METHODOLOGY FOR ENSURING THE INTEGRATION OF ALARA INTO THE DESIGN OF THE *AP1000*™ REACTOR

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1. INTRODUCTION

The **AP1000™** pressurized water reactor is a Generation III+ Pressurized Water Reactor designed by Westinghouse Electric Company LLC. The power plant is designed to produce at least 1000 MWe and incorporates several improvements over the Generation II nuclear power plants in regards to ALARA (As Low As Reasonably Achievable), or ALARP (As Low As Reasonably Practicable) design philosophies, in order to reduce the expected radiation exposure of plant personnel. These improvements have been based on operating experience and various industry reports. Westinghouse has been able to ensure the incorporation of many of these ALARA improvements into the **AP1000** design by using a variety of methods, including the creation of an ALARA Guidelines Manual, certain restrictions expressed in the Design Control Document, as well as multiple types of reviews involving subject matter experts.

2. ALARA GUIDELINES MANUAL

The ALARA Guidelines Manual is an important part of the integration of ALARA into the design of the **AP1000** reactor. It provides a resource to the design engineers into the background of ALARA as well as many methods for implementation.

One section of the manual discusses the U.S. federal regulations regarding ALARA. The US NRC has several regulatory guides concerning ALARA, including Regulatory Guide 8.8 ("Information Relevant to Ensuring that Occupational Radiation Exposures at Nuclear Power Stations Will Be as Low as Is Reasonably Achievable"), Regulatory Guide 8.10 ("Operating Philosophy for Maintaining Occupational Radiation Exposures as Low as Is Reasonably Achievable"), and Regulatory Guide 8.19 ("Occupational Radiation Dose Assessment in Light-Water Reactor Power Plants -- Design Stage Man-Rem Estimates"). These regulatory guides describe specific design features which must be considered (provisions for remote operation of equipment and components, provisions for resin and sludge handling systems, etc.), the meaning of the ALARA philosophy, as well as the method of completing design stage dose assessments. Two sections of the Code of Federal Regulations are also discussed, including 10 CFR part 20 and 10 CFR Part 50. These sections discuss the annual dose limits as well as Safety Analysis Report requirements regarding ALARA. These regulations are also similar to the regulations of other countries, including the Technical Assessment Guide (TAG) T/AST/005 “ND Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable,” the guide “Principles and Guidelines to Assist HSE in its Judgments that Duty-Holders have Reduced Risk As Low As Reasonably Practicable,” and IRR99 “The Ionising Radiations Regulations” which are regulations set forth by the U.K. Health and Safety Executive. The designs of all of the systems of the **AP1000** reactor must adhere to these regulations, so it is important that the design engineers understand the requirements that are set forth.

Since some design engineers may not have a strong background in radiation, one section is dedicated to general radiation types and sources. This gives summaries on what alpha particles, beta particles, gamma rays, and neutrons are, as well as where they typically come from. It also discusses the important isotopes seen in power plants, including H-3, N-16, Cs-137, I-131, Xe-133, and Kr-85. This section also goes into detail regarding activated corrosion products (crud). Since crud is the cause of a majority of the radiation exposure at nuclear power plants, it is important that design engineers have a good understanding of what it is. The composition and physical properties are explained. The common sources of Co-58 and Co-60 are also described. Likely crud traps are also discussed, including heat transfer areas and areas with momentum changes. This will then allow the engineer to design their system with a better understanding on how to reduce the amount of crud in the system and result in lower plant dose rates.

The Plant Radiation Fields section discusses the typical radiation fields seen near many of the systems in a nuclear power plant. This covers the reactor cavity, reactor vessel and vessel head, Steam Generators, Reactor Coolant Pumps, and Pressurizer, as well as the main pieces of equipment located in the Chemical and Volume Control System, Normal Residual Heat Removal System, Liquid Radwaste System, Gaseous Radwaste System, Solid Radwaste System, and the Spent Fuel Pool Cooling System. This is beneficial to the design engineers since it shows where high dose rates are likely to occur. It will also give the engineer a better idea of how much shielding or distance from the sources will be required in order to ensure that the power plant personnel can safely complete maintenance or operations in the area. This also allows for a better understanding of where instrumentation or valves should be located in order to ensure that the operator will be exposed to an acceptable amount of radiation.

The manual also discusses various dose reduction methods and their effectiveness in existing plants as well as design guidelines. This covers many aspects, including crud source reduction, surface smoothing, chemistry controls, filtration, decontamination, work time reduction, distance, shielding, and contamination mitigation. Although this section does not set requirements for the implementation of all of these methods, many of them have been included in the **AP1000** reactor design. One example of crud source reduction is the cobalt limit for the steam generator tubing. While many existing power plant steam generators contain 0.045 weight percent cobalt, the **AP1000** steam generator tubes will not contain more than 0.015 weight percent cobalt. Since the tubes have such a large surface area, the steam generators are a large source of the total cobalt input into the reactor coolant. Therefore having this large reduction in weight percent will have a significant reduction of the amount of cobalt that can enter the reactor coolant system, resulting in a significant reduction in plant dose rates. Surface smoothing will be utilized in the steam generator channel heads and divider plate. These surfaces will be electropolished, which will reduce the amount of crud that can deposit on the area, resulting in lower steam generator maintenance doses. Another example of surface smoothing is the pre-service passivation of the steam generator tubing, which will create a corrosion resistant chrome rich outer layer of the tubing. This reduces the amount of nickel and cobalt that is input into the reactor coolant, resulting in lower plant dose rates. For chemistry controls, Zinc addition is one method that will be used, which will reduce overall plant corrosion and crud deposits, resulting in lower plant radiation fields. For filtration, the spent fuel pool water will be filtered to not only reduce the activity of the water, but also increase visibility, resulting in a decrease in the amount of worker time required in the area. Cleanouts are installed on piping where crud traps could develop which allows for easy decontamination of the area. This allows operators to clean out the crud trap using demineralized water or air from a lower dose area. An example of work time reduction is seen through the use of the permanent reactor cavity seal ring. This seal ring does not need to be removed/installed every outage, resulting in lower exposure times during refueling. Distance is implemented, for example, using reach rods for manually operated valves in high radiation areas. In particular, the valves required for the operation of the demineralizers are operated through steel shielding utilizing the reach rods. The appropriate use of shielding can be documented by the use of closed circuit televisions for the operation of the crane during resin transfers. This allows the operator to be in a well shielded position, resulting in a much lower radiation exposure. The spread of contamination is limited by the separation between the radiologically controlled areas and the non-radiologically controlled areas of the auxiliary building. This separation requires an operator to completely leave the auxiliary building in order to travel between the two sections, allowing any contamination to be identified before the operator can enter the non-radiologically controlled area of the auxiliary building.

This section also includes a Design Checklist for ALARA. This checklist includes 38 questions regarding Time Minimization, Distance Maximization, Shielding, and Source Reduction. These questions range from general questions like "Have design features been utilized which reduce work-time?" to more specific questions like "Are valves installed in a stem-up orientation?" This provides the engineers with an easy reference for many different aspects of ALARA which must be considered throughout the design process.

3. Design Control Document

There are also many ALARA requirements established in the **AP1000** Design Control Document (DCD). One of these is the cobalt content limitations. Since Co-60 is a large contributor to the overall Occupational Radiation Exposure in a Nuclear power plant, it is important to reduce the total input of cobalt into the system. Limits have been established for the steam generator tubing and other steam generator surfaces, components in high neutron flux, auxiliary heat exchangers, weld clad surfaces, and other primary components. One such restriction is for equipment external to the active core, but located in a region of high neutron flux, which cannot exceed 0.05 weight percent. By setting these restrictions, the DCD ensures some reduction in the cobalt input into the reactor coolant system. This will then cause a reduction in the crud deposits throughout the system, resulting in lower overall dose rates.

The DCD also includes several design features from the ALARA Guidelines Manual which must be implemented in the plant. These include many design features for specific pieces of equipment, including a sludge control system for the steam generators, which will reduce sludge lancing requirements. It is also required that highly radioactive rooms contain supplemental/redundant lighting. Therefore, when a lamp goes out, it is not necessary to immediately replace the light bulb and the replacement can be scheduled when radiation levels are lower, or when replacement is more convenient (such as at times when the room is being accessed for other purposes). The demineralizers are also designed to be able to remotely and hydraulically transfer spent resins and can be flushed out using demineralized water.

Layout design features are also discussed. Shielded valve modules are utilized, which allow valve operations and maintenance to be completed at lower dose rates. Instruments are also typically located in low radiation areas. For instruments that are required to be located in a high radiation area, they are designed to be removed quickly. Some are also provided in duplicate to reduce the need to access the area. Embedded pipes have also been eliminated, with few exceptions. This allows for easy inspection of the pipes and minimizes the possibility for undetected leakage to occur.

4. REVIEWS

There are two types of reviews that are completed for each system which allows for an opportunity to ensure that ALARA has been fully considered in the design of the various systems of the **AP1000** reactor. These are the Design Reviews and the COMIT Reviews. Every major system undergoes at least three design reviews, a preliminary, intermediate, and final. For more complex systems, multiple intermediate design reviews may be necessary. The design reviews are used to ensure that the system is able to complete the tasks that it is intended to complete. Each of these reviews will have professionals of various backgrounds, including chemistry, layout, and procedures, as well as personnel from existing power plants. For the systems which involve radioactive sources, or are located within radioactive areas, an engineer from the Radiation Engineering & Analysis (REA) group is present and is able to identify issues which may cause unnecessary radiation exposure and an action item, known as a chit, will be filed. These chits must also be resolved and approved by the engineer who identifies the issue before the design can be fully finalized.

After the final design review of the system a COMIT (Constructability, Operability, Maintainability, Inspectability, and Testability) Review is completed for the system. These COMIT reviews go much more in-depth in regards to how operators will have to interact with the system. As with the design reviews, many professionals with various backgrounds will be at each of these reviews, including an engineer from the REA group if applicable. At these reviews, the components and operations are looked at in more detail. The purpose of this review is to ensure that operators are physically able to complete all of the tasks necessary in regards to the construction, operation, maintenance, inspection, and testing of the related equipment and components. At this review, the REA engineer is able to identify whether there are any instances in which the operator will be required to get too close to a radioactive source, or any other radioactive concerns. If such a concern is identified, then the engineer will file a chit that must be resolved before the implementation of the system.

In some cases, dose assessments of the system will need to be completed in order to resolve some of the chits created during these reviews. When a full dose assessment is required, the total annual dose from the regular operations and maintenance of the system are examined. This is done by first determining how many plant personnel are required for each activity and where they will be located, as well as the duration of each activity. The expected dose rate in the area is then determined by considering all of the sources located near the operator's position. The maintenance activities for the system not only consider the maintenance of the large pieces of equipment, but also consider valve and instrumentation maintenance when applicable. When a large source of Occupational Radiation Exposure (ORE) is identified, then suggestions are made as to ways to reduce this to more acceptable levels.

As a result of these reviews, several design changes will need to be completed. Before a design change can be put into effect, it must first be submitted through a Design Change Proposal (DCP). The proposal is distributed to a large number of groups in order to determine overall impact. Radiation Protection and Shielding are examples of disciplines that participate in the impact review process of each DCP. Therefore, changes which could increase dose rates or exposure times of personnel can be identified before they are implemented. If the change is shown to cause a significant increase in personnel exposure, the design change will then need to either be altered, or rejected completely.