

Code Requirements for Fuel Handling Equipment at Nuclear Power Plant

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This study provides technical information about the nuclear fuel handling process, which consists of various subprocesses starting from new fuel receipt to spent fuel shipment at a nuclear power plant and the design requirements of fuel handling equipment. The fuel handling system is an integrated system of equipment, tools, and procedures that allow refueling, handling and storage of fuel assemblies, which comprise the fuel handling process. The understanding and reaffirming of detailed code requirements are requested for application to the design of the fuel handling and storage facility. We reviewed the design requirements of the fuel handling equipment for its adequate cooling, prevention of criticality, its operability and maintainability, and for the prevention of fuel damage and radiological release. Furthermore, we discussed additional technical issues related to upgrading the current code requirements based on the modification of the fuel handling equipment. The suggested information provided in this paper would be beneficial to enhance the safety and the reliability of the fuel handling equipment during the handling of new and spent fuel.

Keywords: Fuel handling, Fuel handling equipment, Refueling, ANSI/ANS-57.1

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1. Introduction

This study provides technical information for the fuel handling process starting from new fuel receipt to spent fuel shipment at a nuclear power plant and the design requirements of fuel handling equipment (FHE). The FHE should be designed in the viewpoints of safety functions for fuel handling, efficiency for operation and maintenance of the FHE and decommission at a nuclear power plant. Technical information provided in this paper would be beneficial suggestion to enhance the safety and the reliability of the FHE during the handling of new and spent fuel.

2. Configuration and Arrangement of Fuel Handling Equipment

The fuel handling system is an integrated system of equipment, tools, and procedures that allow refueling, handling and storage of fuel assemblies from the receipt of new fuel container to the shipment of spent fuel cask. The FHE moves fuel assemblies within reactor, transfers them to the spent fuel storage pool for interim storage, testing and inspection, loads them into a cask for in-site storage or off-site shipping. Control components relocated within the reactor core are also handled for inspection, repair, or

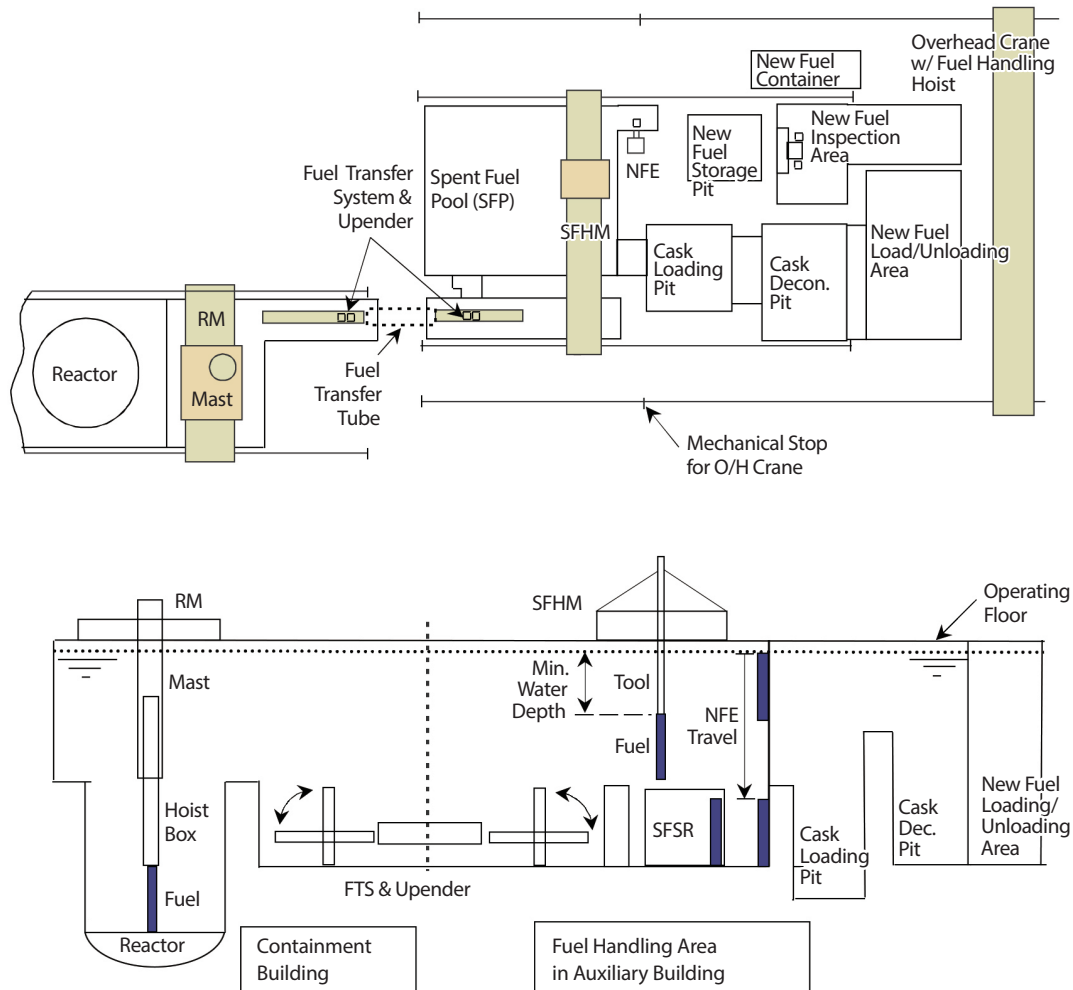


Fig. 1. Typical General Arrangement of Fuel Handling Equipment.

disposal, as required.

The major components of the system are the Refueling Machine (RM), the Spent Fuel Handling Machine (SFHM), the Fuel Transfer System (FTS), the New Fuel Elevator (NFE), the CEA Change Platform (CEACP), the CEA Elevator (CEAE), and various tools. The overhead crane in the auxiliary building and the polar crane in the containment building are used for handling heavy components such as reactor internals and a spent fuel cask. Fig. 1 shows the arrangement of the FHE in the containment building and the fuel handling area in auxiliary building. As a main equipment, the RM which is a traveling bridge and trolley structure in the containment building, is used to transport new and spent fuel assembly from the reactor core to the transfer system upender. Fig. 2 shows details of the RM. It is also used to move the ICI/CEA transport container from the transport container storage rack to the

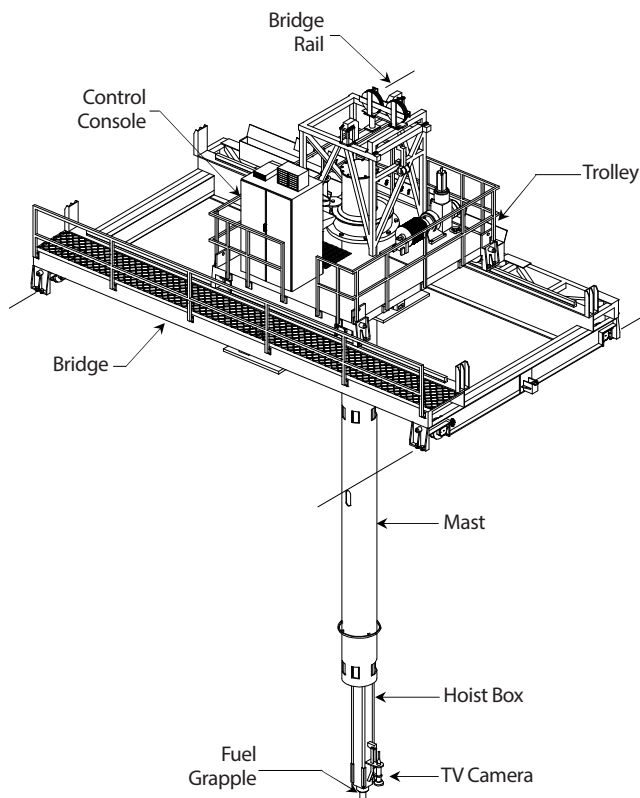


Fig. 2. Refueling Machine.

transfer system upender and to handle the dummy fuel during equipment testing. The RM hoist box with grapple assembly is supported by the trolley and is used to load and unload fuel assemblies in the reactor and the transfer system upender. When the RM is operating over the reactor, the hoist box is extended out of the mast. The grapple is lowered out of the hoist box and locked onto the fuel assembly. The fuel assembly is then raised into the hoist box and the hoist box raised into the mast. The SFHM (see Fig. 3 for details) located in the fuel handling area consists of a bridge, a trolley, and a hoist tripod assembly. It moves on rails so as to provide area coverage for the new and spent fuel storage racks, the new fuel elevator (NFE), the cask loading pit, the new fuel inspection area, the spent fuel inspection station and the FTS upender in refueling canal of the fuel handling area. The cask handling overhead crane is used for receiving a new fuel container in the new fuel loading/unloading area and for shipment of a spent fuel cask in the cask loading pit and the decontamination pit. The fuel handling auxiliary hoist of the overhead crane is used for handling

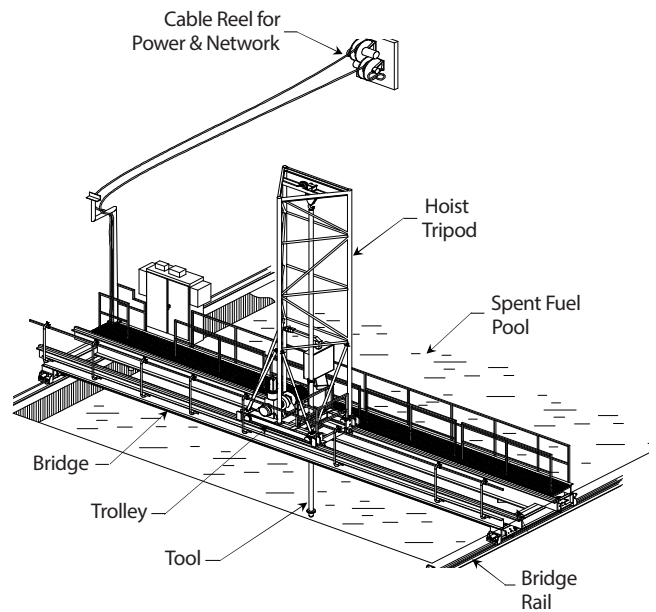


Fig. 3. Spent Fuel Handling Machine.

the new fuel assembly during transfer from the new fuel container in the laydown area to the new fuel inspection station. Before new fuel assemblies are placed in the spent fuel storage racks at the beginning of plant installation, mechanical stops are installed on the overhead crane bridge rails to prevent passage of the hoist over the Spent Fuel Pool (SFP). The overhead crane hoist has a specific hoist loading capacity and incorporates a variable speed and electrical interlocks to control bridge and trolley travel.

3. Fuel Handling From New Fuel Receipt to Spent Fuel Shipment

The fuel handling procedures from new fuel receipt to spent fuel shipment are provided in this section. These procedures are divided into 4 categories as follows; 1) receipt, inspection and storage of the new fuel assembly, 2) preparation of the new fuel assembly for refueling, 3) refueling between the reactor core and the Spent Fuel Storage Rack (SFSR), 4) packing and shipment of the spent fuel assembly. Fig. 4 shows transfer path from the new fuel receipt to spent fuel shipment between the containment building and

fuel handling area in the auxiliary building.

3.1 Receipt, Inspection and Storage of New Fuel

After arrival of a new fuel container, the containers are transferred and secured to the operating floor in the new fuel laydown area. The new fuel handling tool, attached to the fuel handling hoist, is then locked to a fuel assembly and it is removed from the container. Next, the new fuel assembly is inspected by a new fuel inspection device before placement into the new fuel storage racks and the operation repeated until all fuel assemblies have been placed into the racks.

3.2 Preparation of New Fuel for Refueling

Prior to refueling operations, a new fuel assembly is removed from the new fuel storage racks and transferred to the new fuel elevator by using the SFHM or the fuel handling hoist. The new fuel elevator lowers a fuel assembly into the spent fuel pool to allow the SFHM to transfer a new fuel assembly to the spent fuel storage rack in the spent fuel pool or to the transfer upender.

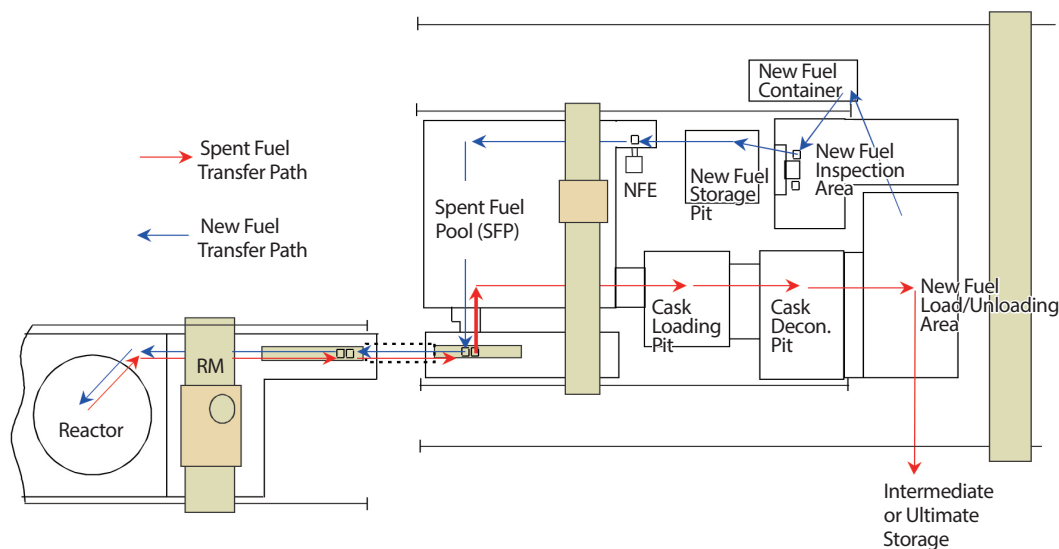


Fig. 4. Transfer Path from Fuel receipt to Spent Fuel shipment.

3.3 Refueling Between Reactor Core and Spent Fuel Storage Rack

During refueling operation in domestic nuclear power plants, all the fuel assemblies are removed from the reactor core for inspection and maintenance of the main components as scheduled. For unloading from a reactor, the spent fuel assembly is moved underwater to the transfer carriage in the containment building by using the RM and the transfer carriage is set to the horizontal position. After the fuel has passed through the transfer tube, the upender machine in the fuel handling area returns the transfer carriage to the vertical position. The SFHM removes the spent fuel assembly from the upended transfer carriage and places it to the spent fuel storage rack. This process continues until all fuel assemblies have been transferred to the spent fuel storage rack. Typically, one-third of the fuel assemblies during a refueling outage are replaced and rearranged in the reactor core. The spent fuel assemblies, after being in the reactor for 3 to 6 years, are stored underwater in the spent fuel pool for a suitable decay period that is typically a minimum of five years. Fig. 5 shows refueling procedure and main activities during refueling outage. Fuel handling is an important task, which is large portion (35%) in the total refueling time, as a critical path. The procedure and detailed activities for shut-

down /startup prior to fuel offloading/ loading in the reactor core are provided in Fig. 5. During and after the spent fuel discharge from the reactor to the spent fuel pool, spent fuel assemblies are examined by visual inspection and ultrasonic test in the refueling canal or the spent fuel pool.

3.4 Packing and Shipment of Spent Fuel

The SFHM transfers the spent fuel assembly from the storage racks to the spent fuel cask for the intermediate storage. This operation is implemented when the fuel cask loading pit is filled with the same water level of the spent fuel storage pool water and the gate between the spent fuel pool and the cask loading pit is opened. After the spent fuel assemblies are loaded into the cask, the cask is sealed and transferred to the cask decontamination pit with the cask handling hoist. Then it is transferred to the truck loading & un-loading area with the cask handling hoist for intermediate and/or ultimate storage. The cask handling overhead crane is restricted from moving the spent fuel cask over the spent fuel pool which could be damaged by dropping the cask in accordance with position of Regulatory Guide 1.13 [1]. Provisions in design of the cask handling crane are provided to prevent any heavy load drop resulting in damage to safety-related systems and/or component

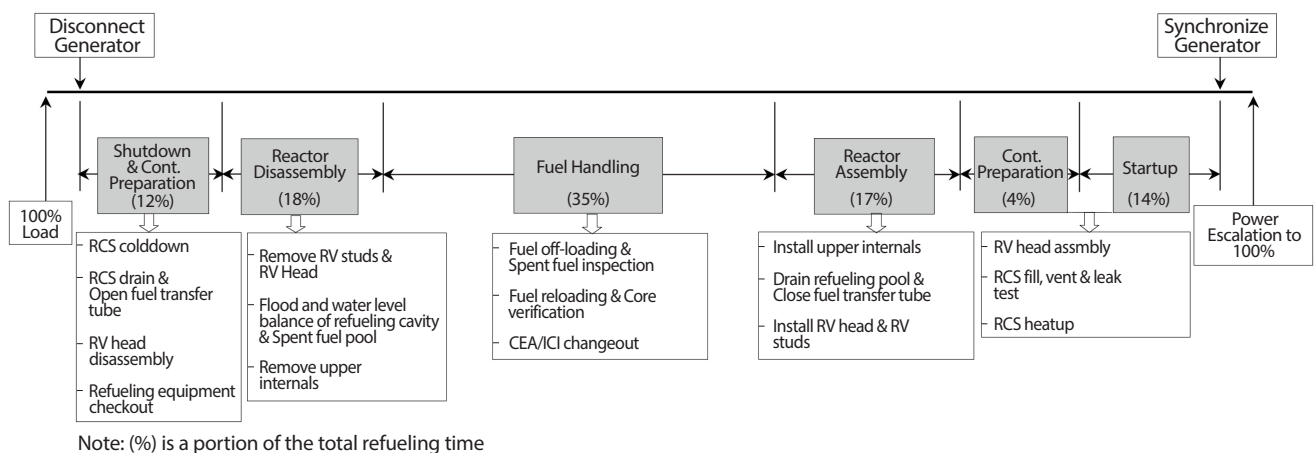


Fig. 5. Refueling procedure and main activities during refueling outage (typical).

during load handling. These provisions include mechanical stops, electrical interlocks and administrative controls. Another regulatory guideline, NUREG-0612 [2] describes the alternative approaches to provide acceptable measures for the control of heavy loads.

4. Design Requirements for Fuel Handling Equipment

Domestic licensing of the FHE requires that the equipment be designed to ensure adequate safety under anticipated operating and accident. These section identify and define the functions of the major interlocks contained in the FHE. The FHE should be designed to ensure protection to plant personal and to the public, adequate coolant circulation for protection of the fuel from thermal damage, prevention of criticality, prevention of fuel damage and radiological release. To meet these design requirements, the fuel handling system should be designed to handle fuel assemblies using the equipment and the guidelines with a high degree of reliability. The reliability of efficiency can be achieved in design of the fuel handling system by using simple and direct operation. All machines in each fuel handling system are networked together to provide a simple method for communicating machine status and other pertinent information from one machine to another. The ANSI/ANS 57.1 [3] defines the design requirement for the FHE. The equipment includes interlocks, travel-limit features, and other protective devices to minimize the possibility of mishandling or equipment malfunction that could result in advertent damage to fuel assemblies and potential fission product release. Design stresses for equipment involved in grappling, latching, translating, rotating, supporting, or hoisting fuel assemblies should be designed to ensure that there will not be a structural failure of any part of the handling equipment which would result in dropping or damaging a fuel assembly. Design life, radiation damage resistance, maintainability and ease of decontamination should be considered in the design

of the equipment. System components should be designed and installed to allow testing and maintenance as design requirements specified in Regulatory documents [1, 4] and industry standards [3, 5]. In order to meet design criteria for the FHE, the provisions for a protection from a physical fuel damage and a radiological release, residual heat removal capability and maintenance of a sub-criticality, and an operability and maintainability specified in the industrial codes and regulatory documents should be considered.

4.1 Protection From a Fuel Damage and a Radiological Material Release

To prevent any damage to the fuel assemblies that uncover in a condition of radiological release or potential offsite exposures to the public, safety devices should be designed for the system of the FHE. The components for the FHE involved in grappling and hoisting fuel assemblies should be designed to ensure that there would not be a structural failure of any part of the FHE that would result in damaging of the fuel assemblies. The safety devices such as grapples and latches which carry a fuel assembly should be designed such that an accidental opening is mechanically prevented. Following mechanical and electrical interlock system in the design of the FHE should be designed to prevent any damage to fuel assembly and to provide for a personnel safety as follows: 1) Underload and Overload interlock to prevent a potential cause of mechanical damage to the spent fuel assembly, 2) Up-Position and Down-Position interlock to ensure suitable radiation shielding, 3) Mechanical hard-stop for a translation limitation, 4) Up-Limit (or down-limit) for a physical limitation to hoisting, 5) Slow zone interlock for a travel region in specific zones and elevations, 6) Non-simultaneous motion interlock against simultaneous hoisting and translation, 7) Grapple release interlock, 8) Bridge and Trolley Travel interlock to translating in secure zones, 9) Slack Cable interlock actuated to prevent a further downward position, 10) Translation inhibit interlock, 11) Interfaced interlock between the RM (or SFHM) and the FTS

Table 1. Interlock Design Requirement of Fuel Handling Equipment (typical)

	Undeload/ Overload	Up/Down Position	End-Travel (Hard-stop)	Up-Limit	Non- Simultaneous Motion	Bridge/Trolley Travel	Translation Inhibit
Fuel Handling Machine	X ^a	X	X	X	X ^b	X ^b	X ^{b,c}
New Fuel Elevator	X ^d	X		X			
Auxiliary Fuel Handling Crane	X ^e	X	X	X ^f	X ^b	X ^{b,c}	
Fuel Transfer Mechanism	X		X				
U-pender	X	X	X				
Refueling Machine	X	X	X	X	X ^b	X ^b	X ^{b,c}

NOTE:

^a Except when handling new fuel assemblies or new control components out of water.^b Except when hand or manually actuated.^c Except with jogging circuit with approximately 1.5-mm (1/16-in.) increments.^d To prevent raising elevator containing a fuel assembly.^e Special restriction over fuel pool to limit load to that which racks and liners are designed to withstand.^f Main power cut-out switch to prevent “two blocking”.

upender to ensure a proper equipment positioning. Table 1 shows the typical interlock design requirement of the FHE.

4.2 Cooling, Shielding and Prevention of Criticality

All the FHE should be designed to prevent an accidental criticality during fuel handling. In the event of an unexpected failure, the fuel assembly should remain in a safe condition and location for an adequate cooling and shielding. Removal of decay heat during spent fuel handling is also an important safety consideration for protection of fuel cladding failures or mechanical damage. The component of the FHE should be designed so that the operators will not be exposed to $\geq 2.5 \text{ mrem}\cdot\text{h}^{-1}$ from a spent fuel elevated to the up position at a normal operating water level [3]. Lifting a fuel above the maximum height is prevented by a positive mechanical stop. Provisions for maintaining adequate water levels are important not only for fuel cooling, but also for

the shielding effect. The pictorial illustration of minimum water depth for an operator shielding is shown in Fig. 1.

4.3 Operability and Maintainability

The FHE should be designed to operate in an efficient manner with a high degree of reliability. Design life, radiation damage resistance, maintainability, and the ease of a decontamination should be considered to the design of the FHE in an initial design step and its equipment should be located in areas accessible for an operation, testing, inspection, and maintenance. The components of the FHE should be standardized one by the industrial standards to permit an easy replacement of the parts between similar pieces of equipment. Maximum use should be made of the commercially standard available parts and hard-ware. All the components which are normally submerged in refueling water should be removable and / or replaceable with ease without lowering the refueling pool water levels. All the control

components of the FHE should be located in removable modules with quick disconnects to permit a removal from the containment building at the end of a refueling outage.

5. Proposal on Upgrade of Design Criteria for FHE

The ANSI/ANS-57.1 [3] was first issued in 1980 as a guideline for the designer of the FHE. This guideline has been reviewed and reaffirmed in 1992 and 2005 without reflecting recent industry initiatives. The design of FHE has been improved to enhance safety function in fuel handling and to increase operation efficiency by modifying the components and control system during the construction in domestic nuclear power plants since the mid of 2005. An operator interface is proposed to provide with the FHE control console that includes a monitor. The monitor provides the operators with easy-to-understand information on interlock status, current load conditions and bridge, trolley, and hoist position indicating the location of the machine with respect to the reactor and the spent fuel storage racks. The additional design requirements are clarified and proposed for upgrade of the current code requirements as follows:

- 1) design criteria for off-index operation of the RM at Reactor,
- 2) design criteria for hoist slow speed zone for the RM and the SFHM,
- 3) design criteria for interlock system between the RM (or SFHM) and the FTS Upender,
- 4) design criteria for application of multi selection switches for various fuel handling,
- 5) design criteria for cooling requirement in case of fuel stuck in the RM and the fuel transfer tube,
- 6) design criteria for fuel hoisting load recording and fuel movement log,
- 7) design criteria for configuration of operating signals and switches in the control console for operators,
- 8) design criteria for the sensors (the encoders and the load cells) for operation reliability of the FHE,
- 9) design criteria for function of the self-diagnosis system.

These new design criteria will enhance the safety in fuel handling for the FHE.

6. Conclusions

The fuel handling process and design requirements for the FHE based on the regulatory documents and the industrial codes and standards are reviewed. The design requirements of the FHE for its adequate cooling, prevention of criticality, its operability and maintainability, and for the prevention of fuel damage and radiological release were reviewed. Additional technical issues related to upgrading the current code requirements based on the modification of the fuel handling equipment are suggested. The suggested information provided in this paper would be beneficial to enhance the safety and the reliability of the FHE during the handling of new and spent fuel.

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