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# Armenian Nuclear Power Plant: USNRC Assistance Programme for Seismic Upgrade and Safety Analysis*

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## ABSTRACT

This paper summarizes the U.S. Nuclear Regulatory Commissions's (USNRC) technical support program activities associated with the Armenian Nuclear Power Plant (ANPP) safety upgrade. The USNRC program, integrated within the overall IAEA-led initiative for safety re-evaluation of the WWER plants, has as its main thrust the technical support to the Armenian Nuclear Regulatory Authority (ANRA) through close collaboration with the scientific staff at Brookhaven National Laboratory (BNL). Several major technical areas of support to ANRA form the basis of the NRC program. These include the seismic re-evaluation and upgrade of the ANPP, safety evaluation of critical systems, and the generation of the Safety Analysis Report (SAR). Specifically, the seismic re-evaluation of the ANPP is part of a broader activity that involves the re-assessment of the seismic hazard at the site, the identification of the Safe Shutdown Equipment at the plant and the evaluation of their seismic capacity, the detailed modeling and analysis of the critical facilities at ANPP, and the generation of the Floor Response Spectra (FRS). Based on the new spectra that incorporate all new findings (hazard, site soil, structure, etc.), the overall capacity of the main structures and the seismic capacity of the critical systems are being re-evaluated. In addition, analyses of critical safe shutdown systems and safe shutdown processes are being performed to ensure both the capabilities of the operating systems and the enhancement of safety due to system upgrades. At present, one of the principal goals of the USNRC's regulatory assistance activities with ANRA is enhancing ANRA's regulatory oversight of high-priority safety issues (both generic and plant-specific) associated with operation of the ANPP. As such, assisting ANRA in understanding and assessing plant-specific seismic and other safety issues associated with the ANPP is a high priority given the ANPP's being located in a seismically active area. This activity is somewhat unique, as the ANPP is currently the only reactor of its kind operating in such a seismically active area.

## INTRODUCTION

Following the Spitak earthquake of 1988 in Armenia, and despite the fact that no damage was observed at the Armenian Nuclear Power Plant (ANPP), both WWER 440-270 type units were shut down and the newest unit (Unit 2) went back into operation in 1995. The restart of Unit 2 went ahead after a number of IAEA-led safety review missions and recommendations for plant upgrade addressing the seismic vulnerability of the plant. In 1999 an IAEA Technical Guidelines Programme for the Seismic Re-evaluation of the ANPP [1] was issued and agreed upon between the ANPP and the Armenian Nuclear Regulatory Authority (ANRA). Within these guidelines the seismic issues that need to be addressed and the responsibilities of the various organizations participating in the effort were identified.

The US NRC, in the framework of its International Programs, has participated in the bilateral cooperation between the US and the Soviet Union focusing on the exchange of information related to the safety of civilian nuclear power plants since 1988. Initial activities focused on exchanging information on technical issues of interest to both sides (i.e., fire protection and radiation embrittlement of metals). Following the breakup of the Soviet Union, this program was expanded to provide to countries of the now former Soviet Union and of Central and Eastern Europe assistance in making safety improvements to their civilian nuclear power plants (led by the U.S. Department of Energy) and for strengthening nuclear safety and regulatory oversight (led by the USNRC). In 1995, in recognition of the impending restart of the ANPP, USNRC's regulatory assistance activities were expanded to include support for the Armenian Nuclear Regulatory Authority (ANRA). All USNRC assistance activities with ANRA (including seismic issues) are closely coordinated with other regulatory assistance programs (for example, efforts being conducted by the IAEA, by the European Commission's TACIS program and the United Kingdom). Regulatory assistance activities are also coordinated with assistance programs for the ANPP (for example, efforts being conducted by the U.S. Department of Energy). As part of the continuation of the existing technical support program, the US NRC was to provide technical expertise to ANRA whose primary role in the upgrade program is to independently evaluate and verify key aspects of the seismic upgrade effort. These include the verification of the procedures and evaluation of floor response spectra (FRS) at the superstructures of the NPP, the independent validation of the geo-technical data at the NPP site, the acceptance of procedures and criteria for the probabilistic seismic hazard analysis for the site and finally, the overseeing

* Views expressed in this document are not necessarily views of the USNRC

of the plant seismic walk-downs. The US NRC, in collaboration with Brookhaven National Laboratory, has been very active in this on-going effort through dedicated technical visits and information exchange with ANRA technical staff, participation in IAEA-organized missions, transfer of expertise and technical tools to allow ANRA to perform independent, large–scale seismic analyses, and conducting of parallel studies performed at BNL.

In addition to the seismic issues, the technical support program included a wider spectrum of safety-related activities at ANPP through ANRA. Specifically, safety concerns regarding the performance of critical reactor systems, such as the primary side feed and bleed (F&B) operation in the event of total loss of off-site power due to a seismic event, were being addressed. ANPP was designed so that the residual and accumulated heat removal after shutdown was primarily performed by maintaining feed-water supply to the secondary sides of the steam generators (SG) and dumping steam to the atmosphere or to the turbine condensers, or water to the technological condenser in the water-water mode. The primary side feed and bleed (F&B) possibility was not considered in the original design. Furthermore, to make matters more challenging, the primary F&B procedure application was prevented by a lack of safety valves in the pressurizer qualified for steam-water mixture, which was necessary to relieve the coolant to the relief tank and then to the confinement. As a result, and during the ANPP Unit 2 upgrade, the original pressurizer safety valves (PRZ SV,) were replaced by the new higher capacity valves qualified for steam-water mixture. The installation of new valves allowed application of primary side F&B operation as a backup measure to remove the residual and accumulated heat from the core. In a later section an analysis performed on the new system is described. The primary goal was to demonstrate the core cooling capability of the plant using the high-pressure injection (HPI) system (feed) and pressurizer safety valves (bleed) and to evaluate temperature changes in the Borated Water Supply Tank (BWST). The Regulatory Authority of Armenia will utilize results of the analyses for endorsement of F&B procedures. Furthermore, technical support activities associated with open issues of the new dry fuel storage facility, including seismic safety, and the Safety Analysis Report (SAR), including cask drop safety assessment, were initiated.

This paper summarizes the key safety issues at ANPP and especially those connected to the seismic hazard, the status of the on-going re-evaluation process that addresses these issues, the US NRC role and contribution to the overall activity and finally, some discussion on the value of the collaborative effort of the many international entities converging to the issues surrounding the nuclear facility.

In summary, during that shutdown period at ANPP, and following IAEA-mission recommendations, extensive structural strengthening of Unit 2 was implemented. These recommendations, conditional to the plant restart, covered the following three important aspects, namely, (a) verification of the geological stability of the site, (b) assessment of the peak ground motion anticipated at the site through a state-of-the-art comprehensive seismic hazard analysis, and (c) the establishment of a comprehensive re-evaluation program that will address the seismic capacity of structures, systems and components in accordance with international procedures and practice. By incorporating the advice of international experts and identifying the necessary steps needed to be taken for an acceptable seismic upgrade of the plant, a baseline technical guidelines document [1] was issued by the IAEA. A key element in the re-evaluation/upgrade process was the establishment of the Safe Shutdown Equipment List (SSEL) which, when identified, will be re-examined with the new seismic input and plant analysis for its adequate seismic capacity and expected functioning during the review-level earthquake. Plant seismic walk-downs were to also take place to assess the state of both the SSEL and other key systems.

## 2.0 SAFETY ISSUES AT ANPP

In this section the key elements of the safety re-evaluation and upgrade at ANPP, and specifically those that the US NRC technical assistance program is an integral part of, are described and the status of the various supporting analyses is discussed. Specifically, these elements include the identification of the safe-shutdown equipment, the definition of seismic hazard at the site, including the newly initiated PSHA study, the uncertainties and contribution to the seismic input at the plant of the local subsurface stratigraphy, the generation of floor response spectra based on the latest information on seismic input, site subsurface soil conditions and structural information and, finally, safety analysis of key emergency systems.

### Generation of the Safe-Shutdown Equipment List

Based on the IAEA guidelines [1] established as a path to the seismic upgrade of the ANPP, the SSEL should identify the minimum set of equipment necessary to ensure the performance of the plant safety system during and after a reference earthquake (review-level earthquake). The main functions to be assured during and after such earthquake are: (a) reactivity control, (b) reactor coolant system pressure control, (c) reactor coolant system inventory control, and (d) reactor decay heat removal.

The SSEL should also identify functional performance requirements for each of the components by addressing whether the system should be operational after the earthquake or should merely maintain its leak-tightness. Some of the key systems whose functions fall within the scope of this key task are the primary coolant system, the volume compensation system, the safety injection system, the containment spray system, the emergency feedwater system, the emergency cooldown system through the secondary circuit, and the secondary coolant system over-pressurize protection system.

The main responsibility in assembling this critical list belongs to the plant and the plant designer. The process, which represents one of the most critical elements in the plant re-evaluation and upgrade effort, is an ongoing one. Upon its completion, the capacity of the systems identified within the list will be re-evaluated based on the new seismic information that includes the Review Level Earthquake and the generation of appropriate FRS.

***Seismic Hazard - Input***

During the design stage of the two ANPP units, some provisions were made to account for seismic loads and making these two units the only Soviet-era reactors designed to withstand some level of earthquake loads. The availability of historical records of seismic activity in the general area played a role in accounting for earthquake protection of the reactor. Furthermore, questions about the quality of the soil in the subsurface, and the possible effect during a postulated earthquake, led to the measure of removing the soil beneath the reactor shafts and replacing it with concrete to the top of a stiff layer that is assumed to be the bedrock for the site. Figure 1 depicts the cross sections of the reactor main building where the special design of reactor shaft and its interface with the surrounding rock and the general soil stratigraphy is depicted.

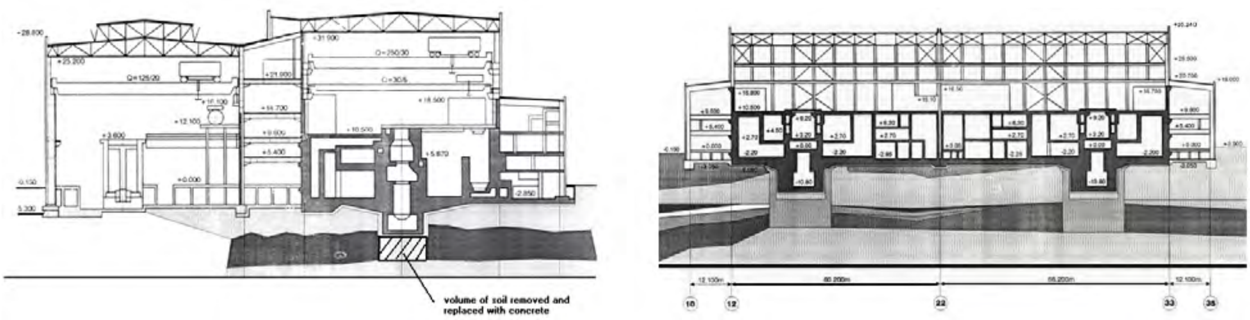


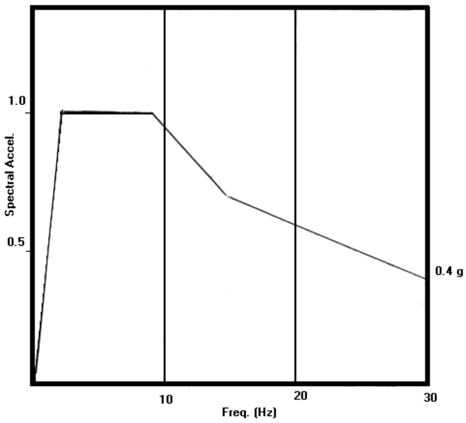

**Figure 1: Armenian NPP Cross Sections Including Details of Soil/Structure Interface**

For the original design and construction of ANPP, the design spectrum shown in Figure 2 was used. No fault characterization or attenuation laws have been identified as the source of the shape, peak ground acceleration (PGA) and amplification of the proposed spectra. The spectrum calls for a maximum ground acceleration of **0.4g** for the reactor shaft and **0.2g** for the rest of the reactor compartment. For higher elevations in the superstructure, amplification factors up to 3 were recommended. Following the destructive Spitak earthquake in late 1988 and the discovery of additional fault lines in the region, concerns were raised over the adequacy of seismic safety measures at the plant. A preliminary re-assessment of the seismic hazard by Armenian and international organizations in the early 1990’s resulted in a new review-level earthquake with a free-field surface horizontal peak ground acceleration of **0.35g**. Since that time, new active faults have been identified near the power plant and there are ongoing studies to include the new information in the seismic map pertinent to the ANPP site. Prompted by the new information, the plant and the regulator have proposed a probabilistic seismic hazard assessment (PSHA) to redefine the maximum credible earthquake for the plant.

In the “Technical Guidelines for the Seismic Re-evaluation Programme of the Armenian Nuclear Power Plant – Unit 2” [1] it was determined that previous attempts to calculate dynamic FRS for ANPP Unit 2 are inadequate and it was agreed that the re-evaluation process be based on the US NUREG/CR-0098 rock spectrum for 0.35g PGA corresponding to the 50$^{th}$ percentile (for 5% damping). This is mainly due to the fact that the NUREG spectrum envelops the generated site-specific spectrum for all frequencies. The new reference spectrum is shown in Figure 3 along with other site-specific spectra generated by various studies.

**Seismic Hazard – Probabilistic Seismic Hazard Analysis**

While a reference spectrum has been “adopted” in order to proceed with the re-evaluation process at the plant, the effort to establish a spectrum that closely represents the seismic picture at the site still continues. As mentioned above, during the period between 1992-95, a series of seismic hazard studies for the ANPP site were performed. These resulted in the generation of free-field acceleration spectra at the site as they appear in Figure 3. Due to the fact that important information regarding the local seismic activity (even though some of the studies included local earthquakes), fault characteristics, micro-zonation, etc. the NUREG-0098 50% confidence level spectrum was selected to represent the review level earthquake (RLE).



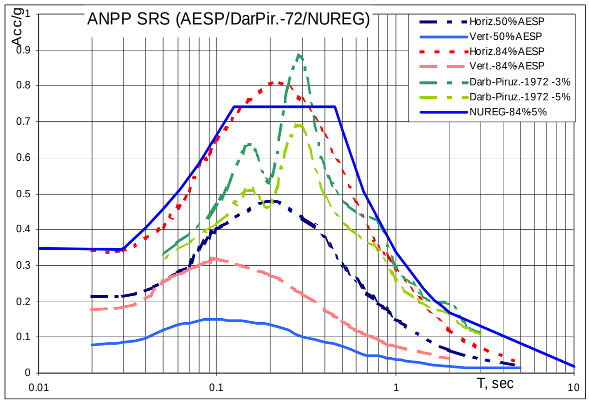
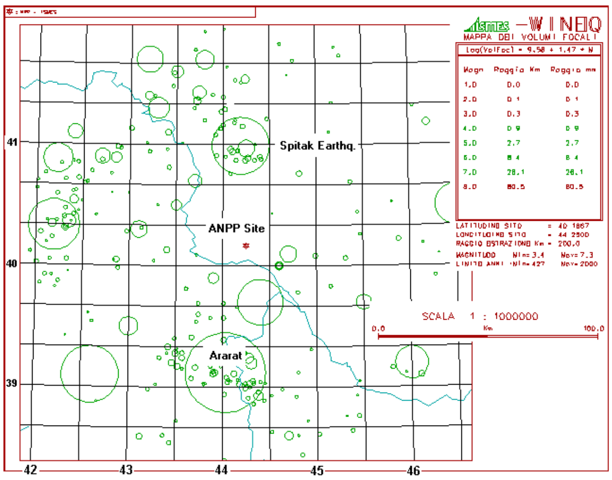




**Figure 2: Original ANPP Design Spectrum**

**Figure 3: Estimated Free-field Response Spectra at ANPP**

Since 1995, more information has surfaced regarding new faults near the ANPP site and their potential to define the most credible earthquake. Further, from newly installed seismic arrays, the activity near ANPP has been continuously monitored.



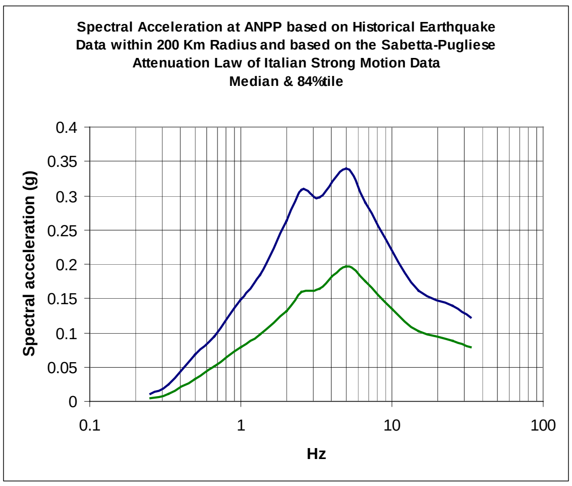




**Figure 4: Seismic Map over 200Km around ANPP Map**

**Figure 5: Generated Spectra at ANPP from Seismic**

These new findings have prompted the intent to perform a new Probabilistic Seismic Hazard Analysis (PSHA). While the PSHA study is under way, an exercise was performed using historical earthquake data around the site and employing the Sabetta-Pugliese attenuation law. The goal of such an exercise was to assess whether the strong but distant historical earthquakes control the properties of the spectrum at the site. Figure 4 depicts the events used within a 200 km radius from ANPP and Figure 5 shows the 50% and 84% spectra resulting from the attenuation law employed. The peak acceleration values calculated with this attenuation law and the seismic data are significantly lower than what has been derived from the various studies in the period of 1994-95. To test the relevance of the attenuation law to the Armenian site the response spectra at ANPP was evaluated using only the Spitak earthquake. As shown in Figure 6, this attenuation law produces a peak horizontal acceleration of 0.052 g that happens to fall very close to what was observed at the site during the event.

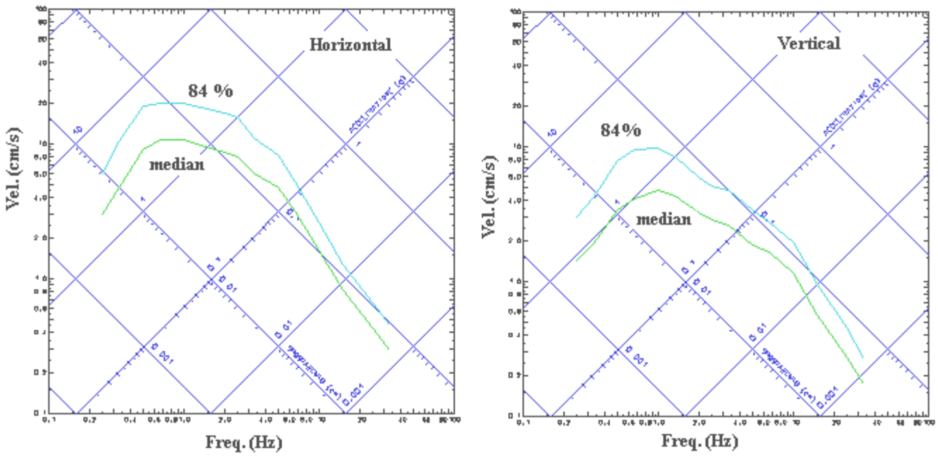



**Figure 6: Earthquake Spectra at ANPP from just the 1988 Spitak Earthquake and Sabetta-Pugliese Attenuation Law**

## Site Characterization

Site characterization prior to the construction of the plant revealed that within the basalt layers that make up the near-surface strata there exists layers or weathered rock with shear wave velocities as low as 300m/s while the alternating basalt layers exhibit velocities of ~ 1200m/s on average. It is estimated that the water table is about 86-96m below surface. Recent site investigations focused on the top 66-70m of layered soil and developed a more detailed profile of the surface layers where the nuclear facility is founded. As noted earlier, the questionable soil beneath the two reactor shafts was removed and replaced by concrete down to the next layer of competent rock (see Figure 1). A recent geophysical study, yet to be fully verified, has shown that the weak layers exhibit velocities much higher than previously assumed.

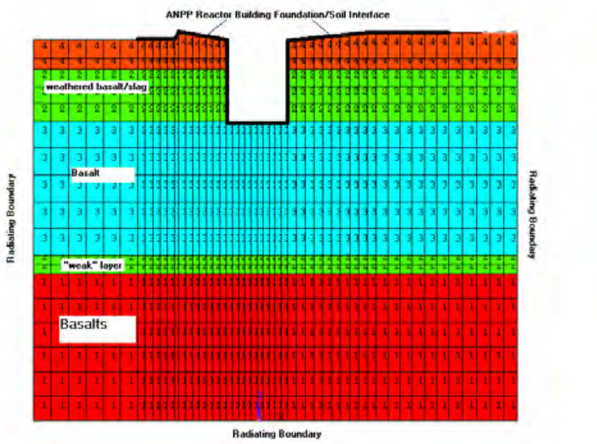
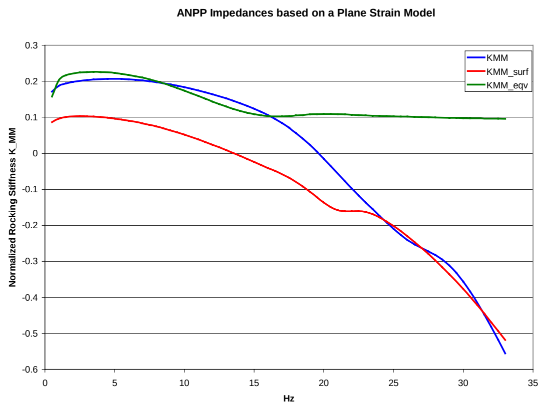



**Figure 7: Detailed FE Model of ANPP Foundation/Soil Interface and Subsurface for Impedance Calculations**

From the site seismic response and the SSI point of view, the existence of such layers, combined with the particular design of the reactor foundation, could have an effect on the overall seismic response of the superstructures at the ANPP. As a result, site response analyses have been initiated using the capabilities of the SHAKE code. Given that no experimental data on the soils at the ANPP site regarding degradation behavior under high strains, the limited available site-specific data are matched to available degradation curves of similar soils. To address the key question of how the complex soil profile beneath the reactor, and especially those layers of low velocity soil, may affect the soil-structure interaction component of the overall seismic response, a detailed impedance analysis was performed by utilizing the procedures of the POROSLAM [6] finite element code. The effects of certain simplified assumptions that have been implemented in previous studies were particularly evaluated. These include the treatment of the foundation as a flat basemat resting on an "equivalent" homogeneous half space, the estimation of soil stiffness and damping from frequency independent formulae, and the elimination of the particular design of the reactor building foundation, namely the shaft design.  Figure 7 is a finite element description of the reactor foundation/soil interface and of the layers down to the competent rock. The presence of the weak layers is accounted for in the above model. In previous studies, two key variations of the true geometry were used. Specifically, in both approaches the embedment of the reactor shaft was ignored while the soil was treated either as a layered soil or as an "equivalent" soil. The latter leads to a surface foundation resting on a homogeneous half-space case.



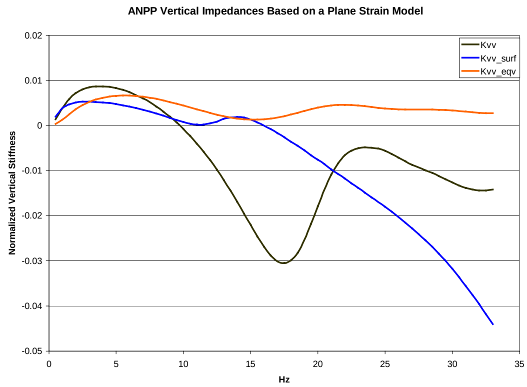




**Figure 8: Impedance Functions (real part) for Rocking and Vertical ANPP Foundation Motions**

Shown in Figure 8 are the real parts of rocking and vertical impedance that result from the analysis of the three models. While significant differences appear at the higher frequencies, in the low frequency range, that is of more importance to the reactor response, the soil impedance is not drastically affected. The effort is continued, however, by taking into account both the revised layer properties and layer structure beneath the reactor at ANPP.

## In-Structure Floor Response Spectra

The ultimate goal, after addressing issues that define the site seismic hazard, the site response leading to the appropriate earthquake input, and the soil structure interaction, is the generation of the FRS for the ANPP structures. Specifically, the seismic capacity of the structures and of the critical subsystems (identified earlier as part of the safe shutdown equipment lists) is to be assessed based on FRS resulting from a comprehensive analysis that, in addition to the seismic input and soil information, will take into account the state of the existing structures. While the original design did account for seismic structural provisions in the main structures, the amplification of ground acceleration through the structure was not properly accounted for. With the assistance of the US DOE seismic walk-downs were performed at the site and have identified all critical systems and their potential structural deficiencies in the event of an earthquake. The final FRS accelerations will determine the level of upgrade that may be needed to maintain safety in the event of a credible earthquake that may affect the site.

The Armenian regulator ANRA, with technical assistance through the US NRC program, has been performing detailed seismic analyses in an effort to derive competent FRS that can be used for plant structures and system evaluation. For that purpose a host of specialty codes (such as STARDYNE, SASSI, DIGES, and proSHAKE) have been utilized. With the aid of these codes all the components of the seismic problems at ANPP have been integrated into a system that accounts for the site response, the foundation input, the SSI component, and the detailed modeling of the structure. Figure 9 depicts generated spectra at different elevations in the reactor building at ANPP.

## Safety of Critical ANPP sub-systems – An Example Case

In the following section, the operation of one of the critical systems (whose failure due to total loss of power can be attributed to a seismic event) is examined. Specifically, the response of the primary and secondary feedwater system is examined from the thermal-hydraulic point of view. The seismic capacity of the system is not addressed at this time awaiting the generation of the appropriate seismic input (FRS).

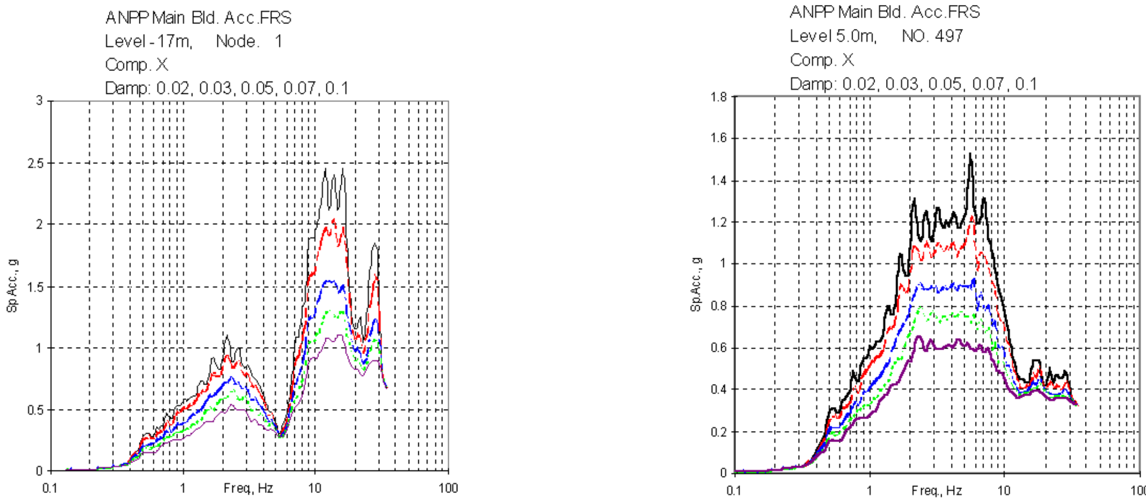



**Figure 9: Floor Response Spectra in the ANPP Main Building (courtesy Mr. P. Zadoyan, private communication)**

The Armenian NPP was designed so that the residual and accumulated heat removal after shutdown was primarily performed by maintaining feedwater supply to the secondary sides of the steam generators SGs and by dumping steam either to the atmosphere or to the turbine condensers. The primary side F&B possibility was not considered in the original design. Furthermore, the primary F&B procedure application was prevented by a lack of safety valves in the pressurizer qualified for steam-water mixture, which were necessary to relieve the coolant to the relief tank and then to the confinement.

In the course of the ANPP Unit 2 upgrade, the original PRZ SVs were replaced by the new higher capacity valves qualified for steam-water mixture. The installation of new valves allowed application of primary side F&B operation as a backup measure to remove the residual and accumulated heat from the core. The objective of the current analysis was to demonstrate the core cooling capability of the plant using the high pressure injection (HPI) system (feed) and PRZ SVs (bleed) and to evaluate temperature changes in the Borated Water Supply Tank (BWST). Upon completion of the overall analysis ANRA, will utilize the results for the qualification and acceptance of F&B procedure.

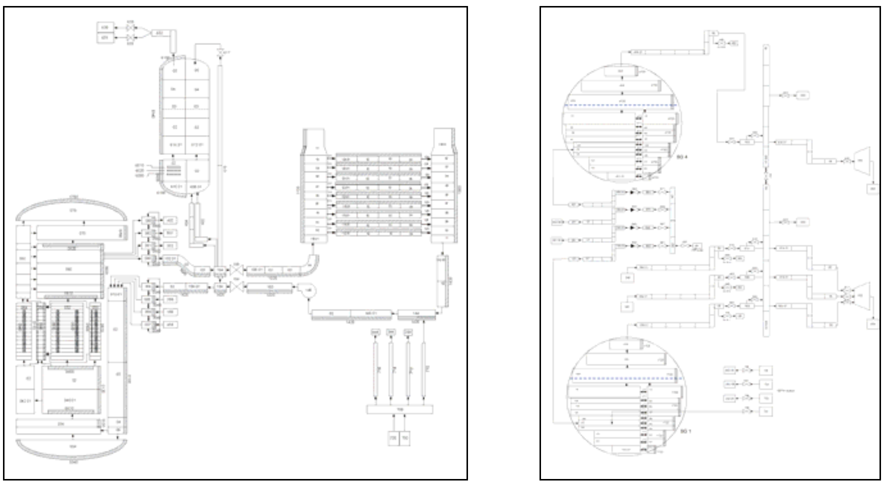


**Figure 10: RELAP 5 Modeling of ANPP Primary and Secondary Sides**

The analysis considered a hypothetical case with a total loss of the SG feedwater. Figure 10 depicts the primary and secondary side system discretization based on RELAP5 modeling. This case assumed can potentially be realized during a loss of offsite power, or due to damage of the turbine hall (where feedwater systems are located), or damage of the demineralized water tanks during a seismic event. The transient was assumed to begin with a loss of power, which caused a reactor scram, primary coolant pump coast-down and loss of secondary feedwater. It is assumed that initially the reactor is cooled by natural circulation in the primary loop, which was sustained by the remaining water in the secondary sides of the SGs. The analyses indicated that this state may last for about 3 hours. At the end of this period, the remaining water in the SGs had run out and the heat generation rate on the primary side began to exceed the heat removal rate through the SGs. The F&B operation should start any time before this time to supplement and ultimately replace the heat removed in the SG.

Results of the analysis demonstrate that the feed and bleed operation is capable of maintaining the plant in a condition of adequate heat removal for several hours, and provide ample time to restore the SG feedwater supply.

## 3.0 SUMMARY

In this paper a brief description of the different facets of the US NRC technical assistance program to the Armenian Nuclear Regulatory Authority was presented along with some representative results of the different safety studies that have been undertaken in the course of the re-evaluation and seismic upgrade of the Armenian power plant. While the seismic issues constitute the main thrust of the upgrade effort at the plant, given that the Spitak earthquake was the initiator of the safety re-assessment, the study of critical systems at the plant has become a significant component of the overall effort. The upgrade at ANPP, in addition to ensuring the seismic capacity of structures, systems and components due to the revised seismic hazards at the site, has incorporated the upgrade of reactor systems that are an integral part of the safe shutdown equipment list (SSEL) whose performance is linked to more than a seismic event as an initiator.

Key to the upgrade at the plant is, of course, the re-assessment of the complete seismic problem which starts with the appropriate definition of the seismic hazard at the site, the answering of questions associated with the subsurface, and the structural condition of the plant structures. All these tasks are in progress and for their completion a number of international organizations are actively participating. Such wide collaboration and merging of expertise is significant in that issues the international nuclear reactor community is continuously tackling (seismic re-assessment, life extension, etc.) are addressed in this case study of ANPP and findings with regard to seismic or system safety can very well apply to other NPPs around the world. Needless to say, the safety of a plant such as the ANPP is important not only to Armenian NPP and Armenian regulator ANRA, but to the whole nuclear community which cannot afford another mishap anywhere in the world.

Lastly, a key output of the US NRC technical assistance program and other international programs is that Armenian scientists are now able to interact with experts from other parts of the world, utilize techniques and approaches being practiced in the west, and perform high quality regulatory functions.

## AKNOWLEDGEMENTS

The support of the US NRC is greatly appreciated. Also appreciated is input generated by ANRA’s technical staff.

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