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NUCLEAR CRITICALITY SAFETY IN CANADA

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SÉCURITÉ NUCLÉAIRE AU CANADA

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RÉSUMÉ

La façon d'aborder la question de la sécurité nucléaire au Canada a été influencée par l'évolution historique des participants. Les rôles tenus par les organismes gouvernementaux et l'industrie privée, depuis l'adoption de la Loi sur le contrôle de l'énergie atomique au Canada en 1946, sont décrits brièvement afin de brosser un tableau de la conjoncture actuelle et des orientations qu'elle pourrait prendre plus tard. La sécurité nucléaire met l'accent sur le contrôle des substances qualifiées au Canada de matières fissiles spéciales. Suit un bref exposé de l'évolution chronologique de la réglementation actuelle régissant les matières fissiles spéciales et de ses principes directeurs. Des événements ultérieurs ont entraîné un changement d'orientation du processus de réglementation, qui n'a pas encore été entièrement intégré dans la législation et la réglementation canadiennes. Les tentatives actuelles en vue d'élaborer davantage les règlements régissant la sécurité nucléaire sont décrites.

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ABSTRACT

The approach taken to nuclear criticality safety in Canada has been influenced by the historical development of participants. The roles played by governmental agencies and private industry since the Atomic Energy Control Act was passed into Canadian Law in 1946 are outlined to set the scene for the current situation and directions that may be taken in the future. Nuclear criticality safety puts emphasis on the control of materials called special fissionable material in Canada. A brief account is given of the historical development and philosophy underlying the existing regulations governing special fissionable material. Subsequent events have led to a change in emphasis in the regulatory process that has not yet been fully integrated into Canadian legislation and regulations. Current efforts towards further development of regulations governing the practice of nuclear criticality safety are described.

INTRODUCTION

The Atomic Energy Control Act was passed in 1946. It established the Atomic Energy Control Board and the first regulations were issued the following year. For nearly 10 years no material that constitutes a criticality hazard, now called special fissionable material in Canada, was handled by the Canadian nuclear industry which consisted of two other governmental agencies. In the late 1950's, enriched uranium began to be used in these agencies in a redirected research program. In the early 1960's private industry began to manufacture nuclear fuel as technology was transferred from the governmental agencies. During this period the philosophy was developed to keep the regulations as general and as simple as possible consistent with safety, security and economic considerations. Regulations and Board orders were consolidated and re-issued in 1960 and again in 1974 although the latter, which are the current Atomic Energy Control Regulations, were restructured and included interim developments in facility licensing.

The Regulations require all special fissionable material to be licensed although neither contain specific provisions for nuclear criticality safety. As new programs involving different groups and materials developed, licensing procedures and measures for their control were devised. After a period of assessment and adjustment, standard procedures were developed for continuing programs. Once established they were reviewed frequently and adapted to the then current conditions. This approach was made possible by the small size of the program and the nature of the programs developed for nuclear criticality safety at the various organizations.

Since 1974 a number of developments have occurred that have affected this approach to the legislation and regulation of nuclear matters in Canada. In 1976 the Nuclear Liability Act was promulgated. This was also the year that a law reform commission, studying various aspects of Canadian law, reported on a study of the Atomic Energy Control Act, the Regulations and the licensing practices of the Atomic Energy Control Board. This led to the introduction into the House of Commons of Bill C-14, a proposed "Nuclear Control Administration Act", but it was not enacted into law before the legislature was prorogued in 1977. It has not been subsequently re-introduced to Parliament but all the major political parties in Canada have expressed their intention for reform. The last government proposed a nuclear inquiry in its "Speech from the Throne" but it was defeated before the inquiry was established. The new government has not yet convened.

Concurrent with these developments, and even preceding them, increased awareness of the acts of terrorism and related activities throughout the world resulted in the adoption of increased measures for physical protection of special fissionable materials. This has directly affected the course of development of the Canadian nuclear fuel manufacturing industry. It has also led to a proposed revision of the regulations for physical security that have been released for public comment. This action is among the first of its kind in the regulation of the nuclear industry in Canada and follows the concepts underlying the reform legislation that was proposed.

For nuclear criticality safety new regulations and a licensing guide have been drafted and are currently being developed within the AECB. The principles and practices on which they are based will be described.

HISTORICAL BACKGROUND - The Industrial Scene

During World War II, two of the government agencies currently participating in the nuclear industrial scene were developed. These predecessors of Eldorado Nuclear Limited (ENL) and Atomic Energy of Canada Limited (AECL) participated in the Manhatten Project - ENL supplied natural uranium through its mining and refining activities and AECL provided basic research through the NRX reactor at Chalk River (heavy water moderator, natural uranium fuel).

In the late 1950's AECL began to import small quantities of enriched uranium from the United States to enhance their research capability and for several years the only activity with special fissionable material was at Chalk River. It was also a time that McMaster University at Hamilton, Ontario was installing a pool test reactor. The receipt of fuel from the U.S. in 1959 marked the first time enriched uranium was located outside ENL or AECL.

About the same time technology was being transferred to private industry which began to develop a reactor fuel manufacturing capability to supply fuel for the prototype heavy water-moderated power reactors (NPD and Douglas Point, forerunners of the CANDU-PHWR reactors). These reactors are fuelled with natural uranium but they use booster rods containing enriched uranium and AECL's research program required enriched uranium for experimental elements and fuel bundles. They were manufactured in the private sector after material was refined by ENL to feed the manufacturing processes being developed.

In 1963 construction started on the WR-1 reactor (heavy water moderated, organic cooled research reactor at AECL's Whiteshell Nuclear Reactor Establishment in Manitoba) which uses slightly enriched fuel. By this time the research reactors at AECL's Chalk River Nuclear Laboratory (NRX, NRU) were in advanced stages of conversion to operate with enriched fuel in order to gain reactivity for the expanding experimental program to support the power reactor program. The mid 1960's were also a time when natural uranium fuel production was experiencing "booms" and "busts". The work on SFM helped to fill the low periods until the late 1960's when other reactors were ordered. By this time the program with SFM was of a modest size.

Activities with SFM expanded in the early 1970's with the conversion of the Nuclear Power Demonstration (NPD) reactor to operate with partially enriched fuel, the advent of the SLOWPOKE reactors, and manufacture of booster rods for Ontario Hydro's Bruce reactors. However, the introduction of physical security measures has had a significant impact. None of the facilities, except AECL which was already a protected place and Ontario Hydro, undertook the expense of upgrading their facilities to meet the standard of protection demanded for highly enriched uranium. This, along with the success of the Pickering reactors and others like it that are currently under construction and do not use booster rods led to a significant restructuring of that part of the industry handling SFM. It had become a service rather than a necessity to remain in business. Currently the emphasis is on the production of natural uranium fuel. Fuel containing special fissionable material is still being handled but at a reduced rate since AECL began to manufacture its own fuel for the NRX and NRU reactors.

Throughout this period ENL continued to play its key role in the conversion and refining of materials to forms used at the head end of fuel bundle manufacture.

To date, no criticality accidents have occurred in Canada outside of reactors. In fact, no criticality has occurred outside reactors because there are no facilities to do critical mass experiments with special fissionable materials. Criticality data used in Canada come from the open literature originating in the critical mass laboratories in the United States, the United Kingdom and France.

DEVELOPMENT OF NUCLEAR CRITICALITY SAFETY PRACTICES AND THE REGULATORY SCENE

The Atomic Energy Control Board created by the Atomic Energy Control Act in 1946 is a Crown corporation. It is a regulatory body which controls the development, application and use of atomic energy through the authority of the Act and through associated regulations. By means of a comprehensive licensing system it controls all dealings in prescribed atomic energy substances and equipment which include special fissionable material. Control is effected by requiring all perspective licensees to make application to the Board and to include with that application all relevant information on the details of substances and equipment and its proposed use, as well as operational and safety procedures and equipment, qualifications and experience of users or operators, radioactive waste proposals, environmental considerations, etc. This information is assessed by the Board's technical staff and advisers, and, if the application is found acceptable an appropriate licence is then issued. Board inspection officers visit licensees to assure their compliance with the licence and with the Atomic Energy Control Regulations.

The Act also permits the AECB to enter into international agreements on behalf of Canada and these are implemented through its licensing system. Import and export of prescribed substances and equipment are controlled in co-operation with other federal government agencies. Provisions of the Non-Proliferation Treaty are administered under the safeguards agreement with the International Atomic Energy Agency (IAEA), which provides for inspection of the canadian nuclear program by their officers.

Certification of transport packages and provisions for physical security are administered by the AECB. Although not bound by formal agreements, the AECB is guided by the IAEA who is in turn guided by working groups of experts in which Canada participates.

Until the late 1950's the AECB took little interest in fuel fabricated with enriched uranium. However it's interest was aroused when AECL began importing small quantities of enriched uranium for its experimental program. At Chalk River a criticality panel was set up in 1956 to develop procedures for the safe handling of materials that constitute a criticality hazard. Its services were offered to the AECB to evaluate criticality hazards involved in transportation, use and storage of SFM. As the Board had no expertise in this area, the offer was accepted and this arrangement continued informally until 1959 when the AECB formally requested AECL to assess licence applications and to recommend licence conditions. AECL agreed and its role as adviser was later expanded to include inspection. During this time each project was separately licensed and a number of basic principles and practices were established that have been carried forward and further developed.

With the expansion of the industry in the early 1960's training became a requirement with the transfer of technology. The number of licensing actions grew and AECL requested to be relieved of its role as inspector which could have been seen to conflict with its other roles. Within a year the Board assigned staff for inspection and for training by the panel. The number of licensing actions continued to increase and a further reduction in the role of AECL was requested by withdrawing from off-site assessments. By 1963 the AECB was carrying out nuclear criticality safety assessments and licensing directly with decreasing inputs from the panel except in unusual cases. This arrangement continues today.

The mid 1960's brought participation in the development of the IAEA transport regulations and an increasing number of projects. The latter led to the introduction of General Licences related to facilities, equipment and procedures for established methods of manufacture and the development of recording and reporting requirements for specific projects done under them. Specific licences continued to be used for other projects and further refinement of principles and practices of preventive measures for nuclear criticality control and licensing occurred. Material possessed at any one time by licensees had grown to the point where protective measures were also developed. Criticality detection and alarm systems were installed in appropriate facilities and emergency procedures were developed.

The Board hired its first full time staff member specifically to deal with nuclear criticality safety licensing in 1970. About this time the private sector was developing criticality safety committees along the lines of those in ENL and AECL. This was in response to the continuing increase in the number and variety of projects and led to authorized, but limited, internal approval procedures for specific projects within General Licences. This led to further development of licensing requirements for administrative and organizational matters.

In the interim the Non-Proliferation Treaty came into force and Canada affirmed its non-millitary application of nuclear energy by being among the first nations to ratify it and to work out a safeguards agreement with the IAEA. This led to the development of formalized and uniform material accounting practices to comply with the agreement. Concurrently provisions for nuclear criticality safety were developed to show compliance with material-related limits in controlled areas. These are combined on the accounting forms but a new term, Balance After Processing (BAP), was introduced for nuclear criticality safety to make a distinction between the conflicting requirements for handling unaccounted for balances when inventories are taken, and at the termination of projects. The IAEA safeguards system assumes material unaccounted for (MUF) to have been diverted whereas practices for nuclear criticality safety require balances after processing to be assumed present until demonstrated to be absent.

About the same time the Atomic Energy Control Regulations were being revised to restructure them and to include practices for licensing facilities and other provisions that were not in the 1960 Regulations. Although their introduction in 1974 meant that the AECB no longer issued licenses specifically for special fissionable materials, it had little impact on the nuclear criticality safety programs of licensees other than to integrate their SFM licences along with other licences held into a consolidated licence for all activities at a nuclear facility. This led to more formal documentation of the organization and administration of nuclear criticality safety programs. General and Specific Licences that were previously issued became general and specific approvals under the new consolidated licence or led to licence amendments.

In the early 1970's the Nuclear Liability Act was passed and was later promulgated in 1976. It requires the Atomic Energy Control Board to designate Nuclear Installations for purposes of the Act and to prescribe, with approval of Treasury Board, an amount of Basic Insurance for such installations. Among other things, the Act places absolute liability on operators of a Nuclear Installation for a breach of the duties imposed, requires that 75 million dollars of insurance be carried with approved insurers, and provides for establishment of a commission if a nuclear incident causes damage in excess of this amount. For licensees handling SFM a nuclear incident would be a criticality accident. The AECB designates as Nuclear Installations those facilities that possess a quantity of SFM in excess of a critindex, which will be explained later. At this time the AECB firmed up its requirement for licensees to implement protective measures whenever they are designated as a Nuclear Installation.

The mid 1970's were also a time when societies attitudes and perceptions toward technology were changing. The media was increasingly expressing concern about environmental pollution, other impacts of technology, greater freedom of information etc. Against this backdrop other events occurred that would affect the nuclear criticality safety program in Canada.

Among others, the reforms in the ill fated Bill C-14 made provisions for an expanded Nuclear Control Board to replace the existing Atomic Energy Control Board, and made provisions to further clarify the existing separation of the regulatory role of the government (AECB) from other roles the government fills in the nuclear industry (AECL and ENL). It also provided for more detailed regulations and for increased public participation. On the other hand, the Atomic Energy Control Act, enacted in the post war era, specifically prohibits the release of information. This has been strictly interpreted by the Board in the past, but it has recently been seized by nuclear critics who are pressing for more freedom of information. Early this year the AECB announced a proposed policy to make licensing documents public at the beginning of next month. It is currently out for comment and makes, among others, provisions for protecting information that may be of a commercial proprietary nature. Its full impact and final form are not yet clear but it appears that an application for licence with proprietary information in it will have to be partitioned and that the portion that is to be in the public domain may have to contain summaries of protected information sufficient to demonstrate safety.

CURRENT REGULATION OF NUCLEAR CRITICALITY SAFETY

The existing Regulations require SFM to be licensed but only provide general requirements for making application to the AECB for a licence. As a general policy the AECB has been, for several years, developing licensing guidelines for more specific guidance and interpretation of the general requirements in the Regulations. However none were prepared for the licensing of SFM as this was considered to be a low priority because of the perceived competence of licensees and the historical development of their licences. More recently the AECB has also been actively developing a more comprehensive set of regulations.

As part of this program a set of regulations and a licensing guideline were recently drafted to develop a regulatory base for nuclear criticality safety. The approach taken is generic to nuclear criticality safety and sets out practices developed in Canada. It would be premature to present them in detail now because of their preliminary nature. Nevertheless it is appropriate to describe underlying principles and practices that have been developed over the years to control the interaction of neutrons in units and arrays of SFM.

Principles

The following ten principles guide technical and administrative practices to be taken to prevent accidental criticality:

1) All undertakings with SFM shall be done in accordance with written documents.

2) Written documents shall be subjected to independent review prior to the start of any undertaking.

3) A safety analysis and other documents supporting an application for review shall show, taking into account incident conditions, that an adequate margin of safety will be maintained to prevent inadvertent criticality. The double contingency principle is normally used to determine adequacy.

4) The scope and amount of detail in an application shall be sufficient for the reviewer to be able to understand the proposal; to be able to evaluate incident conditions; and to be able to concur, independently, with the judgement of the applicant that nuclear criticality safety will be maintained if the proposed controls and procedures needed to implement them are followed.

5) Any parameter that is not controlled or cannot otherwise be shown to be limited shall have the value assigned to it that results in the maximum multiplication factor for the unit or array.

6) Concurrent processing of SFM should be avoided to the extent practical and provided for in the nuclear criticality safety program.

7) SFM that is not required for operations shall be contained and stored.

8) Physical measures of control are preferred to administrative measures of control.

9) Changes or substitutions of material in a control area or of control procedures shall not be undertaken until it has been ascertained that the effects of such a proposal on the interaction of neutrons in the SFM has been assessed, reviewed and approved. This should not be restricted to SFM only, nor should it be restricted to controlled areas if proposed changes may affect the conditions incident to a control area.

10) Persons handling SFM shall have been trained or instructed in nuclear criticality safety to the extent needed to carry out their functional role in the nuclear criticality safety program.

An eleventh principle is added for protective measures in the event that criticality occurs in spite of the preventive measures taken:

11) Protective measures and emergency procedures should be provided when the quantity of material possessed could cause accidental criticality under incident conditions.

The term "incident conditions" has been used several times. Along with the proposed measures of control it has a profound effect on the depth and detail in a safety analysis. Incident conditions are considered in three categories. "Normal conditions" are to be declared so that ranges of conditions that are considered normal are defined. All normal conditions are to be provided for by the proposed control measures. "Abnormal conditions" are the set of credible conditions beyond normal and include man-made and environmental events. "Extreme conditions" are those conditions beyond abnormal that may be conceivable but that are deemed to be incredible and are therefore not provided for in the proposed control measures. Extreme conditions are to be stated and the rationale for the choice is to be provided, for example, the maximum magnitude of an earthquake selected for the design of equipment. The set of abnormal conditions is therefore bounded and control measures are to provide for them to the extent required by application of the double contingency principle.

These principles are described in the proposed licensing guideline. They are further developed and interpreted in it to explain in more detail how they affect licensing and the development of a nuclear criticality safety program. However details of technical data and technical practices, such as validation, that are well documented in the literature are not included in the guidelines. The licensee is free to choose whatever method of analysis that will satisfy the review process (internally and by the AECB and its advisers). This has lead to an informal practice in that the AECB encourages licensees to discuss potential problem areas of licensing before they make application.

Practices

A number of control and procedural measures have led to four basic licensing practices:

1) If possession of SFM can be 100 grams or more, a nuclear criticality safety program (NCSP) is required.

2) Commensurate with the hazard, the NCSP is to provide measures to prevent accidental criticality.

3) If possession of SFM may exceed a critindex, the NCSP is to provide protective measures.

4) Before SFM is released for shipment the licensee is to:

   a) determine that the consignee holds a valid licence, and

   b) for shipments exceeding 100 g, receive assurance from the consignee that its receipt would not violate provisions of its NCSP.

The preventive measures required for the second basic practice were further developed to include the following:

a) all operations with SFM are to be done in accordance with written procedures and personnel are to have been trained in their use;

b) descriptions of facilities, equipment, procedures, related documents and changes made to them that set out measures for controlling the spatial distribution of SFM are to be assessed in a safety analysis for their adequacy to provide nuclear criticality safety under incident conditions;

c) documents resulting from b) are to be reviewed and approved prior to their use;

d) deficiencies in the NCSP discovered during operation or audit are to be investigated and follow up action is to be taken to prevent their recurrence.

The protective measures to be taken for the third basic practice have also been further developed to include the following:

a) equipment is to be installed to detect the occurrence of criticality in the areas under control of the NCSP and to initiate:

   i) an alarm signal for evacuation of personnel to an area safe from radiation or other hazard; and

   ii) any provisions made in the NCSP for automatic measures to prevent subsequent or continued criticality.

b) passive neutron detection devices are to be placed in personnel monitoring devices and at selected locations throughout the facility to guide post-accident actions.

The term "critindex" has been used in the third basic licensing practice. This has also been found to be a useful concept where different species of SFM may be handled in a controlled area over a period of time (for example enriched uranium of different assays). Critindex is defined as the ratio of the mass of a given species of SFM to 85% of the smallest critical mass of the same species of SFM moderated and reflected by water. The margin of safety is included as a contingent measure for errors. A critindex is also called a current possession unit (CPU) for purposes of accounting and is a measure of criticality hazard. As an example, a mass of 62 kg of uranium enriched to 3 weight per cent U-235, U(3), would have a critindex of one assigned to it, as would 0.75 kg of U(93). This concept is used for controlling current possession in areas that may have different materials at different work stations: for example, an area with 5 work stations each under batch control that may have fuel elements at various stages of manufacture for different experiments. If the batch limit for each work station is 42% of a smallest critical mass (0.5 critindex) the area would be limited to a current possession of 2.5 current possession units. For control, each batch of material to be issued from storage to the area would be assigned the appropriate number of CPU's. In this example, if a request for material were to exceed the 2.5 CPU limit for an area, control action would be required before the material would be released. This concept is also applied to unaccounted-for-material remaining after material balances are done. BAP is considered to be a burden against an area's possession limit and the burden is assigned to the area in CPU's. As the burden accumulates an index of criticality hazard is indicated and it is used for the basis of control action, for example to initiate a search if the burden reaches control levels specified in the nuclear criticality safety program.

The AECB also requires that reports be prepared periodically to demonstrate compliance with the terms of the license. Monthly reports are to be made showing movements of SFM through control areas, material balances performed (preliminary - before the next project is handled, and final - when the program is terminated and material balance records are to become dormant) and the accumulation of BAP in control areas. As the need arises, reports are to be made of investigations made into deficiencies of the NCSP discovered during operation or audit. They should include recommendations made to prevent their recurrence. Annual reports should review the performance of the NCSP and summarize the monthly reports and deficiency reports issued in the period under review. Follow-up action from the latter should also be included.

The Board may also exempt licensees from specific measures or practices where they are inappropriate or alternate arrangements are made. The latter has contributed to the current set of principles and practices.

Application For a Licence

The above measures are to be set out in the application for a licence. Recent applications for handling SFM have included the following information:

1) The name and address of the prospective licensee;

2) Summary statements of:

   a) the nature and quantity of SFM for which a licence is sought, that already possessed and that for which a licence is pending;

   b) limits to be placed on the SFM in controlled areas;

   c) the proposed duration of the project;

   d) intended use of the SFM; and

   e) a list of supporting documents;

3) A list of areas in which SFM is to be handled and the signature of the criticality control officer in charge of each; and

4) The name, title and signature of the individual authorized to act on behalf of the prospective licensee.

The supporting information for item 2(e) includes the following elements of a nuclear criticality safety program:

1) policies, principles, and objectives guiding the program;

2) organization of human resources including roles, responsibility and the assignment of authority to individuals and committees that are to function for nuclear criticality safety independent to the extent possible of operational and other functional responsibilities;

3) qualification and experience of key personnel;

4) training program;

5) facilities, equipment and other resources;

6) procedures and related services for the NCSP such as:

   a) safety review

   b) transport and transfers of SFM

   c) handling excess and scrap SFM not in the main stream of processing

   d) material accounting

e) audit and quality assurance

f) storage

g) physical security

h) health monitoring

i) records

j) reports

k) labels and signs

These elements are usually documented in a facility licensing manual that accompanies an original application and are updated on subsequent applications.

Where the AECB authorizes an approval system internal to the licence, the facility licensing manual is expanded to include:

a) a description of the independent review procedure;

b) the composition of the review committee;

c) limits on the nature and type of approvals which can be authorized to define the interface between the approval system of the licensee and the AECB licensing process; and

d) provisions made for AECB participation to audit the proceedings of the committee and the operation of the system.

The draft guidelines expand on this topical outline of the contents of an application for licence by explaining and interpreting their intent: to guide the preparation of documents describing the elements, principles and practices of nuclear criticality safety program at a facility. Because of the nature of nuclear criticalilty safety these requirements can be extensive if the operations at a facility and the measures taken for control of SFM are complex. On the other hand, they may be simple. The AECB encourages implementation of simple, straightforward and practical controls in the interest of safety. It also encourages brevity in the documents - but not to the extent of their being incomplete.

THE FUTURE

The preceding is an outline of principles, practices and documents currently required in the Atomic Energy Control Board's comprehensive licensing system as it applies to special fissionable materials that may constitute a criticality hazard.

The new regulations being developed will set out essential matters for licensing SFM. The guidelines will provide an expansion of their intent and provide interpretations and guidance for the documentation and practices of the nuclear criticality safety program required at a facility. The regulations and guidelines will be available from the Atomic Energy Control Board when they have been developed to the point of issuing them for public comment.