory commission (NRC) staff (1) reviews the information provided in the SAR for compliance with the regulations, (2) issues requests for additional information (RAIs) as necessary, (3) reviews RAI responses, (4) resolves technical issues with applicants or licensees, and (5) produces a safety evaluation report (SER) documenting its findings. The scope and level of detail of the staff's safety review is based on the guidance of NUREG-0800, standard review plan (SRP). The sections of the SRP that are applicable to this area are as follows: – SRP 3.9.5, Reactor Pressure Vessel Internals; – SRP 4.5.1, Control Rod Drive Structural Materials; – SRP 4.5.2, Reactor Internal and Core Support Structure Materials. The staff also considers emerging technical and construction issues, operating experience, and lessons learned related to this category.
What type of confirmatory analysis (if any) is performed?	None**.**
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The applicable NRC Regulatory Requirements are listed below: 1. 10 CFR Part 50, Appendix A, GDC 1, Quality Standards and Records; 2. 10 CFR Part 50, Appendix A, GDC2, Design Bases for Protection Against Natural Phenomena; 3. 10 CFR Part 50, Appendix A, GDC 4, Environmental and Dynamic Effects Design Bases; 4. 10 CFR Part 50, Appendix A, GDC 10, Reactor Design; 5. 10 CFR Part 50, Appendix A, GDC 14, Reactor Coolant Pressure Boundary; 6. 10 CFR Part 50, Appendix A, GDC 26, Reactivity Control System Redundancy and Capability; 7. 10 CFR 50.55a, Codes and Standards; 8. 10 CFR 52.80(a), Requirement for COL application to contain the proposed inspection, tests, analyses, and acceptance criteria (ITAAC). NRC guidance documents that provide an acceptable approach for satisfying the applicable regulatory requirements in this review area include: 1. RG 1.20, Comprehensive Vibration Assessment Program for Reactor Internals During Preoperational and Initial Startup Testing; 2. RG 1.44, Control on the Use of Sensitized Stainless Steel; 3. RG 1.85, Materials Code Case Acceptability ASME Section III Division.

	Applicable Codes and Standards related to this area include: 1. ASME B&PV Code, Section II; 2. ASME B&PV Code, Section III; 3. ASME B&PV Code, Section V; 4. ASME B&PV Code, Section IX.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Materials engineer; – Mechanical engineer.
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to complete a formal training and qualification programme prior to performing safety reviews independently. Other specialised training, experience, and education that is needed to successfully perform reviews in this technical area include: – Knowledge of the Codes and Standards for material selection; – Knowledge of or experience with welding and NDE; – Experience in metallurgy.
Level of effort in each review area.	600 hours.

APPENDIX C
NUCLEAR DESIGN AND CORE NUCLEAR PERFORMANCE
(E.G, CORE DESIGN, SHUTDOWN MARGINS, INSTRUMENTATION)

Summary table

Country	Is this area reviewed?	Are confirmatory analyses performed?	Expertise of reviewers	Level of effort
Canada	Yes.	Yes.		3 months. (480 hours).
Finland	Yes.	Yes.	No formal requirements.	45 working days (360 hours).
France	Yes.	Yes.	No formal requirements. TSO staff typically have long experience (more than 10 years) on the topic.	—[1]
Japan	Yes.	Yes.	Civil, structural and mechanical engineers.. Generally, staff who have more than 10-year experience are taken on the task.	—[2]
Korea	Yes.	Yes.	Nuclear engineer.	300 working days. (2 400 hours).
Russia	Yes.	Yes.	Nuclear engineers.	75 man days- (600 hours)[2].
Slovakia	Yes.	No.	Technical engineer.	—[3]
Slovenia	Yes.	Yes.	Nuclear engineer, reactor physicist, electrical engineer.	600 hours[4].
United Kingdom	Yes.	Yes.	No formal requirements.	80 working days. (640 hours).
United States	Yes.	Yes.	Nuclear engineer	2 000 hours[5].

Notes:

1. In France, the amount of effort needed to review a new design depends on the degree of novelty in the design.
2. In Japan and Russia, resources (hours) are not set up for each individual review area.
3. In Slovakia, the standard level of effort for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.

4. In Slovenia, the level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.
   If previously approved codes are submitted then the review time would be significantly less.

Nuclear Design and Core Nuclear Performance	**Canada CNSC**
Design information provided by applicant.	Section 6.4.3, nuclear design and core nuclear performance, of the CNSC licence application guide RD/GD-369, licence to construction a nuclear power plant specifies information to be provided by the applicant for the plant's nuclear design and core nuclear performance. The applicant is expected to describe the design basis requirements established for: – nuclear design of the fuel; – reactivity control systems (including nuclear and reactivity control limits such as excess reactivity, fuel burn-up, reactivity feedbacks); – core design lifetime; – fuel replacement strategies; – reactivity coefficients; – stability criteria; – maximum controlled reactivity insertion and removal rates; – control of power distributions; – shutdown margins; – rod speeds and stuck rod criteria; – chemical and mechanical shim control; – neutron poison requirements; – all shutdown provisions. The description provided by the applicant should also include the following applicable areas of the design: – fuel enrichment distributions; – Burnable poison distributions; – physical features of the lattice or assemblies relevant to nuclear design parameters; – delayed neutron fractions and neutron lifetimes; – core lifetime and burn-up; – Plutonium build-up; – Soluble poison insertion rates; – Xenon burnout or any other transient requirements. Further detailed information should be provided the applicant in the following specific areas, as appropriate: – power distributions; – reactivity coefficients; – reactivity control requirements; – reactivity devices; – criticality during refuelling; – reactor core stability, irradiation issues; – analytical methods used (with verification and validation information and uncertainties); – testing and inspection plans; – operational limits and conditions.

Analysis, reviews and/or research performed by the reviewer and scope of review.	CNSC will review the following topics to determine if the applicant has made adequate provisions to undertake the licensed activity in the area of nuclear design and core nuclear performance: – the applicant's relevant design bases and design requirements that meets appropriate CNSC regulatory requirements and expectations; – all design and operating core and fuel pin power distributions expected during reactor life-time under steady-state and transient conditions as well as distributions used in accident analyses; – reactivity coefficients corresponding to changes in power, temperature, density and void for all operating states and accident conditions, supporting experimental evidence and conservative values used in steady-state, stability and accident analyses; – reactivity control requirements and control provisions. these include requirements for all operating states, power changes, both short-term and long-term reactivity changes, bulk and spatial control functions, reactivity devices and associated groupings and configuration patterns; – refuelling strategies and associated reactor core criticality evaluations; – reactor core stability analyses. shutdown requirements and shutdown margins; – reactor vessel materials irradiation as applicable; – analytical methods. these include nuclear data libraries and methods used in nuclear design and associated experimental support; and, – proposed commissioning and periodic verification and testing programmes.
What type of confirmatory analysis (if any) is performed?	CNSC will perform the following analysis as required: – independent code qualification (verification/validation) by using independent experiments, and set up simplified benchmark problems models for inter-code comparison with the third-party independent codes; – independent model verification of licensee's safety case submissions.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The requirements and expectations found in the following documents should be met: – REGDOC-2.5.2 (draft), Design of New Nuclear Power Plants; – RD/GD-369, Licence to Construction a Nuclear Power Plant; – REGDOC-2.4.1 (draft), Safety Analysis: Deterministic Safety Analysis; – REGDOC-2.4.1 (draft), Safety Analysis: Probabilistic Safety Assessment (PSA) for Nuclear Power Plants; – WI-2.01-CON-11NNNN-006.4.3, Application for Licence to Construct – Assess Nuclear Design and Core Nuclear Performance; – CSA/CAN3-N290.1-80, Requirements for the Shutdown Systems of CANDU Nuclear Power Plants, December 1980, reaffirmed 1998; – CSA N286.7-99, Quality Assurance of Analytical, Scientific, and Design Computer Programs for Nuclear Power Plants; – IAEA SSR 2/1, Safety of Nuclear Power Plants: Design; – IAEA, NS-G-1.12, Design of the Reactor Core for Nuclear Power Plants, IAEA Safety Standards Series.

Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– extensive knowledge of nuclear standards, regulatory documents, guidelines particularly those pertaining to reactor physics; – experience in the design and operations of nuclear power plants; – knowledge of reactor physics (lattice physics and core physics), and physics-related experiments; – knowledge of key reactor system performance; – knowledge of safety analysis tools, methods and requirements; – knowledge of nuclear safety principles.
Specialized training, experience and/or education needed for the review of this topic.	– a university degree in science or engineering (masters or higher level degree would be an asset); – extensive experience in the principles of design, operation and safety assessment of nuclear power plants.
Level of effort in each review area.	Senior staff: 3 month review period for construction Licence Application review.

Nuclear Design and Core Nuclear Performance	Finland STUK
Design information provided by applicant.	Documentation describing: – reactor physics design; – thermal-hydraulic design: - pressure loss; - critical heat flux; – system design of the core instrumentation.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of the system description; Independent analyses of the core main parameters.
What type of confirmatory analysis (if any) is performed?	Determination of the key safety parameters (shutdown margin, power distribution etc.).
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	YVL Guide 2.2, YVL Guide 1.0.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Reactor physics.
Level of effort in each review area.	Regulatory review: 45 working days.

Nuclear Design and Core Nuclear Performance	France ASN
Design information provided by applicant.	The applicant provides the following information in the safety analysis report: – safety requirements, functional criteria, design requirements; – design basis; – overall description of the core; – power distribution; – reactivity coefficients; – under-criticality margin in the fuel building; – instrumentation design and requirements; – computing methods and tools. The functional capability of the instrumentation is demonstrated by qualification tests.
Analysis, reviews and/or research performed by the reviewer and scope of review.	A comprehensive analysis of the safety file (Safety Analysis Report + supporting documents) provided by the applicant is performed by the TSO. The following items are reviewed in detail: – acceptability of the analysis methods used for the safety demonstration; – qualification of the computing codes used; – acceptability of the hypotheses, study rules and safety criteria used; – appropriateness of the way the instrumentation is taken into account in the accidents and transients studies; – qualification of the instrumentation.
What type of confirmatory analysis (if any) is performed?	Confirmatory analyses are performed only if particular problems are encountered during the assessment of the applicant's safety file, for instance doubts on the capabilities of computational codes to model the relevant phenomena and to predict the values used in the safety criteria.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	There is no standard or code in France on this topic. Acceptance criteria are defined by the applicant. There is at present no regulatory guidance on them. A draft guide on PWR design, prepared by ASN and IRSN, will give some guidance on the safety requirements, but acceptance criteria will remain in the hands of the applicant.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	There is no requirement on skills applicable to the nuclear design.
Specialized training, experience and/or education needed for the review of this topic.	The staff performing the technical review at our TSO has a long experience (more than 10 years) of this topic.
Level of effort in each review area.	The amount of effort needed to review a new core design strongly depends on the degree of novelty of this design. For a completely new design, like EPR's core, it takes one to several years to perform the review.

Nuclear Design and Core Nuclear Performance	Japan NRA
Design information provided by applicant.	In the establishment permit application stage, the following information is provided in the application: – main nuclear limiting values (reactivity shut-down margin, maximum reactivity addition rate by a control rod cluster, the maximum reactivity value of a control rod cluster, moderator temperature coefficient, and Doppler coefficient); – main thermal limiting values (BWR: minimum critical power ratio (MCPR) and a fuel rod maximum linear power density, PWR: minimum departure from nucleate boiling ratio (DNBR) and a fuel rod maximum linear power density). In addition, in construction work approval application stage, the following information is provided: – reactor types, rated thermal output, excess reactivity and reactivity coefficient (moderator temperature coefficient, Doppler coefficient (PWRs only), void coefficient (PWRs only), pressure coefficient (PWRs only), fuel rod temperature coefficient (BWRs only), moderator void coefficient (BWRs only), and power reactivity coefficient (BWRs only)),as well as moderator material names, types, and composition; – shape of reactor core, the number of fuel assemblies, effective core height, and equivalent core diameter, etc.; – the names, types, compositions, main dimensions (PWRs only), materials (PWRs only), and number (PWRs only) of reflectors; – the names, types, main dimensions, materials and number of thermal shields (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials and number of reactor vessel bodies, and the types and the number at initial loading of monitoring specimens, as well as the places where they are attached, etc. (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials and number of reactor pressure vessel bodies, and the types and the number at initial loading of monitoring specimens, as well as the places where they are attached, etc. (BWRs only); – the basic design policy and the related applied standards for the reactor body; – the quality control methods for the design and the construction.
Analysis, reviews and/or research performed by the reviewer and scope of review.	These activities are to conform to the requirements, standards, criteria, and the like described below.
What type of confirmatory analysis (if any) is performed?	In the establishment permit application stage, adequacy of an applicant's analytic method and the analysis results are verified. Independent evaluation is also performed to comprehend the uncertainties of the analytic method, if needed.

Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The following regulatory requirements and guides are applicable to this technical area: – the NRA Ordinance Concerning the Installation and Operation of Commercial Power Reactors (S53 #77); – the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (H25 #5); – the Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (#1306193); – the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (H25 #6); – the Regulatory Guide of the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (#1306194); – the NRA Ordinance on Technical Standards for Nuclear Fuel Material Being Used as a Fuel in Commercial Power Reactors (H25 #7); – guide for Evaluation of Effectiveness of Preventive Measures Against Core Damage and Containment Vessel Failure of Commercial Power Reactors (#13061915); – guide for Establish Permit Application of Commercial Power Reactors (#13061919); – the Standard Review Plan on Technical Capability of Severe Accident Management of Commercial NPPs (#1306197); – guide for Procedure of Construction Work Approval (#13061920).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: manager and engineer; – Junior: engineer; – TSO: researcher. Generally the staff who have more than 10-year experience are taken on the task.
Specialized training, experience and/or education needed for the review of this topic.	– Basic training for the examiner for nuclear safety; – Practical application training for the examiner for nuclear safety.
Level of effort in each review area.	Resources (hours) is not set up for the individual review area. Regarding the standard processing duration, 2 years is set up for the basic design of an entire plant, and 3 months per one application is set up for construction work approval. Divided application is granted for construction work approval.

Nuclear Design and Core Nuclear Performance	**Korea** **KINS**
Design information provided by applicant.	The following information is provided in the application: – description of the core power distributions and uncertainty analyses – design bases for reactivity control systems; – reactivity control requirements and control provisions; – pressure vessel irradiation and computer codes used in the analysis; – control rod patterns and reactivity worths.
Analysis, reviews and/or research performed by the reviewer and scope of review.	In a review of a construction permit application for a new nuclear power plant, the regulatory body verifies whether the nuclear power plant will sufficiently meet the related legislation and technical standards by looking into the application documents submitted by applicants, such as the Preliminary Safety Analysis Report, Radiation Environmental Report, Quality Assurance Program for Construction, and so on. In a review for an operating license of a new nuclear power plant, the regulatory body reviews the application document such as the Final Safety Analysis Report, technical specifications for operation, Quality Assurance Program for Operation, and so on: 1. KINS SRG Section 4.2: Thermal, mechanical, and materials design of the fuel system; 2. KINS SRG Section 4.4: Thermal margins, adequacies of power distribution limits, the effects of corrosion products (crud), and the acceptability of hydraulic loads; 3. KINS SRG 15: Postulated fuel failures resulting from overheating of cladding, overheating of fuel pellets, excessive fuel enthalpy, pellet/cladding interaction; 4. KINS SRG Section 15.4.8~9: Reactivity accidents; 5. KINS SRG Section 9.1.1~2: New fuel will be maintained in a subcritical status during all credible conditions; 6. KINS SRG Section 5.3.1~2: The neutron-induced embrittlement of the reactor vessel materials; 7. KINS SRG Section 7.1~6: Instrumentation and control (I&C).
What type of confirmatory analysis (if any) is performed?	"SCALE" (a modular computer code system for performing standardised computer analyses for licensing evaluation).
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	1. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 17, Reactor Design; 2. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 18, Inherent Protection of Reactor; 3. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 19, Suppression of Reactor Power and Power Distribution Oscillations; 4. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 20, Instrumentation and Control System; 5. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 21, Reactor Coolant Pressure Boundary; 6. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 26, Protection System; 7. Regulation on Technical Standards for Nuclear Reactor Facilities,

	Articles 28, Reactivity Control System; 8. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 35, Reactor Core, etc.; 9. KINS Regulatory Criteria Chapter 5.3, Nuclear Design; 10. KINS Regulatory Standards Chapter 6.3, Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence; 11. KINS Safety Review Guideline 4.3, Nuclear Design.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Nuclear engineers.
Specialized training, experience and/or education needed for the review of this topic.	– 2 years of practical experience in nuclear safety regulation organisations; – each technical staff member takes at least 40 hours of training a year. The following Specialized Training, Experience and/or education are needed for the review, but are not limited to: – knowledge of nuclear physics; – experience in reactor core design.
Level of effort in each review area.	2 400 hours.

Nuclear Design and Core Nuclear Performance	Russia SEC NRS
Design information provided by applicant.	Safety analysis report (chapter 4 which contains description of reactor core including neutronic characteristics). Also all materials referenced in the mentioned above SAR chapter have to be submitted to Regulatory Body.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review that the documentation provided included all information required in the Federal Norms and regulations and that the acceptance criteria given in either Federal Norms and regulations or in plant design are met. Independent analyses of the core main parameters.
What type of confirmatory analysis (if any) is performed?	Determination of the key core parameters (power distribution, reactivity coefficients etc.).
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– OPB-88/97, General provision on ensuring NPP safety; – NP-006-98, Requirements for Content of Safety Analysis Report for NPP with reactor of VVER-type; – NP-082-07, Nuclear safety rules for reactor installations of nuclear power plants ; – NP-061-05, Safety rules for storage and transportation of nuclear fuel at nuclear facilities.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Reactor physics.
Level of effort in each review area.	In Russia, men-hours are not set up for each individual review area. Expert judgement of efforts review is appr. 75 man-days.

Nuclear Design and Core Nuclear Performance	Slovakia UJD
Design information provided by applicant.	– description and design basis; – nuclear parameters monitoring program; – justification of safety margins; – independent design evaluation; – uncertainties of nuclear parameters determination (power level and distribution, nuclear kinetic parameters).
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of the submitted documentation, if it conforms to atomic act and regulations. Evaluate if the systems are in compliance with all requirements arising from applicable regulations, codes and standards. Evaluation of the neutron-physical core characteristics.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	BNS I.6.2/2013 – Requirements for a description of the reactor and its design in the SAR. BNS II.3.3/2011 - Metallurgical products and spare parts for nuclear facilities.- requirements. BNS II.5.6/2009 – Rules for the design, manufacture, construction, maintenance and repairs of the machinery and technological components of nuclear power plant equipment of the VVER 440 type. The requirements from regional and international standards are covered in these documentations.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: technical engineer; – Junior: technical engineer; – TSO: technical engineer.
Specialized training, experience and/or education needed for the review of this topic.	Experience with evaluation and safety analysis**.** Extensive knowledge in nuclear physics and nuclear parameters determination.
Level of effort in each review area.	Review of the submitted design information is a part of approval process which is performed as an administrative procedure based on administrative proceeding code. Based on this act we have 60 days for approval of the submitted documentation. In case that we need more time (for example if we need review from TSO or the other support organisation) we can ask our chairperson about extending the period for approval. In some cases, which are strictly defined in the atomic act the time period for reviewing is longer. These cases are as follows: – four months if siting of nuclear installation, except repository is concerned; – six months if nuclear installation commissioning or decommissioning stage is concerned; – one year if building authorisation, siting and closure of repository or repeated authorisation for operation of a nuclear installation are concerned.

Nuclear Design and Core Nuclear Performance	Slovenia SNSA
Design information provided by applicant.	– design basis and design evaluation (cladding, fuel materials, fuel rod performance, fuel assembly, in core control components); – description (fuel rods, fuel assembly structure, incore control components); – analytical methods in nuclear design and core nuclear performance; – surveillance programme.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Scope of review: – evaluate that the applicant has provided complete information as required by applicable guides and industrial standards; – independent check of some results of analysis to confirmatory analysis; – review the results of testing, inspection and surveillance. Ensure that the reactor core has been designed so that: – shutdown margin will be established; – core coolability will always be maintained, even after severe postulated accidents; – fuel damage is not expected during condition i and condition ii events; – the fuel assemblies are designed to withstand loads induced during shipping, handling and core loading; – all fuel assemblies have provisions for the insertion of in core instrumentation necessary for plant operation; – reactivity control for power operations and reactivity shutdown conditions will be established.
What type of confirmatory analysis (if any) is performed?	Independent core design calculations.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	Regulatory guidance: Rules on Radiation and Nuclear Safety Factors IAEA safety standards.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: nuclear engineer, reactor physicist, electrical engineer; – Junior: nuclear engineer; – TSO: nuclear engineer, reactor physicist, electrical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– core design calculations, reactor core measurements, T-H analysis and calculations, Instrumentation and control.
Level of effort in each review area.	– Regulator: 200 hours; – TSO' review time: 400 hours**.**

Nuclear Design and Core Nuclear Performance	**United Kingdom ONR**
Design information provided by applicant.	– details of code qualification; – three dimensional data on power distribution; – core design specification (reactivity, burn-up of the fuel, reactivity coefficient, power distribution, inserted reactivity); – properties of the fuel (e.g. enrichment of the fuel elements); – information of neutron absorbers; – shutdown margin calculations; – control rod patterns; – reactivity parameters; – justification of compliance with safety analysis bounding design limits; – confirmation of core dynamic performance.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of: – code qualification; – core design strategy; – adequacy of nuclear data; – reflector effects. Ensure that the core has been designed so that: – core dynamic response promotes inherent safety; – safety analysis limits are respected in normal operation and faults; – safe shutdown can be established.
What type of confirmatory analysis (if any) is performed?	Independent core design and kinetic performance calculations.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	NII Safety assessment principles.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Completion of regulatory training and assessment; – No formal requirements.

Specialized training, experience and/or education needed for the review of this topic.	Basic knowledge in nuclear power plants and systems. Experts having training and experience in: – fuel behaviour and modelling; – fault analysis; – reactor physics; – thermal-hydraulics.
Level of effort in each review area.	– Regulatory review: 30 working days; – TSO: 50 working days.

Nuclear Design and Core Nuclear Performance	United States NRC
Design information provided by applicant.	As part of the SAR, the applicant should describe the following: – design bases for the nuclear design of the fuel and reactivity control systems; – full quantitative information on calculated power distributions; – description of the design power distributions and peaking factors to be used in the transient and accident analyses; – translation of the design power distributions into operating power distributions; – requirements for instruments, including calibration, and any calculations involved in their use to measure or infer in-core power distributions; – reactivity coefficients calculations; – shutdown margin calculations; – control rod patterns and associated rod worths; – uncertainty analyses for calculated values including where possible a comparison to applicable experiments; – reactor stability; – technical specifications.
Analysis, reviews and/or research performed by the reviewer and scope of review.	The nuclear regulatory commission (NRC) staff (1) reviews the information provided in the SAR for compliance with the regulations, (2) issues requests for additional information (RAIs) as necessary, (3) reviews RAI responses, (4) resolves technical issues with applicants or licensees, and (5) produces a safety evaluation report (SER) documenting its findings. The scope and level of detail of the staff's safety review is based on the guidance of NUREG-0800, standard review plan (SRP). The sections of the SRP that are applicable to this area are as follows: – SRP 4.3, Nuclear Design. The staff also considers emerging technical and construction issues, operating experience, and lessons learned related to this category.
What type of confirmatory analysis (if any) is performed?	Depends on the reactor design and nuclear physics code submitted by the applicant. If a new reactor design, fuel or physics code is proposed then confirmatory analyses are typically performed. Examples of when confirmatory analyses are performed include smaller, high leakage LWR cores, a new type of burnable absorber or a new reactor physics code is proposed. However, If an already approved code, with established bias and uncertainties for the proposed fuel/core design is submitted confirmatory analyses are not typically performed.

Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The applicable NRC Regulatory Requirements are listed below: 1. 10 CFR Part 50, Appendix A, GDC 10, Reactor Design; 2. 10 CFR Part 50, Appendix A, GDC 11, Reactor Inherent Protection; 3. 10 CFR Part 50, Appendix A, GDC 12, Suppression of Reactor Power Oscillations; 4. 10 CFR Part 50, Appendix A, GDC 13, Instrumentation and Control; 5. 10 CFR Part 50, Appendix A, GDC 20, Protection System Functions; 6. 10 CFR Part 50, Appendix A, GDC 25, Protection System Requirements for Reactivity Control Malfunctions; 7. 10 CFR Part 50, Appendix A, GDC 26, Reactivity Control System Redundancy and Capability; 8. 10 CFR Part 50, Appendix A, GDC 27, Combined Reactivity Control Systems Capability; 9. 10 CFR Part 50, Appendix A, GDC 28, Reactivity Limits. The NRC guidance documents that provide an acceptable approach for satisfying the applicable regulatory requirements are listed as follows: 1. RG 1.77, Assumptions for Evaluating a Control Rod Ejection Accident for Pressurized Water Reactors; 2. RG 1.126, An Acceptable Model and Related Statistical Methods for Fuel Densification.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Nuclear engineer.
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to complete a formal training and qualification programme prior to performing safety reviews independently. Other specialised training, experience, and education that is needed to successfully perform reviews in this technical area include: – knowledge of nuclear physics; – experience in reactor core design.
Level of effort in each review area.	2 000 hours – estimate includes staff review of new or revised reports and codes. If previously approved codes are submitted then the review time would be significantly less. Explanation: If a new or revised core physics topical report is submitted, and confirmatory analyses are performed, the level of review effort is 1 000-1 300 hours. If approved codes and fuel/core designs are used the applicability review is 300 hours. If new or modified incore instrumentation is used an additional 800-1 000 hours of review is typically necessary.

APPENDIX D
THERMAL AND HYDRAULIC DESIGN

Summary table

Country	Is this area reviewed?	Are confirmatory analyses performed?	Expertise of reviewers	Level of effort
Canada	Yes.	Yes.		3 months. (480 hours).
Finland	Yes.	Yes.	No formal requirements.	2 705 working days. (21 640 hours).
France	Yes.	No.	No formal requirements. TSO staff typically have long experience (more than 10 years) on the topic.	—[1]
Japan	Yes.	Yes.	Civil, structural and mechanical engineers. Generally, staff who have more than 10-year experience are taken on the task.	—[2]
Korea	Yes.	Yes.	Nuclear engineer.	2 000 hours
Russia	Yes.	Yes.	Nuclear engineer.	75 man days - (600 hours)[2].
Slovakia	Yes.	No.	Technical engineer.	—[3]
Slovenia	Yes.	Yes.	Nuclear engineer, mechanical engineer.	600 hours[4].
United Kingdom	Yes.	Yes.	No formal requirements.	30 working days[5]. (240 hours).
United States	Yes.	Yes.	Reactor systems engineer.	1 500 hours[6].

Notes:

1. In France, the amount of effort needed to review a new design depends on the degree of novelty in the design.
2. In Japan and Russia, resources (hours) are not set up for each individual review area.
3. In Slovakia, the standard level of effort for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.
4. In Slovenia, the level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.

5. TSO level of effort provided as part of the estimate given for the fuel system design review.
6. If previously approved codes are submitted then the review time would be significantly less.

Thermal and Hydraulic Design	**Canada CNSC**
Design information provided by applicant.	Section 6.4.4, core thermal-hydraulic design, of the CNSC licence application guide rd/gd-369, licence to construction a nuclear power plant specifies information to be provided by applicant for the plant's core thermal-hydraulic design: – information concerning the reactor and reactor coolant system thermal-hydraulic design should be provided, including the following; – design basis requirements, the thermal and hydraulic design for the reactor core and attendant structures, and the interface requirements for the thermal and hydraulic design of the reactor coolant system; – analytical tools, methods, and computer codes (with codes for verification, and validation information and uncertainties) used to calculate thermal and hydraulic parameters; – flow, pressure, void, and temperature distributions, and the specification of their limiting values and a comparison with design limits; – justification for the thermal-hydraulic stability of the core, for example, stability in forced or natural circulation flow against: - neutronic/thermal-hydraulic feedback; - flow oscillations; - parallel channel instabilities.
Analysis, reviews and/or research performed by the reviewer and scope of review.	The following reviews will be performed by CNSC staff: – establishment of safety limits and safety system settings related to core thermal-hydraulics that are consistent with the intended plant operating envelope; – analytical tools, methods, procedures and computer codes used to calculate thermal-hydraulic parameters; – data serving to support new correlations or changes in accepted correlations; data serving to validate the analytical tools, methods, procedures and computer codes; – calculated parameters characterising core thermal and hydraulic performances such as flow, pressure, void, and temperature distributions, including assumptions in the equations and solution techniques used in the thermal-hydraulic calculations; – uncertainty analysis methodologies and the uncertainties of key variables and correlations such as critical heat flux (CHF), critical channel power (CCP), single- and two-phase pressure drops, etc.; – demonstration of core stability in normal operating condition and anticipated operational occurrences (AOOs).
What type of confirmatory analysis (if any) is performed?	The following confirmation analysis will be performed by CNSC staff: – the fuel sheath is not damaged as a result of normal operation and AOOs; – fuel sheath damage in an accident is never so severe as to prevent control rod / shutoff rod insertion when it is required (in PWR design), or as to challenge the subsequent barrier (e.g., pressure tube in CANDU design, or pressure vessel in PWR design); – the number of fuel sheath failures is not underestimated for postulated accidents. To achieve these design objectives, a proper thermal-hydraulic design of the reactor core and associated systems is required

	to assure that sufficient margin exists with regard to maintaining adequate heat transfer from the fuel to the reactor coolant system to prevent fuel sheath overheating.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The requirements and expectations found in the following documents should be met: – REGDOC-2.5.2 (draft), Design of New Nuclear Power Plants; – RD/GD-369, Licence to Construction a Nuclear Power Plant; – REGDOC-2.4.1 (draft), Safety Analysis: Deterministic Safety Analysis; – REGDOC-2.4.1 (draft), Safety Analysis: Probabilistic Safety Assessment (PSA) for Nuclear Power Plants; – CNSC Work Instruction, How to Assess the Core Thermalhydraulic Design: Application for Licence to Construct for a Reactor Facility, WI-2.01-CON-11NNNN-006.4.4; – IAEA SSR 2/1, Safety of Nuclear Power Plants: Design; – IAEA, NS-G-1.12, Design of the Reactor Core for Nuclear Power Plants, IAEA Safety Standards Series.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– extensive knowledge of nuclear standards, regulatory documents, guidelines particularly those pertaining to core thermal-hydraulics; – experience in the design and operations of core design used in nuclear facilities; – knowledge of thermal-hydaulics; – knowledge of safety analysis; – knowledge of nuclear safety principles.
Specialized training, experience and/or education needed for the review of this topic.	– a university degree in science or engineering (masters or higher level degree would be an asset); – extensive experience in the principles of design, operation and safety assessment of nuclear power plants.
Level of effort in each review area.	Senior staff: 3 month review period for construction licence application review.

Thermal and Hydraulic Design	Finland STUK
Design information provided by applicant.	– thermal-hydraulic conditions under shutdown and all power states; – the largest hydraulic loads on core and RCS components during normal operation and design-basis accident conditions; – critical heat flux or critical power ratio correlations; – parameters characterising thermal performance.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– independent computer calculations to substantiate the analyses, and experiments if needed; – evaluate that the applicant has provided complete information as required by applicable guides and standards. Scope of review: – confirm that the thermal and hydraulic design of the core and the reactor coolant system (RCS); - uses validated analytical methods; - provides acceptable margins of safety from conditions that would lead to fuel damage during normal reactor operation and anticipated operational occurrences (AOOs); - is not susceptible to thermal-hydraulic instability; - core coolability will always be maintained in all postulated accidents.
What type of confirmatory analysis (if any) is performed?	– independent computer calculations to substantiate the analyses; – experiments if needed; – expert judgments.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	YVL guides (2.2, 2.4, 6.2).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	– Training in thermal-hydraulics; – Experience with thermal-hydraulics computer code.
Level of effort in each review area.	– Regulator review: 255 working days; – TSO oversight: 150 days; – TSO: 2 300 working days.

Thermal and Hydraulic Design	**France ASN**

Design information provided by applicant.	The applicant provides the following information in the Safety Analysis Report:
	– thermal-hydraulic design of the core;
	– design of the primary circuit:
	  - safety requirements;
	  - description of the primary circuit;
	  - integrity of the pressure boundary;
	  - design of the components and subsystems;
	– thermal-hydraulic design of the emergency core cooling system.

Analysis, reviews and/or research performed by the reviewer and scope of review.	A comprehensive review of the safety file (safety analysis report + supporting documents) provided by the applicant is performed by the TSO. The following items are reviewed in detail: – effectiveness of the core cooling; – appropriateness of the emergency core cooling systems according to its functions; – thermal-hydraulic and mechanical design of the fuel assembly.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	There is no standard or code in France on this topic. Acceptance criteria are defined by the applicant. There is at present no regulatory guidance on them. A draft guide on PWR design, prepared by ASN and IRSN, will give some guidance on the safety requirements, but acceptance criteria will remain in the hands of the applicant.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	There is no requirement on skills applicable to the thermal and hydraulic design.
Specialized training, experience and/or education needed for the review of this topic.	The staff performing the technical review at our TSO has a long experience (more than 10 years) of this topic.
Level of effort in each review area.	The amount of effort needed to review a new design of reactivity control systems strongly depends on the degree of novelty of this design considered.

<table>
<tr><th>Thermal and Hydraulic Design</th><th>Japan
NRA</th></tr>
<tr><td>Design information provided by applicant.</td><td>In the establishment permit application stage, the following information is provided in the application:
– primary cooling equipment (coolant type, number and structure of main devices and pipes and coolant temperature and pressure);
– secondary cooling equipment (coolant type and number and structure of main devices);
– emergency cooling equipment (Coolant type and number and structure of main devices);
– other major items (auxiliary systems of primary cooling equipment, secondary cooling equipment and emergency cooling equipment at normal operation or accident).
In addition, in construction work approval application stage, the following information is provided:
– the type and purity of the primary coolant, and the pressure and temperature of the primary coolant at the inlet and outlet ports of the reactor vessel body (PWRs only);
– the type and purity of the reactor coolant, and the pressure and temperature of the reactor coolant at the inlet and outlet ports of the reactor pressure vessel body (BWRs only);
– the flow rate of the primary coolant in the core of the reactor vessel body (PWRs only);
– the reactor coolant flow rate and the steam generation amount at the core in the reactor pressure vessel body (BWRs only);
– the pressurizer pressure (PWRs only);
– the reactor coolant recirculation system (BWRs only);
– the primary coolant circulation system (PWRs only);
– the reactor coolant circulation system (BWRs only);
– the main steam and water supply system (PWRs only);
– residual heat removal system;
– the emergency core cooling system and other reactor water injection systems;
– the chemical and volume control system (PWRs only);
– the reactor coolant supply system (BWRs only);
– the reactor auxiliary cooling system;
– the reactor coolant cleanup system (BWRs only);
– the names, types, measurement ranges, and number of devices monitoring primary coolant leakage in the reactor containment vessel, as well as the places where they are installed (PWRs only);
– the names, types, measurement ranges, and number of devices monitoring reactor coolant leakage in the reactor containment vessel, as well as the places where they are installed (BWRs only);
– steam turbines and the system attached to steam turbines;
– the basic design policy and the related applied standards for the reactor cooling system facilities (excluding steam turbines);
– the quality control methods for the design and the construction.</td></tr>
</table>

Analysis, reviews and/or research performed by the reviewer and scope of review.	These activities are to conform to the standards, criteria, and the like described below.
What type of confirmatory analysis (if any) is performed?	In the establishment permit application stage, adequacy of an applicant's analytic method and the analysis results are verified. Independent evaluation is also performed to comprehend the uncertainties of the analytic method, if needed.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The following regulatory requirements and guides are applicable to this technical area: – the NRA Ordinance Concerning the Installation and Operation of Commercial Power Reactors (S53 #77); – the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (H25 #5); – the Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (#1306193); – the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (H25 #6); – the Regulatory Guide of the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (#1306194); – the NRA Ordinance on Technical Standards for Nuclear Fuel Material Being Used as a Fuel in Commercial Power Reactors (H25 #7); – guide for Evaluation of Effectiveness of Preventive Measures Against Core Damage and Containment Vessel Failure of Commercial Power Reactors (#13061915); – guide for Establish Permit Application of Commercial Power Reactors (#13061919); – the Standard Review Plan on Technical Capability of Severe Accident Management of Commercial NPPs (#1306197); – guide for Procedure of Construction Work Approval (#13061920).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: manager and engineer; – Junior: engineer; – TSO: researcher. Generally the staff who have more than 10-year experience are taken on the task.
Specialized training, experience and/or education needed for the review of this topic.	– Basic training for the examiner for nuclear safety; – Practical application training for the examiner for nuclear safety.
Level of effort in each review area.	Resources (hours) is not set up for the individual review area. Regarding the standard processing duration, 2 years is set up for establishment permit of an entire plant, and 3 months per one application are set up for construction work approval. Divided application is granted for construction work approval.

Thermal and Hydraulic Design	Korea KINS
Design information provided by applicant.	The following information is provided in the application: – comparison of thermal-hydraulic design parameters with previously approved reactors of similar design and predicted radial and axial distributions of steam quality and steam void fractions; – testing and verification techniques used (uncertainty analysis methodology and the uncertainties of variables and correlations); – coolant pressure drops and hydraulic loads, CHF or critical power ratio correlations.
Analysis, reviews and/or research performed by the reviewer and scope of review.	In a review of a construction permit application for a new nuclear power plant, the regulatory body verifies whether the nuclear power plant will sufficiently meet the related legislation and technical standards by looking into the application documents submitted by applicants, such as the Preliminary Safety Analysis Report, Radiation Environmental Report, Quality Assurance Program for Construction, and so on. In a review for an operating license of a new nuclear power plant, the regulatory body reviews the application document such as the Final Safety Analysis Report, technical specifications for operation, Quality Assurance Program for Operation, and so on. Scope of review: 1. KINS SRG Section 4.3: Core monitoring techniques that rely on in core or ex-core neutron sensor inputs; 2. KINS SRG Section 3.9.3 & 3.9.6: Components and structures under accident loads and the preoperational vibration test program; 3. KINS SRG Section 7.2: The core protection and reactor protection hardware; 4. KINS SRG Section 7.5: ICC monitoring system hardware; 5. KINS SRG Section 13.2.1 & 13.2.2: Training program; 6. KINS SRG Section 13.3: Emergency procedure guidelines (EPGs); 7. KINS SRG Section 18: Human factor 8. KINS SRG Section 19: Shutdown risk assessment.
What type of confirmatory analysis (if any) is performed?	COBRA code: Thermal-Hydraulics code for transient analysis of nuclear reactor vessels and primary coolant systems.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	1. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 17, Reactor Design; 2. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 19, Suppression of Reactor Power and Power Distribution Oscillations; 3. KINS Regulatory Criteria Chapter 5.4, Thermal-hydraulic design; 4. KINS Safety Review Guideline 4.4, Thermal-hydraulic design.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Nuclear engineer.

Specialized training, experience and/or education needed for the review of this topic.	– 2 years of practical experience in nuclear safety regulation organisations; – each technical staff member takes at least 40 hours of training a year. The following specialized training, experience and/or education are needed for the review, but are not limited to: – experience in thermal-hydraulics.
Level of effort in each review area.	2 000 hours.

Thermal and Hydraulic Design	**Russia SEC NRS**
Design information provided by applicant.	Safety analysis report (chapter 4 which has description of reactor thermal-hydraulic properties). Also all materials referenced in the mentioned above SAR chapter have to be submitted to Regulatory Body.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review that the documentation provided included all information required in the Federal Norms and regulations and that the acceptance criteria given in either Federal Norms and regulations or in plant design are met. Independent calculations of core cooling condition for normal operation and for transients including accidents.
What type of confirmatory analysis (if any) is performed?	Independent analyses of core cooling condition for normal operation and for transients including accidents. Such analyses are made by TSO using codes different from the codes used by industry.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– OPB-88/97, General provision on ensuring NPP safety; – NP-006-98, Requirements for Content of Safety Analysis Report for NPP with reactor of VVER-type; – NP-082-07, Nuclear safety rules for reactor installations of nuclear power plants; – NP-061-05, Safety rules for storage and transportation of nuclear fuel at nuclear facilities.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Experience with thermal-hydraulics computer codes.
Level of effort in each review area.	In Russia men-hours are not set up for each individual review area. Expert judgement of efforts review is appr. 75 man-days.

Thermal and Hydraulic Design	Slovakia UJD
Design information provided by applicant.	– describing of the thermo-hydraulic requirements for core and related reactor components as well as connection requirements with cooling system`s thermo-hydraulic; – thermo-hydraulic characteristics of the fuel assembly, core and primary circuit; – describing of analytical method and calculation program used for thermo-hydraulic calculation; – critical heat flux; – coolant flow distribution, heat flow distribution, pressure and temperature with limitation specification; – safety operation limitation.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of the submitted documentation, if it conforms to atomic act and regulations. Evaluate if the systems are in compliance with all requirements arising from applicable regulations, codes and standards. Confirm that the thermal-hydraulic design uses acceptable analytical methods and provides acceptable margins of safety from conditions that would lead to fuel damage during normal reactor operation and anticipated operational occurrences.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	BNS I.6.2/2013 – Requirements for a description of the reactor and its design in the SAR. BNS II.3.3/2011 – Metallurgical products and spare parts for nuclear facilities.- requirements. BNS II.5.6/2009 – Rules for the design, manufacture, construction, maintenance and repairs of the machinery and technological components of nuclear power plant equipment of the VVER 440 type. The requirements from regional and international standards are covered in these documentations.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: technical engineer; – Junior: technical engineer; – TSO: technical engineer.
Specialized training, experience and/or education needed for the review of this topic.	Experience with thermal-hydraulic.
Level of effort in each review area.	Review of the submitted design information is a part of approval process which is performed as an administrative procedure based on administrative proceeding code. Based on this act we have 60 days for approval of the submitted documentation. In case that we need more time (for example if we need review from TSO or the other support organisation) we can ask our chairperson about extending the period for approval. In some cases, which are strictly defined in the atomic act the time period for reviewing is longer. These

	cases are as follows: – four months if siting of nuclear installation, except repository is concerned; – six months if nuclear installation commissioning or decommissioning stage is concerned; – one year if building authorisation, siting and closure of repository or repeated authorisation for operation of a nuclear installation are concerned.

Thermal and Hydraulic Design	Slovenia SNSA
Design information provided by applicant.	– design basis and design evaluation (DNB, critical heat flux, critical power ratio correlations, fuel temperature, stability, etc.); – description of the thermal-hydraulic (t-h) of the reactor coolant system; – methods, computer codes for t-h calculations, results of calculations with uncertainties. Testing and verification and instrumentation application.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Scope of review: – evaluate that the applicant has provided complete information as required by applicable guides and industrial standards; – independent check of some results of analysis to confirmatory analysis; – review the results of testing, inspection and surveillance. Ensure that the systems has been designed so that: – uses acceptable analytical methods; – provides acceptable margins of safety from conditions that would lead to fuel damage during normal reactor operation and anticipated operational occurrences and is not susceptible to thermal-hydraulic instability; – core coolability will always be maintained, even after severe postulated accidents.
What type of confirmatory analysis (if any) is performed?	Independent T-H calculations.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	Regulatory guidance: Rules on Radiation and Nuclear Safety Factors. IAEA safety standards.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: nuclear engineer, mechanical engineer; – Junior: nuclear engineer, mechanical engineer; – TSO: nuclear engineer, mechanical engineer.
Specialized training, experience and/or education needed for the review of this topic.	Training in thermal-hydraulics: – calculations methods, using T-H computer codes; – uncertainty analysis calculations.
Level of effort in each review area.	– Regulator: 200 hours; – TSO' review time: 400 hours.

Thermal and Hydraulic Design	United Kingdom ONR
Design information provided by applicant.	– the largest hydraulic loads on core and RCS components during normal operation and design-basis accident conditions; – critical heat flux; – flow-induced fretting; – impact of irradiation-induced growth and bow on flow field; – core boiling and void fraction; – parameters characterising thermal performance.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– qualification of codes and methods of calculation; – adequacy of uncertainty allowances in CHF analysis; – impact of fuel ballooning on fault performance.
What type of confirmatory analysis (if any) is performed?	– adequacy of uncertainty allowances in CHF analysis; – impact of fuel ballooning on fault performance
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	NII safety assessment principles.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Completion of regulatory training and assessment; – No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Basic knowledge in nuclear power plants and systems. Experts having training and experience in: – fault analysis; – thermal-hydraulics.
Level of effort in each review area.	– Regulatory review: 30 working days; – For TSO effort see fuel design above.

Thermal and Hydraulic Design	United States NRC
Design information provided by applicant.	As part of the SAR, the applicant should describe the thermal-hydraulic characteristics of the reactor design and include the following: – comparison of thermal-hydraulic design parameters with previously approved reactors of similar design; – critical heat flux ratios; – core average and maximum linear heat generation rates; – predicted radial and axial distributions of steam quality and steam void fractions; – coolant pressure drops and hydraulic loads; – flux tilt considerations; – plant configuration related to thermal-hydraulic design; – critical heat flux or critical power ratio correlations; – core hydraulics evaluation; – testing and verification techniques used; – functional requirements for instrumentation.
Analysis, reviews and/or research performed by the reviewer and scope of review.	The Nuclear Regulatory Commission (NRC) staff (1) reviews the information provided in the SAR for compliance with the regulations, (2) issues requests for additional information (RAIs) as necessary, (3) reviews RAI responses, (4) resolves technical issues with applicants or licensees, and (5) produces a safety evaluation report (SER) documenting its findings. The scope and level of detail of the staff's safety review is based on the guidance of NUREG-0800, Standard Review Plan (SRP). The sections of the SRP that are applicable to this area are as follows: – SRP 4.4, "Thermal and Hydraulic Design". The staff also considers emerging technical and construction issues, operating experience, and lessons learned related to this category.
What type of confirmatory analysis (if any) is performed?	Confirmatory analyses are typically only performed if a new code is submitted especially if the code uses unique solution methods (e.g. if the code deterministically calculated DNBR). However, If the code has been previously approved and well established for the expected operating conditions (limitations and uncertainties are well defined) confirmatory analyses are usually not performed. The staff may perform confirmatory calculations to verify statistical uncertainty methods.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	The applicable NRC Regulatory Requirements are listed below: 1. 10 CFR Part 50, Appendix A, GDC 10, "Reactor Design"; 2. 10 CFR Part 50, Appendix A, GDC 12, "Suppression of Reactor Power Oscillations". The NRC guidance documents that provide an acceptable approach for satisfying the applicable regulatory requirements are listed as follows: 1. RG 1.68, "Initial Test Programs for Water-Cooled Nuclear Power Plants"; 2. RG 1.133, 'Loose Parts Detection Program for the Primary system of Light-Water-Cooled Reactor".

Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Reactor Systems Engineer familiar within core or sub-channel thermal-hydraulic analysis, experimentally derived CHF measurements and associated correlation development.
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to complete a formal training and qualification programme prior to performing safety reviews independently. Other specialised training, experience, and education that is needed to successfully perform reviews in this technical area include: – experience in thermal-hydraulics.
Level of effort in each review area.	1 500 hours – estimate includes staff review of new sub-channel code, new CHF correlation, and a new statistical uncertainty method. If previously approved codes and existing methods are submitted then the review time would be significantly less. Explanation: The level of effort is based on whether submittal covers CHF correlation development and method to establish a DNBR safety analysis limit (typically a statistical method which combines uncertainties). If the submittal contains a sub-channel code review in addition to CHF correlation development and a new (unapproved) statistical uncertainty method the total review time ranges from 1 200-1 500 hours. If an existing approved sub-channel code, approved statistical uncertainty method and existing CHF correlation is used the review time is 300-500 hours.

APPENDIX E
REACTOR MATERIALS

Summary table

Country	Is this area reviewed?	Are confirmatory analyses performed?	Expertise of reviewers	Level of effort
Canada	Yes.	Yes.	Combined knowledge and experience in material selection, fabrication, welding, material degradation, examination and inspection.	600 hours.
Finland	Yes.	Yes.	Materials scientist/engineer.	110 working days. (880 hours).
France	Yes.	Yes.	Mechanical engineer, materials engineer, risk assessment engineer.	
Japan	Yes.	Yes.	Civil, structural and mechanical engineer. Generally, staff who have more than 10-year experience are taken on the task.	—[1]
Korea	Yes.	No.	Materials engineer	500 hours.
Russia	Yes.	No.	Nuclear engineer, mechanical engineer	50 man days - (400 hours)[1].
Slovakia	Yes.	Yes.	Technical engineer	—[2]
Slovenia	Yes.	No.	Nuclear engineer, mechanical engineer.	400 hours[3].
United Kingdom	Yes.	Yes.	No formal requirements.	30 working days[4]. (240 hours).
United States	Yes.	No.	Materials engineer.	500 hours.

Notes:

1. In Japan and Russia, resources (hours) are not set up for each individual review area.

2. In Slovakia, the standard level of effort for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.
3. In Slovenia, the level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.
4. TSO level of effort provided as part of the estimate given for the fuel system design review.

<table>
<tr><th>Reactor Materials</th><th>Canada
CNSC</th></tr>
<tr><td>Design information provided by applicant.</td><td>Section 6.4.5, reactor materials, of the CNSC licence application guide rd/gd-369, licence to construct a nuclear power plant specifies that the applicant should provide:
– material specifications, including:
- chemical, physical and mechanical properties;
- resistance to corrosion;
- dimensional stability, strength, toughness, crack tolerance, and hardness;
- micro-structure and material fabrication details, where this is important.
– properties and required performance of seals, gaskets and fasteners in the primary pressure boundary;
– material surveillance programme that will address potential material degradation for all components, particularly for components operated in high radiation fields, in order to determine the metallurgical or other degradation effects of factors such as irradiation, stress corrosion cracking, flow-accelerated corrosion, thermal embrittlement, vibration fatigue, and other aging mechanisms.
Where a new material is introduced, it shall be systematically tested before being brought into service. The applicant should provide information and data from supporting research and development programs, and from examination of relevant experience from similar applications to demonstrate that the new material meets its design requirements and design limits.</td></tr>
<tr><td>Analysis, reviews and/or research performed by the reviewer and scope of review.</td><td>CNSC work instruction document, WI-2.01-CON-11NNNN-006.4.5, Reactor Materials provides guidance on assessment of this topic. Specifically, reactor materials are developed/selected, fabricated, installed, tested and inspected in complying with the expectations in RD-337 §7.7, pressure-retaining SSCs, § 8.1, reactor core, § 8.2, reactor coolant system.
CNSC staff will examine the following topics:
– material specifications;
– fabrication process;
– welding process;
– compatibility with service environments;
– examination and inspection methods;
– material surveillance programme.</td></tr>
<tr><td>What type of confirmatory analysis (if any) is performed?</td><td>Confirmatory analysis is performed to verify material homogeneity for large initial ingot size, large finished part size, complex forming operations, and specific conditions that might restrict the representativity of inspections and tests or severe stress conditions.
For reactor materials that are not specified in the code or code cases, the acceptability will be considered on an individual basis with considerations of their chemical composition, microstructure, mechanical properties, weldability, and physical changes of the material. Where a new material is introduced, the adequacy for its design duty and adequacy for remaining fit during the lifetime are confirmed by a combination of supporting research and development programs and by examination of relevant experience from similar applications. An adequate qualification programme should be established to test new materials before being brought into service, and then</td></tr>
</table>

	to monitor in service to verify that the expected behavior is achieved. If special processes are used for fabrication of reactor materials, confirmatory analysis is performed to 1) determine whether there are any Code restrictions on its use, 2) confirm the adequacy of the process in providing components with suitable mechanical and physical properties, 3) determine the effects of such processes on material degradation, and 4) identify whether special requirements for nondestructive examination are needed. Special configurations and materials may need modified methods and techniques for examination. If such special examination procedures are developed, confirmatory analysis is performed to ensure that they are equivalent or superior to the techniques described in ASME Section V, and are capable of producing meaningful results under the special conditions.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The requirements and expectations found in the following documents should be met: – CNSC RD-337, design of new nuclear power plants; – CNSC WI-2.01-CON-11NNNN-006.4.5. Applicable sections of the following codes and standards may also be used in the review: – CSA N285.0, "general requirements for pressure-retaining systems and Components in CANDU nuclear power plants"; – CAS N285.6, "material standards for reactor components for CANDU nuclear power plants"; – CSA N285.2, "requirements for class 1c, 2c and 3c pressure-retaining components and supports in CANDU nuclear power plants"; – CSA N285.4, "periodic inspection of CANDU nuclear power plant components"; – ASTM B350 / B350M, "zirconium and zirconium alloy ingots for nuclear application"; – ASTM B351, "hot-rolled and cold-finished zirconium and zirconium alloy bars, rod, and wire for nuclear application"; – ASTM B352, "zirconium and zirconium alloy sheet, strip, and plate for nuclear application"; – ASTM B353, "wrought zirconium and zirconium alloy seamless and welded tubes for nuclear service (except nuclear fuel cladding)"; – ASME code Section III, "Rules for Construction of Nuclear Facility Components"; – ASME code Section II, "materials"; – ASME Section V, "non destructive examination" ; – ASME Section IX, "Welding and brazing qualifications"; – ASTM E-185, "standard practice for design of surveillance programs for light-water moderated nuclear power reactor vessels". In some cases, applying code requirements alone may not be sufficient. The following are examples of additional expectations: – for ferritic PWR reactor vessel materials, the amount of residual elements shall be controlled to such levels that the fracture toughness is acceptable at the end of life condition; – For fastener materials, surface treatments, plating, or thread lubricants used should be compatible with the materials, and stable at

	operating temperatures; – austenitic stainless steel RPB materials should be fabricated with measures to 1) avoid sensitization; 2) control cleaning and contamination during handling, storage, testing, and fabrication; 3) control cold working; 4) ensure proper selection of thermal insulation material; 5) achieve appropriate mechanical properties and fracture toughness; – the designer should minimize the use of materials containing cobalt as an alloying element in order to minimize activation of the material; – for clad welding, material known to have susceptibility to underclad cracking should not be weld clad by high-heat-input welding processes and should be qualified for use to demonstrate that underclad cracking is not induced; – for welding ferritic steels, minimum preheat and maximum interpass temperatures should be specified and the welding procedure should be qualified at the minimum preheat temperature. for production welds, the preheat temperature should be maintained until a post-weld heat treatment has been performed.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	The review requires combined knowledge and experience in material selection, fabrication, welding, material degradation, examination and inspection.
Specialized training, experience and/or education needed for the review of this topic.	Specialised training, experience and education that is needed to perform reviews in this technical area include: – knowledge and experience with the CNSC regulations and processes; – knowledge and experience with the relevant codes and standards; – a minimum of bachelor degree in materials science, metallurgy, or materials engineering; – direct work experience in nuclear industry.
Level of effort in each review area.	600 hours.

Reactor Materials	Finland STUK
Design information provided by applicant.	– material data file.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– STUK's inspectors inspect all documents by themselves. The inspection is performed by specialist from different branch of technology (process, component, strength, manufacturing, quality, NDT, QA).
What type of confirmatory analysis (if any) is performed?	– material data file.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	– RCCM.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– No formal requirements. – Senior: - M.Sc/engineer; - working experience of sector. – Junior: - M.Sc/engineer. – TSO: - Spesialist of sector. Competence of research institute shall be evaluation by audit.
Specialized training, experience and/or education needed for the review of this topic.	
Level of effort in each review area.	110 working days.

Reactor Materials	**France** **ASN**
Design information provided by applicant.	For reactor materials that composed the primary and secondary circuit, the design information is provided by the manufacturer as a part of the documentation submitted to assess the conformity of a N1 NPE.
Analysis, reviews and/or research performed by the reviewer and scope of review.	According to NPE regulation, for N1 NPE (primary and second circuits) ASN performs an examination of the design, and determinates their conformity with essential safety requirements.
What type of confirmatory analysis (if any) is performed?	A conformity assessment that leads to a certification.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	The technical basis of such assessment are regulatory requirements (essential safety requirements), standards harmonised, codes and general standards.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: mechanical, material, risk assessment; – Junior: mechanical engineer; – TSO: mechanical, material, risk assessment.
Specialized training, experience and/or education needed for the review of this topic.	Knowledge of nuclear power plant design and operation, metallurgy, manufacturing process, safety risk analysis, non-destructive tests.
Level of effort in each review area.	During this review, ASN is supported by a TSO (notified agreed body).

Reactor Materials	Japan NRA
Design information provided by applicant.	In the establishment permit application stage, the following information is provided in the application: – structure of reactor core (support structures of fuel assembly and reflector, lattice shape of core and main dimensions, etc.); – fuel assembly (type of fuel materials, type of cladding materials, structure of a fuel element, structure of a fuel assembly); – structure of a reactor vessel (main dimensions, materials, consideration to non-ductile fracture). In addition, in construction work approval application stage, the following information is provided: – reactor types, rated thermal output, excess reactivity and reactivity coefficient (moderator temperature coefficient, Doppler coefficient (PWRs only), void coefficient(PWRs only), pressure coefficient (PWRs only), fuel rod temperature coefficient (BWRs only), moderator void coefficient (BWRs only), and power reactivity coefficient (BWRs only)), as well as moderator material names, types, and composition; – shape of reactor core, the number of fuel assemblies, effective core height, and equivalent core diameter, etc.; – the names, types, compositions, main dimensions (PWRs only), materials (PWRs only), and number (PWRs only) of reflectors; – the names, types, main dimensions, materials, and number of thermal shields (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials and number of reactor vessel bodies, and the types and the number at initial loading of monitoring specimens, as well as the places where they are attached, etc. (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials and number of reactor pressure vessel bodies, and the types and the number at initial loading of monitoring specimens, as well as the places where they are attached, etc. (BWRs only); – the basic design policy and the related applied standards for the reactor body; – the quality control methods for the design and the construction.
Analysis, reviews and/or research performed by the reviewer and scope of review.	These activities are to conform to the requirements, standards, criteria, and the like described below.
What type of confirmatory analysis (if any) is performed?	In the establishment permit application stage, adequacy of an applicant's analytic method and the analysis results are verified. Independent evaluation is also performed to comprehend the uncertainties of the analytic method, if needed.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from**	The following regulatory requirements and guides are applicable to this technical area: – the NRA Ordinance Concerning the Installation and Operation of Commercial Power Reactors (S53 #77); – the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (H25 #5);

Accident analysis, regulatory guidance).	– the Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (#1306193); – the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (H25 #6); – the Regulatory Guide of the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (#1306194); – the NRA Ordinance on Technical Standards for Nuclear Fuel Material Being Used as a Fuel in Commercial Power Reactors (H25 #7); – guide for Evaluation of Effectiveness of Preventive Measures Against Core Damage and Containment Vessel Failure of Commercial Power Reactors (#13061915); – guide for Establish Permit Application of Commercial Power Reactors (#13061919); – the Standard Review Plan on Technical Capability of Severe Accident Management of Commercial NPPs (#1306197); – guide for Procedure of Construction Work Approval (#13061920).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: manager and engineer; – Junior: engineer; – TSO: researcher. Generally the staff who have more than 10-year experience are taken on the task.
Specialized training, experience and/or education needed for the review of this topic.	– Basic training for the examiner for nuclear safety; – Practical application training for the examiner for nuclear safety.
Level of effort in each review area.	Resources (hours) is not set up for the individual review area. Regarding the standard processing duration, 2 years is set up for establishment permit of an entire plant, and 3 months per one application are set up for construction work approval. Divided application is granted for construction work approval.

Reactor Materials	Korea KINS
Design information provided by applicant.	The following information is provided in the application: – the materials are compatible with the service environment so that unacceptable degradation due to corrosion or stress corrosion of the component will not occur during its lifetime; – fabrication and processing of austenitic stainless steel components – cleaning and cleanliness control; – non-destructive examination methods; – controls on welding.
Analysis, reviews and/or research performed by the reviewer and scope of review.	In a review of a construction permit application for a new nuclear power plant, the regulatory body verifies whether the nuclear power plant will sufficiently meet the related legislation and technical standards by looking into the application documents submitted by applicants, such as the Preliminary Safety Analysis Report, Radiation Environmental Report, Quality Assurance Program for Construction, and so on. In a review for an operating license of a new nuclear power plant, the regulatory body reviews the application document such as the Final Safety Analysis Report, technical specifications for operation, Quality Assurance Program for Operation, and so on. Scope of Review: 1. KINS SRG Section 5.2.3: Reactor Coolant Pressure Boundary Materials; 2. KINS SRG Section 5.3.1: Reactor Vessel Materials; 3. KINS SRG Section 3.9.4: Reactor Pressure Vessel Internals; 4. KINS SRG Section 4.2: Review of the mechanical design, thermal performance, and chemical compatibility of the reactivity control elements; 5. KINS SRG Section 12.1: Assuring That Occupational Radiation Exposures Are As Low As Is Reasonably Achievable; 6. KINS SRG Section 3.13: Threaded fastener.
What type of confirmatory analysis (if any) is performed?	None.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 12, Safety Classes and Standards; – Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 21, Reactor Coolant Pressure Boundary; – Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 28, Reactivity Control System; – Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 36, Reactivity Control Material Drive Mechanism; – NSSC Notice No.2014-19, Guidelines for Application of Korea Electric Power Industry Code (KEPIC) as technical Standards of Nuclear Reactor Facilities; – KINS Regulatory Criteria Chapter 5.5, The control rod drive system (CRDS); – KINS Safety Review Guideline 4.5.1, The control rod drive system material.

Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Materials engineer.
Specialized training, experience and/or education needed for the review of this topic.	– 2 years of practical experience in nuclear safety regulation organisations; – Each technical staff member takes at least 40 hours of training a year. The following specialised training, experience and/or education are needed for the review, but are not limited to: – knowledge of or experience with welding and NDE; – experience in metallurgy and materials selection; – experience with ASME code; – knowledge of welding and non-destructive examination.
Level of effort in each review area.	500 hours.

Reactor Materials	Russia SEC NRS
Design information provided by applicant.	Safety analysis report (chapter 4 which contains description of reactor materials). Also all documents referenced in the mentioned above SAR chapter have to be submitted to Regulatory Body.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review that the documentation provided included all information required in the Federal Norms and regulations and that the acceptance criteria given in either Federal Norms and regulations or in plant design are met.
What type of confirmatory analysis (if any) is performed?	None.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– OPB-88/97 General provision on ensuring NPP safety; – NP-006-98 Requirements for Content of Safety Analysis Report for NPP with reactor of VVER-type; – NP-082-07 Nuclear safety rules for reactor installations of nuclear power plants; – NP-061-05 Safety rules for storage and transportation of nuclear fuel at nuclear facilities.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Familiarisation with nuclear materials.
Level of effort in each review area.	In Russia men-hours are not set up for each individual review area. Expert judgment of efforts review is appr. 50 man-days.

Reactor Materials	Slovakia UJD
Design information provided by applicant.	– reactor materials specifications; – qualification and classification; – the pressure–temperature limits; – requirements for management of aging; – requirements for processes of procurement, design, manufacture, storage transport, installation, commissioning and operation; – requirements for technical operating and maintenance procedures, including requirements for the manner and scope of pre-operational and operational checks; – documentation of the suitability of metallurgical semi-finished products and welding filler.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– Evaluate that the applicant meets all requirements of the Authority, generally applicable legislation, special regulations and Slovak technical standards; – Review the results of testing, inspection and surveillance.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	BNS I.6.2/2013 – Requirements for a description of the reactor and its design in the SAR. BNS II.3.3/2011 – Metallurgical products and spare parts for nuclear facilities.- requirements. BNS II.5.6/2009 – Rules for the design, manufacture, construction, maintenance and repairs of the machinery and technological components of nuclear power plant equipment of the VVER 440 type. The requirements from regional and international standards are covered in these documentations.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: technical engineer; – Junior: technical engineer; – TSO: technical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– Experience in evaluation of design; – Knowledge about nuclear facilities.
Level of effort in each review area.	Review of the submitted design information is a part of approval process which is performed as an administrative procedure based on administrative proceeding code. Based on this act we have 60 days for approval of the submitted documentation. In case that we need more time (for example if we need review from TSO or the other support organization) we can ask our chairperson about extending the period for approval. In some cases, which are strictly defined in the atomic act the time period for reviewing is longer. These cases are as follows: – four months if siting of nuclear installation, except repository is

	concerned; – six months if nuclear installation commissioning or decommissioning stage is concerned; – one year if building authorisation, siting and closure of repository or repeated authorisation for operation of a nuclear installation are concerned.

Reactor Materials	**Slovenia** **SNSA**
Design information provided by applicant.	– the information of all reactor internals materials specifications; – controls on welding; – non-destructive examination; – fabrication and processing of components; – contamination protection and cleaning of materials.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Scope of review: – evaluate that the applicant has provided complete information as required by applicable guides and industrial standards. Review the results of testing, inspection and surveillance.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	Regulatory guidance: rules on radiation and nuclear safety factors IAEA safety standards
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: nuclear engineer, materials engineer; – Junior: nuclear engineer, materials engineer; – TSO: nuclear engineer, materials engineer.
Specialized training, experience and/or education needed for the review of this topic.	Knowledge of the codes and standards for material selection.
Level of effort in each review area.	– Regulator: 100 hours; – TSO' review time: 300 hours**.**

Reactor Materials	United Kingdom ONR
Design information provided by applicant.	– component design data; – operation experience data; – detailed justification for novel materials.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– review of operation-experience data; – assessment of suitability arguments.
What type of confirmatory analysis (if any) is performed?	See fuel performance above.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	NII Safety assessment principles.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Completion of regulatory training and assessment; – No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Basic knowledge in nuclear power plants and systems. Experts having training and experience in: – fault analysis; – material performance; – Structural Integrity.
Level of effort in each review area.	– regulatory review: 30 working days; – for TSO effort see fuel design above.

<table>
<tr><th>Reactor Materials</th><th>United States
NRC</th></tr>
<tr><td>Design information provided by applicant.</td><td>As part of the SAR, the applicant should describe the following:
– mechanical, chemical, thermal, and irradiation properties, where applicable, of the fuel cladding, fuel, spacer grid and channel boxes, and absorber materials;
– the base and weld materials specifications for all control rod drive, core support, reactor internals, reactor vessel, and applicable attachments and appurtenances;
– controls on welding;
– non-destructive examination procedures;
– fabrication and processing of austenitic stainless steel components;
– physical properties, fabrication, and heat treatment of special purpose materials used in the control rod drive mechanisms, reactor internals, and core supports.</td></tr>
<tr><td>Analysis, reviews and/or research performed by the reviewer and scope of review.</td><td>The Nuclear Regulatory Commission (NRC) staff (1) reviews the information provided in the SAR for compliance with the regulations, (2) issues requests for additional information (RAIs) as necessary, (3) reviews RAI responses, (4) resolves technical issues with applicants or licensees, and (5) produces a safety evaluation report (SER) documenting its findings. The scope and level of detail of the staff’s safety review is based on the guidance of NUREG-0800, Standard Review Plan (SRP). The sections of the SRP that are applicable to this area are as follows:
– SRP 4.2, “Fuel System Design”;
– SRP 4.5.1, “Control Rod Structural Materials”;
– SRP 4.5.2, “Reactor Internal and Core Support Structure Materials’;
– SRP 5.2.3, “Reactor Coolant Pressure Boundary Materials”;
– SRP 5.3.1, “Reactor Vessel Materials”.
The staff also considers emerging technical and construction issues, operating experience, and lessons learned related to this category.</td></tr>
<tr><td>What type of confirmatory analysis (if any) is performed?</td><td>None.</td></tr>
<tr><td>Technical basis:
• Standards;
• Codes;
• Acceptance criteria.
(e.g, can come from Accident analysis, regulatory guidance).</td><td>The applicable NRC Regulatory Requirements are listed below:
1. 10 CFR Part 50, Appendix A, GDC 1, “Quality Standards and Records”;
2. 10 CFR Part 50, Appendix A, GDC 4, “Environmental and Dynamic Effects Design Bases”;
3. 10 CFR Part 50, Appendix A, GDC 10, “Reactor Design”;
4. 10 CFR Part 50, Appendix A, GDC 14, “Reactor Coolant Pressure Boundary”;
5. 10 CFR Part 50, Appendix A, GDC 26, “Reactivity Control System Redundancy and Capability”;
6. 10 CFR Part 50, Appendix A, GDC 30, “Quality of Reactor Coolant Pressure Boundary”;
7. 10 CFR Part 50, Appendix A, GDC 31, “Fracture Prevention of the Reactor Coolant Pressure Boundary”;
8. 10 CFR Part 50, Appendix A, GDC 32, “Inspection of Reactor Coolant Pressure Boundary”;</td></tr>
</table>

	9. 10 CFR Part 50, Appendix A, GDC 35, “Emergency Core Cooling.” 10. 10 CFR Part 50, Appendix B, “Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants”; 11. 10 CFR Part 50, Appendix G, “Fracture Toughness Requirements.” 12. 10 CFR 50.46, “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors”; 13. 10 CFR 50.55a, “Codes and Standards”. The NRC guidance documents that provide an acceptable approach for satisfying the applicable regulatory requirements are listed as follows: 1. RG 1.31, “Control of Ferrite Content in Stainless Steel Weld Metal”; 2. RG 1.34, “Control of Electroslag Weld Properties”; 3. RG 1.43, “Control of Stainless Steel Weld Cladding of Low-Alloy Steel Components”; 4. RG 1.44, “Control of the Use of Sensitized Stainless Steel”; 5. RG 1.50, “Control of Preheat Temperature for Welding of Low-Alloy Steel”; 6. RG 1.65, “Materials and Inspections for Reactor Vessel Closure Studs”; 7. RG 1.71, “Welder Qualification for Areas of Limited Accessibility”; 8. RG 1.84, “Design, Fabrication, and Materials Code Case Acceptability, ASME Section III”. Note: Guidance documents are not a substitute for regulations, and compliance with guidance documents is not required. The applicable Codes and Standards related to this area are: 1. ASME B&PV Code Section II ; 2. ASME B&PV Code Section III ; 3. ASTM A262, “Detecting Susceptibility to Intergranular Attack in Stainless Steels”.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Materials engineer.
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to complete a formal training and qualification programme prior to performing safety reviews independently. Other specialised training, experience, and education that is needed to successfully perform reviews in this technical area include: – experience in metallurgy and materials selection; – experience with ASME code; – knowledge of welding and non-destructive examination.
Level of effort in each review area.	500 hours.

APPENDIX F
FUNCTIONAL DESIGN OF REACTIVITY CONTROL SYSTEM
(E.G. CONTROL RODS, BORON)

Summary table

Country	Is this area reviewed?	Are confirmatory analyses performed?	Expertise of reviewers	Level of effort
Canada	Yes.	Yes.		8 months (1 280 hours).
Finland	Yes.	Yes.	No formal requirements.	30 working days. (240 hours).
France	Yes	Yes.	No formal requirements. TSO staff typically have long experience on the topic.	—[1]
Japan	Yes.	Yes.	Civil, structural and mechanical engineers. Generally, staff who have more than 10-year experience are taken on the task.	—[2]
Korea	Yes.	No.	Materials or mechanical engineer.	480 hours.
Russia	Yes.	No.	Nuclear engineer, mechanical engineer.	30 man days - (240 hours)[2].
Slovakia	Yes.	No.	Technical engineer.	—[3]
Slovenia	Yes.	No.	Nuclear engineer, mechanical engineer.	600 hours[4].
United Kingdom	Yes.	No.	No formal requirements.	30 working days. (240 hours).
United States	Yes.	No.	Mechanical engineer, reactor systems engineer.	1 550 hours[5].

Notes:

1. In France, the amount of effort needed to review a new design depends on the degree of novelty in the design.
2. In Japan and Russia, resources (hours) are not set up for each individual review area.
3. In Slovakia, the standard level of effort for the review of submitted documentation is defined by regulation and dependent upon the activity to be approved.
4. In Slovenia, the level of effort was estimated from the analysis, which was prepared in order to assess the resources needed in case of construction of new nuclear power plants.

If standard control rod drive designs are submitted then the review time would be significantly less.

Functional Design of Reactivity Control Systems	Canada CNSC
Design information provided by applicant.	Section 6.6.1, reactivity control systems, of the CNSC licence application guide rd/gd-369, licence to construction a nuclear power plant and the CNSC document WI-2.15.00-VDR-011NND-006, assess the means of reactor shutdown, specify the information to be provided by the applicant on the design of reactivity control system. Submitted information by the applicant should include the following details: – design basis requirements for the systems namely, the reactivity control mechanisms during normal operation (reactor regulating systems) and of the two independent means of shutting down the reactor (shutdown systems) from any anticipated reactor state during operation; – description of the physical mechanisms used for control of reactivity by the reactor regulating systems and for inserting the negative reactivity by the two shutdown systems; – demonstration that the reactivity control systems, including any essential ancillary equipment, are designed to provide the required functional performance and are properly isolated from other equipment; – details about the rate of negative reactivity insertion and the maximum reactivity depth for each of the systems as well as the maximum possible positive reactivity addition rate while changing between operational states of the core; – description on the fail-safe mode of design for drive mechanisms used in the shutdown systems; – reliability of each of the reactivity control systems; – description on the conservative assumptions including the single failure criterion used in selecting the number of active elements in the shutdown systems; – details about the burn-up and the corresponding reactivity worth change of the active elements of the control systems parked in-core during reactor operation; – trip logic and list of trip parameters used for actuation of the shutdown systems for various design basis events; – trip coverage maps for anticipated design basis events for both shutdown systems; – description about the instrumentation systems for monitoring the core reactivity and their interaction with the reactivity control mechanisms; – description on how the necessary independence, separation and diversity as expected by regdoc-2.5.2, have been achieved; – details of analysis methods and data used in assessing the effectiveness of the shutdown system, including treatment of uncertainties in the analysis data and assessment of uncertainties from the assumptions used in the analyses; – estimated values of reactivity coefficients relevant for the safety and their effect on the shutdown depth for different core states; – details about qualification and commissioning tests and periodic tests to be carried out, in order to ensure that the equipment and system performance comply with the design requirements and meet the claims

	for their performance made in the safety analysis; – interfaces with safety analysis (deterministic and probabilistic) and the safety analysis acceptance criteria; – list of the codes and standards being used for design of shutdown means. Taken together, the details on the safety system instrumentation and control systems and the reactivity control systems should meet the expectations for shutdown means, as stated in REGDOC-2.5.2.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review detail on this topic is given in the CNSC document WI-2.15.00-VDR-011NND-006, assess the means of reactor shutdown. To determine the adequacy of the design of reactivity control systems in achieving the safe operation of the reactor, the following areas will be reviewed: – the applicant's relevant design bases and design requirements in this area are established as required by appropriate CNSC regulatory requirements, standards and expectations; – reactivity coefficients corresponding to changes in power, temperature, density and void for all operating states and accident conditions, supporting experimental evidence and conservative values used in steady-state, stability and accident analyses; – reactivity control requirements and control provisions. these include requirements for all operating states, power changes, both short-term and long-term reactivity changes, bulk and spatial control functions, reactivity devices and associated groupings and configuration patterns; – reactivity worth of each components of the reactor control systems for different rector states and under single failure criteria; – capability of the reactor regulating system in maintaining the steady state reference power distribution under all anticipated operational occurrences; – reactor stability analysis to confirm that there is no power shape oscillations for all anticipated reactor configurations; – performance of each of the reactivity control systems in meeting their design expectations, from the safety analysis simulations; – safety analysis for all bounding design basis events to confirm that the performance of the shutdown systems complies with their design requirements in providing sufficient subcritical margin; – subcritical margin achieved by each of the shutdown systems for design basis events; – analysis methods, nuclear data libraries, initial and boundary conditions used in the safety analysis, and the computer codes used for design and safety analysis; – independence of signals and signal processing for each of the different reactivity control mechanism; – availability of backup trip parameters for the shutdown systems for all design basis events; – trip coverage maps to confirm that there is no window in the trip coverage for all operating states; – proposed commissioning tests to confirm the predicted performance of components during the design and periodic testing to verify that the component performance is with in the design margin.

What type of confirmatory analysis (if any) is performed?	CNSC will perform the following verification analysis using independent computer codes and nuclear data library: – independent simulation of the reference reactor configuration as a code to code comparison for the reference design parameters; – estimate important parameters like reactivity worth of different components in the reactivity control design; – typical xenon transient simulations; – transient simulation of typical bounding design basis events.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	The following documents will be used in the review: – REGDOC-2.5.2 (draft), Design of New Nuclear Power Plants; – RD/GD-369, Licence to Construction a Nuclear Power Plant; – REGDOC-2.4.1 (draft), Safety Analysis: Deterministic Safety Analysis; – REGDOC-2.4.1 (draft), Safety Analysis: Probabilistic Safety Assessment (PSA) for Nuclear Power Plants; – WI-2.15.00-VDR-11NND-006, Assess the Means of Reactor Shutdown, EDOCS# 3588184; – USNRC, 10 CFR Appendix A to Part 50-General Design Criteria for Nuclear Power Plants (Criteria 20 to 29); – R-8, Requirements for Shutdown Systems for CANDU Nuclear Power Plants; – CSA/CAN3-N290.1-80, Requirements for the Shutdown Systems of CANDU Nuclear Power Plants, December 1980, reaffirmed 2013; – CSA N286.7-99, Quality Assurance of Analytical, Scientific, and Design Computer Programs for Nuclear Power Plants; – IAEA SSR 2/1, Safety of Nuclear Power Plants: Design; – IAEA, NS-G-1.12, Design of the Reactor Core for Nuclear Power Plants, IAEA Safety Standards Series; – IAEA, NS-G-1.3, Instrumentation and Control Systems Important to Safety in Nuclear Power Plants, IAEA Safety Standards Series.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– extensive knowledge of nuclear standards, regulatory documents, guidelines particularly those pertaining to reactor physics; – experience in the design and operations of nuclear power plants; – knowledge of reactor physics (lattice physics and core physics), and physics-related experiments; – knowledge of the reactor instrumentation systems and the associated electronics and its interfacing with the reactor control systems; – knowledge of key reactor system performance; – knowledge of safety analysis tools, methods and requirements; – knowledge of nuclear safety principles.
Specialized training, experience and/or education needed for the review of this topic.	– a university degree in science or engineering (masters or higher level degree would be an asset); – extensive experience in the principles of design, operation and safety assessment of nuclear power plants; – experience in using computer codes for reactor physics and safety analysis; – experience in nuclear instrumentation and electronics signal processing for reactor operation.

Level of effort in each review area.	– six month review period for a senior staff having expertise in reactor safety analysis; – two month review period for another senior staff with expertise in nuclear instrumentation and electronics.

Functional Design of Reactivity Control Systems	Finland STUK
Design information provided by applicant.	System descriptions.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of the system description.
What type of confirmatory analysis (if any) is performed?	Engineering judgement.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	YVL Guides 2.2, 1.0.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	Reactor physics.
Level of effort in each review area.	30 working days.

Functional Design of Reactivity Control Systems	France ASN
Design information provided by applicant.	The applicant provides the following information in the Safety Analysis Report: – design of the control rod system : number, location, efficiency; – design of the boron injection system : injection lines, vessels, command; The functional capability of the control rods system is demonstrated by a combination of qualification tests and qualification calculations.
Analysis, reviews and/or research performed by the reviewer and scope of review.	A review of the safety file (Safety Analysis Report + supporting documents) provided by the applicant is performed by the TSO. The following items are reviewed in detail: – design of the reactivity control systems according to redundancy requirements; – qualification of the control rod system against accidental conditions; – sufficiency of the reactivity control systems as regards incidental and accidental operation**.**
What type of confirmatory analysis (if any) is performed?	Confirmatory analyses are performed only in case particular problems are encountered when reviewing the applicant's safety file, for instance doubts on the capabilities of computational codes to model the relevant phenomena and to predict the values used in the safety criteria.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	General design requirements like single failure criterion, equipment classification are found in the basic safety rules series. Acceptance criteria are defined by the applicant. There is at present no regulatory guidance on them. A draft guide on PWR design, prepared by ASN and IRSN, will give some guidance on the safety requirements, but acceptance criteria will remain in the hands of the applicant.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	There is no requirement on skills applicable to the design of the reactivity control systems.
Specialized training, experience and/or education needed for the review of this topic.	The staff performing the technical review at our TSO has a long experience (more than 10 years) of this topic.
Level of effort in each review area.	The amount of effort needed to review a new design of reactivity control systems strongly depends on the degree of novelty of this design considered.

Functional Design of Reactivity Control Systems	Japan NRA
Design information provided by applicant.	In the establishment permit application stage, the following information are provided in the application: – instrumentation (nuclear instrumentation types and other major instrumentation types); – safety protection circuits (reactor shutdown circuit type and other major safety protection circuit types); – control equipment (number and structure of control materials, number and structure of control material drive equipment and reactivity control capacity); – emergency control equipment (number and structure of control materials, number and structure of main devices and reactivity control capacity). In addition, in construction work approval application stage, the following information is provided: – control method and control technique; – control materials; – the names, types, maximum operating pressures and temperatures, main dimensions, materials, drive methods, number, installed locations, drive velocity, and insertion time of the control rod drivers; and the types, output power, and number of motors, as well as the locations where they are installed (permanent types and portable types must be described separately) (PWRs only); – the names, types, maximum operating pressures and temperatures, main dimensions, materials, drive methods, number, installed locations, drive velocity, and insertion time of the control rod drive mechanism; and for electric drive mechanisms, the types, output power, and number of motors, as well as the locations where they are installed (permanent types and portable types must be described separately) (BWRs only); – the standby liquid control system; – the boron thermal recovery system (PWRs only); – the instruments (including the operation ranges of alarm devices if any of them exist); – the types of signals for emergencies reactor shutdown, the types and the number of detectors, as well as the locations where they are attached, the number of signals required for emergencies reactor shutdown, their setting values, and the conditions that inhibit transmitting signals for emergencies reactor shutdown; – the types of signals that activate the engineered safety system, the types and the number of detectors, as well as the locations where they are attached, the number of signals required for activating the engineered safety system, their setting values, and the conditions that inhibit transmitting engineered safety system activation signals; – the control air system; – the reactor coolant recirculation pump power supply (BWRs only); – the basic design policy and the related applied standards for the instrumentation and control system facilities;

	– the quality control methods for the design and the construction.
Analysis, reviews and/or research performed by the reviewer and scope of review.	These activities are to conform to the requirements, standards, criteria, and the like described below.
What type of confirmatory analysis (if any) is performed?	In the establishment permit application stage, adequacy of an applicant's analytic method and the analysis results are verified. Independent evaluation is also performed to comprehend the uncertainties of the analytic method, if needed.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The following regulatory requirements and guides are applicable to this technical area: – the NRA Ordinance Concerning the Installation and Operation of Commercial Power Reactors (S53 #77); – the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (H25 #5); – the Regulatory Guide of the NRA Ordinance on Standards for the Location, Structure and Equipment of Commercial Power Reactors (#1306193); – the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (H25 #6); – the Regulatory Guide of the NRA Ordinance on Technical Standards for Commercial Power Reactor Facilities (#1306194); – the NRA Ordinance on Technical Standards for Nuclear Fuel Material Being Used as a Fuel in Commercial Power Reactors (H25 #7); – guide for Evaluation of Effectiveness of Preventive Measures Against Core Damage and Containment Vessel Failure of Commercial Power Reactors (#13061915); – guide for Establish Permit Application of Commercial Power Reactors (#13061919); – the Standard Review Plan on Technical Capability of Severe Accident Management of Commercial NPPs (#1306197); guide for Procedure of Construction Work Approval (#13061920).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: manager and engineer; – Junior: engineer; – TSO: researcher. Generally the staff who have more than 10-year experience are taken on the task.
Specialized training, experience and/or education needed for the review of this topic.	– basic training for the examiner for nuclear safety; – practical application training for the examiner for nuclear safety.
Level of effort in each review area.	Resources (hours) is not set up for the individual review area. Regarding the standard processing duration, 2 years is set up for establishment permit of an entire plant, and 3 months per one application are set up for construction work approval. Divided application is granted for construction work approval.

<table>
<tr><th>Functional Design of Reactivity Control Systems</th><th>Korea
KINS</th></tr>
<tr><td>Design information provided by applicant.</td><td>The following information is provided in the application:
– the functional performance of the control rod drive system (CRDS);
– essential portions can be isolated from nonessential portions;
– the CRDS cooling system meets the design requirements;
– the functional tests verify the proper rod insertion, withdrawal, and scram operation times, or that the inspections, tests, analysis, and acceptance criteria.</td></tr>
<tr><td>Analysis, reviews and/or research performed by the reviewer and scope of review.</td><td>In a review of a construction permit application for a new nuclear power plant, the regulatory body verifies whether the nuclear power plant will sufficiently meet the related legislation and technical standards by looking into the application documents submitted by applicants, such as the Preliminary Safety Analysis Report, Radiation Environmental Report, Quality Assurance Program for Construction, and so on. In a review for an operating license of a new nuclear power plant, the regulatory body reviews the application document such as the Final Safety Analysis Report, technical specifications for operation, Quality Assurance Program for Operation, and so on.
Scope of review:
1. KINS SRG Section 15: The reactivity and response characteristics of the reactivity control system;
2. KINS SRG Section 4.3: Reactivity control requirements;
3. KINS SRG Section 6.3: Safety Injection System;
4. KINS SRG Section 7.2: Failure modes and effects analyses to ensure that a single failure occurring in the control rod system;
5. KINS SRG Section 3.9.4: The control rods drive mechanisms to perform their mechanical functions (e.g., rod insertion and withdrawal, scram operation and time);
6. KINS SRG Section 3~: The ability of Seismic Category I structures housing the system and supporting systems;
7. KINS SRG Section 7.1: Electrical systems (sensing, control, and power);
8. KINS SRG Section 3.4.1: Internal flooding;
9. KINS SRG Section 9.5.1: Fire protection;
10. KINS SRG Section 3.10~11: Seismic qualification of Category I instrumentation and electrical equipment;
11. KINS SRG Section 9.3.4: Reactor thermal hydraulic systems.</td></tr>
<tr><td>What type of confirmatory analysis (if any) is performed?</td><td>None.</td></tr>
<tr><td>Technical basis:
• Standards;
• Codes;
• Acceptance criteria.
(e.g, can come from</td><td>1. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 15, Environmental Effects Design Bases, etc.;
2. Regulation on Technical Standards for Nuclear Reactor Facilities, Articles 26, Protection System;
3. Regulation on Technical Standards for Nuclear Reactor Facilities,</td></tr>
</table>

Accident analysis, regulatory guidance).	Articles 28, Reactivity Control System; 4. KINS Regulatory Criteria, Chapter 5.5, the control rod drive system (CRDS); 5. KINS Regulatory Standards, Chapter 4.6, the control rod drive system (CRDS).
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	Material or mechanical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– 2 years of practical experience in nuclear safety regulation organisations; – 2 years of practical experience in nuclear safety regulation organization. The following specialised training, experience and/or education are needed for the review, but are not limited to: – experience in BWR and PWR plant systems; – experience with codes and standards (ASME, ASTM, etc.); – experience in transient and accident analyses; – experience in internal and external hazards.
Level of effort in each review area.	480 hours.

Functional Design of Reactivity Control Systems	**Russia** **SEC NRS**
Design information provided by applicant.	Safety analysis report (chapters 4 and 7 which contain description of reactivity control system). Also all materials referenced in the mentioned above SAR chapter have to be submitted to Regulatory Body.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review that the documentation provided included all information required in the Federal Norms and regulations and that the acceptance criteria given in either Federal Norms and regulations or in plant design are met.
What type of confirmatory analysis (if any) is performed?	Engineering judgement.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	– OPB-88/97, General provision on ensuring NPP safety; – NP-006-98, Requirements for Content of Safety Analysis Report for NPP with reactor of VVER-type; – NP-082-07, Nuclear safety rules for reactor installations of nuclear power plants; – NP-061-05, Safety rules for storage and transportation of nuclear fuel at nuclear facilities; – NP-086-12, Rules for designing and operation of reactivity control systems.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	No formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	– Reactor physics; – Mechanical engineering.
Level of effort in each review area.	In Russia men-hours are not set up for each individual review area. Expert judgement of efforts review is appr. 30 man-days.

Functional Design of Reactivity Control Systems	Slovakia UJD
Design information provided by applicant.	– technical description; – functional description; – operational conditions; – combined activity evaluation; – requirements for technical operating and maintenance procedures, including requirements for the manner and scope of pre-operational and operational checks; – reliability analysis.
Analysis, reviews and/or research performed by the reviewer and scope of review.	– evaluate that the applicant meets all requirements of the authority, generally applicable legislation, special regulations and slovak technical standards; – review the results of testing, inspection and surveillance.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	BNS I.6.2/2013 – Requirements for a description of the reactor and its design in the SAR. BNS II.3.3/2011 – Metallurgical products and spare parts for nuclear facilities.-requirements. BNS II.5.6/2009 – Rules for the design, manufacture, construction, maintenance and repairs of the machinery and technological components of nuclear power plant equipment of the VVER 440 type. The requirements from regional and international standards are covered in these documentations.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: technical engineer; – Junior: technical engineer; – TSO: technical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– Experience in evaluation of design; – Knowledge about nuclear facilities.
Level of effort in each review area.	Review of the submitted design information is a part of approval process which is performed as an administrative procedure based on administrative proceeding code. Based on this act we have 60 days for approval of the submitted documentation. In case that we need more time (for example if we need review from TSO or the other support organisation) we can ask our chairperson about extending the period for approval. In some cases, which are strictly defined in the atomic act the time period for reviewing is longer. These cases are as follows: – four months if siting of nuclear installation, except repository is concerned; – six months if nuclear installation commissioning or decommissioning stage is concerned;

	– one year if building authorisation, siting and closure of repository or repeated authorisation for operation of a nuclear installation are concerned.

Functional Design of Reactivity Control Systems	Slovenia SNSA
Design information provided by applicant.	– design basis and design information for control rods drive mechanisms (CRDS) and boron injection system; – testing and verification; – information for combined performance of reactivity control systems.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Scope of review: – evaluate that the applicant has provided complete information as required by applicable guides and industrial standards; – ensure that the ability to perform its safety-related functions is not compromised by adverse environmental conditions; – review the results of testing, inspection and surveillance; – ensure that the systems has been designed so that the CRDS performs its intended safety function, reactor trip, by putting the reactor in a subcritical condition when a safety system setting is approached, with any assumed credible failure of a single active component.
What type of confirmatory analysis (if any) is performed?	
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria.** **(e.g, can come from Accident analysis, regulatory guidance).**	Regulatory guidance: Rules on Radiation and Nuclear Safety Factors. IAEA safety standards.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– Senior: nuclear engineer, mechanical engineer; – Junior: nuclear engineer, mechanical engineer; – TSO: nuclear engineer, mechanical engineer.
Specialized training, experience and/or education needed for the review of this topic.	– knowledge of the codes and standards; – well understanding and experience in the area of reactor physics - reactor kinetics.
Level of effort in each review area.	– Regulator: 200 hours; – TSO' review time: 400 hours.

Functional Design of Reactivity Control Systems	United Kingdom ONR
Design information provided by applicant.	– design basis and design information for CRDM and boron injection system; – component design data; – operation experience data; – operating and safety limits; – functional tests of reactivity control system.
Analysis, reviews and/or research performed by the reviewer and scope of review.	Review of: – functional design and experience; – justification of limits. Assessment of novel components or materials.
What type of confirmatory analysis (if any) is performed?	None.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	NII Safety assessment principles.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– completion of regulatory training and assessment; – no formal requirements.
Specialized training, experience and/or education needed for the review of this topic.	– basic knowledge in nuclear power plants and systems; – experts having training and experience in: - fault analysis; - material performance.
Level of effort in each review area.	30 working days.

Functional Design of Reactivity Control Systems	United States NRC
Design information provided by applicant.	As part of the SAR, the applicant should describe or provide the following: – information for the control rod drive system (CRDS) including drawings, summary of the method of operation, process flow diagrams, piping and instrumentation diagrams, and component descriptions and characteristics; – specific design codes, load combinations, allowable stress and deformation limits, and other criteria used in designing the control rod drive system; – the functions of all related ancillary equipment and hydraulic systems; – the failure mode and effects analyses of the CRDS; – the CRDS functional testing and operability assurance program; – the Chemical and Volume Control System (PWRs Only) including safety, inspection, testing, and instrumentation requirements if the CVCS system performs a safety related function(s) (PWRs only); – seismic qualification especially prior to the isolation valves (PWRs only); – system capability to dilute the RCS (PWRs only); – if the CVCS is used for RCP seal injection (PWRs only); – the Standby Liquid Control System (BWRs Only) including safety, inspection, testing, and instrumentation requirements.
Analysis, reviews and/or research performed by the reviewer and scope of review.	The nuclear regulatory commission (NRC) staff (1) reviews the information provided in the SAR for compliance with the regulations, (2) issues requests for additional information (RAIs) as necessary, (3) reviews RAI responses, (4) resolves technical issues with applicants or licensees, and (5) produces a safety evaluation report (SER) documenting its findings. The scope and level of detail of the staff's safety review is based on the guidance of NUREG-0800, standard review plan (SRP). The sections of the SRP that are applicable to this area are as follows: – SRP 3.9.4, control rod drive systems; – SRP 4.6, functional design of control rod drive system; – SRP 9.3.4, chemical and volume control system (PWR)(including boron recovery system); – SRP 9.3.5, standby liquid control system (BWR). The staff also considers emerging technical and construction issues, operating experience, and lessons learned related to this category.
What type of confirmatory analysis (if any) is performed?	Typically, no confirmatory analyses are performed in this area.
Technical basis: • **Standards;** • **Codes;** • **Acceptance criteria. (e.g, can come from Accident analysis, regulatory guidance).**	The applicable NRC Regulatory Requirements are listed below: 1. 10 CFR Part 50, Appendix A, GDC 1, Quality Standards and Records; 2. 10 CFR Part 50, Appendix A, GDC 2, Design Bases for Protection Against Natural Phenomena; 3. 10 CFR Part 50, Appendix A, GDC 4, Environmental and Dynamic Effects Design Bases; 4. 10 CFR Part 50, Appendix A, GDC 5, Sharing of Structures, Systems, and Components;

	5. 10 CFR Part 50, Appendix A, GDC 14, Reactor Coolant Pressure Boundary; 6. 10 CFR Part 50, Appendix A, GDC 23, Protection System Failure Modes; 7. 10 CFR Part 50, Appendix A, GDC 25, Protection System Requirements for Reactivity Control Malfunctions; 8. 10 CFR Part 50, Appendix A, GDC 26, Reactivity Control System Redundancy and Capability; 9. 10 CFR Part 50, Appendix A, GDC 27, Combined Reactivity Control Systems Capability; 10. 10 CFR Part 50, Appendix A, GDC 28, Reactivity Limits; 11. 10 CFR Part 50, Appendix A, GDC 29, Protection Against Anticipated Operational Occurrences; 12. 10 CFR Part 50, Appendix A, GDC 33, Reactor Coolant Makeup; 13. 10 CFR Part 50, Appendix A, GDC 35, Emergency Core Cooling; 14. 10 CFR Part 50, Appendix A, GDC 60, Control of Release of Radioactive Material to the Environment; 15. 10 CFR Part 50, Appendix A, GDC 61, Fuel Storage and Handling and Radioactivity Control; 16. 10 CFR 50.34(f), Additional TMI-Related Requirements; 17. 10 CFR 50.62, Requirements for Reduction of Risk from Anticipated Transients without Scram (ATWS) Event for Light-Water-Cooled Nuclear Power Plants; 18. 10 CFR 50.63, Loss of All Alternating Current Power; 19. 10 CFR 52.80(a), Requirement for COL application to contain the proposed inspection, tests, analyses, and acceptance criteria (ITAAC). The NRC guidance documents that provide an acceptable approach for satisfying the applicable regulatory requirements are listed as follows: 1. RG 1.26, Quality Group Classifications and Standards for Water, Steam, and Radioactive-Waste-Containing Components of Nuclear Power Plants; 2. RG 1.29, Seismic Design Classification; 3. RG 1.155, Station Blackout. Note: Guidance documents are not a substitute for regulations, and compliance with guidance documents is not required.
Skill sets required by (education): • **senior (regulator);** • **junior (regulator);** • **TSO.**	– mechanical engineer; – reactor systems engineer.
Specialized training, experience and/or education needed for the review of this topic.	All technical reviewers are required to complete a formal training and qualification programme prior to performing safety reviews independently. Other specialized training, experience, and education that is needed to successfully perform reviews in this technical area include: – experience in BWR and PWR plant systems;

	– experience with Codes and Standards (ASME, ASTM, etc); – experience in transient and accident analyses; – experience in internal and external hazards; – experience with CFD for SRP 9.3.5 if necessary.
Level of effort in each review area.	1 550 hours – estimate includes staff review of new designs with confirmatory analyses performed. If standard control rod drive designs are submitted then the review time would be significantly less. Explanation: – SRP 3.9.4 approximately 500 hours; – SRP 4.6, for standard control drive designs, 150 hours; for new designs which include test reports approximately 400 hours; – SRP 9.3.4 approximately 100 hour assuming a non-safety related system; – SRP 9.3.5 approximately 100 without confirmatory analyses. Up to 500 hours if CFD calculations are performed.