HUMAN FACTORS CONSIDERATIONS IN RD-337: DESIGN OF NEW NUCLEAR POWER PLANTS.

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Abstract

In the near future, Canada expects to build several new nuclear power plants. As a means for conveying the expectations of the Canadian Nuclear Safety Commission, document RD-337: *Design of New Nuclear Power Plants*, concerning the design of new water-cooled nuclear power plants, has been developed. This document establishes a set of comprehensive design expectations that build upon IAEA document NS-R-1, *Safety of Nuclear Power Plants: Design*. The CNSC document includes coverage of topics such as environmental protection, aging, human factors, security, safeguards, transportation, and accident and emergency response planning. This paper explains how Human Factors issues pervade RD-337.

1. Introduction

The Canadian Nuclear Safety Commission (CNSC) has developed a new regulatory document called RD-337: *Design of New Nuclear Power Plants* [1]. This document concerns the design of new water-cooled nuclear power plants (NPP) in Canada, and establishes a set of comprehensive design expectations. These expectations are risk-informed and align with accepted international standards and practices.

2. Scope

RD-337 is based upon the principles set forth by the International Atomic Energy Agency (IAEA) in NS-R-1, *Safety of Nuclear Power Plants: Design* [2]. These principles have been adapted to Canadian regulatory expectations. The document addresses the interface between NPP design and other topics, one of which is Human Factors. RD-337 applies to all licensing phases from the earliest stages of design through to decommissioning.

RD-337 was written to be technology-neutral with respect to water-cooled reactors, and includes guidance concerning issues such as:

1. Establishing the safety goals and objectives for design;
2. Utilizing safety principles in the design;
3. Applying safety management principles;
4. Designing systems, structures, and components;
5. Interfacing engineering aspects, plant features, facility layout, and

6. Integrating safety assessments into the design process.

3. Relevant requirements

There are several provisions in the *Nuclear Safety and Control Act* (NSCA) and its associated regulations that are relevant to RD-337. They include:

1. Subsection 24(4) of the NSCA
2. Subsection 24(5) of the NSCA
3. Paragraph 3(1)(*i*) of the *General Nuclear Safety and Control Regulations*
4. Paragraph 12(1)(*f*) of the *General Nuclear Safety and Control Regulations*
5. Paragraph 5(*i*) of the *Class I Nuclear Facilities Regulations*
6. Other sections of the *Class I Nuclear Facilities Regulations*, as well as sections of the the *Nuclear Security Regulations* that pertain to the design of a new nuclear power plant.

These clauses relate in large part to the information that must be provided by a license applicant, and which relates to the design of the facility.

4. Human factors in RD-337

"Human Factors" in the general sense refers to those factors that can influence human performance. This includes such factors as human-machine interface design, lighting, noise, procedures and job aids, training, management and supervision, safety culture, and organizational processes. Each of these (and other) factors can influence how humans perform anywhere within the facility, at any phase in the life cycle of the plant. This refers not just to the nuclear side of the plant, but also to the conventional part of the plant (e.g., turbine, switchyard, also known as "balance of plant"). As a consequence, it is necessary to address Human Factors issues in all aspects of the design of a nuclear facility.

It is important to understand that the Human Factors issues must be given a broad consideration across RD-337, given that when licensees apply for a license to prepare site, construct, or operate a facility, they will be expected to show how they have dealt with the Human Factors issues for the relevant clauses throughout RD-337.

It may appear at first glance that the inclusion of Human Factors in RD-337 is straightforward and described fully in section 7.21 "Human Factors." While this is part of the picture, section 7.21 does not cover the entire scope of Human Factors considerations in the design of a new nuclear power plant. It is necessary that other clauses of RD-337 also be included in the consideration of Human Factors issues relevant to the design of a new facility. In fact, there are many clauses in RD-337 that include Human Factors issues.

5. Discussion

5.1 Integrated Approach

The CNSC is taking an integrated approach to the inclusion of Human Factors in the design of new nuclear facilities. This involves consideration of Human Factors issues as they pertain to all areas of the facility, and for a variety of functions. The perspective is that the impact of applying the discipline of Human Factors upon a system is only effective where these issues are considered within the design process, rather than dealing with inadequacies in the system once it is operational. The earlier in time that Human Factors issues are considered, preferably from the earliest stages of design, the higher the effectiveness that will be achieved, and the fewer costly modifications will be necessary at later points in the process. Further to the point on integration, one can see from the list above that there will be a significant interaction between and among engineering disciplines, among others, in implementing a holistic approach to the design of nuclear facilities. It is expected that licensees would also implement an integrated approach, with Human Factors specialists taking the lead on specific Human Factors topics, while with other topics they would contribute to the activities carried out by the specialists in those other areas. In this way, Human Factors would be integrated into design and related activities.

5.2 Historical Background

An early indication of the use of this approach was presented to licensees in a document produced by the Atomic Energy Control Board in 1995. This document, *Human Factors Guides* [3], provided information regarding the expectations for consideration of Human Factors in the design of a nuclear facility. Part D of that document, "Human Factors Design Integration Guide", addressed Human Factors issues appropriate for the design of general plant areas. The topics discussed in that guide included: plant layout and facility access; floors; signs, labels and coding; lighting; thermal environment; noise; vibration; environmental hazards; procedure design; controls and displays; human-machine interface; communications; workstation design; video display terminals; seating; manual handling; tools; maintainability; and personal protective equipment. The various clauses presented in RD-337 require consideration of these and additional Human Factors issues.

5.3 Scope of Human Factors

While it may not be apparent from the title of some of these clauses that Human Factors issues should be considered, a closer inspection will reveal that there are issues within each that make consideration of Human Factors in these areas imperative. Many of these sections focus on specific topics that may be seen as subsets of the larger topics or issues discussed in clause 7.21, the over-arching Human Factors clause. Certainly the many

additional clauses are linked in an integrated manner with the issues identified in clause 7.21, which is the foundation clause, in a manner of speaking, for Human Factors. Examples of clauses with links are:

5.0	Safety Management During Design
5.1	Design Authority
5.2	Design Management
7.2	Plant Design Envelope

which pertain to the *knowledge and expertise in Human Factors* that is necessary to both design and maintain the design of the plant. These clauses link to the first paragraph in clause 7.21.

A detailed example can be seen in clause 5.2 Design Management. The RD-337 text reads as follows:

> *Appropriate design management is expected to achieve the following objectives:*
> *1. SSCs important to safety meet their respective design requirements;* This includes consideration of Human Factors requirements for the human-machine interfaces associated with these Structures, Systems and Components.
> *2. Due account is taken of the human capabilities and limitations of personnel;* This indicates consideration of Human Factors issues of various kinds, both cognitive and physical.
> *3. Safety design information necessary for safe operation and maintenance of the plant and any subsequent plant modifications is preserved;* Human Factors considerations should be made in designing for both operations and maintenance. This information should be retained with other design information.
> *4. OLCs are provided for incorporation into the plant administrative and operational procedures;* Human Factors issues of various kinds are considered in the Operating Limits and Conditions, potentially including such matters as staffing and hours of work, among others.
> *5. The plant design facilitates maintenance throughout the life of the plant;* It is essential that the activities carried out during maintenance be considered at the earliest stages of design. This will make it possible to optimize the maintainability of the plant, and to minimize human error during maintenance.
> *6. The results of the deterministic and probabilistic safety assessments are taken into account;* This would include human reliability assessment information.
> *7. Due consideration is given to the prevention of accidents and mitigation of their consequences;* This may be done, in part, through consideration of the human elements in significant events, which can count for up to 80% of all events [4, 5]. This would include review of operating experience information from operating facilities, and consideration of Human Factors in the range of safety analysis activities. Again, Human Factors considerations can have a large impact here.

8.10.1	Main Control Room
8.10.2	Secondary Control Room
8.10.3	Emergency Support Centre

which are related to the Human Factors aspects of the design of the *control centres.* These clauses link to the sixth paragraph in clause 7.21.

5.3	Quality Assurance Program
5.4	Proven Engineering Practices

which pertain to Human Factors *verification and validation* activities. These clauses link to the seventh paragraph in clause 7.21.

4.2.4	Accident Mitigation and Management
4.3.3	Operational Limits and Conditions
6.3	Accident Prevention and Plant Safety Characteristics
7.3.1	Normal Operation

which address matters related to the development and use of *procedures.* These clauses link to the fourth paragraph in clause 7.21.

5.5	Operational Experience and Safety Research
5.6	Safety Assessment

which relate to the use of *operating experience* in developing the human-machine interface and operability aspects of the design. These clauses link to the second paragraph in clause 7.21.

6.2	Safety Functions
7.3.3	Design Basis Accidents
7.3.4	Beyond Design Basis Accident
7.9.1	Instrumentation and Control: General Considerations
7.9.2	Use of Computer-based Systems or Equipment
7.9.3	Post-accident Instrumentation
8.4.3	Means of Shutdown: Monitoring and Operator Action
8.10.1.1	Safety Parameter Display System

which address matters related to the Human Factors aspects of the design of *displays and controls*. These clauses link to the tenth and eleventh paragraphs in clause 7.21.

6.6	Facility Layout
7.3.2	Anticipated Operational Occurrences
7.15.3	Lifting of Large Loads
7.19	Transport and Packaging for Fuel and Radioactive Waste
8.6.7	Containment Air Locks
8.10.4	Equipment Requirements for Accident Conditions

which pertain to *ergonomic factors.* These clauses link to the fourth paragraph in clause 7.21.

A second detailed example can be seen in clause 8.10.4 Equipment Requirements for Accident Conditions. The RD-337 text reads as follows:

> *If operator action is required for actuation of any safety system or safety support system equipment, all of the following expectations apply:*

The term "operator action" indicates that Human Factors engineering activities and design processes should be used, which result in effective human-system interface designs that are compatible with human information requirements, capabilities and limitations. This equipment must also be safely operated and maintained in the operational environment, which has Human Factors implications for design.

1. There are clear, well-defined, validated, and readily available operating procedures that identify the necessary actions; In the development of procedures a systematic process must be used using accepted Human Factors procedure-writing principles and practices. This includes planning, research, and drafting the procedure using proper formatting and presentation techniques. The procedure must then be validated to demonstrate that it can be used as intended without the user making errors.

2. There is instrumentation in the control rooms to provide clear and unambiguous indication of the necessity for operator action; In designing displays it is necessary to take into account human capabilities and limitations, and the manner in which humans process information. A Human Factors program, including validation activities, should be applied to develop instrumentation that can be used effectively and without error.

3. Following indication of the necessity for operator action inside the MCR, there is at least 15 minutes available before the operator action is required; This allows the operator to assess the situation and decide on the appropriate procedure to follow to control and mitigate the event in a calm, methodical manner, without being rushed, *and*

4. Following indication of the necessity for operator action outside the MCR, there is a minimum of 30 minutes available before the operator action is required. This allows the field staff to actually get to the field location, assess and respond to the situation in a calm, methodical manner.

4.3.1	Defence in Depth
5.0	Safety Management During Design

which relate to *safety culture*. These clauses link to the third and fourth paragraphs in clause 7.21.

It should be noted that the above are merely examples of a few of the many Human Factors links between clauses in RD-337, and a few of the possible links to clause 7.21.

In looking at RD-337, as it relates to Human Factors, one could apply the rule of thumb: "if humans are involved in designing, maintaining or operating the facility, Human Factors issues must be considered. " For example, if humans use remotely-operated valves or heavy-lift cranes, then the human-machine interface of that equipment should be designed according to Human Factors principles and standards. If humans use procedures, either paper or electronic, for maintenance, normal operations, or emergency situations, then those procedures should be designed using Human Factors principles. If a control station is to be used by humans, either in the Main Control Room or at a field location, then the controls and displays should be designed according to Human Factors

principles and standards. In other words, the consideration of Human Factors applies to anything that may be used by humans, throughout the plant, on both the nuclear and non-nuclear sides.

An additional factor for licensees to consider is the oversight provided to contractors designing the non-nuclear side of the plant. As an example, one vendor, Company x, may design the nuclear side of the plant, using modern Human Factors standards. It may be the case, however, that the non-nuclear side of the plant is designed by a different vendor, Company Y, which may be unfamiliar with Human Factors standards. It is important to note that the license applicant will be expected to demonstrate how they, the applicant, have provided oversight over both the nuclear and the non-nuclear vendors such that the Human Factors-related clauses of RD-337 have been satisfied.

The complete list of all the Human Factors-relevant clauses in RD-337 are listed in Table 1.

Table 1 RD-337 clauses relevant to human factors

Clause	Section Title
4.2.4	Accident Mitigation and Management
4.3.1	Defence in Depth
4.3.3	Operational Limits and Conditions
5.0	Safety Management During Design
5.1	Design Authority
5.2	Design Management
5.3	Quality Assurance Program
5.4	Proven Engineering Practices
5.5	Operational Experience and Safety Research
5.6	Safety Assessment
5.7	Design Documentation
6.1	Application of Defence-in-depth
6.2	Safety Functions
6.3	Accident Prevention and Plant Safety Characteristics
6.6	Facility Layout
7.2	Plant Design Envelope
7.3.1	Normal Operation
7.3.2	Anticipated Operational Occurrences
7.3.3	Design Basis Accidents
7.3.4	Beyond Design Basis Accident
7.4	Postulated Initiating Events Considered in the Design
7.6.4	Allowance for Equipment Outages
7.8	Equipment Environmental Qualification
7.9.1	Instrumentation and Control: General Considerations
7.9.2	Use of Computer-based Systems or Equipment
7.9.3	Post-accident Instrumentation

7.12.2	Safety to Life
7.14	In-service Testing, Maintenance, Repair, Inspection, and Monitoring
7.15.3	Lifting of Large Loads
7.16	Commissioning
7.19	Transport and Packaging for Fuel and Radioactive Waste
7.20	Escape Routes and Means of Communication
7.21	Human Factors
7.22.1	Robustness against Malevolent Acts: Design Principles
7.24	Decommissioning
8.2.1	In-service Pressure Boundary Inspection
8.4.3	Means of Shutdown: Monitoring and Operator Action
8.5	Emergency Core Cooling System
8.6.6	Containment Isolation
8.6.7	Containment Air Locks
8.8	Emergency Heat Removal System
8.10.1	Main Control Room
8.10.1.1	Safety Parameter Display System
8.10.2	Secondary Control Room
8.10.3	Emergency Support Centre
8.10.4	Equipment Requirements for Accident Conditions
8.12.1	Handling and Storage of Non-Irradiated Fuel
8.12.2	Handling and Storage of Irradiated Fuel
8.13	Radiation Protection
9.2	Safety Analysis: Analysis Objectives
9.3	Hazards Analysis
9.5	Probabilistic Safety Assessment

6. Summary

The CNSC is itself using, and expecting licensees to use, an approach to the design of new nuclear facilities that integrates Human Factors into the various design activities. CNSC document RD-337: *Design of New Nuclear Power Plants* presents expectations for the design of new nuclear facilities. Within that document are fifty-two clauses that are relevant to the application of Human Factors in design. RD-337 can be obtained from the CNSC website at:

http://www.nuclearsafety.gc.ca/eng/lawsregs/regulatorydocuments/published/index.cfm

7. References

[1] Canadian Nuclear Safety Commission, *RD-337: Design of New Nuclear Power Plants*. Ottawa, November 2008.

[2] International Atomic Energy Agency, IAEA Safety Standard Series NS-R-1, *Safety of Nuclear Power Plants: Design*, 2000.
[3] Atomic Energy Control Board, *Human Factors Guides*, INFO-0605, October 1993.
[4] Department of Energy, *Human Performance Handbook*, November 2007.
[5] Reason J., *Managing the Risks of Organizational Accidents*, Ashgate Publishing, Aldershot, 1997.