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A new methodology to identify Structures, Systems, and Components needed to cope with Design Extended Conditions in the scope of a Nuclear Power Plant Long Term Operation

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Abstract: To obtain the License Renewal (LR) for the Long-Term Operation (LTO) of a Nuclear Power Plants (NPPs) is important ensuring the integrity of Structures, Systems, and Components (SSCs). Additionally, the SSCs must continue to perform their intended functions under Design Extended Conditions (DEC). DEC encompasses a wide range of conditions beyond the design basis, including both severe and non-severe scenarios. The ageing process can compromise the intended functions of SSCs in a NPP. NPPs must demonstrate their ability to cope with DEC without compromising safety. The objective of this paper is to describe one methodology have been developed to identify SSCs with scope of LR needed to cope with the DEC in LTO. The proposed methodology follows the recommendation of U.S. Nuclear Regulatory Commission (NRC) requirements and the International Atomic Energy Agency (IAEA) safety standards and demonstrating their commitment to safety and environmental protection. The main contributions of the new methodology is to identify the systems, components and subcomponents needed to cope with design extensions conditions that not have Maintenance Program (MP) or Aging Management Program (AMP) and address these components in the plant level AMP or recommend an Aging Managements Review (AMR) according to their characteristic and function. Accomplish the intended safety functions of SSCs throughout the plant's operational lifetime including during LTO is crucial to safety and reliable operation of the plant. An example of application of the proposed methodology is presented.

Keywords: Design Extended Condition (DEC), Long-Term Operation (LTO), Nuclear Power Plants (NPPs), aging management.

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Nova metodologia para identificar as Estructuras, Sistemas e Componentes necessários para lidar com as Condições Estendidas de Projeto no escopo da Extensão de Vida Útil de uma usina nuclear

Resumo: Para obter a License Renewal – LR (licença de renovação) para a Extensão de Vida Útil – LTO (operação de longo prazo) de uma Nuclear Power Plant – NPP (usina nuclear), é importante garantir a integridade das Structures, Systems, and Components - SSCs (Estruturas, Sistemas e Componentes). Além disso, as SSCs devem continuar a desempenhar as funções pretendidas sob Design Extended Conditions – DEC (Condições Estendidas de Projeto). As DEC abrangem uma ampla gama de condições além da base do projeto, incluindo cenários severos e não severos. O processo de envelhecimento pode comprometer as funções pretendidas das SSCs em uma planta nuclear. As plantas nucleares devem demonstrar a sua capacidade de lidar com as DEC sem comprometer a segurança. O objetivo deste artigo é descrever uma metodologia desenvolvida para identificar as SSCs com escopo de LR necessárias para lidar com as DEC na LTO. A metodologia proposta segue as recomendações dos requisitos da U.S. Nuclear Regulatory Commission - US NRC (Comissão Reguladora Nuclear dos EUA) e dos padrões de segurança da International Atomic Energy Agency - IAEA (Agencia Internacional de Energia Atómica) e demonstra seu compromisso com a segurança e a proteção ambiental. As principais contribuições da nova metodologia são identificar os sistemas, componentes e subcomponentes necessários para lidar com as condições extendidas de projeto que não possuem Maintenance Program, MP (Programa de Manutenção) ou Aging Management Program, AMP (Programa de Gerenciamento de Envelhecimento) e abordar esses componentes no AMP em nível de planta ou recomendar uma o Aging Managements Review, AMR (Revisão do Programa Gerenciamento de Envelhecimento) de acordo com sua característica e função. Cumprir as funções de segurança pretendidas das SSCs durante toda a vida operacional da planta, inclusive durante a LTO, é crucial para a segurança e a operação confiável da planta. É apresentado um exemplo de aplicação da metodologia proposta.

Palavras-chave: Condições Estendidas de Projeto (DEC), extensão de vida útil (LTO), usina nuclear (NPP), gestão de envelhecimento.

1. INTRODUCTION

A lot of Nuclear Power Plants (NPPs) were designed to initial 40-year licensed period. These licenses typically have a limited duration, often around 40 years. License renewal processes involve rigorous assessments of a plant's safety, including Aging Management Programs (AMP) of System, Structures and Components (SSCs) to address the effects of deterioration during extended operational period. For the long-term operation (LTO) of NPPs are of crucial importance to ensure their integrity and the availability the required safety function of SSCs. Additionally, it is vital that SSCs ensuring the continued safe operation during Design Extended Conditions (DEC), and these considerations are taken into account during license renewal evaluations.

1.1. Design Extended Condition (DEC)

DEC refers to the condition beyond the normal operating design basis for which a nuclear power plant is specifically designed to ensure safety margins and adequate protection. DEC comprises both event conditions without significant fuel degradation and with core melting [1]. DEC include severe accidents. Currently, Chapter 19 of the Final Safety Analysis Report (FSAR) includes the analysis of severe accidents [2]. In Severe Accident Management Guidelines (SAMGs), various means and resources play a crucial role in accident mitigation strategies. SAMGs focus on limiting the effects of accidents resulting in significant fuel damage and minimizing releases to the environment. The objective of these guidelines is to stop the progression of fuel damage and provide specific actions for accident management. SAMGs play a critical role during DEC situations. SAMGs provide a support for managing unexpected conditions, including those associated with DEC. The Severe Accident Management (SAM) strategy, are the base for the SAMG implementation.

The concept of the design extension conditions is addressed in IAEA Safety Requirements SSR-2/1 Rev. 1 [1] with further details elaborated in IAEA Safety Guide SSG-88 [3].

The IAEA SSG-48 [4] recommends including in the scope of aging management (and LTO respectively) with respect to DEC in para 5.16 (c):

- SSCs needed to cope with design extension conditions or to mitigate the consequences of severe accidents.

1.2. FLEX strategies

The U. S. Nuclear Energy Institute (USNEI) published the Diverse and Flexible Coping Strategies (FLEX) Implementation Guide" [5] in response to the Fukushima Daiichi nuclear disaster that occurred in 2011. The accident highlighted the need for enhanced safety measures and coping strategies for extreme external events (e.g., seismic events, external flooding, etc.) at nuclear power plants. NEI 12-06 report provides FLEX strategies to enhance defense-in-depth (DiD) and address beyond-design-basis external events, such as extreme loss of access to the ultimate heat sink (LUHS) and loss of off-site power, emergency diesel generators and any alternate AC power source (ELAP) simultaneously on a site. FLEX strategies not only increases robustness of the plant against external hazards, but also helps to cope with the DECs or to mitigate the consequences of severe accidents with alternative human actions and the use of on-site and off-side portable equipment. The objectives is restoring the main plant safety function avoiding a significant degradation of the reactor's fuel and spend fuel pool, avoid the hydrogen explosion, and enhanced protection of integrity of the fuel pool and the containment. FLEX includes deploying portable and mobile equipment operated by diesel (such as generators, pumps and air compressor) to provide backup power and cooling. This helps maintain safety systems even when the main power supply is lost. Their mobility allows for flexibility in responding to emergencies. In addition, FLEX encourages identifying and using alternative water sources (e.g., nearby rivers or seawater) for cooling purposes. This ensures a continuous cooling supply for essential equipment.

The U.S. NRC in the Regulatory Guide 1.226 Rev.0 [6] endorsed the guidance provided in NEI 12-06 Rev. 4 [5].

The objective of this paper is to describe one methodology have been developed to identify SSCs with scope of license renewal needed to cope with the DEC in LTO an NPP.

FLEX strategies [5], it may not cover every conceivable strategy or address specific plant design variations. FLEX strategies should be adapted to the specific plant’s needs. Modifications on the design of the plant might be necessary to ensure effective implementation.

SAMGs are critical tools for ensuring nuclear safety during severe accidents, and their development and implementation vary across countries based on their specific regulatory frameworks and plant designs.

The identification of SSCs to cope with DEC includes:

- Post-Fukushima FLEX equipment’s at NPP, and
- Equipment that needs to operate in the severe accident in accordance with relevant SAMGs.

1.3. Relation between FLEX stratigies and SAMGs

FLEX strategies can be used in the SAMG or Severe Accident Management Guidelines, SAG).

The integration of the FLEX and SAMG strategies into the DECs is essential for a comprehensive nuclear safety approach.

FLEX strategies and SAMGs are vital components to copping with DEC in nuclear facilities. They provide the tools and procedures necessary to mitigate the consequences of severe accidents, ensuring the continued safety and protection of the public and the environment during the current and extended lifetime of the nuclear power plant.

1.4. Conventional methodology for Long Term Operation (LTO)

The most NPP applying United States Nuclear Regulatory Commission (USNRC) requirements, such as 10 CFR 54 “License Renewal Rules” (LRA) [7] and 10 CFR 50.65, "Maintenance Rule" (MR) [8] in the NPP Long Term Operation (LTO) Program.

The focus of the License Renewal Rule is on the management of aging degradation of passive and long-lived SSCs at the NPPs. Passive, long lived SSCs within the scope of 10 CFR Part 54 are subject to an Aging Management Review (AMR) to maintain safety during the extended license period (i.e., additional 20 years of operation). Passive components are concrete structures, containment vessels, water storage tanks, heat exchangers, cables, valve and pump bodies, and piping. Long-lived items are those that are not subject to replacement.

Aging of active components, which are excluded from 10 CFR Part 54 scope, is accomplished through the “Maintenance Rule” (10 CFR Part 65). The Maintenance Rule implement effective programs for maintenance (preventive, corrective, and surveillance testing), inspection, and testing of safety-related SSCs to prevent degradation of SSCs and maintain their continued reliability during the plant’s operational life.

NUREG-1800 Appendix A [9] incorporates the utilization of NUREG-1801 (2010) [10] for assessing AMPs. NUREG-1801 provide the generic Aging Management Programs (AMP) to identify the basis for determining their adequacy without change and when they should be enhancements during license renewal.

Preventive maintenance is generally performed during the shutdown modes, and its time interval is about 12–18 months. Regular testing, inspection, and preventive maintenance is performed during the normal operation modes, and it is time interval is generally a few days or a few weeks. Corrective maintenances are performed after failures, and their intervals are not fixed and their time intervals may vary from days, weeks or months.

The safety classification of SSCs [11] is not discussed in this work. Others work [12-14] addresses this topic.

Active components (such as pumps, valves, and electrical systems) need regular maintenance to ensure their functionality.

The screening process uses the results of 10 CFR Part 54 scoping to identify those components to be subject to AMR.

The conventional methodology not includes the SSCs needed to cope with DEC.

2. PROPOSED METHODOLOGY

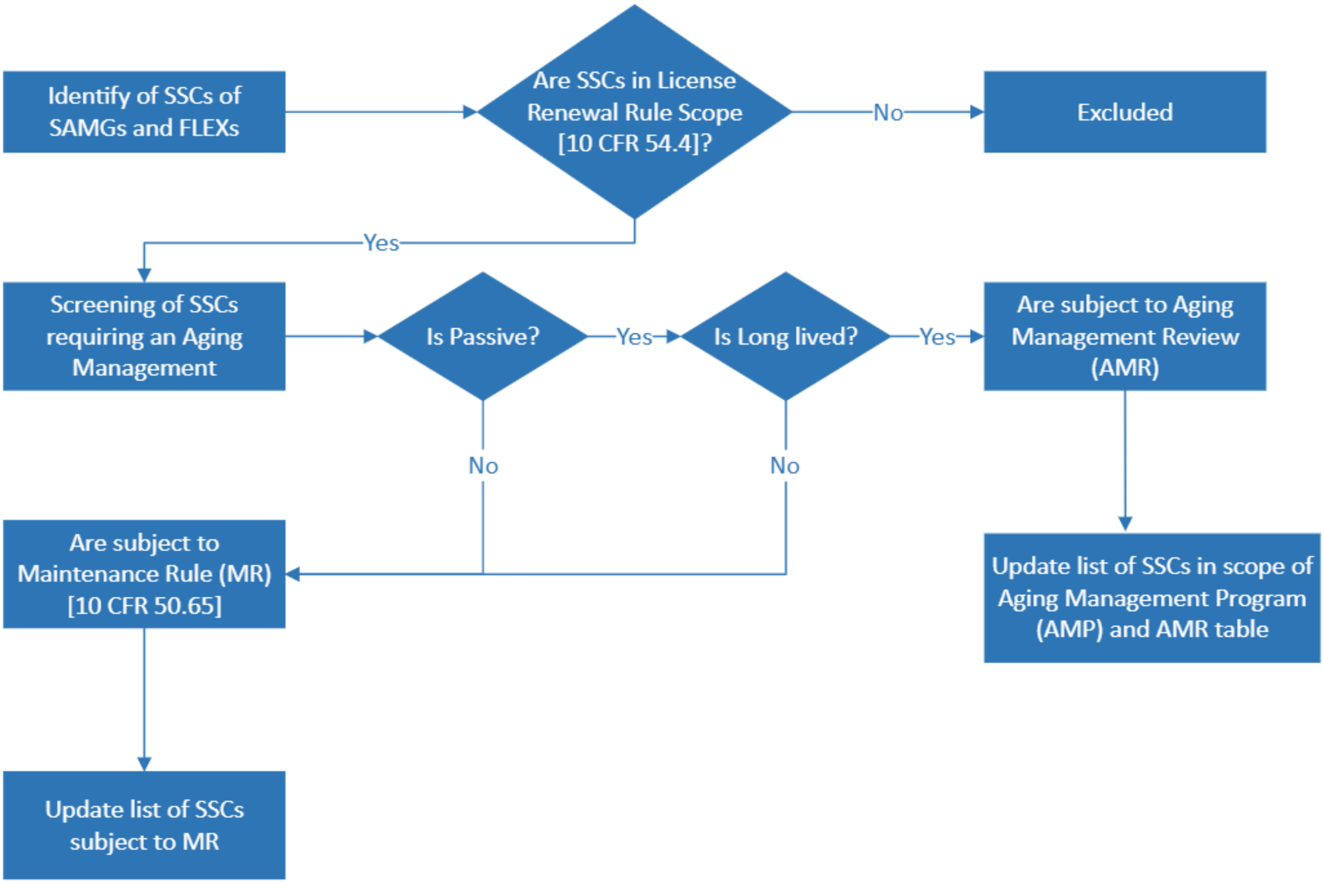
The proposed methodology to identify SSCs needed to cope with DEC in the scope of a NPP LTO was divided into main steps as outline below:

1. Identify of SSCs –based on the SAMGs and FLEXs strategies.
2. List of SSCs are in scope of License Renewal Rule as stated in 10 CFR 54.4 Components that do not fulfill all these criteria are not subject to an Aging Management Review (exclusion criteria).
3. Screening of SSCs requiring Aging Management. The screening process identifies the SSCs in passive, active and long-lived. The passive and long-lived are subject to AMR. The active are subject to Maintenance Rule (10 CFR 50.65).
4. Update list of SSCs subject to MR.
5. Update list of SSCs with scope of AMP and AMR table.

To perform the scoping and screening, it is necessary to consult the SSCs databases of the NPP.

These steps of the proposed methodology are shown in the Figure 1, Table 1 and 2.

Figure 1: Proposed methodology to identification of important SSC for coping with Design Extension Conditions in Long Term Operation of NPP. Source: Authors



The AMR process involves reviewing AMP for various combinations of system (e.g. reactor coolant system), structure (e.g. reactor coolant pumps), or component (e.g. piping), critical location or part, material (e.g. stainless steel), environment (e.g. reactor coolant), and ageing effect, and degradation mechanism (e.g. stress corrosion cracking). The AMR evaluates the effectiveness of these AMPs and ensures that they can effectively manage ageing effects to maintain the intended safety functions of SSCs throughout the plant's operational lifetime (including LTO).

2.1. An example os application of the proposed methodology

2.1.1. Identify of SSCs –based on the SAMGs and FLEXs strategies

Table 1: List of SSCs based on the SMAGs and FLEXs.

Item	Group	Description
Mobile Diesel Generator	FLEX	Restoring the cooling function of reactor and spent fuel pool against Extended Loss of Alternating current (AC) power (ELAP) ELAP accidents
Portable Diesel pump	FLEX	During the Ultimate Heat Sink (UHS) the water inventory remains available.
Portable Air Compressor	FLEX	Using to supply air for Air Instrument Systems important to managing the response to the accident.
Passive Autocatalytic Recombiner (PAR) [15]	SAG	Removes hydrogen from the containment during a severe accident avoiding the hydrogen explosions.
Filtered Containment Venting System (FCVS) [16]	SAG	System designed to minimize the release of fission products during a severe nuclear accident avoiding the containment overpressure failure.
Valve X	SAG	System X
Pipping Y	SAG	System Y

Source: Authors

2.1.2. Analyze scope of License Renewal Rule based on 10 CFR 54.4

The scope of license renewal for nuclear power plants as specified in 10 CFR 54.4, includes safety-related systems, structures, and components, as well as nonsafety-related systems and those relied upon in safety analyses:

1. Safety-Related Systems, Structures, and Components (SSCs): These are crucial elements that must remain functional during and after design-basis events to ensure nuclear safety.

    1.1. Integrity of the Reactor Coolant Pressure Boundary: This refers to systems and components that maintain the primary coolant system's integrity, preventing leaks that could compromise reactor safety.

   1.2. Capability to Shut Down and Maintain Safe Shutdown: Systems that allow for the safe shutdown of the reactor in emergencies, ensuring it can be safely cooled and controlled.

   1.3. Capability to Prevent or Mitigate Consequences of Accidents: Systems and structures designed to prevent accidents or mitigate their consequences to prevent offsite exposures and protect public health and safety.

2. Nonsafety-Related SSC: These include components whose failure could impact the functions of safety-related systems mentioned above. While not directly related to safety functions during accidents, they are important for overall plant reliability and operational efficiency.
3. SSC Relied on in Safety Analyses: These systems are essential for demonstrating compliance with regulatory requirements for various scenarios:

   3.1. Fire Protection: Systems that prevent and mitigate the impact of fires on safety-related equipment.

   3.2. Environmental Qualification: Equipment and components that remain functional under environmental conditions encountered during normal operation and postulated accidents.

   3.3. Pressurized Thermal Shock (PTS): Systems that resist fracture due to rapid temperature changes.

   3.4. Anticipated Transients Without Scram (ATWS): Systems that ensure safe reactor response during abnormal transient conditions.

   3.5. Station Blackout (SBO): Systems that maintain core cooling and containment integrity during loss of offsite power.

Compliance with these requirements ensures that the NPP can continue to operate safely and effectively during the extended period covered by license renewal beyond the initial 40 years.

2.1.3. Screening process. Classify in active or passive

Table 2: Classification in active or passive the SSCs.

Item	Classification	Subject to MR	Subject to AMP
Mobile Diesel Generator	active	X	
Portable Diesel pump	active	X	
Portable Air Compressor	active	X	
Passive Autocatalytic Recombiner (PAR) [12]	passive		X
Filtered Containment Venting System (FCVS) [13]	active	X	
Valve X	active + passive	N/D	N/D
Pipping Y	passive	N/D	N/D

Source: Authors

3. RESULTS AND DISCUSSIONS

The components (“Valve” X and “Piping” Y) as are within the scope of license renewal (54.4) should be included in the list of AMR and AMP or Maintenance Program according to Licensing Renewal Applications (LRA) in the context to LTO.

Components subject to AMR are those components that perform an intended function without moving parts or without a change in configuration or properties and are not subject to replacement based on qualified life or specified period (passive).

In the United States of America, the in-service inspection, maintenance testing, and repair of NPP components is based on American Society of Mechanical Engineers Section XI (ASME Section XI) Boiler and Pressure Vessel Code (BPVC) requirements [14].

The AMR is updated typically every 5 to 10 years, or as required by national regulations.

AMR tables can be used to determine if new AMPs need to be developed.

The example of application of the proposed methodology is hypothetical because the NPP is composed by hundreds of components to cope de DEC.

The methodology proposed complies with the US NRC requirements and the IAEA safety standards.

- Complies with the guidance provided in NEI 12-06 Rev. 4 "Diverse and Flexible Coping Strategies (FLEX) Implementation Guide" [5], that was endorsed by the US NRC [6];
- Meets the intent of the Requirement 20: Design extension conditions of IAEA Safety Requirements SSR 2/1 (Rev.1) [1];
- Meets the intent of the Recommendations provided in para 7.20, in particular para. 5.16(c) of the IAEA Safety Guide SSG-48 [4].

The proposed methodology allowing identifying the:

- SSCs are required for coping with DEC not addressed for renewal of operating licenses during long term operation period;
- SSCs credited in Severe Accident Management (SAG) Program and currently are not included in in AMP or MR programs.

The contribution of proposed methodology for identifying structures, systems, and components (SSCs) crucial for coping with Design Extension Conditions (DEC) in the context of Nuclear Power Plant (NPP) Long Term Operation (LTO) is significant for ensuring the safety and reliability of nuclear power plants to continue operating beyond their originally lifetime.

The main contribution of proposed methodology is that identify SSC that did not have Maintenance or Aging Management Program and address these components in the plant Maintenance Programs or recommend an Aging Managements Review according to their characteristic and function. The identification of the most critical SSCs to copping with the DEC and prioritizing maintenance, inspection, and replacement activities can help optimize the allocation of resources and ensure the efficient operation of nuclear power plants during their extended lifetimes.

Accomplish the intended safety functions of SSCs throughout the plant's operational lifetime including during LTO is crucial to safety and reliable operation of the plant.

In addition, maintaining the long-term operation of nuclear power plants is essential for ensuring a stable, low-carbon energy matrix.

4. CONCLUSIONS

The new methodology proposed in this paper identifies the most important SSCs with scope of license renewal needed to cope with the DEC in LTO a NPP.

We expect that the methodology presented in this paper can be applied in the Angra 1 NPP.

The methodology allows the identification of SSCs credited in the SAM Program but not included in the AMP and MR that is essential for maintaining safety and reliable operation of the NPP.

Another contribution is that the identification of SSCs not included in the AMP and MR to the license renewal process for extended operation can reduce the risk resulting from aging effects and ensuring the continued safe operation of nuclear power plants.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

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