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Nuclear Criticality Safety Management for Enriched Fuel Handling Operations at Bruce Power

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Abstract

With the possibility in the future of operating with enriched fuel, Bruce Power several years ago established a program for managing risk of nuclear criticality in its fuel handling operations. Although this risk would be inherently low, rigorous standards were adopted, based primarily on the relevant clauses in the American Nuclear Society standards for nuclear criticality safety. Experience gained in connection with a demonstration irradiation of an enriched fuel design and with preparations for possible large scale use of enriched fuel has been favourable, but has led to some improvements to the program. Bruce Power believes that its nuclear criticality safety program will in all respects be appropriate for any enriched fuel handling operations it will undertake and consistent with the typical Canadian approach to assure safety in reactor operations.

1. Introduction

1.1 Why Bruce Power has a criticality safety program

The accidental occurrence of nuclear criticality outside a reactor is not a realistic possibility with natural uranium fuel. In the almost 60 years since the first Canadian power reactor was started at Rolphton, Ontario, all power reactors built in Canada have used natural uranium. The possibility of an unintended occurrence of criticality has therefore been a consideration for Canadian power reactor operators only in the context of the highly robust protection provided by the reactor control, cooling and containment systems.

For the last several years, Bruce Power has been preparing for the possibility of operating with enriched fuel. This was one among several options for improving safety margin in its current reactors. It is also likely that any new power reactors built by Bruce Power will use enriched fuel. Conservative analysis undertaken by Bruce Power early in its preparations indicated that, although the occurrence of criticality outside of a reactor would still be very unlikely, this risk cannot be entirely dismissed for probable enriched fuel designs. Bruce Power therefore adopted a formal *criticality safety program* for the purpose of managing this risk, i.e. to ensure that highly robust protection against the accidental occurrence of criticality is provided also during the handling and storage of enriched fuel outside its reactors.

1.2 Purpose and outline of this paper

This paper describes and discusses Bruce Power's criticality safety program. The objective is to provide information that may be pertinent and helpful where other enriched fuel operations are being contemplated within the Canadian nuclear industry. Experience to date and the resulting changes to the program are described. The following topics are addressed:

- Program history.
- Program basis and outline.
- Program management.
- Criticality safety technical capability.
- Criticality safety evaluation process.
- Verifications and approvals.
- Training.
- Canadian industry cooperation.

1.3 Terminology

Key terms used in this paper are as follows:

- Assurance that the risk of criticality outside reactors is sufficiently low is referred to as *nuclear criticality safety*, or more commonly, *criticality safety*. The emphasis is on the prevention of criticality, i.e. by ensuring that accidents that cause criticality are not credible (in a technical sense discussed later), although criticality safety also includes assurance that any residual risk due to criticality is acceptable.
- The process of establishing and maintaining these assurances is referred to as *nuclear criticality safety management*.
- The formal requirements governing this process are referred to as the *nuclear criticality safety management program*, or simply the *criticality safety program*.
- Requirements on fuel handling operations that are adopted to ensure that criticality accidents are not credible are referred to as *criticality safety controls*.
- The amount by which an arrangement of fissile material is subcritical is referred to as the *subcritical margin*. Subcritical margin is represented in terms of k_{eff}, i.e. the *effective neutron multiplication factor.*
- Systematic review of a fuel handling operation to identify the accidents and other contingencies that potentially reduce the subcritical margin is referred to as *hazards analysis*.
- A hazards analysis, together with its supporting calculations of k_{eff}, is referred to as the *criticality safety evaluation* of the fuel handling operation.

All occurrences of the term *criticality* henceforth in this paper refer to the unintended occurrence of nuclear criticality in the handling or storage of reactor fuel outside of reactors, and hence without the benefit of the engineered systems that normally provide control, cooling and containment where active fuel may be present in our nuclear operations.

2. Program History

Bruce Power's criticality safety program was established originally as part of the preparations to perform a demonstration irradiation of an enriched fuel design in one of its reactors. The basis for the program was defined in 2004 and formal governing documents were issued in 2005.

Although the demonstration irradiation was to involve only a small number of enriched fuel bundles, i.e. presenting no real risk of criticality, it was nevertheless used as an opportunity to exercise all aspects of the program. This culminated in the application of several criticality safety controls during the handling and storage of the enriched fuel bundles used in the demonstration irradiation.

As preparations for the demonstration irradiation wound down in mid-2006, preparations began for possible large scale use of enriched fuel.

For the small number of enriched fuel bundles required for the demonstration irradiation, criticality safety controls were found to be unnecessary for handling the bundles after their irradiation. (This likely would not be true for the thousands of irradiated fuel assemblies that would eventually result from large scale use of enriched fuel.) The criticality safety controls that were adopted for the purpose of the demonstration irradiation were therefore suspended after the final set of enriched fuel bundles was fuelled into the target reactor in late 2007. The program has since focused almost entirely on preparations for large scale use of enriched fuel.

The experience to date has resulted in several improvements to the criticality safety program. Emerging regulatory expectations have also affected the program.

3. Program Basis and Outline

Risk of criticality would be inherently low in the handling and storage of enriched fuel for large scale use by Bruce Power, due to relatively low enrichment and physically robust design of the fuel assemblies and the fuel storage systems. Accidents and other contingencies that could sufficiently rearrange the fissile materials, in the presence of other materials that potentially have neutron moderating and/or reflecting properties, i.e. such that a critical configuration is possible, would be very improbable. Bruce Power nevertheless adopted rigorous standards as the basis for its criticality safety program. This is in keeping with the basic philosophy and principles that characterize the overall Canadian approach to assure nuclear safety.

Although the Canadian Nuclear Safety Commission subsequently introduced a set of requirements, criticality safety was not addressed comprehensively in formal Canadian standards and regulations when Bruce Power initially established its program. A review of various related international standards was therefore done. (The original research was done by Mr. Walter Thompson of the then Nuclear Safety Solutions Ltd., now AMEC NSS – www.amecnss.com.) American, British and IAEA guidance were considered. Discussions were also held with Cameco Fuel Manufacturing (then called Zircatec Precision Industries), who is Bruce Power's fuel supplier, and with the CNSC. It was concluded that the relevant clauses from the ANSI/ANS Series 8 standards[1] on criticality safety provided an appropriate basis for Bruce Power's program. Based on the original research and several additional reviews informed by subsequent training and experience, relevant requirements in the following ANSI documents have been identified.

ANSI Number	Title
8.1	Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors
8.3	Criticality Accident Alarm System
8.7	Guide for Nuclear Criticality Safety in the Storage of Fissile Materials
8.17	Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors
8. 19	Administrative Practices for Nuclear Criticality Safety
8.20	Nuclear Criticality Safety Training
8.23	Nuclear Criticality Accident Emergency Planning and Response
8.24	Validation of Neutron Transport Methods for Nuclear Criticality Safety Calculations
8.26	Criticality Safety Engineer Training and Qualification Program

A noteworthy difference between Bruce Power's program and the ANSI guidance is in connection with ANSI's *double contingency principle*. ANSI expresses this principle as follows (ANSI-8.1, Paragraph 4.2.2):

> *Process designs should incorporate sufficient factors of safety to require at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.*

In place of the double contingency principle, Bruce Power adopted the corresponding principle of the IAEA (Reference 10, Paragraphs 4.2 and 5.2), which may be summarized as follows:

> *The design of the fuel handling systems should be such as to ensure subcriticality even if two independent abnormal events occur simultaneously.*

Both principles may be seen as implementations of the following more general ANSI requirement (ANSI-8.1, Paragraph 4.1.2):

> *Before a new operation with fissionable material is begun, or before an existing operation is changed, it shall be determined that the entire process will be subcritical under both normal and credible abnormal conditions*

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[1] That is, American Nuclear Society (ANS) standards approved by the American National Standards Institute (ANSI).

Bruce Power interprets the IAEA principle essentially as requiring wherever practicable redundancy in its protection against criticality in the enriched fuel handling operations, and believes that this sets the appropriate level of quality of the defense in depth. The necessity to provide robust defense in depth is, of course, one of the most fundamental principles in Canada's approach to nuclear safety generally, as it is in most of the world

To avoid confusion with respect to ANSI's definition of the double contingency principle, the term *principle of redundant protection* is used in this paper to refer to Bruce Power's use of the corresponding IAEA principle.

Bruce Power's program today reflects several additional practices and criteria that have been observed in other jurisdictions and/or are required by the CNSC. Key among these are the following.

- An arbitrary 50 mk safety margin is applied to accommodate unknown errors in calculations of subcritical margin. ANSI requires the application of an arbitrary safety margin (ANSI-8.17, Paragraph 5.1), but does not specify its value. A margin of 5% of the calculated k_{eff} is recommended by the IAEA (Reference 11, Paragraph 216) and is commonly used in other jurisdictions, although smaller values have also been used, with justification. The CNSC requires the use of a 5% margin. The use of 50 mk addresses their requirement conservatively.
- Where favorable biases in calculations of subcritical margin have been demonstrated (i.e. where the calculations over-predict k_{eff}), they are not credited. This additional conservatism has been practiced in the United Kingdom. It is also required by the CNSC.
- The hazards analyses apply a limit on the frequency of accident sequences for which consequential criticality cannot be ruled out. This represents a further elaboration of the ANSI requirement to prevent criticality for all credible conditions (ANSI-8.1, Paragraph 4.1.2), i.e. in addition to the principle of redundant protection. It is an increasingly common practice in other jurisdictions to employ an event frequency limit (e.g. Reference 12). The CNSC specifies a limit of once per one million years. The frequency limit is the CNSC's "bottom line", so to speak, on acceptable likelihood of criticality. In other words, an accident may be considered to be non-credible if it is shown to be less frequent than 10^{-6}/year. Bruce Power applies the principle of redundant protection as an additional risk goal.
- The hazards analyses also consider whether there are non-credible accident sequences that should be assessed further as a basis for emergency planning, i.e. if this proves to be necessary to ensure that the total risk of criticality is acceptable. This is a regulatory expectation both in the United States (Reference 12) and (implicitly) in the United Kingdom (References 13 and 14). The CNSC also requires this and in addition requires that "consequences [of criticality accidents do] not violate criteria established by international standards … and national guidance as a trigger for public evacuation". Based on the referenced national guidance (Reference 15), Bruce Power has interpreted this as a whole body dose limit of 50 mSv for any exposed member of the public outside of its nuclear power plant exclusion zone.

- Formal probabilistic methods are used in the hazards analyses. This becomes necessary with the adoption of a limit on the frequency of criticality accidents.

Bruce Power's criticality safety program manual implements the applicable ANSI standards and the other requirements within an administrative framework that is appropriate to Bruce Power's overall management system, as follows.

1) Program ownership is established appropriately within Bruce Power's organization.
2) Several new administrative and technical roles that are specific to criticality safety are defined and they are assigned appropriately within Bruce Power's organization.
3) The criticality safety management process is proceduralized.
4) Appropriate interfaces with other Bruce Power business processes are established and some new requirements in several of those processes are defined.

The criticality safety management procedure addresses the following.

a) Initiation of the process when it is necessary to consider the possibility that a proposed change or *station condition*[2] could affect criticality safety.
b) Assurance that all such impacts are identified, properly assessed, and appropriately dispositioned.
c) Assurance that personnel have the knowledge and skills necessary to fulfill the related programmatic and operational requirements.
d) Provision of the approvals and supporting verifications that are necessary to allow the affected operations to commence or to continue.
e) Monitoring of compliance with the requirements.
f) Continuous improvement of the program as experience dictates and to keep it current with the applicable standards and other relevant requirements.

Apart from the ultimate necessity to ensure compliance with the resulting requirements on the enriched fuel handling operations, i.e. with the criticality safety controls, criticality safety management is at its core essentially a design basis activity (Step b). As such the key interfaces of the program with other business processes and the quality assurance requirements addressed in the other elements of the program are essentially what are common to all design basis processes. Thus, while it is prudent to provide integrated governance of the criticality safety management process, the criticality safety program manual may be viewed largely as a road map through the various other business processes that it utilizes. Indeed, most of the requirements of ANSI that form much of the basis for Bruce Power's criticality safety program correlate closely to more general principles of sound engineering and operation in nuclear reactor facilities. Some of the configuration management requirements and technical and administrative roles that may seem to be unique to criticality safety also in fact correlate closely to best practices more generally in the nuclear power industry. Even some of the technical and quality

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[2] The term *station condition* refers to any discovery that represents an actual or potential loss to the business. It could be an event that has occurred, a condition that exists or is anticipated, a deficiency in a procedure, an error in an analysis, etc.

assurance requirements in the criticality safety evaluation process, which is discussed in Section 6, are similar to corresponding requirements on reactor safety analysis. Indeed, criticality safety evaluation is treated by Bruce Power as a particular instance of its *nuclear safety assessment* process, which also embraces reactor safety analysis and probabilistic risk assessment and resides in Bruce Power's *plant design basis management* program.

A discussion of several key aspects of the criticality safety program follows.

4. Program Management

ANSI provides several general principles of criticality safety program management, but does not specify particular roles or an organization for program management. Bruce Power's program defines and assigns several specific program management roles.

Ownership of the program was originally assigned to the Chief Engineer, who in turn delegated day to day oversight and authority to the Reactor Safety Engineering Department manager. Very early in the program it was decided to establish a committee to exercise the oversight role, with the Reactor Safety Engineering Department manager as Chair. The committee, called the *Criticality Review Panel* (CRP), currently comprises four mid-level managers representing the main participants in the criticality safety program.

The Secretary of the CRP facilitates all interventions of the CRP. It has evolved that the CRP Secretary also maintains the criticality safety program manual and acts in effect as the overall administrator of the criticality safety program. Program authority continues to reside with the CRP itself or with the program owner.

The CRP recently accepted a proposal to transfer its authority in the criticality safety program to a new position called the Criticality Safety Manager. In effect, the role of Criticality Safety Manager will combine the program administration role currently played by the CRP Secretary with the authority currently held by the CRP, resulting in more efficient administration. Bruce Power has broader-based mechanisms and committees for providing independent management oversight, e.g. the Plant Operational Review Committee, which can be called upon by the criticality safety program if and when such oversight is deemed to be necessary.

5. Criticality Safety Technical Capability

The Criticality Review Panel is supported technically by the *Nuclear Criticality Safety Staff*. The roles and responsibilities of the NCS Staff are essentially as defined in the related requirements of ANSI[3].

Each member of the NCS Staff is assigned by one of the CRP members from his/her respective organization.

The composition and core responsibilities of NCS Staff are as follows:

- The *NCS Analyst* is a reactor physics safety analyst who is also trained in the use of the tools and methods required for calculation of subcritical margin. The NCS

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[3] See ANSI-8.1-4.1.1, -4.1.6; ANSI-8.19-4.4, -5.2, -6.1 to -6.7, -7.5; ANSI-8.20-5.3

Analyst determines when it is necessary to perform a criticality safety evaluation, i.e. based on reviews of proposed plant changes or evaluations of station conditions. When a criticality safety evaluation is required, it is led by the NCS Analyst. Authority for the performance of criticality safety evaluations is delegated to the NCS Analyst via his manager.

- The *NCS Design Engineer* is knowledgeable about the fuel handling systems and proficient in the plant design engineering processes. The NCS Design Engineer participates in the reviews that are necessary to determine when criticality safety is impacted and assists the NCS Analyst in the performance of criticality safety evaluations by acting as an interface with the plant design engineering processes.
- The *NCS System Engineer* is a fuel handling process engineer. The NCS System Engineer also participates in the reviews that are necessary to determine when criticality safety is impacted and assists the NCS Analyst in the performance of criticality safety evaluations by acting as an interface with the fuel handling processes.
- The *NCS Advisor* is a member of the reactor safety engineering organization. Like the NCS Design and System Engineers, the NCS Advisor participates in the reviews that are necessary to determine when criticality safety is impacted. The NCS Advisor assists the NCS Analyst in the performance of criticality safety evaluations by acting as an interface with the various Bruce Power processes for planning the mitigation of accidents. When the position of Criticality Safety Manager is established, the NCS Advisor will also provide direct support to the Criticality Safety Manager in his/her administrative role including, most importantly, the maintenance of the program governing documents. The latter responsibility will necessitate a deep understanding of the principles and standards that form the basis for the criticality safety program. This will position the NCS Advisor to act as a general consultant to Bruce Power personnel on criticality safety-related matters.

Together, the NCS Staff also:

- Support implementation of criticality safety controls, and more generally provide technical guidance for the design of equipment and processes and the development of operating procedures where criticality safety is a consideration.
- Support the preparation and delivery of nuclear criticality safety-related training.
- Provide technical guidance to the supervisors of the enriched fuel handling operations.
- Provide independent reviews of the enriched fuel handling operations.

The NCS Staff are administratively independent of the affected operations, as required by ANSI/ANS-8.1, Paragraph 4.1.1.

After the transfer of criticality safety program authority, the members of the NCS Staff will be accountable to the Criticality Safety Manager in their program roles.

6. Criticality Safety Evaluation

Step (b) in the criticality safety management process outlined earlier (see Section 3) is the core process around which most of the criticality safety program revolves, i.e.:

> Assurance that all proposed changes and discoveries are reviewed for potential impacts on criticality safety and that all such impacts are properly assessed and appropriately dispositioned.

This is essentially the *criticality safety evaluation* process, together with its interfaces at the front end with the processes for controlling changes to the plant and for responding to discoveries, and with the engineering processes at the back end that accept and implement the impacts of the evaluations.

Criticality safety evaluation itself consists essentially of the hazards analyses, which identify the relevant accident sequences and assess their likelihoods, and the supporting assessments of subcritical margin for the credible accident sequences. The hazards analysis is also used as the basis for identifying any non-credible accidents for which consequential criticality cannot be ruled out and hence for which a planned response and an assessment of dose consequences are required.

Criticality safety evaluation defines any requirements on the fuel handling operations that are necessary to ensure that criticality accidents are non-credible, i.e. the *criticality safety controls*. Based on a strict application of the principle of redundant protection, the outcome of this aspect of the criticality safety evaluation process could be conceived of as a system of primary and secondary controls, although additional controls might be necessary based on prudent engineering and/or on application of the 10^{-6}/year limit on the frequency of criticality accidents. On the other hand, for situations where strict compliance with the principle of redundant protection is impractical, a robust demonstration that the 10^{-6}/year limit is met may be sufficient.

As explained earlier, one of the key roles of the NCS Staff is to oversee the preparation of criticality safety evaluations. However, due to their relative inexperience when the criticality safety program was undertaken and because a comprehensive basis for their formal qualification had not yet been defined, expert consultants have been used so far to prepare Bruce Power's criticality safety evaluations.

Bruce Power employs computer codes to calculate subcritical margin. The criticality safety evaluation for the enriched fuel demonstration irradiation used the MONK code (Reference 16). MONK is also used in the United Kingdom. The criticality safety evaluation for the demonstration irradiation was prepared by Nuclear Safety Solutions Ltd. (now called AMEC NSS) with the assistance of analysts in the United Kingdom. A more recent criticality safety evaluation, prepared for possible large scale use of enriched fuel, employed the MCNP code (Reference 17). MCNP is used widely in the United States and is familiar to Bruce Power analysts from its use in reactor safety analysis. This criticality safety evaluation was prepared by an American company, Nuclear Safety Associates (www.nuclearassociates.com). An American company was chosen because Bruce Power's criticality safety program is based substantially on the American approach.

Although consultants have been employed so far to prepare Bruce Power's criticality safety evaluations, members of the NCS Staff and other Bruce Power employees have been intimately involved to ensure that the conditions, accidents and contingencies considered in the analysis properly reflected the enriched fuel handling operations under consideration, and to ensure that the controls defined in the analysis were optimized in relation to the other constraints. The involvement of the NCS Staff also helped prepare them to assume greater responsibility going forward in the criticality safety evaluation process.

Both MONK and MCNP have been validated in compliance with the related requirements of ANSI and for the particular applications. Subcritical margin was assessed using these codes with due consideration of the modeling errors and uncertainties quantified in the validation exercises, and subject to the additional safety margin requirements described earlier. The basis for the validation, i.e. the results of relevant experiments, is available entirely in the literature, with the sole exception of the potential effect of heavy water as a moderator or reflector. However, the calculated subcritical margin is large in the small handful of situations where heavy water could be present (light water is the moderator/reflector in most postulated accidents of concern). The availability of only indirect evidence of the validity of the calculated contribution due to the heavy water is therefore considered to be acceptable.

A somewhat intuitive approach was taken to prepare the hazards analysis for the enriched fuel demonstration irradiation mentioned earlier and subject only to the principle of redundant protection, i.e.

> *The design of the fuel handling systems should be such as to ensure subcriticality even if two independent abnormal events occur simultaneously.*

This was acceptable for the small number of enriched fuel bundles required for the demonstration irradiation, given the manifestly very low risk of criticality. Also, at the time that analysis was done the CNSC had not yet issued its requirements for criticality safety, which include the 10^{-6}/year limit on the frequency of criticality accidents. For the purpose of the analysis for potential large scale use of enriched fuel, Nuclear Safety Associates introduced more systematic probabilistic methods in the hazards analysis, as mentioned earlier.

The criticality safety evaluation for the demonstration irradiation defined a small handful of controls on the handling and storage of the enriched fuel, in terms of design requirements on the packaging of the enriched fuel bundles and in terms of procedural requirements on the handling of the packages and of the bundles after they were removed from the packages. The criticality safety evaluation for the demonstration irradiation did not explicitly address non-credible accidents.

The criticality safety evaluation that was undertaken in support of possible large scale use of enriched fuel yielded a number of criticality safety controls. Controls of each of the three fundamental types were identified, i.e. passive engineered, active engineered and administrative[4]. Together the controls would serve two basic purposes. Some would

[4] A *passive engineered control* is one that is implemented by means of a physical barrier that does not require a change of state to achieve the intended effect. An *active engineered control* requires a change of

reduce the likelihood of the initiating events of concern, e.g. controls on combustibles would reduce the likelihood of fires that could disrupt the fuel geometry and introduce a moderator (fire water). The others would serve as barriers to the occurrence of criticality as a consequence of the initiating events, e.g. a limit on fuel package storage elevation would reduce the potential falling distance in several postulated accidents. Together the controls would ensure that accidents that cause criticality are not credible.

Bruce Power has not yet completed an assessment of the potential for non-credible accidents to cause criticality. However, it is clear that the types of accidents, if any, for which criticality could not be ruled out with high confidence will be very improbable even for large scale use of enriched fuel in a power reactor. Likely it will nevertheless be necessary to address the question as to what is an appropriate planned response for such accidents. In particular, any provisions necessary to ensure that an appropriate response is triggered when required will have to be determined and whether the planned response would achieve adequate protection of workers and the public will have to be assessed. With respect to triggering the response, the question whether an engineered criticality detection and alarm system is required will have to be addressed. ANSI notes that the potential for false alarms could have implications for plant safety in other respects (ANSI-8.3, Paragraph 4.1.3), e.g. because they could result in the evacuation of personnel who are required for reactor safety purposes. The basis for assessing whether the planned response would achieve adequate protection of workers and the public would, on the other hand, depend on the type of event and potentially on other safety considerations that might be relevant in the event. In principle it would also depend on the likelihood of the event, since in general more severe consequences are acceptable for lower probability events. However, as already mentioned, the CNSC has in effect enunciated a single limit on public dose for all criticality accidents.

7. Verifications and Approvals

Bruce Power's criticality safety program requires approvals supported by rigorous verifications before new or significantly modified enriched fuel handling operations may commence, or to allow existing operations to continue where conditions that are possibly adverse to criticality safety have been identified. This is typical in processes that can significantly affect the basis for the facility design, particularly aspects of the design basis that determine the facility safety case. The following sequence of approvals for enriched fuel handling operations at Bruce Power has evolved. Generally speaking, these approvals would be required if the safety case for the operation required a new or revised criticality safety evaluation.

- The criticality safety evaluation must be approved by the Criticality Review Panel.
- CRP concurrence with the operation is required. This concurrence would be contingent on a set of demonstrated conditions that verifies corporate readiness for the operation.

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state to achieve the intended effect. An *administrative control* is implemented procedurally, i.e., by means of mandatory requirements on human activities.

- CNSC approval of the operation is required if it entails an increase in risk of criticality and/or if it is necessary to introduce or modify controls to maintain an acceptable level of risk. CNSC approval would be granted based on acceptability of the criticality safety program and of the criticality safety evaluation.
- The criticality safety program owner's approval of the operation is required. This approval would be obtained in the context of the *available for service* process that is standard for all design changes. It would be granted based on CRP concurrence, on CNSC approval (if it is required) and on the fulfillment of any conditions that may have been specified by the CRP or the CNSC.

The above approvals and concurrences by the CRP will be transferred to the Criticality Safety Manager in the planned new organization discussed earlier.

The requirement to verify corporate readiness for enriched fuel handling operations has evolved into a somewhat complex process. This is partly in response to experience in the United States that has been shared with Bruce Power by its consultant, Nuclear Safety Associates. However, each of the various aspects of the process is comparable to an activity that is already conducted by Bruce Power in connection with reactor safety. In the case of reactor safety, these activities have evolved over many years and within several separate but interacting business processes. The integrated approach in the criticality safety program is consistent with the American model.

Verification of corporate readiness for enriched fuel handling operations would also be an on-going process. Two broad aspects of readiness would be monitored, as follows.

- *Operational readiness*, i.e.:
  - the operations continue to comply with the administrative criticality safety controls;
  - the engineered criticality safety controls continue to be properly implemented in terms of the configurations of structures, systems and components (SSCs);
  - SSC configurations and operating procedures continue to be as otherwise represented in the criticality safety evaluation.
- *Programmatic readiness*, i.e.:
  - the criticality safety program continues to be well defined and properly administered;
  - formal qualifications of personnel continue to be properly defined;
  - the necessary qualifications of personnel are being maintained.

The following would, of course, be essential elements of this on-going verification process:

- Excellent configuration management.
- Excellent conduct of operations and supporting engineering processes, including management of interfaces.
- Corporate commitment to a rigorous worker training and qualification program.

- Periodic program reviews.
- Effective processes for responding to discoveries.

8. Training

Because of the following factors, a simplified approach was taken by Bruce Power to define the training required for the demonstration irradiation of an enriched fuel design that was mentioned earlier.

- The number of enriched fuel bundles required for the demonstration irradiation was small.
- The individual movements of enriched fuel packages and bundles were few, spread over a relatively short period, and closely monitored.
- External criticality safety experts were retained to carry out the necessary analyses.

The *Nuclear Criticality Safety Short Course* offered annually by the University of New Mexico (www-chne.unm.edu/crit/information.htm) was selected as the initial training for the criticality safety program staff, i.e. for the Chair and Secretary of the Criticality Review Panel and for the members of the NCS Staff. This one week course covers a broad range of topics, most of which are relevant to Bruce Power's needs. Some group exercises in the course help establish a practical understanding of the double contingency principle, most of which is translatable to Bruce Power's use of the corresponding IAEA principle. This course will probably continue to be used as part of the orientation for Bruce Power's criticality safety program staff, i.e. for the Criticality Safety Manager and the members of the NCS Staff. However, the course is not considered to be sufficient going forward to fully qualify members of the NCS Staff with respect to their technical responsibilities in the criticality safety program.

A separate half day course was run to orient the fuel handling operators with respect to the small handful of criticality safety controls they would be responsible for during the demonstration irradiation. The same course was also used to provide a broad cross-section of personnel with basic awareness of criticality safety, of the criticality safety program, and of the criticality safety controls required for the demonstration irradiation.

As Bruce Power progresses toward possible large scale use of enriched fuel, personnel in diverse areas of the business potentially will have indirect roles in the criticality safety program due to the program interfaces with other business processes. For such personnel, criticality safety might only be an occasional consideration. The program interfaces would thus be attended by the problem of how to provide and maintain the levels of awareness of criticality safety that are necessary to ensure that the requirements at the interfaces would always be met. This problem is already familiar to all of us in the Nuclear Industry due to the complex interdependency of our business processes. Effective strategies to address this problem have evolved over many years based on our experience. Drawing from this experience, Bruce Power will employ several means when required to inculcate in personnel appropriate awareness of criticality safety and of the criticality safety program.

ANSI requires that, where criticality safety training is required, refresher training must be delivered at least once every two years (ANSI-8.20, Paragraph 6.2). No distinction is made in this respect among the various types of positions that require criticality safety training. Bruce Power is interpreting this as a requirement to *requalify* personnel in their criticality safety roles. The significance of this adjustment of the terminology is important. To qualify a person is to demonstrate their ability to perform their tasks. Simply training a person does not necessarily achieve this and indeed repeating initial training may not be necessary. The method to requalify a person can and should vary depending on the sorts of tasks that are being performed and how frequently they are performed. Thus, for personnel who are frequently involved in criticality safety-related activities, requalification might be administered substantially on-the-job. On the other hand, personnel who have important responsibilities with respect to criticality safety, but are not frequently involved in criticality safety-related activities may have to be requalified by other means, e.g. course training, workshops.

Bruce Power subscribes to INPO's *systematic approach to training* (SAT) model for defining personnel qualifications and developing and maintaining the associated training (Reference 18). Although the SAT approach was not applied rigorously to establish the training required for its enriched fuel demonstration irradiation, Bruce Power will apply it fully when required to define comprehensively the training and qualification of personnel that are necessary for large scale use of enriched fuel.

9. Canadian Industry Cooperation

Bruce Power is not the only Canadian company to have an interest in criticality safety. Nor would the possible use of enriched fuel by Bruce Power or by any other Canadian nuclear utility be the first use of enriched uranium in Canada. However, the large scale use of enriched fuel in power reactors would greatly increase the scale of Canadian enriched fuel handling operations. This has raised the profile of criticality safety in Canada. An important indication of this has been the introduction by the CNSC of an extensive set of requirements on criticality safety.

Stakeholders in the industry have recently started talking together about common interests in the area of criticality safety and about ways that they can support one another. A working group has been struck to help facilitate this cooperation. The members currently are as follows:

- Atomic Energy of Canada Ltd.
- Bruce Power
- Cameco Fuel Manufacturing Inc. (formerly Zircatec Precision Industries)
- GE, Hitachi, Nuclear Energy Canada (fuel manufacturing division)
- McMaster University (nuclear research facility)
- Ontario Power Generation
- AMEC NSS (formerly Nuclear Safety Solutions)
- University of Ontario Institute of Technology

The working group will address the future evolution of Canadian requirements on criticality safety and more generally will help establish consistent and excellent nuclear criticality safety practices in Canada. Some possible benefits are as follows:

- Common Canadian standards for criticality safety.
- Sharing of experience.
- Common solutions to common problems.
- Standardized tools for criticality safety analysis, e.g. the computer codes that are used to calculate subcritical margin. This would be analogous to the increasing standardization of tools that are used in Canada for reactor safety analysis.
- Joint representation in international standards committees, such as the American Nuclear Society working groups that maintain the ANSI/ANS standards for criticality safety.

The working group is just getting off the ground, so there is not much to report in terms of specific accomplishments. However, past experience with working groups in the nuclear industry, e.g. through the CANDU Owners Group (COG), shows that, not only are they beneficial, but they are essential to ensure both an effective and an efficient approach to safety.

10. Conclusions

The following conclusions may be drawn.

1. Bruce Power's criticality safety program is consistent with the approach to manage criticality safety in other jurisdictions.
2. Criticality safety management revolves around the criticality safety evaluation process.
3. Criticality safety evaluation is a design basis process with the typical types of interfaces with the engineering and configuration management processes and with the processes for responding to discoveries, among others.
4. Risk would be inherently low in any enriched fuel handling operations undertaken by Bruce Power, but the conservative approach in the criticality safety evaluations could nevertheless result in explicit criticality safety controls.
5. Criticality safety management is attended by several familiar issues concerning the practicability of establishing and maintaining appropriate qualifications of personnel.
6. Industry cooperation will be both beneficial and necessary to establishing and maintaining an excellent and consistent approach to managing criticality safety in Canada.

Bruce Power believes that its criticality safety program will in all respects be shown to be appropriate for any enriched fuel handling operations that it undertakes and consistent with the typical Canadian approach to assure safety in reactor operations.

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