EPRI Groundwater Assessment for TVA's Sequoyah Nuclear Plant

Assessment Final Report

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A. Introduction

An assessment of radioactive groundwater contamination at Sequoyah Nuclear Plant (SQN) and the groundwater protection program at Sequoyah was performed March 26 through 30, 2007. This assessment was sponsored by the Electric Power Research Institute (EPRI) and was conducted to:

- review the status of the investigations of radioactive contamination of groundwater performed to date,
- evaluate the interpretation of the available data,
- provide the SQN staff with recommendations for proceeding with the ongoing investigation, and
- provide recommendations for implementing the draft EPRI document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants" (March 2007).

The assessment included the following:

mm/2

1. Review of the radiological events contained in the files required by 10 CFR 50.75 (g).
2. Review of the documents prepared in support of the Nuclear Energy Institute (NEI) groundwater protection initiative.
3. Review of various hydrogeologic reports and investigations related to evaluation of the potential for impacts to groundwater.
4. Review of laboratory analytical data, including the results of recent analyses for radioactivity in groundwater samples collected from available monitoring wells.
5. Review of selected plant sketches and drawings.
6. Review of testing performed on the radioactive waste discharge pipe line.
7. A site tour.
8. Discussions with selected site personnel.

The assessment team members have extensive experience in groundwater investigations at commercial nuclear power plants. Their expertise includes radiological evaluations, plant operations, groundwater sampling and analysis, groundwater monitoring well design and installation, characterization of hydrogeologic flow domains, hydrogeologic interpretations of groundwater contaminant fate and transport, and non-destructive evaluations (NDE).

B. Summary Findings

Status of Investigations Completed to Date

The assessment team concludes that the presence of tritium and/or other radionuclides in the shallow aquifer at SQN poses no significant threat to the environment, to human health, or to any applicable regulatory criteria.

The recommendations presented in this assessment report are directed toward assisting the SQN staff in determining the sources of the radiological contamination that has been measured in groundwater at the site and to understand its distribution and movement in the environment. These recommendations are offered in the context of the currently evolving industry initiative and EPRI groundwater protection guidelines to better understand and report the impacts to groundwater from operations at nuclear power plants.

It is evident from the EPRI assessment that SQN has made substantial efforts to investigate impacts to groundwater and that a considerable volume of data pertaining to the distribution and movement of radiological contaminants at the site has been collected. Approximately 25 groundwater monitoring wells are present at the site, and some have been sampled since 2003 for tritium and other radionuclides.

A hydrogeological investigation of the industrial area of the SQN plant site had been completed shortly before the site visit of the EPRI assessment team. That investigation included sampling of groundwater in approximately 30 locations from small-diameter borings advanced below the water table with a Geoprobe. One-inch diameter monitoring wells were constructed in four of these Geoprobe borings. These and selected existing monitoring wells are sampled at various frequencies; some weekly and some monthly. A report summarizing the results of that investigation was expected during the middle of April, 2007 and was not available for review by the EPRI assessment team.

Interpretation of the Available Data

The available groundwater elevation and tritium concentration data for Well 31 suggest a correlation over time with the operation of the circulation water system and/or to changes in the elevation of the regional surface water system. The location of this well corresponds to sites of historical surface spills and contamination events, most notably the overflow of a sump in the Unit 2 Additional Equipment Building in 1998, and the discovery of radioactivity in soil at the outfall of the Unit 2 RWST moat drain pipe in 1995.

This possible correlation suggests that the observed trends in tritium concentration in groundwater may be associated with historical spills rather than an ongoing leak. Rising groundwater levels may remobilize tritium suspended within the vadose zone below the sites of the historical leaks. A potential leak in the radioactive waste discharge pipeline, which passes underground near Well 31, was suspected as the source, but this appears to have been disproved by hydro testing completed in 2006. Investigation of a potential leak in the fuel transfer canal (near Well 21) is in progress and has been inconclusive to date.

Proceeding With the Ongoing Investigation

Additional investigation should be undertaken to confirm the correlation between groundwater levels, circulation water or surface water levels, and tritium concentrations in groundwater, and then to determine its cause. The additional investigation should include the determination of the distribution of tritium contamination in site soils above the water table in the vicinity of the historical spills noted above, and the measurement of water elevation changes in the discharge channel and site monitoring wells. Two or three additional shallow monitoring wells to the northwest and south of the Unit 2 RWST would also help to characterize groundwater level fluctuations and the source of tritium in existing Wells 31, 29 and 21.

The evaluation team recommends that the following lines of inquiry be considered to further investigate the source(s) of tritium that have been measured in groundwater at SQN:

- Sample shallow soil within the vadose zone in the vicinity of the locations of historical spills of radioactive liquids, and analyze those samples for tritium to determine what concentrations remain in the local soils.

- Install data-logging pressure transducers in the cooling water discharge channel, the intake forebay, and several groundwater monitoring wells. Evaluate the resulting hydrographs to identify potential correlation between groundwater elevations and the measured tritium concentrations at those locations (as has already been demonstrated in Well 31, as shown in Figure 1). Correlation of changes in surface water and groundwater elevations may identify a link between groundwater levels and plant operations (e.g., from the reduced flow of circulating water during refueling outages). Such a link may explain the apparent correlation between tritium levels in Well 31 and the timing of the recent refueling outages of Unit 1 and Unit 2 (Figures 2 and 3).

- Monitor selected water quality parameters such as temperature, dissolved oxygen, pH, and conductivity in the discharge channel and in nearby monitoring wells to evaluate the hydraulic connection between the discharge channel and nearby groundwater.

- Install approximately four additional monitoring wells in the vicinity of Well GP-13 to more fully bound the groundwater impacts resulting from the 1997 spill of approximately 3,000 gallons of radioactive liquid to the rad waste yard adjacent to the railroad bay door. At the location of these new monitoring wells, sample the soil in the vadose zone.

- Consider installing one or two monitoring wells into the shallow bedrock in the vicinity of Well 31. All of the existing wells are relatively shallow, and are completed within the sediments overlying bedrock. It may be significant that Well 31, with one of the highest tritium concentrations (currently about 10,000 pCi/L), is the deepest existing well at 32.3 feet below grade. An undetected tritium plume, confined within fractures in the shallow bedrock that are hydraulically connected to surface water in the discharge channel, could account for the observed correlation of groundwater level and tritium concentration in Well 31. This hypothesis should be tested.

- Groundwater samples currently are collected either with small diameter bailers or with auto samplers. These sampling methods are relatively fast and inexpensive, and if tritium is the only analyte of interest, they may be acceptable. However, as discussed in greater detail below, both methods can introduce significant sampling bias to the analytical results for other radionuclides. The assessment team recommends that other methods be used when collecting samples to be analyzed for radionuclides other than tritium.

- Analytical results provided by the Western Area Radiological Laboratory (WARL) are currently reported as either "not detected" or as the detected concentration. The laboratory reporting format should provide more detail, including the result (positive or negative), the analytical uncertainty, and the minimum detection limit for each sample.

Implementation of the Draft EPRI Guidance Document

The SQN staff will need to develop formal programs and procedures to implement the Draft EPRI Document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants" (March 2007). These procedures are needed to ensure that valid, scientifically and legally defensible data is collected, maintained and evaluated with the appropriate standard of care. The procedures should include:

- Establish Data Quality Objectives (DQOs) for groundwater sampling.
  - Define Minimum Detectable Concentration (MDC) requirements, and the criteria for defining positive detection of radionuclides.
- Establish analytical protocols for groundwater samples.
  - Define suites of radionuclides to be analyzed.
  - Document analytical methods to achieve required MDCs.
- Establish procedures for sample collection, storage, shipment, and chain-of-custody documentation.
  - Document sample volume, container, and preservation requirements.
  - Establish a sampling schedule.
- Establish a procedure to validate analytical results.
- Establish a database to document, retain, and allow for convenient retrieval of groundwater data.
  - Document field notes and the water quality parameters measured during groundwater sampling.
  - Manage groundwater analytical results, including field and laboratory QC data.

- Establish DQOs for monitoring well drilling.
- Establish a database to document, retain and allow for convenient retrieval of monitoring well data, including:
  - Water-level elevations
  - Subsurface stratigraphy
  - Monitoring well construction details
  - Monitoring well survey data
- Establish a procedure to monitor the physical condition of existing monitoring wells and to track the completion of required maintenance.

C. Observations and Recommendations

1. Evaluation of Elevated Tritium Concentrations Measured in Monitoring Wells 31, 29 and 21

The staff at SQN has considered two potential sources of the tritium observed in Wells 31, 29 and 21: 1) a leak in the radioactive waste discharge pipeline, which passes underground near Well 31, and 2) a leak in the bellows where the fuel transfer tube enters the Unit 2 reactor containment building. The radioactive waste pipeline was isolated in 2006, and then removed from service and tested with both air and fluid pressure. This testing appears to have shown that the radioactive waste pipeline is not leaking. A leak in the bellows of the fuel transfer tube at the Watts Bar Nuclear Plant, which is of the same design as at SQN, has lead the staff at SQN to suspect that a similar situation could exist there. Testing of this system is underway at SQN and has not yet identified a leak.

The EPRI evaluation team believes that at least three historical surface spills of radioactive liquids could be contributing sources of the tritium observed in Wells 31, 29 and 21. In 1995, radionuclides including Co-58, Co-60, Cs-134 and Cs-137, were identified in the soil at the outfall of the Unit 2 refueling water storage tank (RWST) moat drain pipe. No remediation of this area was conducted. Well 31 is located within approximately 200 feet of the Unit 2 RWST and in an inferred downgradient direction.

Similarly, in 2002 radioactivity was identified in the soil surrounding the Unit 1 RWST moat drain. Although contaminated soil was removed from this area based on measured concentrations of gamma-emitting radionuclides (primarily Co-58, Co-60 and Cs-137), tritium concentrations were not measured, and it is likely that a substantial volume of tritium remained in the soil. Wells 21, 29 and 31 are located several hundred feet from the Unit 1 RWST, in an inferred downgradient direction.

In 1998 a sump in the Unit 2 Additional Equipment Building overflowed, causing a release of radioactive liquid through a door and into the surrounding soil and a storm drain. Contaminated soil was removed to a depth of approximately one foot below grade. The extent of contamination was determined based upon measurement of the principal gamma emitters (Co-58, Co-60, Cs-134, Cs-137, and Mn-54) to a lower limit of detection of 5E-7 µCi/gram. However, tritium concentrations were not measured, and it is likely that a substantial volume of tritium remained in the soil. The area of the spill from the Unit 2 Additional Equipment Building is located to the east of the Unit 2 reactor containment building, in the vicinity of Wells 21, 29 and 31.

An evaluation of tritium concentrations and water levels in Well 31, and water levels in several nearby wells (Figure 1), shows a direct correlation between tritium concentrations in Well 31 and groundwater elevations. As groundwater levels in Well 31 rise and fall, so do tritium concentrations. Figure 1 shows that groundwater levels in Wells 31, 29 and 21 fluctuate up to approximately 7 feet on an annual cycle, with maximum and minimum levels occurring around July and January, respectively. These levels may correspond with the controlled flows in the Tennessee River (which also affect the water level in the cooling water discharge channel) and suggest a hydraulic connection of groundwater in these wells with flow in the river and/or the discharge channel.

Figure 1 shows that other wells west of the discharge channel (Wells 30, 32 and 33) have much smaller fluctuations in water levels, with little or no annual cycle apparent. This observation suggests that Wells 31, 29 and 21 may be hydraulically connected to the discharge channel by some natural stratigraphic feature or by some underground utility that provides a preferential flow path.

The observed patterns of groundwater levels and tritium concentrations in Well 31 suggest that rising groundwater levels may encounter tritium that was released to the soil during one or more of the historical surface spills noted above, and that is now suspended by capillary forces above the water table in the vadose zone. The rising water levels may remobilize a portion of the tritium, which contributes to the increased concentrations measured in groundwater sampled from the well during periods of high water levels.

Figures 2 and 3 show the variation in tritium levels in Well 31 during the periods spanning the last two refueling outages in Unit 2 and Unit 1, respectively. These figures show that tritium concentrations in Well 31 are lowest during the outages and increase immediately following the outages. Because the flow of cooling water is reduced during outages, it is likely that the water level in the discharge channel is lower during outages. Lower tritium levels in Well 31 during outages support the conceptual model of rising groundwater remobilizing tritium from historical surface spills that is suspended in the vadose zone.

The EPRI assessment team recommends that the shallow soil in the vicinity of the historical surface spills noted above be sampled and analyzed for tritium. If significant concentrations of tritium are detected in the shallow soils, it would be reasonable to conclude that the historical surface spills are the source of the tritium measured in Wells 31, 29 and 21, rather than an ongoing leak in an active structure, system, or component (SSC). Confirmation of the presence of tritium in the soil would not dictate that it be removed immediately, but may provide an explanation for the observed distribution of tritium in groundwater.

The team also recommends the installation of two or three additional monitoring wells to the northwest and south of the Unit 2 RWST. These wells will allow further characterization of the tritium plume identified in Wells 31, 29 and 21. Groundwater samples from the proposed new wells and from Wells 31, 29 and 21 should also be analyzed for Sr-90. This radionuclide is more mobile in groundwater than almost all other species except tritium. If the source of tritium in these wells is an active leak from an SSC, Sr-90 may be present in the local groundwater.

To evaluate another possible mechanism responsible for the tritium detected in Well 31 and nearby wells, SQN should consider installing one or two monitoring wells into the shallow bedrock in the vicinity of Well 31. All of the existing wells are relatively shallow, and are completed within the sediments overlying bedrock. It may be significant that Well 31, with one of the highest tritium concentrations (currently about 10,000 pCi/L), is the deepest existing well at 32.3 feet below grade. An undetected tritium plume confined within fractures in the shallow bedrock that are hydraulically connected to surface water in the discharge channel might account for the observed correlation of groundwater level and tritium concentration in Well 31.

To further examine the relationship between groundwater and surface water in monitoring wells in the vicinity of the cooling water discharge channel, the assessment team also recommends installation of data-logging pressure transducers in several wells, the discharge channel and the intake forebay. Hydrographs of the recorded water levels can be compared to determine what correlation exists between the monitored locations.

Some commercially available models of transducers simultaneously log temperature and water level. Water temperature in the discharge channel is several degrees warmer than river water or groundwater. Therefore, temperature may be a useful tracer to monitor the interaction of surface and groundwater in the vicinity of the discharge channel. Other easily measured water quality indicators such as pH, dissolved oxygen, and conductivity should also be considered for monitoring the interaction of surface water and groundwater. These lines of investigation may shed additional light on the relationship between groundwater levels, tritium, and the source of the tritium.

Figure 1

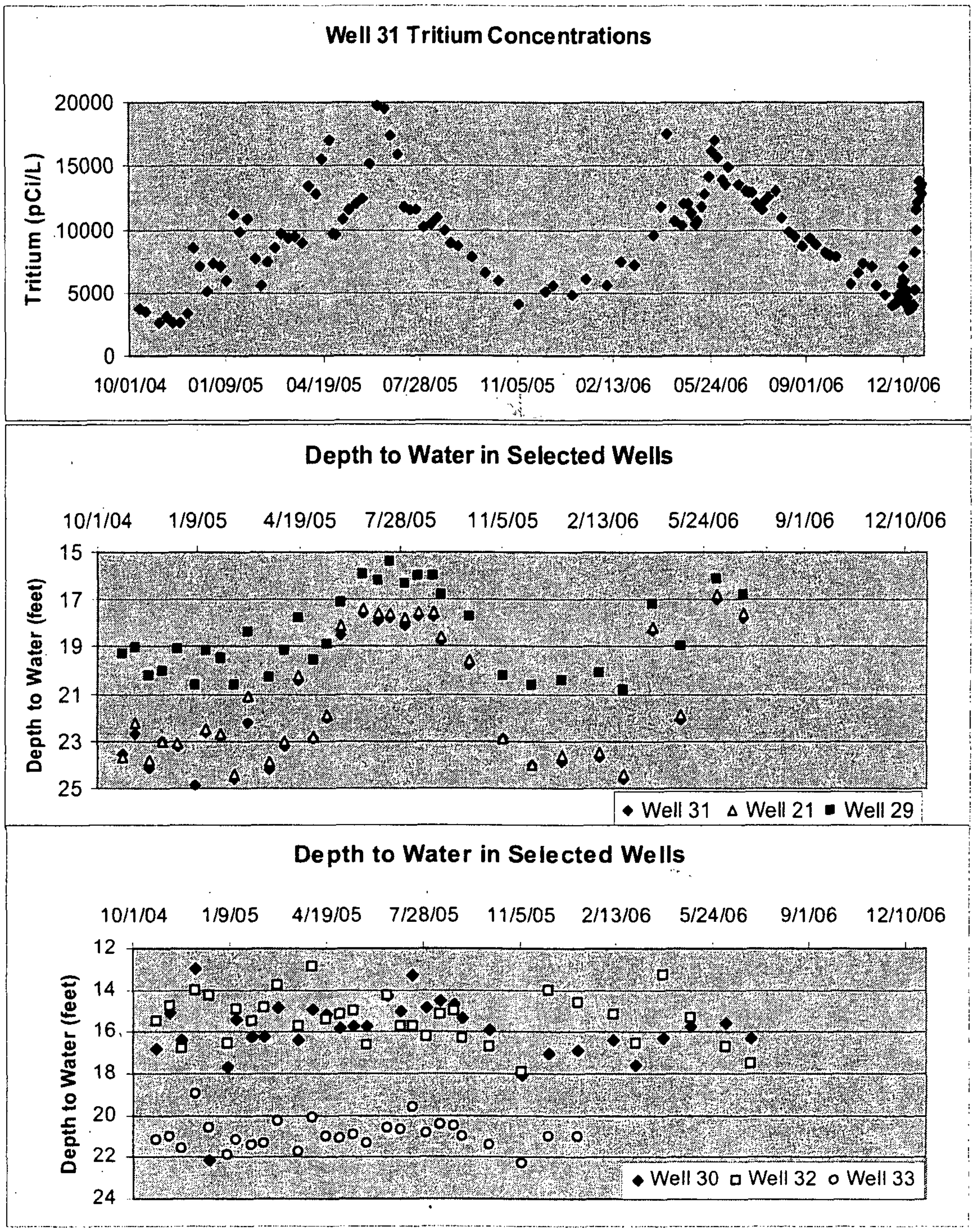

Well 31 Tritium Concentrations
Tritium (pCi/L)
20000
15000
10000
5000
0
10/01/04 01/09/05 04/19/05 07/28/05 11/05/05 02/13/06 05/24/06 09/01/06 12/10/06
Depth to Water in Selected Wells
10/1/04 1/9/05 4/19/05 7/28/05 11/5/05 2/13/06 5/24/06 9/1/06 12/10/06
Depth to Water (feet)
15
17
19
21
23
25
Well 31 Well 21 Well 29
Depth to Water in Selected Wells
10/1/04 1/9/05 4/19/05 7/28/05 11/5/05 2/13/06 5/24/06 9/1/06 12/10/06
Depth to Water (feet)
12
14
16
18
20
22
24
Well 30 Well 32 Well 33

Figure 2

Well 31 Tritium Concentration During Unit 2 Outage Ending December 26, 2006

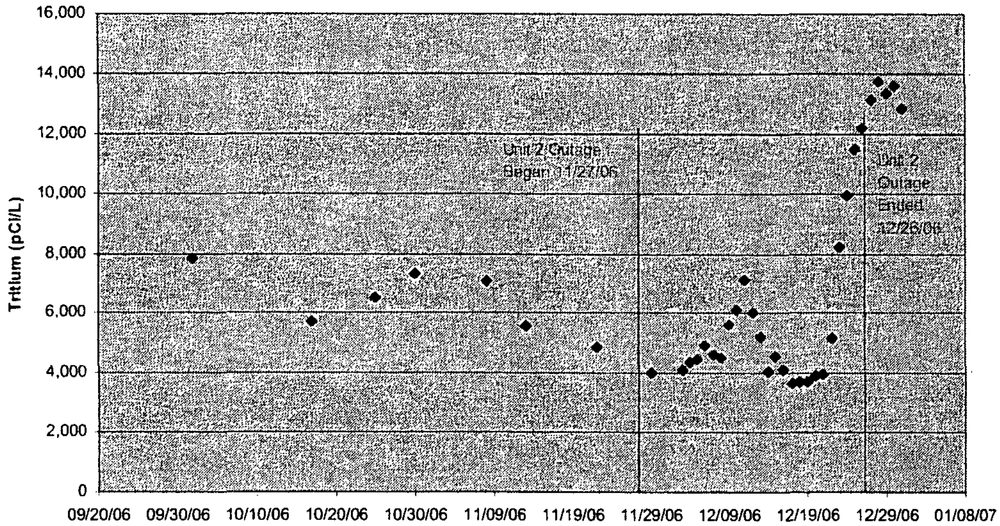
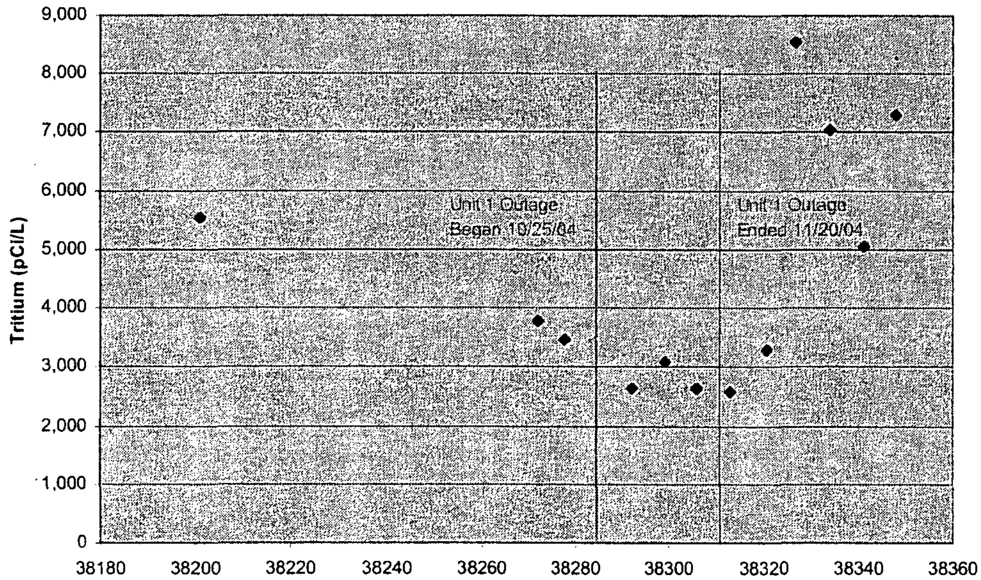


Figure 3

Well 31 Tritium Concentration During Unit 1 Outage Ending Nov 20, 2004

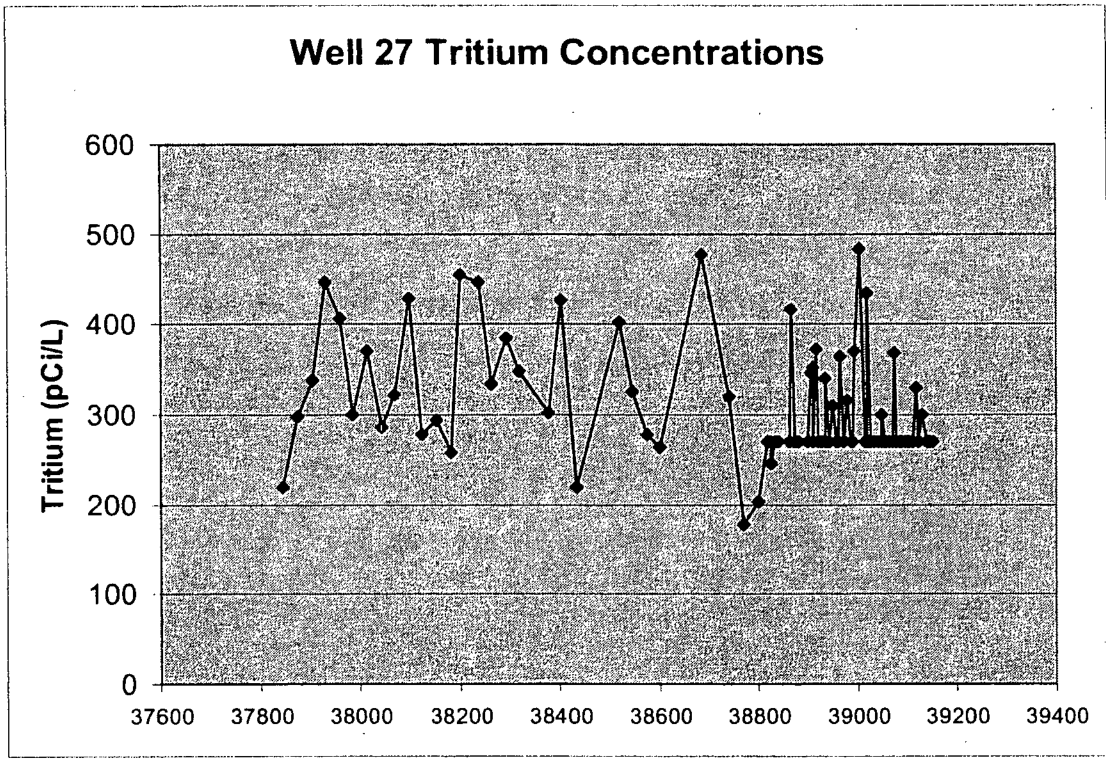


2.0 Evaluation of Elevated Tritium Concentrations Measured in Monitoring Well 27

Well 27 was installed in 2002 to monitor groundwater adjacent to the turbine building sump discharge pipeline. Initial quarterly samples from the well did not contain tritium. Tritium was first detected in Well 27 in September 2003. Since that time the concentration has fluctuated through a very narrow range from less than the MDC of 220 or 270 pCi/L, to a maximum of 484 pCi/L on October 17, 2006. Since December 2006, through the latest weekly sample (March 19, 2007) analyzed prior to the visit of the EPRI assessment team, tritium was virtually undetected in Well 27. Figure 4 shows the indistinct trend in tritium concentrations in this well.

The assessment team believes that the concentrations of tritium measured in Well 27 may be due to the slow attenuation of tritium which was released during historical surface spills and is suspended above the water table in the vadose zone. The team recommends sampling of shallow soil above the water table in the vicinity of the historical surface spills to confirm the presence of tritium, and to characterize its nature and extent. The objective of the recommended sampling and analysis would be to validate the conceptual model that postulates the presence of residual tritium from the historical surface spills, and to demonstrate that this residual tritium may be the source of the tritium which is measured in Well 27. While such validation will not rule out the possibility of another source of tritium, such as an actively leaking SSC, it will offer credible evidence of an alternative source.

Figure 4



3.0 Evaluation of Elevated Tritium Concentrations Measured in Monitoring Well GP-13

In 1997, an estimated 600 to 1,000 gallons of radioactive liquid leaked from the Modularized Transfer Demineralization System (MFTDS) and were spilled to the rad waste yard immediately adjacent to the railroad bay door. The liquid influent to the MFTDS at the time of the spill contained 4.84E-2 μCi/ml (4.84E7 pCi/L) of radioactivity, which probably does not include the tritium inventory. However, it is reasonable to expect that the tritium concentrations ranged from 10^6 to 10^7 pCi/L. A french drain system ran parallel to the railroad tracks, and during the initial response to the spill, a vortex of spilled water was observed entering the drain in an area around rotted railroad ties.

Contaminated asphalt and soil and most of the french drain were excavated and removed, based on measured concentrations of gamma-emitting radionuclides (primarily Co-58, Co-60, Cs-134, and Cs-137). However, no attempt was made to remove concrete pads containing banks of electrical conduit that were contaminated, or to clean culverts with inaccessible contaminated soil. Although no measurements of tritium in soil were made during the remediation, it seems obvious that a substantial amount of tritium from this spill entered the soil and was not recovered.

Well GP-13 was installed during the recently completed hydrogeological study of the SQN plant site. This well is located in the area of the 1997 spill, along the former railroad immediately inside the radiological control area. Weekly groundwater samples from the well collected in February and March 2007 contained from 1.5E4 to 1.8E4 pCi/L of tritium.

The assessment team recommends that Well GP-13 be equipped with a data-logging pressure transducer to monitor groundwater level and temperature. The water levels recorded by this instrument over several months can be correlated with tritium concentrations measured in the well. A positive correlation could indicate the remobilization of tritium suspended in the shallow soil by rising water levels.

Sampling and analysis of the shallow soil is also recommended to confirm the continued presence of tritium in the soil, and to confirm that it is the likely source of the concentrations measured in GP-13. Temperature data may also prove insightful if a hydraulic connection between groundwater and surface water exists at this location. Installation of three or four additional monitoring wells would help to bound the extent of the contamination observed in Well GP-13, and may suggest a reason for the increased tritium level recently measured in the Radiological Environmental Monitoring Program (REMP) Well 6, located to the north of Well GP-13.

One groundwater sample from GP-13 was analyzed for Fe-55, Sr-89, and Sr-90 in February 2007. Although none of these radionuclides was detected, the MDCs of the analyses were likely those used for the 10CFR50/61 analysis for characterization of radiological waste (i.e., <1.6 pCi/L for Fe-55, <7.68 pCi/L for Sr-89, and <5.47 pCi/L for Sr-90). The assessment team recommends that additional groundwater samples from this well be analyzed for these radionuclides, using MDCs that are a small fraction (about 10 percent) of the U.S. EPA maximum contaminant levels (MCLs) for each species.

4.0 Analytical Data

Very few groundwater samples at SQN have been analyzed for any radionuclides other than tritium. As noted previously, Sr-90 is relatively mobile in the environment and its movement within the groundwater is only minimally retarded by adsorption to soil particles compared to almost all other radionuclides (except tritium). If an active leak from an SSC is ongoing, Sr-90 and/or other radionuclides may be present in the local groundwater. For this reason, the assessment team recommends that groundwater samples from selected monitoring wells (Wells GP-13, 21, 27, 29 and 31 at a minimum) be analyzed for Sr-90 and other selected plant-related radionuclides. The analysis for Sr-90 should use an MDC of approximately 1.0 pCi/L, which is a small fraction of the U.S. EPA MCL of 8.0 pCi/L for this radionuclide.

The Multi-Agency Radiological Laboratory Analytical Protocols Manual (MARLAP) suggests the use of the "critical level" in identifying positive analytical activity. An approximation to the "critical level" is to apply a criterion of 2-sigma of the counting error rather than a 3-sigma criterion. Applying a 2-sigma (or "critical level") criterion to the identification of positive activity statistically results in approximately 5 percent of all analytical data being considered positive falsely (a Type 1 error). However, re-sampling to confirm a suspect result, trending the analytical data over a period of several sampling rounds, and consideration of the location of the sample relative to suspected source areas can usually eliminate most false positive results. The assessment team recommends that the SQN staff consider applying a 2-sigma (or "critical level") criterion in determining detection of positive activity in all sample analyses. This approach differs from the 3-sigma criteria used in support of the REMP, which uses the hypothesis that radioactivity is not present, as opposed to the inversion of this for the groundwater monitoring program.

5.0 Procedures and Programs

The current groundwater protection program at SQN does not have a set of procedures to address the following elements:

- Sample planning
- Sample collection, storage, shipment, and chain-of-custody
- Selection of sample analytical suites, analytical methods, and sampling frequency
- Analytical DQOs, including specification of MDCs and criteria for defining positive detection of radionuclides
- Validation of analytical results
- Groundwater and monitoring well data management
- Monitoring well construction and monitoring well closure
- Monitoring well maintenance

In light of the Nuclear Energy Institute (NEI) Groundwater Initiative and the corresponding draft EPRI document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants", it is likely that the recently completed hydrogeological investigation at SQN will mature into a long-term monitoring program. Therefore, the EPRI assessment team recommends that the groundwater monitoring program be refined to include the development of procedures to address the activities listed above. A more formal, procedure-based program will help to ensure that quality data is collected, that it is scientifically and legally defensible, that it is useful for its intended purpose, and that it is maintained and evaluated in a consistent and readily retrievable manner. All of these efforts will help to assure that the groundwater protection program at SQN is implemented with the appropriate standard of care, and that it will facilitate resolution of groundwater contamination issues at the time of plant decommissioning.

6.0 *Hydrogeological* Database

The assessment team recommends that groundwater analytical data and monitoring well construction data be maintained in a database. The first priority in this effort should be to capture and manage the ongoing analytical data in a dedicated database. The ultimate goal should be to capture historical groundwater data, including monitoring well drilling records, well construction details, well survey data, groundwater levels, groundwater sampling records, sample analytical data, and associated laboratory QC data. Each sample result should be assigned a unique identifier to allow easy retrieval and evaluation of investigative data.

7.0 Groundwater Elevation Study With Data-Logging Pressure Transducers

The assessment team recommends that data-logging pressure transducers be installed in stilling wells within the cooling water intake forebay, in the discharge channel, and in 6 to 10 monitoring wells. These devices should be programmed to collect data at approximately 60-minute intervals over at least a 1-year period. Hydrographs of the recorded data can be evaluated to determine if changes in surface water levels (and plant operations such as reduced cooling water flow during refueling outages) can be correlated with groundwater levels.

The water-level data in each well can also be correlated with that well's tritium levels to determine if changes in water level appear to induce changes in tritium concentrations. Such a correlation can be useful in identifying the source of the tritium.

Since water temperature in the discharge channel is several degrees warmer than river water or groundwater, temperature may be a useful tracer to monitor the interaction of surface water and groundwater in the vicinity of the discharge channel. Commercially available transducers that simultaneously log temperature and water level would be useful in this application. Other easily measured water quality indicators such as pH, dissolved oxygen, and conductivity should also be considered for monitoring the interaction of surface water and groundwater. These lines of investigation may provide additional data for the determination of the relationship between tritium and groundwater levels and the source of the tritium.

8.0 Monitoring Well Preventative Maintenance Program

The network of groundwater monitoring wells should be evaluated regularly in an ongoing preventive maintenance program. Samplers should inspect each well during each sampling event to ensure that its structural integrity has not been compromised. The preventive maintenance program should include no less than annual inspection and documentation of the total well depth, the physical condition of each well head, and the means for securing the well against potential vandalism, which would compromise groundwater quality. These efforts will help to ensure that the wells remain intact and capable of providing groundwater samples that are representative of the aquifer in their vicinity.

During the EPRI assessment team's tour of the site, several 1-inch diameter PVC monitoring well casings were observed protruding from the ground, unprotected and without sealing caps. This condition leaves the wells vulnerable to vandalism, introduction of foreign material to the local groundwater, damage by vehicles, and dilution of formation water by precipitation or surface runoff. The surface completions of all monitoring wells should be protected by locking steel guard pipes that extend a few feet above grade and are set in concrete or in flush-mount steel road boxes set in concrete.

9.0 Groundwater Sampling Frequency

The frequency of groundwater sampling should be standardized and documented. All wells need not be sampled at the same frequency, but the reason for the sampling frequency at each well should be justified and documented. Because groundwater flow velocities usually are relatively slow, quarterly samples generally are adequate to establish long-term trends. In areas where groundwater flow is more rapid (e.g., where surface water influences are large) or in areas under investigation to identify the source of SSC leaks, more frequent sampling may be required.

10.0 Groundwater Sampling Methods

Groundwater at SQN is currently sampled with small diameter bailers (to fit into a 1-inch diameter well) or with auto samplers. If tritium is the only analyte of interest, either method is acceptable. However, both of these methods can introduce sampling bias to the analytical results for all other radionuclides, and adversely affect the ability to collect groundwater samples that are representative of *in situ* conditions.

Groundwater exists under relatively constant and uniform conditions of temperature and pressure. When a sample is collected and brought to the surface, where atmospheric conditions prevail, these physical parameters are changed. These changes induce changes in the solubility of gases, including oxygen and carbon dioxide, which are naturally present in groundwater. Loss of these gases results in an increase in pH, which reduces the solubility and possibly the concentration of many radionuclides potentially in solution.

The pressure decrease inherent in bringing a groundwater sample to the surface can be exacerbated by using suction-lift pumps (e.g., peristaltic pumps such as those in an auto sampler), particularly at lifts exceeding 15 feet, as these pumps may impart substantial negative pressure to the sample during collection. Samples subjected to relatively high ambient air temperature at the ground surface for extended periods, which may occur when using an auto sampler, can lose a significant percentage of dissolved gases, with resulting shifts in pH and redox state, that can induce precipitation of potentially dissolved radionuclides.

Unlike other radionuclides, tritium is not a solute in groundwater. Tritiated water is physically and chemically the same as normal water, except that tritiated water contains some molecules in which the normal hydrogen atom is replaced by tritium – the radioactive isotope of hydrogen. Because tritium is not a solute, changes in temperature and pressure induced during groundwater sampling do not affect its solubility or concentration.

In addition to changes in temperature and pressure, some groundwater sampling techniques may induce agitation and aeration of the sample or entrainment of particulate matter (turbidity). These effects are most pronounced with the use of bailers. Aeration alters the gas content of a sample, which induces changes in pH and solubility of solutes. Exposure of groundwater samples to atmospheric air can result in oxidation of the reduced form of iron (Fe^{2+}), which is common in most groundwater, and co-precipitation of other metals.

Agitation and increase of sample turbidity result in high concentrations of suspended particles to which radionuclides that are not mobile under natural groundwater flow conditions may be adsorbed. Because the amount of agitation and increased turbidity in samples from the same well can vary widely from sample event to sample event, the resulting analytical data for radionuclides present in the groundwater at trace concentrations (e.g., Co, Cs, Fe, Mn and Sr) can reflect spurious increases of these species. The apparent fluctuations in concentration can be large, and can complicate the evaluation of the meaning and significance of the data.

The goal in sample collection should be to use methods that result in the least impact possible to the chemical and physical properties of the water. The use of such methods will optimize efforts to obtain groundwater samples that result in analytical data that is accurate and reproducible, and that can be relied upon to make informed decisions regarding the impacts of contaminants. The accuracy and precision of sample analytical data are only as good as the quality of the samples submitted for analysis, and this quality is strongly controlled by the sampling method.

Many investigators have studied the effects of the method of sampling groundwater on the quality of the resulting analytical data. Although the method is not yet employed universally, a consensus among practitioners suggests that a method referred to as low-flow purging and sampling is the best currently available approach for collecting groundwater samples most representative of conditions within the aquifer. This method of sampling includes the following features:

- Use of a pump (often a gas-driven bladder pump) to purge and sample the well
- Placement of the pump intake within the middle of the wetted portion of the well screen
- Use of a low flow rate (approximately 200 ml/min) that induces no more than approximately 0.3 feet of drawdown during both purging and sampling
- Minimal disturbance of the stagnant water column above the well screen and of the accumulated sediment or colloids at the bottom of the screen

- Monitoring of water quality indicator parameters, including pH, temperature, conductivity, dissolved oxygen, and turbidity, during purging to determine when it is appropriate to collect a sample

- Minimization of sample agitation and atmospheric contact with the sample

- Collection of unfiltered samples for analysis of metals (including radionuclides) to allow estimation of the total contaminant load, which is comprised of both the dissolved and colloidal fraction in the groundwater

The EPRI assessment team recommends that monitoring wells be sampled by the low-flow method at least once annually to provide samples for the analysis of a wider suite of plant-related radionuclides, i.e., in addition to tritium.

11.0 Tritium-Saturated Concrete

Information from several decommissioning nuclear plants has demonstrated that tritium in contact with concrete diffuses into, and is retained within, the bulk structure of the concrete. In these situations, a tritium gradient generally exists, and this radionuclide has been measured in significant concentrations even at the center of concrete walls several feet thick. This phenomenon has important implications regarding the potential for impacts to groundwater. Concrete structures that have been in contact with high concentrations of tritium provide a reservoir that can be a source of the contamination in groundwater. This possibility should be considered when evaluating the occurrence and persistence of low levels of tritium in groundwater at SQN.

This issue may have particular relevance when evaluating the effects of a documented event in the mid-1980s when radioactivity leached through a concrete wall of the Condensate Demineralizer Waste Evaporator Building to the outside surface of the concrete, and from there to the soil outside of the building. It may also pertain to the effects of the former practice of releasing to the soil rainwater that collected in the RWST moats at both Unit 1 and Unit 2. The soil above the water table in these areas should be sampled and analyzed to determine the concentrations of tritium that are present.

12.0 Review of 10 CFR 50.75 (g) Files

Efforts have been made by SQN staff to document the spills and events that could lead to soil, groundwater, and surface water contamination that might persist until the time of decommissioning. From this effort, approximately eight events were identified and documented. The most significant of these events appear to be the following: a) a spill in 1997 from the MFTDS to the rad waste yard adjacent to the railroad bay door, b) the overflow in 1998 of a sump in the Unit 2 Additional Equipment Building, and c) the discovery of radioactivity in the soil near the outfall of the RWST moat drain pipe at Unit 2 in 1995, and at Unit 1 in 2002.

It is not certain whether all of the significant contaminating events have been identified and documented. It seems possible that additional unidentified events have occurred during the 26 years since the plant began operation in 1981. The assessment team recommends that additional interviews of site personnel be conducted to identify any additional contaminating events for inclusion in the files required by 10 CFR 50.75(g). In addition, a copy of the soon-to-be-completed report of the recent hydrogeological investigation of the SQN plant site should be included in the 10 CFR 50.75 (g) file. Additional similar reports that may be prepared in the future should also be added to the file.

13.0 Implementation of the March 2007 Draft EPRI Groundwater Guidelines

The draft EPRI guideline document "Guideline for Implementing a Groundwater Protection Program at Nuclear Power Plants" describes a process for characterizing impacts to groundwater and implementing a groundwater protection program. The process adopts a graded approach which recognizes that some sites will require more investigation than others. Of the three program levels, all sites are expected to implement the elements included in Program Level I. Sites that score a higher Priority Index, because their risk of having significant groundwater impacts is greater, are expected also to undertake additional investigative measures described in Program Levels II or III.

The following is a listing of the elements currently in the draft guideline document for Program Level I, with a brief discussion of how SQN has or should implement them. Although not specifically addressed here, the same baseline list of program elements is relevant to the implementation of a groundwater protection program at the Brown's Ferry and Watts Bar nuclear power plants.

- *Develop the Site Conceptual Model*
  Using a written narrative, maps, and data tables, SQN should formulate a written description of the concentrations of radionuclides that have been detected in groundwater, where they have been detected, what and where the inferred source(s) are, the presumed fate and mechanism of transport of the contaminants in the environment, and the risk to potential receptors. This program element largely will be fulfilled with the soon-to-be-completed report of the recently conducted hydrogeologic investigation ("hydro study") of the site. The Site Conceptual Model will provide a synthesis of what is currently known about groundwater contamination at SQN and will guide any required future investigation.

- *Review aerial photos and engineering drawings*
  This program element was likely completed as part of the recently conducted hydro study of the SQN plant site.

- *Review previous hydrogeologic reports*
  Review all documentation associated with the installation of the existing monitoring wells which were drilled to investigate:
  - the spill of diesel fuel from the auxiliary boiler supply pipeline,
  - potential leaks from the radioactive waste and turbine building sump discharge pipelines,
  - the spill of radioactive water to the rad waste yard adjacent to the railroad bay door.

  This program element was likely completed as part of the recently conducted hydro study of the SQN plant site.

- *Evaluate potential receptors of groundwater contamination*
  Users of groundwater in the vicinity of the plant, including private and public supply wells, should be identified. The annual land use census of the area surrounding the plant, required as a component of the REMP, may be a useful resource to complete this program element.

- *Review state and local regulations*
  These regulations should be reviewed and summarized to ensure that the MDCs of all analytical methods used to characterize groundwater contamination are a small fraction of the applicable criteria, and that SQN is in compliance with reporting requirements for spills and for routine monitoring.

- *Determine groundwater elevation*
  Several groundwater monitoring wells exist at SQN. A synoptic round of water levels measured in each of these wells on the same day should be plotted on a site map and contoured to determine groundwater gradients and the direction of flow. Such a map should be constructed from water levels

measured at various times of the year to determine if significant seasonal variation exists.

- *Evaluate pre-operational groundwater and geologic data*
  This program element includes the review of the geologic characterization conducted during the original plant site investigation and for the preparation of the Final Safety Analysis Report. It was likely completed as part of the recently conducted hydro study.

- *Determine regional hydrogeologic characteristics*
  A review and summary of published reports by the U.S. Geological Survey and the Tennessee Department of Environment and Conservation, Geological Division will satisfy the requirement of this program element. This task has likely been completed in the preparation of the recently conducted hydro study.

- *Establish and document DQOs for well drilling*
  DQOs are used to establish performance and acceptance criteria, which serve as the basis for designing a plan for collecting environmental data of sufficient quality and quantity to support the goals of the study. SQN should document its DQOs for well drilling by addressing the following issues:
    - The purpose of each well
    - The design objectives for each well
    - The rationale for the location and depth of each well
    - The types of soil and groundwater samples that will be collected from each well
    - The types of analyses that will be performed
    - The intended use of the resulting investigative data

- *Install monitoring wells*
  Approximately 25 monitoring wells have been installed at SQN to date. The results of analysis of groundwater samples from these wells should be evaluated in the context of the Site Conceptual Model. If it can be concluded that all sources of groundwater contamination at the site have been identified, no SSCs are currently leaking contaminants to the environment, and all contaminant plumes have been adequately characterized, no additional monitoring wells will be necessary. Any additional wells that may be required should be installed under the supervision of a qualified geoscientist.

- *Determine horizontal distribution and movement*
  A sufficient number of monitoring wells or temporary groundwater sampling points (geoprobes) should be drilled to bound the extent of each identified contaminant plume. SQN should consider drilling additional wells or geoprobes in the vicinity of the RWSTs at both Unit 1 and Unit 2, and to bound the plume identified in Well GP-13.

- *Institute configuration management for well drilling*
  An understanding of the construction details of a monitoring well is necessary when evaluating the results of analysis of groundwater samples collected from the well. The types of well construction details to be documented include:
  - The drilling method
  - The total well depth
  - The depth interval over which the well is open to the aquifer (screen zone)
  - The type and thickness of any filter material adjacent to the screen zone
  - The type and thickness of any seal that isolates the screen zone from overlying or underlying strata

  These details, in addition to a log of the stratigraphy penetrated by each well, the well survey data, and water levels measured in the well, should be managed in a dedicated database to document, retain, and allow for convenient retrieval of the data.

- *Review permitting requirements for well drilling*
  State and local regulations should be reviewed to determine permitting requirements for drilling and abandoning monitoring wells. This task has likely been completed in conjunction with the recently conducted hydro study at SQN.

- *Develop and implement a maintenance program for monitoring wells*
  To be certain that the groundwater sampled from a monitoring well is representative of the water quality within the aquifer near the well, it is important to maintain the integrity of the well casing and surface completion by periodically inspecting these components and promptly initiating any necessary repairs. As noted previously, SQN should improve the surface completions of its monitoring wells to reduce the potential for vandalism, the introduction of foreign materials to the local groundwater, damage by vehicles, and the dilution of formation water by precipitation or surface runoff.

- *Establish and document DQOs for groundwater sampling*
  DQOs are used to establish performance and acceptance criteria, which serve as the basis for designing a plan for collecting environmental data of sufficient quality and quantity to support the goals of the study. SQN should review and revise its existing procedures to ensure that the following groundwater sampling issues are discussed:
  - The purpose and objectives of the samples
  - The number of samples needed for a representative data set
  - The sampling method(s)
  - The water quality indicators to be measured during sampling and their acceptance criteria
  - The method for managing sampling wastes, including purge water
  - The sample analytes
  - The sample holding time(s)
  - The required sample volume, container type(s), and preservative(s)
  - The number and type of field quality control samples
  - The sample handling, labeling, storage, shipment, and chain-of-custody procedures
  - The qualification and training requirements for sampling personnel
  - The applicable regulatory criteria
  - The analytical methods and required MDCs
  - The required analytical method uncertainties
  - The number and type of laboratory quality control samples and acceptance criteria for their analysis
  - The required number of samples per analytical batch
  - The alternate actions to be taken if samples cannot be obtained
  - The alternate actions to be taken if MDCs are not met
  - The method for validation of sample analytical results

- *Establish sample collection procedures*
  A sampling procedure should address the following issues:
  - Sample planning
  - Sample collection methods, including a description of the equipment to be used

- Water-quality indicators to be measured during sampling and their acceptance criteria
- Sample analytes
- Sample holding time(s)
- Required sample volume, container type(s), and preservative(s)
- Number of field quality control samples, such as duplicates, matrix spikes, equipment rinsate blanks, and splits
- Qualification and training requirements for sampling personnel
- Management of sampling waste, including well purge water
- Sample handling, labeling, storage, and shipment
- Sample Chain of Custody
- Analytical data receipt and review

- *Establish analyte list(s)*

Analytes shall, at a minimum, be selected based on the radionuclides contained in the SSCs that are known or from potential sources of groundwater contamination, and shall always include tritium and gamma-emitting radionuclides. Other inputs to the analyte list should include those radionuclides known to have been released to soil and/or groundwater during on-site spills and leaks.

Tritium is always considered to be an analyte because of its abundance within primary cooling water and its mobility within groundwater systems. Those radionuclides with half-lives less than a few days generally are not of interest for groundwater monitoring. Similarly, those radionuclides that are relatively immobile in groundwater (e.g., Am, Cm and Pu) may be removed from the analyte list for selected sampling locations.

- *Establish MDC requirements and criteria for positive detection*

The rationale for establishing the MDCs and the criterion for determining when an analytical result is a positive detection shall be established and documented. Generally, the MDC for each analyte should be a small fraction of the lowest applicable regulatory criteria for that analyte.

It should be noted that in some instances the MDCs for analyses of REMP samples may not be low enough to achieve the DQOs of a groundwater sampling program. It should also be noted that while an existing 10 CFR Part 61 analyte list may be useful in the design of a groundwater protection program, the MDCs used for the Part 61 analyses also may not be sufficiently low enough to achieve the groundwater sampling DQOs.

- *Establish the sampling schedule*

A written sampling schedule and sampling plan consistent with the established DQOs shall be created for each sampling point and analyte. Sampling points may include monitoring wells, water-supply wells, surface water bodies, springs, foundation drains, storm drains, sumps, leaks at structures or components, and basement floors or walls with groundwater in-seepage.

The frequency of sampling can be based on site objectives, but quarterly sampling is generally a good initial approach. The rate of undisturbed groundwater flow is generally slow enough that sampling more frequent than quarterly may not provide additional benefit unless the sample point is close to a potential contaminant source or groundwater flow is rapid. The apparent correlation of tritium concentrations in Well 31 with refueling outages in both Unit 1 and Unit 2 suggests the need for more frequent sampling of this and selected surrounding wells to further investigate the cause of this phenomenon.

- *Validate analytical results*

A consistent documented process shall be established to validate the quality of the analytical data. This process should include the following:

  - An inventory of analytical results to ensure that all data are reported by the analyzing laboratory
  - An evaluation of the achieved laboratory MDCs
  - An evaluation of laboratory QC/QA data
  - An evaluation of any split, duplicate, blank, or spike sample results
  - An evaluation to determine whether the acceptance criteria for each category of quality control samples were achieved

- *Evaluate analytical data*

Evaluation of the analytical data, including a comparison with regulatory criteria, should proceed only after the data have been validated. This evaluation may include statistical analysis for normality and analytical bias, determination of horizontal and vertical spatial correlations, and time-series plots of contaminant concentrations and/or water levels within sample points to identify temporal trends.

Analytical data for matrices other than groundwater may also be of value in evaluating environmental impacts at SQN. These may include measurement of water levels and the chemical or radiological content of precipitation, storm water, building infiltration, and surface water (particularly at the cooling water discharge channel and intake forebay).

- *Evaluate field water quality indicator data*

If measured prior to collecting groundwater samples for radiological analysis, field water-quality indicator data shall be evaluated to ensure that no anomalies are present. The evaluation shall be documented. Typical water quality indicator parameters include:

  - Turbidity
  - Temperature
  - pH
  - Oxidation-reduction potential (ORP)
  - Specific conductivity
  - Dissolved oxygen concentrations

In order to determine when a representative groundwater sample can be obtained, these indicators of water quality typically are measured periodically prior to collection of a sample. If the measurements do not stabilize within specified limits, or if anomalous values of these indicators are measured, they may indicate that the corresponding groundwater sample is not representative of the formation from which it was collected. Accordingly, the significance of the reported analyte concentrations should be evaluated.

- *Provide for management and data quality assessment of analytical data*

Data should be managed in a secure database to ensure that summary results are documented, retained, and readily retrievable. The assessment of data quality should ensure that the following elements are documented for each sample result:

  - Sample identification
  - Sample location or well identification
  - Sample date and time
  - Measured concentration for all radionuclides where results have been reported (whether or not above the detection criteria, or positive or negative)
  - Measurement uncertainty
  - Achieved MDCs
  - Records of data validation and verification

- Whether any validated analytical results exceed applicable site action levels
- Identification of missing sample results

- *Evaluate background radionuclide concentrations*

The presence in the environment of background concentrations of radionuclides that may also be contaminants at SQN should be recognized and evaluated. The analytical complications resulting from the presence of background radioactivity are distinct from those due to analytical bias. They are also unrelated to false-positive detections of radionuclides that are statistically predictable when analyzing at low environmental levels near the MDC.

Radionuclides found in background may be naturally occurring in the environment or may be of anthropogenic origin. Possible sources of background radioactivity in groundwater include the following:

- Minerals in soil and rock
- Cosmogenic processes in the upper atmosphere
- Atmospheric nuclear weapons testing
- Nuclear accidents such as at Chernobyl
- Releases of radionuclides from up-gradient nuclear power plants, hospitals, U.S. Department of Energy facilities, or other facilities that are sources of radioactive material
- Releases of radiochemical pharmaceuticals from up-gradient water treatment plants and landfills

- *Evaluate atmospheric deposition of plant-related radionuclides*

The significance of atmospheric deposition of plant-related radionuclides should be evaluated and documented. Controlled airborne releases from the plant ventilation stack or cooling tower may result in measurable atmospheric deposition of plant-related radionuclides (including tritium) in the vicinity of the owner-controlled area. Some of this material may accumulate on plant roof surfaces and wash into roof drains during precipitation events. Rain may also wash airborne releases onto the soil and building surfaces near the plant.

Discovery at SQN of radioactive contamination on the roof of the auxiliary building in the early 1990s is documented in the 10 CFR 50.75 (g) file. Although remediation of contamination on the roof was completed, it is possible that significant tritium activity remained on the roof surfaces and drains, and may have washed into the soil near the roof drain outfalls.

The impact of this potential source of groundwater contamination may vary substantially with release periods and meteorological conditions. Atmospheric deposition may be a process actively contributing to low-level tritium concentrations in groundwater and would explain the presence of these low-level concentrations when no other potential source can be identified.

- *Evaluate plant-related liquid pathways*

The potential impact from the discharge of cooling water and subsequent re-circulation into plant systems or on-site drinking water should be evaluated and documented. Re-circulation of cooling tower effluent or water from the discharge channel may re-circulate plant-related radionuclides into other plant systems. The potential for this process to occur at SQN should be evaluated.

- *Review and revise the Site Conceptual Model*

Site characterization is an iterative process. Each time new data are developed through such activities as drilling new monitoring wells, sampling soil, testing aquifer parameters, reviewing plant construction records, or periodic groundwater monitoring, that data should be evaluated in the context of the current Site Conceptual Model. If the data are inconsistent with the Site Conceptual Model, then this model should be revised to be consistent with the new data. For example, an increase in contaminant concentrations in an area of the site where they were previously stable would trigger a revision of the model.

- *Perform initial independent review*

After the program elements described above have been completed and documented, a Priority Index has been established for each relevant SSC or work practice, and a Site Conceptual Model has been developed, an independent review shall be conducted. This independent review will provide additional assurance that the Priority Indices calculated for all SSCs and work practices provide an effective evaluation of their potential for creating groundwater contamination and that the Site Conceptual Model is consistent with available information regarding groundwater quality at the site. The review should be performed by individuals that collectively have relevant experience in system operations and design, radiation protection, chemistry, and hydrogeology.

- *Revalidate Priority Index ratings*

A review cycle shall be established and documented for the identification of potential sources of subsurface contamination and for revisiting the calculation of Priority Indices for SSCs and work practices. The rationale for selecting the frequency and methods of reviews should be documented. Justification for

[Extending the review cycle beyond five years shall be based on objective and well understood factors.]