ACR-1000® PRE-PROJECT REGULATORY REVIEW PROGRESS

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Abstract

The ACR-1000® design developed by Atomic Energy of Canada Limited (AECL) is a 1200 MWe-class light-water-cooled, heavy-water-moderated pressure-tube reactor, which has evolved from the well-established CANDU® line of reactors. The ACR-1000 design retains the basic, proven, CANDU design features while incorporating innovations and state-of-the-art technologies to ensure fully competitive safety, operation, performance and economics. Improvements include greater operating and safety margins plus adherence and compliance with the latest safety objectives of designing with due consideration to external events and risk assessment.

AECL initiated a pre-project regulatory review of the ACR-1000 reactor design by the Canadian Nuclear Safety Commission (CNSC) to confirm compliance with regulatory requirements and also incorporate regulatory feedback in the design process to minimize regulatory risks in obtaining construction and operating licences. Regulatory pre-project reviews have also been conducted earlier in the UK and US to ensure that the ACR® design is compliant with international regulatory requirements.

1. Introduction

AECL has developed the Advanced CANDU Reactor[1]1000 (ACR-1000[2]) as an evolutionary advancement of the current CANDU[3] 6 reactor. The ACR-1000 aims at producing electrical power for a capital cost and a unit-energy cost significantly less than that of the current generation of operating nuclear plants, while achieving shorter construction schedule, high plant capacity factor, improved operations and maintenance, increased operating life, and enhanced safety features. The reference ACR-1000 plant design is based on an integrated two-unit plant, using low enriched uranium fuel and light-water coolant, with each unit having a nominal gross output of 1200 MWe.

The ACR-1000 design has evolved from AECL's in-depth knowledge of CANDU systems, components, and materials, as well as the experience and feedback received from owners and operators of CANDU plants. The ACR[4] design retains the proven strengths and features of CANDU reactors, while incorporating innovations and state-of-the-art technology. It also features major improvements in economics, inherent safety characteristics, and performance, while retaining the proven benefits of the CANDU family of nuclear power plants.

[1] Advanced CANDU Reactor is a registered trade-mark of Atomic Energy of Canada Limited (AECL).
[2] ACR-1000 is a registered trade-mark of Atomic Energy of Canada Limited (AECL).
[3] CANDU is a registered trade-mark of Atomic Energy of Canada Limited (AECL).
[4] ACR is a registered trade-mark of Atomic Energy of Canada Limited (AECL).

The CANDU system is ideally suited to this evolutionary approach since the modular fuel channel reactor design can be modified, through a series of incremental changes in the reactor core design, to increase the power output and improve the overall safety, economics, and performance.

Figure 1: ACR-1000 Two-Unit Plant Pictorial Image

The safety enhancements made in the ACR-1000 reactor encompass improved safety margins, performance and reliability of safety related systems. In particular, the use of the CANFLEX-ACR[5] fuel bundle, with lower linear power rating and higher critical heat flux, provides increased operating and safety margins. Safety features draw from those of the existing CANDU plants (e.g., the two independent and diverse shutdown systems), and other features are added to strengthen the safety of the plant (e.g., a passive gravity-driven water supply from a reserve water system to provide various back-up heat sinks). These and other safety improvements [1] serve to reduce the licensing risk of the design in the context of an updated regulatory framework in Canada. Figure 1 shows an ACR-1000 two-unit plant pictorial view. Figure 2 shows a view and cross section of the ACR-1000 containment with the internal systems and equipment.

[5] CANFLEX-ACR is a registered trade-mark of AECL and the Korea Atomic Energy Research Institute (KAERI).

This paper provides an overview of the pre-project review by the Canadian Regulator (CNSC), and the UK Regulators, the Nuclear Installation Inspectorate (NII) and the Environment Agency. Also, the paper demonstrates a good design balance by taking advantage of proven traditional CANDU features with a number of innovations that enhance the safety, operability and maintainability of the reactor. The ACR-1000 design is based on decades of design development and R&D of different CANDU reactor designs in Canada and internationally. More importantly, the ACR-1000 reactor is designed to comply with all applicable Canadian regulatory requirements and the International Atomic Energy Agency (IAEA) safety requirements for design of NPPs [2].

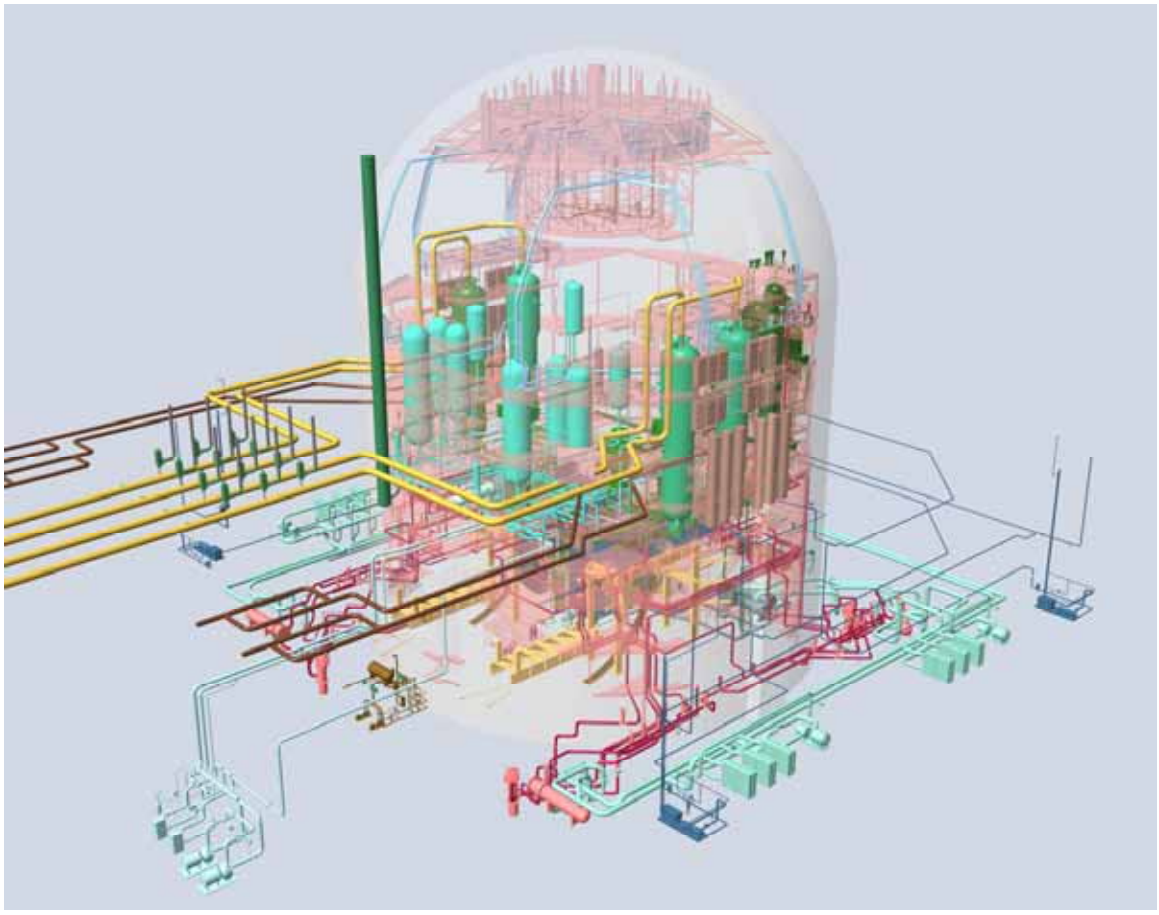

Figure 2: ACR-1000 Containment with the Equipment and Piping Layout

2. ACR-1000 compliance with Canadian and international safety requirements

The ACR-1000 design has been developed to ensure its compliance with the Canadian regulations and regulatory requirements (including RD-337 [3], RD-310 [4], and other relevant regulatory documents), and with the nuclear series of standards that are prepared and issued by the Canadian Standards Association, with the National Building Code of Canada as applicable to NPPs, and with the National Fire Code of Canada. The design also follows relevant sections of the ASME Codes and Standards for boiler and pressure

vessel nuclear components, with the sole exception of the pressure tubes which are subject to special inspection and licensing requirements. Note that failure of a CANDU pressure tube, although unlikely, is a manageable event with limited safety consequences in a CANDU reactor.

As mentioned above, AECL's focus has been to design the ACR-1000 to primarily meet the Canadian regulatory requirements, and thus place the emphasis on ACR-1000 design licensability and construction in Canada. However, as part of international marketing of the ACR-1000 design, reviews that were carried out by the US Nuclear Regulatory Commission (NRC) and the NII in the United Kingdom, demonstrate that the ACR-1000 design is robust and that it will also meet regulatory requirements in foreign jurisdictions. Both the US NRC and the UK NII review experience indicate that the ACR design is consistent with the respective regulators' expectations of a robust design that provides adequate protection against potential accidents in a manner that meets modern international good practice.

AECL has conducted a thorough review of CNSC's Generic Action Items (GAIs) and Operating Experience (OPEX) issues for their applicability to and resolution by the ACR-1000 design. The improvements adopted for the current ACR-1000 reference design addressed all the issues identified in the past by the CNSC, and other international regulators.

In addition, AECL has completed a review of the requirements of the IAEA document NS-R-1, "Safety of Nuclear Power Plants: Design Safety Requirements", to confirm compliance of the ACR-1000 design with the IAEA requirements. This provides confidence that the ACR-1000 design will be licensable and can be deployed in other international jurisdictions.

3. Pre-project design review of ACR-1000 by the CNSC

The AECL primary objective for the ACR-1000 reactor is to support successful deployment of the NPP in Ontario. To achieve this, a pre-project review is being undertaken by the CNSC. AECL's goal of the pre-project review is aimed at obtaining a positive statement for the ACR-1000 design (i.e., no potential fundamental barriers to licensibility), thereby reducing the licensing risk at the time of project commitment in Ontario. The objectives of the pre-project review are to:

- Assess whether the ACR-1000 design is, at an overall level, compliant with the CNSC regulatory requirements;
- Assess whether the design meets the CNSC expectations for new nuclear power plants in Canada; and
- Identify whether there are any potential fundamental barriers to licensing the ACR-1000 design in Canada.

To achieve the above-stated objectives, the CNSC staff assesses the safety and security aspects of the design to identify any potential licensing and technical issues that could constitute a potential fundamental barrier. This review provides an opportunity for the CNSC staff to assess the design prior to any licensing activities, and to identify potential

issues for resolution relating to the ACR-1000 reactor compliance with regulatory requirements and expectations. Such a review will help increase regulatory certainty and ultimately contribute to public safety. The pre-project review consists of two phases starting from April 1, 2008 and ending on August 30, 2009.

Phase 1: This phase is an overall assessment of the information submitted in support of the ACR-1000 design against CNSC regulatory requirements and regulatory documents. Its purpose is to determine whether the design intent is compliant with the CNSC requirements and meets CNSC's expectations for the design of new nuclear power plants in Canada. The Phase 1 review of the ACR-1000 design is now complete and the findings are provided below.

Phase 2: Subsequent to Phase 1, this phase will go into further detail with a focus on identifying whether there are any potential fundamental barriers to licensing the design in Canada. It should be noted that the findings from the Phase 1 review do not in any way prejudge the conclusions of the Phase 2 review.

The pre-project review has been organized in the following focus topical areas:

1. Defence in Depth, Classification of Structures, Systems and Components (SSCs) and Regulatory Dose Limits;
2. Reactor Physics Aspects of Nuclear Design;
3. Fuel Mechanical and Thermalhydraulics Design;
4. Reactor Control System;
5. Shutdown Means;
6. Emergency and Long Term Core Cooling, Emergency Feedwater System;
7. Containment and Reactor Auxiliary Building;
8. Safety Analysis;
9. Heat Transport System Pressure Boundary;
10. Fire Protection;
11. Radiation Protection;
12. Out-of-Core Criticality;
13. Robustness, Security and Safeguards;
14. Severe Accident Prevention and Mitigation;
15. Quality Assurance in Design and Safety Analysis; and
16. Human Factors.

In Phase 1, the CNSC staff reviewed documentation that included the ACR-1000 Technical Description, ACR-1000 Generic Safety Case Report, and the Safety Design Guides used for the design. In performing the Phase 1 review, the CNSC staff aimed to identify items requiring further information, issues requiring further follow-up, issues of clear non-conformance with regulatory expectations, or issues that may lead to potentially significant design changes.

The review included the safety principles, specific design expectations of systems,

structures and components important to safety, robustness of the design against malevolent acts, and a safety analysis that demonstrates the adequacy of the design. The review of these areas sought to ensure that the fundamental safety functions such as reactor control, reactor shutdown, cooling of the reactor core and containment of radioactive material are designed to meet the expectations of the CNSC for new nuclear power plants in Canada.

The Phase 1 review also included an assessment of other aspects, including human factors engineering, radiation protection, protection from fire, protection against out-of-core criticality, quality assurance, safeguards, and security. In addition, initial consideration was given to the extent to which generic or outstanding safety issues (for example, GAIs) have been resolved, and the bases of knowledge for new or innovative design features in the ACR-1000 design.

Phase 1 of the pre-project review was completed in December 2008. The CNSC staff concluded that:

- *"At an overall level the design intent is compliant with the CNSC regulatory requirements and meets the expectations for new nuclear power plants in Canada. This conclusion will be further confirmed during the Phase 2 review when open specific technical items identified for each review area requiring further information are fully addressed. CNSC staff anticipates that these items can be brought to closure during Phase 2"; and*
- *"CNSC staff did not find any issues that would lead to significant design changes."*

The Phase 2 review is currently ongoing, with AECL submitting responses to CNSC findings resulted from the Phase 1 review, and the CNSC staff is performing further assessment in all focus topics areas. The review is scheduled to be completed by the end of August 2009 with issuance of the final pre-project review report.

4. Pre-project design review of ACR-1000 in the UK

The United Kingdom Government published an Energy White Paper in May 2007, and launched a public consultation on the future of nuclear power in the UK. During this time, interested parties were invited to submit proposals to the UK regulators for reactor designs to be subject to the Generic Design Assessment (GDA). AECL proposed the ACR-1000 design to be assessed and in July 2007 was one of the four vendors to start the GDA process with the UK regulators.

The Nuclear Directorate (ND) of the Health and Safety Executive (HSE) is responsible for regulating the nuclear industry in the UK. In particular, the ND is responsible for regulating nuclear safety, security and safeguards. They also maintain a close working relationship with the Environment Agency, which in turn is responsible for regulating the discharges to the environment and disposal of radioactive waste on or from nuclear licensed sites.

The HSE, Environment Agency and the Scottish Environment Protection Agency (SEPA) have devised a GDA process that involves assessment of reactor designs in advance of

licence applications for building a nuclear power station at a specific site. The following regulatory bodies are taking part in this process:

- HSE's NII grants site licences to allow operation of nuclear power stations. They are assessing all safety aspects from the design to the decommissioning of the installation, including the management of radioactive material on site;
- The Office for Civil Nuclear Security (OCNS) is also part of the HSE and regulates the security aspects at all civil nuclear sites. Its responsiblities include assessment of physical security of nuclear material, information security (including IT), nuclear materials in transit and clearances. A security plan is to be approved by the OCNS prior to nuclear material arriving on site; and
- As mentioned previously, the Environment Agency (England and Wales) oversees disposal of radioactive waste, including discharges and emissions of each nuclear site. It approves and enforces environmental permits and licences such as abstracting water from rivers, treatment and disposal of non-radioactive wastes, permits for operation of certain aspects of the 'conventional' plant such as boilers and incinerators.

As these regulatory bodies have independent responsibilities, to facilitate the GDA, a "Joint Programme Office (JPO)" was formed to ensure processes and regulatory positions are aligned, where appropriate. The JPO carries out joint planning and administration activities by all of the above three agencies to support the GDA process.

In August 2007, AECL submitted documentation for Step 2 review in the UK. The submission consisted of a mapping or head document showing how the ACR-1000 design meets each of the requirements, along with a number of supporting documentation. The JPO also conducted a regulatory inspection at AECL's offices in Sheridan Park, Mississauga, Canada in October 2007, focusing on AECL's quality management arrangements. Their inspection confirmed that AECL's quality management arrangements provide a sound basis for the current stage of the UK GDA process. It was also stated that the management system in place is appropriate to control the content and accuracy of the information provided for the GDA.

The UK regulators have completed their assessments on the Step 2 in March 2008, and published the ACR-1000 assessment report on the HSE website. The HSE concluded in the final Phase 2 report that they did not find any serious safety or security shortfalls at this stage to prevent the eventual construction of the ACR-1000 on licensed sites in the UK. The assessment identified a number of topics to be addressed in more detail during the Step 3 and 4 assessments. It was also stated that the HSE found no reasons why the ACR-1000 should not proceed to the next steps of the GDA. Furthermore, the Environment Agency conclusions are that the annual radiation impact of the design would be below the acceptable UK limit, there were no unacceptable matters in the initial submission, and no significant design modifications will likely be needed before a permit is issued.

Because of marketing reasons in the UK and new builds priorities in Ontario in Canada, AECL suspended its application from the regulatory review in the UK in April 2008, thus putting on hold Phases 3 and 4 of the GDA of ACR-1000.

5. Previous pre-project design reviews of ACR-700 and ACR-1000

AECL has conducted pre-project reviews of ACR-700[6] with CNSC and US NRC during the period 2002 to 2005. The ACR-700 reactor is a predecessor of the ACR-1000 reactor, and it was designed primarily for the US market.

Between mid-2002 and 2005 AECL Technologies (AECLT, a wholly owned US subsidiary of Atomic Energy of Canada Limited) was the proponent of pre-application review of the ACR-700 design with the US NRC in the United States.

Under the pre-application review, 13 focus topics were established for the NRC review and about 25 technical meetings were held. Approximately 35 formal documents and more than 300 additional supporting documents were submitted during this time for the NRC review.

The results of the NRC's staff pre-application review have been documented in a Pre-Application Safety Assessment Report (PASAR) that has been issued in October 2004. The review conclusions by the US NRC staff as documented in the PASAR report are as follows:

> *"…Notwithstanding, based on the information provided, the staff believes at this time that AECL will ultimately be able to satisfactorily address these policy, regulatory, and technical issues during the design certification review."*

The CNSC review of the ACR-700 reactor was conducted from 2002 to 2006 in several phases in parallel to the US NRC review. As AECL design effort was transferred from the ACR-700 reactor to the ACR-1000 reactor, the scope of the CNSC pre-project was accordingly changed. During this review performed up to the end of 2006, CNSC staff was engaged in a number of technical meetings, reviewed a large number of ACR-700 and ACR-1000 documents, and submitted to AECL a number of review packages with comments and suggestions.

The regulatory feedback from the US NRC and CNSC early in the design phase of the ACR-700 and ACR-1000 reactors helped AECL to better understand regulatory expectations in Canada and US, and to make further advancements and improvements in the ACR design with the objective to meet the US and Canadian regulatory requirements.

6. Conclusions

The Canadian Nuclear Safety Commission is currently reviewing the ACR-1000 design to identify whether or not there are any potential fundamental barriers to licensibility in Canada. Phase 1 of the pre-project review was focused on compliance with the new Canadian regulatory requirements and expectations for new builds in Canada. The Phase 1 review was completed in December 2008, and compliance of the ACR-1000 design at an overall level was confirmed. The Phase 2 review is in progress, and it is focused on

[6] ACR-700 is a registered trade-mark of Atomic Energy of Canada Limited (AECL).

the review of the ACR-1000 design in a more detailed way. In AECL's view, a positive outcome of the pre-project review should provide sufficient assurance to potential customers that there will be no fundamental barriers to licensing the ACR-1000 reactor design in Canada.

In addition to the pre-project review by CNSC in Canada, the ACR-1000 design was subject to the Phase 2 Generic Design Assessment in the UK, which concluded in 2008 with the statement by the UK regulators that they did not find any serious safety or security shortfalls that could prevent the construction of the ACR-1000 reactor on licensed sites in the UK.

Also, during the early stages of the ACR-700 design, the NRC conducted a pre-project review, which was completed in October 2004 with a statement by the US NRC that the ACR design will ultimately be able to satisfy the US policy, regulatory, and technical requirements during design certification review.

The above regulatory reviews provide assurance to potential customers and stakeholders in Canada and internationally that the ACR-1000 design meets the Canadian and international regulatory requirements, and that the licensing risks associated with regulatory reviews in support of granting of construction and operating licences are minimized and manageable.

7. References

[1] N. Popov, R. Ion, S. Yu, R. Duffey, "ACR-1000®: Advanced CANDU Based on Proven Safety of CANDU Reactors," TOPSAFE Conference, paper A1-094, September 30 – October 3, 2008, Dubrovnik, Croatia.

[2] IAEA, "Safety of Nuclear Power Plants – Requirements", NS-R-1, 2000.

[3] CNSC, "Design of New Nuclear Power Plants", Regulatory Document RD-337, November 2008.

[4] CNSC, "Safety Analysis for Nuclear Power Plants", Regulatory Document RD-310, February 2008.