International Standards on Maintainability and Supportability and Their Application to the Nuclear Industry

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ABSTRACT

This paper is being presented on behalf of the Canadian Sub-committee of the International Electrotechnical Commission (IEC) Technical Committee (TC) 56 – Dependability. The objective is to introduce the CANDU® industry to the IEC maintainability and maintenance support standards. The latter are now referred to as Supportability standards where Supportability consists of Maintenance Support and Logistics.

IEC was founded in 1906 and is the world's leading standardization organization for the preparation and publication of International Standards for all electrical, electronic and related technologies; collectively referred to as "electrotechnologies". Almost 175 TCs and Sub-committees (SCs), and ~700 Project/Maintenance Teams, composed of experts from around the world, perform the standardization work of IEC.

IEC TCs and SCs prepare technical documents on specific subjects within their respective scopes. One such TC is IEC/TC 56 with its scope focused on Dependability - a collective term used for reliability, availability, maintainability, and maintenance support (now supportability). By agreement with International Organization for Standardization, IEC/TC 56 develops generic dependability standards so that they are applicable not only to electrotechnologies but also to other technological systems. As a part of this mandate, IEC/TC 56 has developed and continues to develop/improve, among others, a suit of maintainability and supportability standards.

These standards and application guides can be categorized into two groups, namely, those pertaining to Maintainability, and those pertaining to Supportability. Some details of the following standards and application guides, and how they apply to nuclear industry, will be discussed in this paper.

- Maintainability (IEC 60300-3-10)
- Maintainability requirements and studies during the design and development phase (IEC 60706-2)
- Verification and collection, analysis and presentation of data (IEC 60706-3)
- Testability and diagnostic testing (IEC 60706-5)
- Maintenance and maintenance support (IEC 60300-3-14)
- Reliability Centred Maintenance (IEC 60300-3-11)

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- Specification of maintenance support services (IEC 60300-3-16)
- Integrated logistics support (IEC 60300-3-12)

1. INTRODUCTION

In 1965, the IEC (International Electrotechnical Commission) established a Technical Committee, TC 56, to address reliability standardization responding to a 1962 German proposal later approved by the IEC Committee of Action in 1964 [1]. The initial title of IEC/TC56 was "Reliability of electronic components and equipment". In 1980 the title was amended to "Reliability and Maintainability" to address reliability and associated characteristics applicable to products. In 1989, the title was further changed to "Dependability" to better reflect the technological evolution and business needs on a broader scope of applications based on the concept of dependability as an umbrella term. In 1990, following consultations with ISO (International Organization for Standardization), it was agreed that the scope of TC56's work should no longer be limited to the electrotechnical field, but should address generic dependability issues across all disciplines; thus making IEC/TC56 what is referred to as a "Horizontal Committee". The scope of IEC/TC56, according to its Strategic Business Plan, covers the generic aspects on dependability program management, testing and analytical techniques, software and system dependability, life cycle costing and technical risk assessment. This includes standards and application guides related to component reliability, maintainability and supportability, dependability of systems, technical risk assessment, integrated logistics support, dependability management, management of obsolescence, etc.

This paper focuses on the maintainability and supportability related standards prepared and issued by IEC/TC56.

Note: The words, item, system, equipment, component, product, and SSC (structures, systems and components) have been interchangeably used in this paper as appropriate to the context.

2. DEPENDABILITY

2.1 Definition of dependability

Dependability is the term that has been adopted internationally to cover a range of attributes such as availability, reliability, maintainability and supportability. During design and development phase, reliability and maintainability are most relevant so the term R&M is commonly used. During the operations phase, availability comes into play and the acronym RAM (reliability, availability and maintainability) is prevalent. Sometime this becomes RAMS where the "S" can mean safety or supportability. Very commonly, the term Reliability is used as a blanket term to include all of these attributes. This proliferation of terms leads to considerable misunderstanding of this important engineering discipline and thus adds to the need for standardization.

Dependability is the "ability to perform as and when required" [2]. It applies to any physical item such as a system, product, process or service and may involve hardware, software and human actions (or inactions). Dependability is a collective set of time-related performance characteristics that coexist with other requirements of an item such as output, efficiency, quality, safety, and integrity and, in fact, enhances them.

Dependability does not have a single measure that can be attributed to it but is instead a combination of relevant measures that vary with application. In a broad sense, dependability is the trust that can be placed that an item can provide its required functionality and provides expected value and benefits.

2.2 Attributes of dependability

The main dependability attributes of an item are:

- availability for readiness to operate;
- reliability for continuity of operation;
- maintainability for ease of preventive and corrective maintenance actions;
- supportability for provision of maintenance support and logistics needed to perform maintenance.

Dependability is thus a general term that provides a framework for these attributes as well as others such as recoverability, durability, operability and serviceability. Safety is not considered to be a direct attribute of dependability although they are closely related. Safety is enhanced when dependability is integrated into design and operation of an item.

The interrelationship between the main attributes of dependability and their relationship to some key phases in the life cycle of an item is shown in Figure 1 [3].

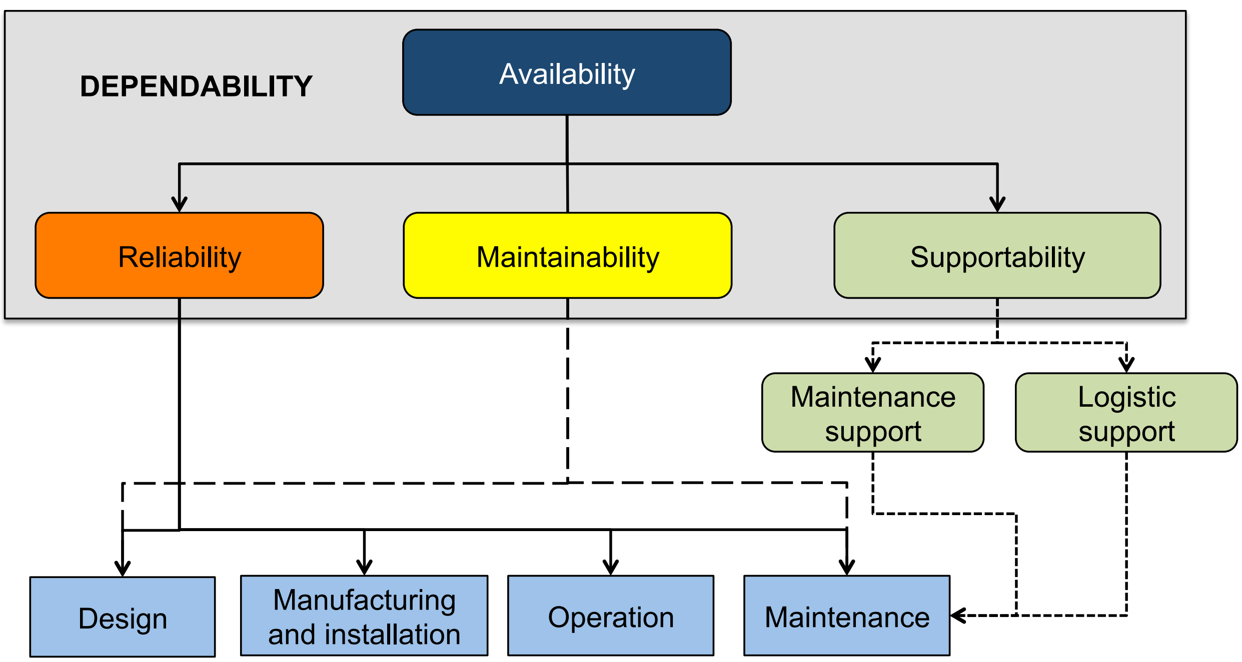

Figure 1: Attributes of dependability in product life cycle

Reliability can defined as the "ability to perform as required, without failure, for a given time interval, under given conditions" [2]. Reliability is an inherent result of the design of an item. The basis for high reliability of an item is its constituents (components, parts) that are designed to resist stresses resulting from applied forces and environmental conditions such as temperature, pressure, and physical and chemical properties. The applied stresses may be static or dynamic. Reliability of the item must then be further enhanced through sound manufacturing and installation techniques. Finally, reliability of the item is sustained by proper operation within prescribed conditions of use and appropriate maintenance.

Maintainability is concerned with the ease, economy, safety, and accuracy in the performance of maintenance activities. Maintainability is defined as the "ability to be retained in, or restored to a state to perform as required, under given conditions of use and maintenance" [2]. Maintainability is dependent on the system design architecture and technology implementation and is guided by maintenance strategies. It is primarily a function of an item's design and installation.

Supportability is the ability for an item to be able to be supported from a maintenance perspective and consists of two components, namely, maintenance support and the logistics required to deliver that maintenance support. The starting point for supportability is the maintainability of the item and this is then combined with specific resources and logistics necessary for the use of the item. It is possible to completely plan and organize the necessary supportability prior to item's operation as is the case with many systems such as a commercial airliner or a railway. However, there are also cases where the maintenance support is only provided when the item is purchased and put into service. A good example would be an industrial gas turbine. The manufacturer will have a recommended maintenance program but it is the responsibility and prerogative of the user how and what maintenance resources will be engaged. The user may choose to involve the OEM either partially or fully in maintenance support. They may decide to outsource the maintenance support to an independent provider or even supply part or all of it themselves.

Availability is the result of a combination of reliability, maintainability and supportability appropriate for the application. For the nuclear industry, it is directly related to plant safety and power generation capability over time.

3. MAINTAINABILITY STANDARDS

3.1 Trends in maintainability and supportability

An overview of recent trends in maintainability and supportability reveals substantial changes that include:

- increased use of condition-based maintenance;
- increased outsourcing of maintenance support and the use of long-term service agreements;
- increased emphasis on human factor considerations;
- wide spread implementation of structured techniques for determining the optimum maintenance program, especially Reliability Centred Maintenance;
- more sophisticated methods for maintenance optimization;
- emphasis on enhancement, refurbishment, life extension, and life management;
- continual cost pressures;
- spare parts agreements with vendors/suppliers and reduction of spare parts inventory by facility operators.

3.2 Maintainability and supportability

Given a system with a certain level of inherent reliability (defined by its design) that is operated within its specifications, maintainability and supportability have a complementary set of attributes that support the maintenance function of the system as presented in Figure 2 [4]. The maintainability attributes together with supportability attributes determine the maintenance performance the systems and its equipment. Supportability attributes can be further divided into those relating to management aspects and those relating to resources required to address maintenance support and logistic support aspects.

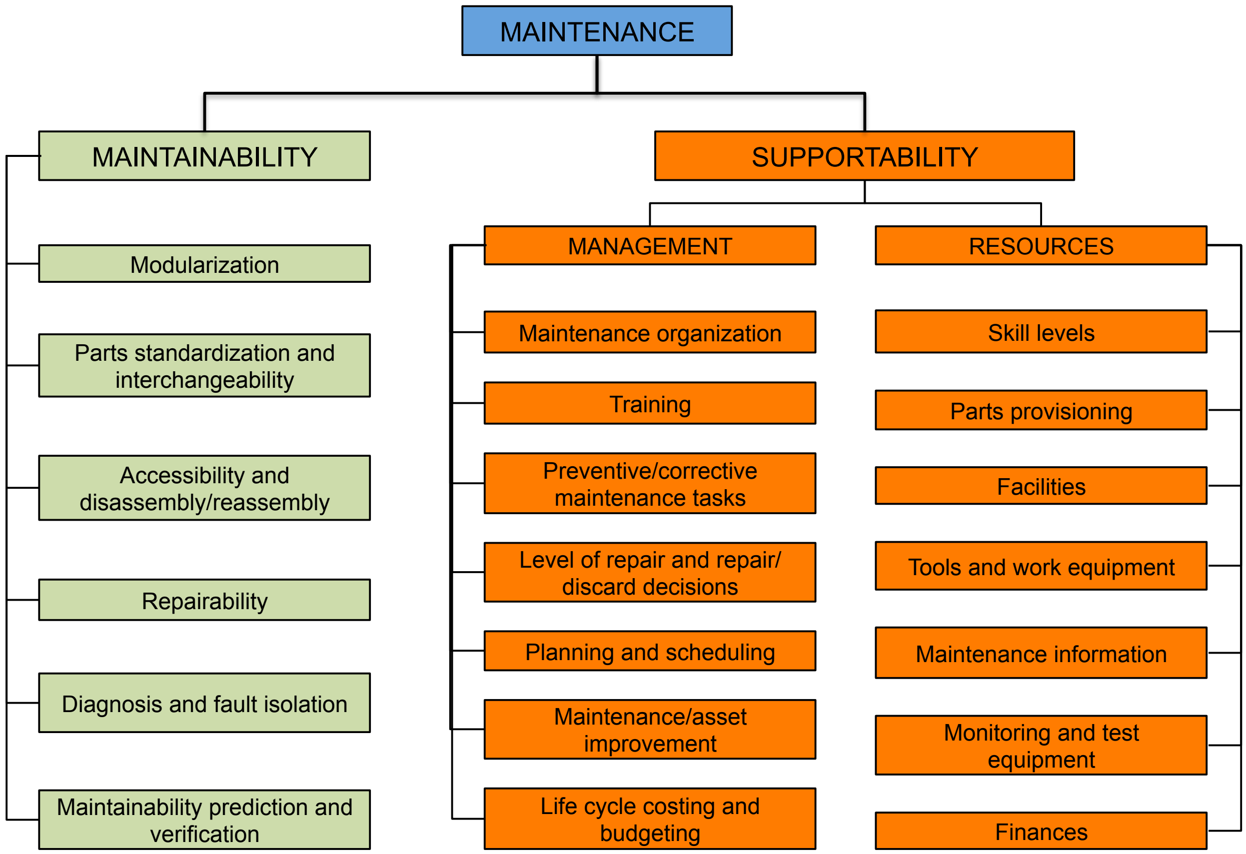

Figure 2: Attributes of maintainability and supportability

Maintainability is an intrinsic characteristic of a system or equipment that is determined by its design and its installation. An item is considered to be maintainable if

- it employs simple design, uses standardized / modular assemblies / components
- its components are readily accessible for removal or repair;
- the skills required to perform the work are as basic as possible given the state of technology of the item;
- diagnostics (either built-in or externally provided by specialized methods or condition monitoring) are available to isolate faults or identify failures;
- standard tools are required for performing maintenance actions;
- comprehensive maintenance documentation (procedures and manuals) are available;
- spare parts are defined and easily acquired;
- repair time is relatively short compared to the scope of the work;
- reassembly is as foolproof as possible;

- software code is developed, documented and maintained using software quality assurance principles / processes.

Designing systems / equipment for maintainability has to compete in projects with other priorities such as cost, schedule and design resources. It is critical to not forget maintainability in view of these competing priorities. Inadequate or neglected maintainability considerations in design of projects such as those relating to nuclear power plants [5] can result in significant long-term negative consequences with immense difficulty and costs to rectify at later stages. Due to this awareness, more recent developments have placed much more emphasis on maintainability and the importance of considering human aspects in maintenance.

Supportability factors are generally determined by the operating organization and often change over the life of the system /equipment. The exception is the process of Integrated Logistic Support discussed in the next section where the entire maintenance support concept is established prior to start of the item's operations phase.

Referring to Figure 2, the most important concern with the required **resources** for supportability is the skill sets of the maintenance staff. Basic skills are needed for general maintenance activities. Some advanced maintenance tasks may require training and certification. The provisioning of spare parts and consumables is also important, without which most maintenance activities are severely constrained. Facilities refer to maintenance-related buildings and yards for maintenance and office staff, repair shops, inventory warehousing and storage of tools and work equipment. Tools and work equipment are another important maintenance resource along with specialized monitoring and test equipment such as portable vibration monitors. Maintenance information may not be an obvious resource but is critical for work order management, planning and scheduling and evaluating maintenance history. Money has to be allocated for all of the above resources and constraints in providing finances to support maintenance.

Again referring to Figure 2, the **management of maintenance** is equally important and dependent on resources. Unless the number of staff involved in maintenance is very small, it will be organized into different departments or sometimes even added to another department such as operations. These organizational units may be geographically split although modern communications technology has done much to counteract physical distances. There is no ideal maintenance organization and the critical management issue is to promote cooperation and communication. The maintenance organization and its supervision and management have the responsibility for ensuring adequate training of staff, planning and scheduling of maintenance activities, the determination of a proper and updated maintenance program of preventive and corrective tasks, policy on the level of repair and repair/discard decisions, improvements, and life cycle costing and budgeting.

3.3 IEC standards on maintainability and supportability

IEC/TC56 standards on maintainability and supportability are interrelated and complementary, as illustrated in Figure 3. While maintainability aspects apply mainly during design and installation, supportability is aimed more at the operational phase where the context changes with external factors and the age of the systems and equipment. IEC/TC56 maintainability and supportability standards are also supported by reliability standards on dependability techniques such as IEC 60812 - Failure modes and effects analysis (FMEA) and IEC 61649 - Weibull analysis.

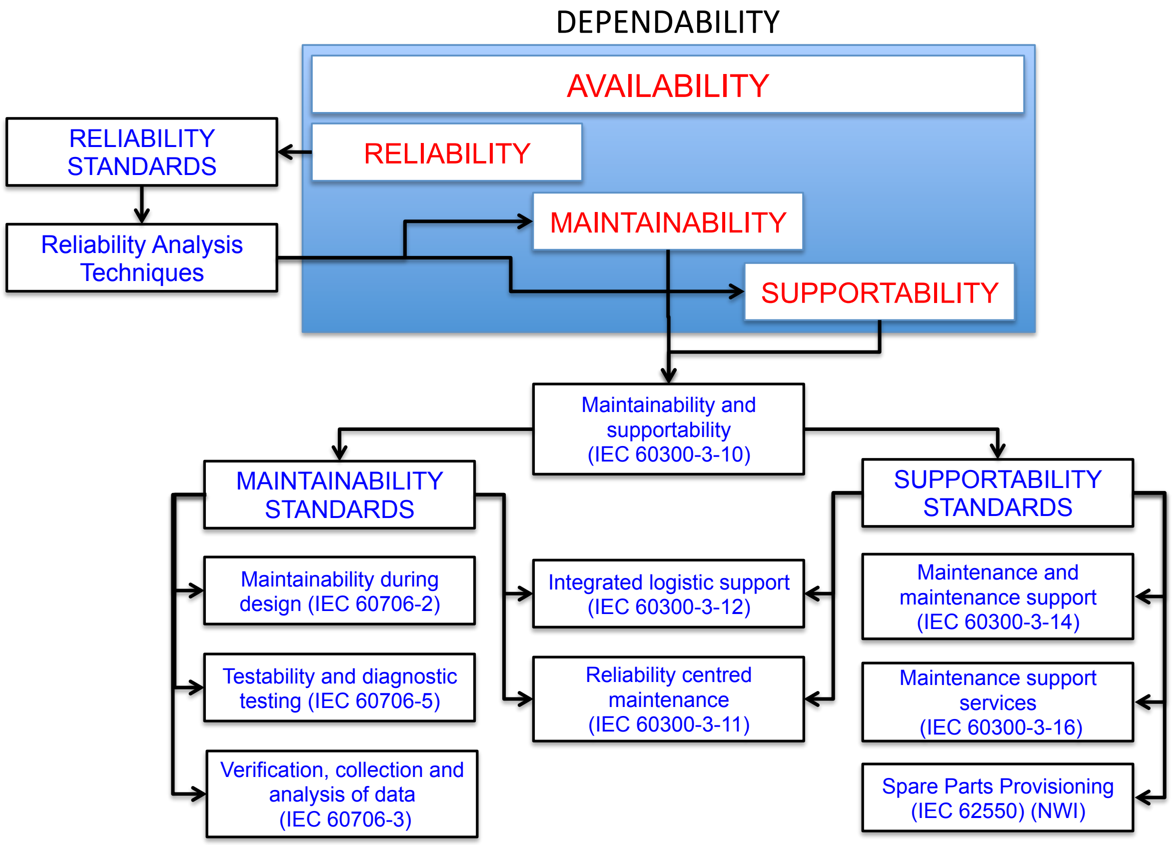

Figure 3: Structure of IEC standards on maintainability and supportability

It should be noted that the suite of IEC maintainability and supportability standards is currently under review and being updated. The standard in Figure 3 that is noted as NWI is New Work Item and will be published in the next year or so.

The lead IEC standard for maintainability and supportability is IEC 60300-3-10. Although, currently this standard is titled as an application guide for Maintainability, it is being repositioned for both maintainability and supportability.

IEC 60300-3-10 Ed. 1.0 Application guide – Maintainability

This application guide can be used to implement a maintainability program covering the concept, design, development, procurement, installation /commissioning, and in-service phases of a system / equipment. It provides guidance on how the maintenance aspects of the tasks should be considered in order to achieve optimum maintainability. It uses other IEC standards, notably, in IEC 60706 series, as reference documents providing guidance on how a specific task should be undertaken.

The following IEC standards are focused on maintainability aspects.

IEC 60706-2 Ed. 2.0 Maintainability of equipment - Part 2: Maintainability requirements and studies during the design and development phase

This part of IEC 60706 series of standards examines the maintainability requirements and related design and use parameter, and provides details of activities necessary to achieve the required maintainability characteristics and their relationship to planning of maintenance. It describes the general approach in reaching maintainability objectives and shows how maintainability characteristics should be specified in a requirements document or contract. It is not intended to be a complete guide on how to specify or to contract for maintainability. Its purpose is to define the range of considerations when maintainability characteristics are included as requirements for the development or the acquisition of an item.

IEC 60706-3 Ed. Maintainability of Equipment – Part 3: Verification, collection and analysis of data

This part of IEC 60706 series of standards describes the various aspects of verification necessary to ensure that the specified maintainability requirements of an item have been met and provides suitable procedures and test methods. This standard also addresses the collection, analysis and presentation of maintainability related data, which may be required during, and at the completion of design and during item's production and operation.

IEC 60706-5 Ed 2.0 Maintainability of Equipment - Part 5 Testability and diagnostic testing

This part of IEC 60760 series provides guidance for the early consideration of testability aspects in design and development, and assists in determining effective test procedures as an integral part of an item's operation and maintenance.

The following IEC standards are focused on supportability aspects.

IEC 60300-3-14 Ed 1.0 Application guide – Maintenance and maintenance support

This standard describes a framework for maintenance and maintenance support and the various minimal common practices that should be undertaken. It outlines, in a generic manner, management processes and techniques related to maintenance and maintenance support that are necessary to achieve adequate dependability to meet the operational needs of the customer. It is applicable to items, which include all types of products, equipment and systems (hardware and associated software). Most of these require a certain level of maintenance to ensure that their required functionality, dependability, capability, economic, safety and regulatory requirements are achieved.

IEC 60300-3-16 Ed 1.0 Application guide - Guidelines for specification of maintenance support services

This standard describes a framework for the specification of services related to the maintenance support of products, systems and equipment that are carried out during the operation and maintenance phase. The purpose of this standard is to outline, in a generic manner, the development of agreements for maintenance support services as well as guidelines for the management and monitoring of these agreements by both the company and the service provider.

IEC 62550 Spare parts provisioning *(under development)*

This standard is intended to describe the requirements, applications and management issues relating to spare parts provisioning to support maintenance and maintenance support activities that sustain continuity of operation of products, equipment and systems for their intended applications. It is expected to be used by a wide range of suppliers, plant / facility owners, maintenance support organizations, etc.

The following standards apply to both maintainability and supportability.

IEC 60300-3-11 Ed. 1.0 Application guide – Reliability centred maintenance

This application guide provides guidelines for the development of an initial preventive maintenance program for structures, systems, equipment and components using reliability centred maintenance (RCM) analysis techniques. RCM analysis can be applied to items such as ground vehicle, ship, nuclear and other power plants, aircraft, etc, which are made up of structures and equipment, e.g., a building, airframe or ship's hull. Typically, an item comprises a number of electrical, mechanical, instrumentation or control systems and subsystems, which can be further broken down into progressively smaller groupings, as required for the purpose of the analysis.

IEC 60300-3-12 Ed. 2.0 Application guide - Integrated logistic support

This standard is an application guide for establishing an integrated logistic support (ILS) management system. It is intended to be used by a wide range of suppliers including large and small companies wishing to offer a competitive and quality item, which is optimized for the purchaser and supplier for the complete life cycle of the item. It also includes common practices and logistic data analyses that are related to ILS.

4. MAINTAINABILITY & SUPPORTABILITY IN NUCLEAR POWER PLANTS

4.1 Need for maintainability and supportability [7, 8, 9, 10, 13]

The need for maintainability and supportability in nuclear power plants arises because the structures, systems, or components / equipment fail (due to the limits to the maximum reliability that can be economically achieved for them) and need corrective maintenance, or to satisfy the need for preventive maintenance. The range of maintenance activities that is involved includes monitoring, inspecting, testing, assessing, calibrating, servicing, overhauling, repairing and replacement. Steps must be taken in the design process to design systems and equipment for improved reliability, maintainability, and supportability resulting in high availability. Maintainability and supportability have usually been considered as a junior partner in the Reliability, Availability and Maintainability (RAM) requirements in RAM Programs that were employed by nuclear utilities in the design of nuclear power plants in North America. There has been a growing realization that maintainability and supportability need attention in their own right. This has been due to the recognition in the utility industry that many of the high costs that are associated with maintenance activities and plant downtime, result from inadequate maintainability and supportability. For example, the cost of replacement energy due to downtime of a nuclear unit of the size of a Pickering unit (~515 MW) in Ontario could easily approach 1M$ per day. In addition to the replacement energy costs, there are costs associated with maintaining the system reserve (System Reserve Costs) and with maintenance activities (maintenance labour, logistics, materials, spare parts, etc.). Additionally, regulatory agencies are also defining the needs for maintenance programs [6].

4.2 Need and incentives for improved maintainability and supportability

It is clear from the review of past experience that plant outages have been caused by or extended due to poor maintainability features, and safety systems have been impaired or temporarily disabled due to maintenance errors. Injuries have occurred because of inadequate design concern for personnel safety features to address conventional and radiation safety, and the productivity of the maintenance personnel has been impaired as a result of insufficient attention to maintainability and supportability requirements. Some of the key concerns identified by plant operators and maintainers include: inadequate system / equipment design; inadequate equipment access; inadequate disassembly / laydown space; inadequate lifting facilities; isolation difficulties; harsh work environment; insufficient power, light, and ventilation services; and high personnel skill / strength demands [10, 11, 13]. Additionally, very little, if any, consideration was given to facilitate work relating to plant refurbishment / life extension thus causing longer refurbishment outages with higher attendant costs. A large percentage of the plant radiation dose is expended during plant maintenance. It is therefore evident that by improving the maintainability and supportability of plant facilities, systems, and components, increases in plant conventional and radiation safety, availability, and productivity occur.

In the past many years, the utilities in North America have been shifting the emphasis to managing existing nuclear plant aging / obsolescence, implementing life cycle management programs, and extending plant lives for another 20-30 years. In order to achieve these objectives, the utilities have established long-term reliability and maintenance plans or for critical structures, systems and components (SSC) – the so called, Life Cycle Management (LCM) Programs. LCM involves systematic methodologies to understand the ageing effects and to ensure that these are detected and mitigated. It is a long-term plan for preventive maintenance, replacement, refurbishment and / or redesign of SSC important to safety and production reliability and to optimize life cycle costs. For existing plants, such plans need to be accommodated within the space, routing and other constraints. Techniques such as Reliability Centred Maintenance (RCM) are used to facilitate achievement of LCM goals [12]. Some nuclear plant design organizations are using processes like COMS (Constructability, Operability, Maintainability and Safety) in plant modification or back-fit processes, although the level of rigour applied needs to be further improved. It is obvious that plant life cycle extension goals can be achieved relatively more effectively if the plant was built with maintainability and supportability in mind.

The new generation of nuclear plants is being designed to achieve a target plant life of 60 years (compared to 30 years initially envisaged for the existing plants) with a lifetime capacity factor of ~ 90%, and a forced outage rate of ~ 1.5%. (50% of the latter may be attributable to the Nuclear Steam Supply System). These are relatively aggressive targets and cannot be achieved without a deliberate and systematic effort to improve the reliability, maintainability and supportability of the critical (e.g., Single Points of Vulnerability) SSCs.

In short, the costs of unavailability and maintenance represent a large incentive for improving plant maintainability and supportability. Worker, radiation and environmental safety also improve by better maintainability and supportability, as it is axiomatic that easy-to-maintain equipment will produce safer plants with fewer accidents and reduced radiation dose to workers.

5. IEC STANDARDS & NUCLEAR POWER PLANT MAINTAINABILITY & SUPPORTABILITY

Several of the issues noted above can be addressed by following a disciplined and systematic approach espoused in IEC standards for addressing maintainability and supportability. As noted earlier, the lead IEC standard on maintainability and supportability, IEC 60300-3-10 provides guidance on the implementation of maintainability and supportability program in different life cycle phases of the nuclear power plants and its SSCs. It identifies tasks such as past experience review, definition of maintenance concept, identification and allocation of maintainability requirements, definition of plant and systems layout, specification of maintainability and supportability requirements in procuring equipment and components, development of maintenance support resource plan, maintenance staff training plans, etc., and provides guidance on how to perform them. Standards IEC 60706-2, IEC 60706-3 and IEC 60706-5 further expand on and give guidance on performing some of the tasks in design and in later phases to achieve optimum maintainability. Similarly, standard IEC 60300-3-14 can help identify for nuclear power plants and its SSCs management processes and techniques that can be used to effectively and efficiently meet the operational needs of the plant and its SSCs while also satisfying any regulatory requirements. If nuclear power plant operator decides to contract out maintenance support services for major pieces of equipment, standard IEC 60300-3-16 can be used to develop and monitor the services contract. Similarly, IEC 62550 may be used in support of determining spare parts provisioning requirements and to optimize spare parts inventory. IEC 60300-3-11 is focused on the technique of Reliability Centred Maintenance (RCM). It can be used to effectively to perform RCM analysis on nuclear power plant systems and equipment to systematically determine the respective maintenance tasks and frequencies based on the probability and consequences of failure. IEC 60300-3-12 deals with Integrated Logistics Support *(ILS)*, which is a management and technical process through which supportability and logistic support considerations are integrated into the design of a system or equipment and taken into account throughout its life cycle. For nuclear power plant systems and equipment, the ILS process can be used to allow for all elements of logistic support to be planned, acquired, tested, and provided in a timely and cost-effective manner. The supplier of the equipment and owner of the plant both benefit from this process through the optimization of the complete life cycle of the equipment.

6. CONCLUSIONS

This paper has provided a brief introduction to the International Electrotechnical Commission (IEC) and its standardization activities. It has highlighted the work of Technical Committee (TC) 56 (IEC/TC56) responsible for standardization in the area of Dependability. The paper further goes to provide internationally accepted definitions of Dependability and its key constituents, namely, Reliability, Availability, Maintainability, and Supportability.

The paper has identified various attributes of Maintainability and Supportability and has provided some discussion on their meaning and role during different life cycle phases of an item.

The key objective in this paper has been to highlight IEC/TC56 standards pertaining to Maintainability and Supportability, and how they can be used in enhancing maintainability and supportability of nuclear power plant systems and equipment. This paper has attempted to do that by identifying the various IEC/TC56 Maintainability and Supportability standards and providing a brief description of each one of them. Based on the experience with existing nuclear power plants, including CANDU plants, the paper has identified some key issues pertaining to inadequate maintainability and supportability of the plants and their SSCs. It has highlighted the need and incentives for making improvements to maintainability and supportability of nuclear power plants. The paper has briefly described how the systematic and disciplined approach espoused in identified IEC/TC56 Maintainability and Supportability standards can be used to address some of the identified issues and enhance maintainability and supportability of the existing and future nuclear power plants and their SSCs.

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