Technical Session Th38

International Panel Discussion on Radiological Sources and Migration in the Subsurface

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Coordinator: **Wendy Reed***

*U.S. NRC, Office of Nuclear Regulatory Research

Rockville, Maryland
March 10, 2011

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Motivation:

Convene a panel of experts to survey international and domestic regulatory and industry programs for experiences in addressing abnormal releases involving subsurface migration of radionuclides at nuclear facilities.

Discussion topics:

- formulation and testing of conceptual models that involve various radionuclide sources
- quantitative performance assessments
- compliance monitoring strategies; and
- selection and application of remediation/corrective action methods related to ground-water protection.

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Focus:

Panelists address questions based on their practical experiences related to these topics.

Expected Outcomes:

- ✓ observations and insights from their experiences, and
- ✓ what regulatory and research initiatives and guidance resulted from these experiences.

Convening this panel follows from a recommendation from the *Ground-Water Task Force Report* to inform the U.S. NRC and stakeholders of international experiences in assessing abnormal releases at nuclear facilities.

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Panelists:

- Michael Rinker, Canadian Nuclear Safety Commission
- Denis Maro, IRSN (French Institute for Radiological Protection & Nuclear Safety)
- Ron Nicholson, EcoMetrix and University of Waterloo
- Boris Faybishenko, Lawrence Berkeley National Laboratory
- Sean Bushart, Electric Power Research Institute
- Richard Conatser, U.S. NRC/NRR
- Richard Raione, U.S. NRC/NRO
- James Noggle, U.S. NRC/Region I Inspector

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Areas of Discussion:

- Monitoring Strategies
- Conceptual Site Models/Modeling
- Corrective Action and Regulatory Compliance

Specific Questions were formulated to explore these topics

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Monitoring Strategies:

- How were monitoring systems designed and used to detect abnormal and routine releases to the subsurface?
  - Was atmospheric deposition monitored;
  - Was contamination of surface water and bottom sediments monitored;
  - Were the saturated and unsaturated zones monitored?
- What specific monitoring data (e.g., hydraulic, radiochemical, geochemical, geophysical, meteorological) and analyses were used to test the conceptual models?
- If remediation was needed, what monitoring data was used to select the remediation methods and to determine their efficacy?

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Conceptual Site Models/Modeling:

- How were conceptual models formulated for the various radionuclide sources (e.g., atmospheric deposition, subsurface leaks from buried pipes or spent fuel pools, etc.) and site-specific features, events and processes?
- Do the conceptual models incorporate:

➢ Uncertainties in sampling and measurement of the radionuclides;
➢ Evolution of the chemical form of the radionuclide in the atmosphere, soil and ground water;
➢ Quantification of dry and wet deposition of the radionuclide (e.g. tritium and carbon-14);
➢ Quantification of organically-bound tritium?

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Conceptual Site Models/Modeling:

- What was learned in the testing of conceptual site models?
- What role did modeling have in estimating and confirming abnormal or non-routine releases where routine releases were also anticipated (e.g. tritium leaks compared to atmospheric tritium release to soil and groundwater)?
- What role did modeling have in estimating and confirming radionuclide migration behavior, and in assessing vulnerabilities to environmental resources (e.g. potable aquifers)?
- For dose modeling of tritium, was the cycling of tritiated water and organically-bound tritium (OBT) in the environment considered? Were dose calculations and consequence analyses for humans only, or were non-human biota also considered?

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Corrective Action and Regulatory Compliance:

- What root-cause analyses were carried out to identify the abnormal release mechanisms and to assist in identifying corrective actions?
- Were concentration or dose criteria used to determine compliance and the need for remediation?
- For environmental risk assessments, what risk parameters were quantified and what were the acceptance criteria?
- What regulatory and research initiatives and guidance resulted from the field studies and analyses?

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Policy on Groundwater Protection

- CNSC intends to adopt a 'goal' for the protection of groundwater
  - Prevention or reduction of contamination to the extent possible, with differential protection being based on use and vulnerability of the local and regional groundwater at each specific site, as well as the technical and economic feasibility of the measures required

Policy on Groundwater Protection

To achieve this goal, a licensee shall:

- Control releases
- Characterize or predict any releases (to groundwater) that would occur after preventive controls are implemented
- Conduct and document an appropriate "end-use analysis"
- Implement a groundwater monitoring program that monitors the performance of controls, as well as groundwater quality

Guidance on Environmental Investigations

Overview of CNSC's four-step approach:

- Site Information Assessment
  - Documents known or potential concerns due to the presence of the contaminant
- Initial Site Investigation
  - Defines the type, magnitude and location of the contamination
- Detailed Site Investigation
  - Describes, more accurately, the amount of contaminant released and assesses its fate and transport
- Risk Management
  - Evaluates risks to human and ecological receptors and leads to mitigation based on those risks

Carbon 14 (^{14}C) and tritium (^{3}H) transfers in grassland around AREVA La Hague nuclear recycling plant: from the atmosphere to the groundwater

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Why studying ^{14}C and ^{3}H (1/2)?

- **Carbon 14 and tritium are substantially released in the atmosphere around:**
  - Nuclear Power Plants (NPP);
  - Nuclear Recycling Plant (NRP).

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Why studying ^{14}C and ^{3}H (2/2)?

- **Still significant uncertainties on ^{14}C and ^{3}H**:
  - sampling and measurement;
  - evolution of the chemical form in the atmosphere, vegetation, soil and groundwater;
  - quantification of dry and wet deposition;
  - quantification of Organically Bound Tritium (OBT).

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The VATO project : VAlidation of TOcatta model

- **To estimate ^{14}C and ^{3}H fluxes in a grassland ecosystem (*raygrass sp*., soil and groundwater in both saturated and unsaturated zones), in relation with:**
  - evolution of air concentrations (day versus night);
  - weather conditions;
  - land use (grazing, maïze silage and hay).
- **To study ^{14}C and ^{3}H transfers to cows and cowmilk as a function of the diet.**

In order to validate the TOCATTA model.

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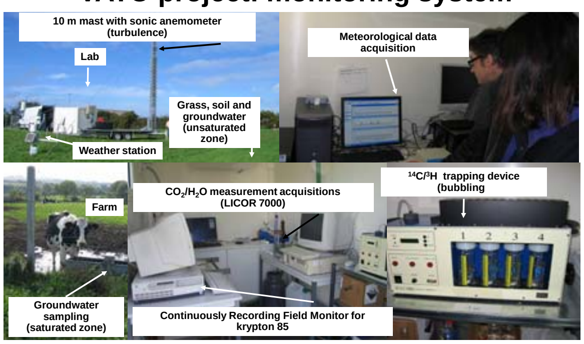
VATO project: monitoring system



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Scope of Nuclear Plant Groundwater Protection Programs

Systems Investigated
- Spent fuel pools
- Buried piping and tanks
- Liquid effluent discharge valves
- Operational leaks and spills

Tritium
- Low levels of tritium observed in on-site monitoring wells
  - U.S. EPA safe drinking water limit is 20,000 pCi/L
- A few sites have detected other radionuclides (Co, Cs, Sr)

Levels observed do not present a health concern to public

Sites have implemented voluntary groundwater protection programs <u>to prevent off-site migration of contamination</u>

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EPRI Groundwater Protection Guidelines (Report 1016099)

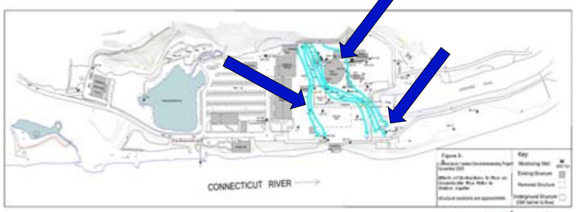
Guidelines Approach

– Provides guidance for development of robust and technically sound *graded approach* to meet the objectives of the Groundwater Protection Initiative

1) Evaluate Systems, Structures, Components (SSCs) and Work Practices

2) Understand Site Hydrogeology and Characteristics

3) Implement Groundwater Monitoring Program



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Connecticut Yankee: Tritium in the Unconfined Aquifer

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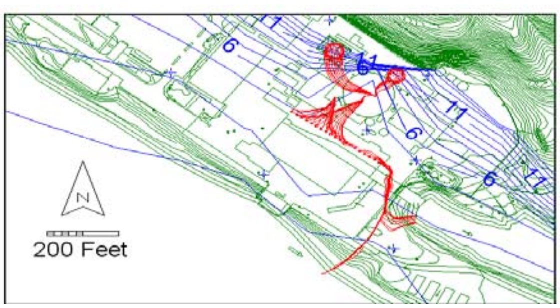
Particle Traces from Groundwater Model Simulation



Results Indicated Three Source Areas

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Evaluating Remediation Efficacy

Example for Monitored Natural Attenuation:

- Continue to monitor contamination concentrations and extent, ensure progress is acceptable to meet remediation objectives
- Ensure any institutional controls continue to be effective
- Ensure site-conceptual models are up to date for the purposes of monitored natural attenuation
- Develop contingency plan if:
  - Contamination migrates beyond established plume or compliance boundary.
  - Contamination is increasing or not decreasing as expected.

CSM - Process

- Conceptual models are usually constructed using the following components:
  - Geologic framework to characterize the subsurface and fluid flow and transport.
  - Hydrologic framework to identify fluid flow processes in the physical framework.
  - Assessment of risk sources such as radionuclide source terms, contaminant chemicals and plausible pathways.
- Radionuclide sources in this case are determined by the reactor design and the source terms of significance are determined based on the level of activity and volume of the tank.

CSM – Uncertainties…

- In the context of hydrologic safety review the requirements are:
  - adequate description of the subsurface, groundwater flow processes, use, and pathways for accidental release of radioactive liquid effluents.
  - Identification of a potable water source
  - Selection of the most conservative but plausible approach

CSM Lessons Learned…

- Longer records of data and proper interpretation and integration of data from different sources is vital for building a good CSM.
  - The different sources include hydrogeologic investigation, core sampling, geophysical methods, pump tests, etc...
- Understanding of data anomalies and what they represent in the overall site hydrology and hydrogeology.
- Proper QA/QC procedures for monitoring data collection, reporting, and analysis.

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CSM – Monitoring Data

- Monitoring data in the context of the safety review of new reactors are limited to data used to construct numerical computer models or analytical models to simulate flow and transport.
- The data requirement is set in 10 CFR 100.20 (c)(3), 10 CFR Part 50, Appendix A, General Design Criterion (GDC) 2, 10 CFR 52.17(a)(1)(vi), for ESP applications, and 10 CFR 52.79(a)(1)(iii).

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The Role of Modeling

- Modeling is an integral part of the new reactor applications review process.
- Pathways to potable water sources identified in the analysis of accidental release of liquid radioactive effluents were greatly enhanced by CSMs and modeling using post-construction scenarios.
- Numerical models are used to simulate the transport of radionuclides in both surface water and groundwater pathways.

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Chernobyl Cooling Pond

- Area ~ 22 km^2 , ~1.5 × 10^8 m^3 of water
- Water is pumped from the Pripyat River to the Cooling Pond

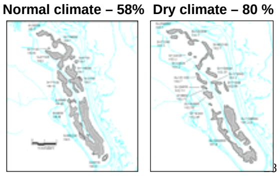
Sources of Contamination

- Dispersed fuel particles, and "hot" particles
- Heavily contaminated water from the reactor basement and soils.
- Total radioactivity >200 TBq, including ^{137}Cs-80%, ^{90}Sr-10%, ^{239,240,241}Pu-10%
- Routine releases of contaminated water

Decommissioning:

Will expose highly contaminated bottom sediments:

Normal climate – 58% Dry climate – 80 %



Monitoring

- 40 cross sections and aerosol sampling stations;
- 138 groundwater monitoring wells;
- 4 stations for sampling surface water and bottom sediments

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Monitoring Systems

- Monitoring atmospheric deposition
  - Post-accident monitoring of aerosol distribution along with modeling studies
  - Resuspension of radionuclides
- Monitoring contamination of surface water and bottom sediments
  - Monitoring of contamination of surface water and bottom sediments since mid-1986.
  - Research sites
- Monitoring saturated and unsaturated zone
  - Post-accident network of groundwater wells, surface water sampling stations
  - Unsaturated (vadose) zone research sites.
- Specific monitoring data and analyses used to test the conceptual models
  - Surface water and groundwater monitoring,
  - tracer and pumping tests,
  - radiochemical, geochemical, meteorological measurements,
  - pilot cooling pond drawdown,
  - resuspension monitoring,
  - monthly sampling and radioactive analysis of water from the input and output canals,
  - radio-ecological studies.

We need new monitoring methods and tools to monitor pond decommissioning and remediation.

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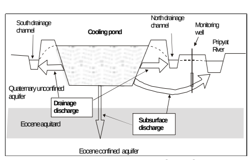
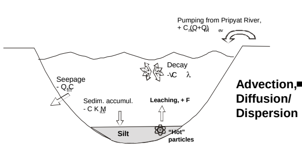
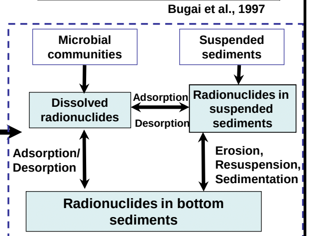
Testing Conceptual Site Models

- Processes affecting hydrological and radionuclide transport in the pond and bottom sediments
- Atmospheric deposition and resuspenstion processes:
  - estimation of a source term;
  - evaluation of the consequences of hypothetical emergency scenarios.
- K_d parameters, which depend on the N ammonia concentration.



Bugai et al., 1997





Modified after M.Zheleznyak

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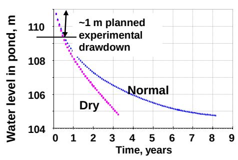
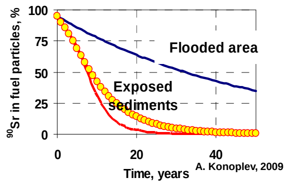
Modeling of Water Level Drawdown, Radionuclide Behavior, and Vulnerabilities of Environmental Resources

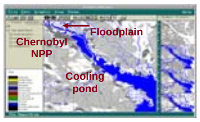


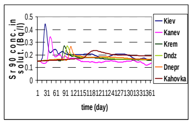
D. Bugai et al., 1999



A. Konoplev, 2009

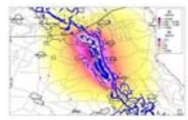
Modeling of the dam break (left) and ^{90}Sr concentration (right) in the Dnieper River reservoirs





M. Zheleznyak et al., 2006

Modeling of additional ^{137}Cs contamination of soil due to sediment resuspension after a hypothetical fire



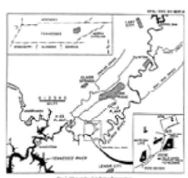
V. Kashparov, et al. 2001

Chernobyl Cooling Pond — a Case Study for Testing Monitoring, Modeling and Remediation Techniques

Savannah River PAR Pond

- Constructed in 1958 as a Cooling Pond for the Savannah River Site's P and R Reactors
- Experimental water level drawdown in 1991 and monitored radionuclide concentrations in water and bottom sediments, as well as erosion of sediments.

Oak Ridge Reservation White Oak Lake



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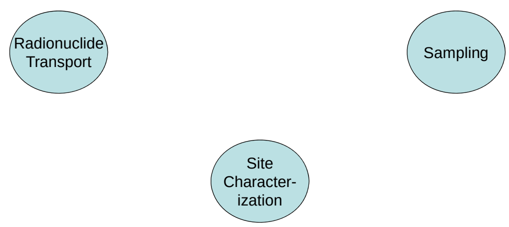
Basic Steps for GW Monitoring



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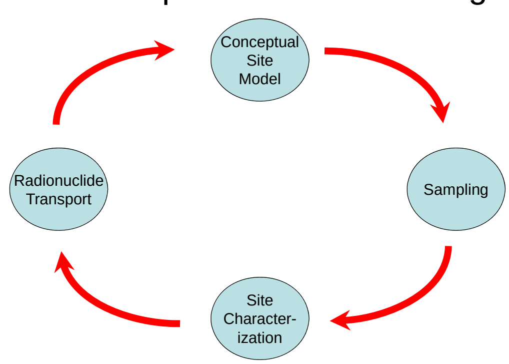
Basic Steps for GW Monitoring



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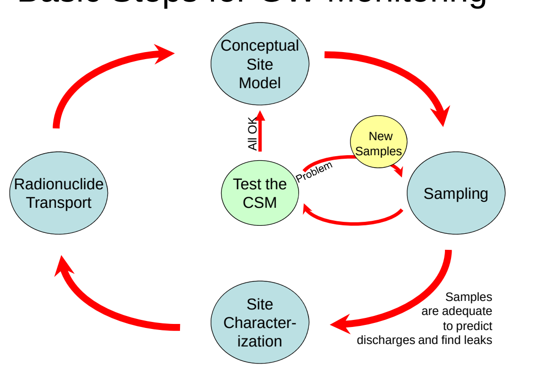
Basic Steps for GW Monitoring



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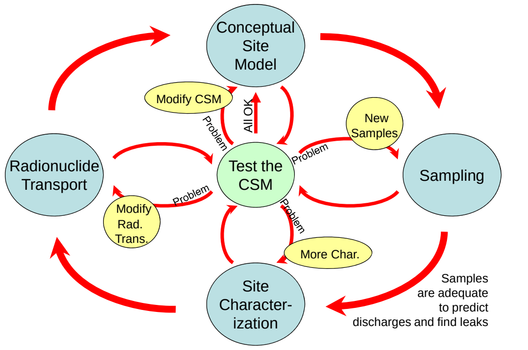
Basic Steps for GW Monitoring



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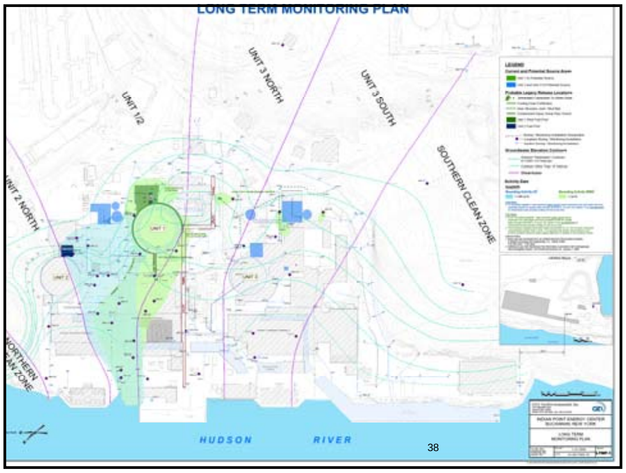

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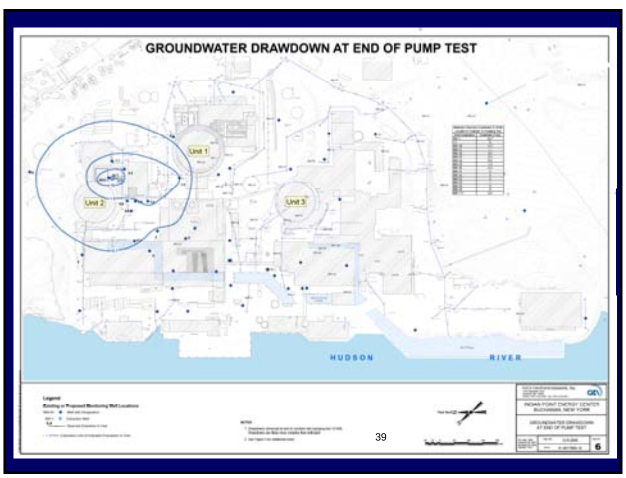

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Unit 1 Building Foundation Drain System

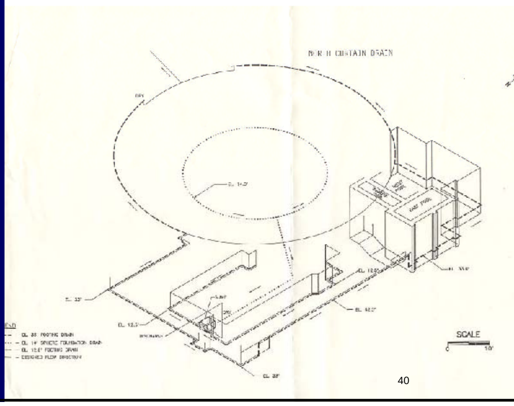
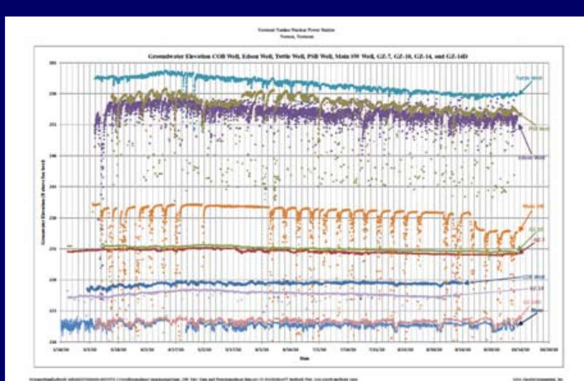


Figure 1
Vermont Yankee Tritium Ground Water Plume



NRC Experiences in Reviewing Abnormal Releases to Ground Water

- NRC has a Website to convey information on tritium and buried pipes at:
  http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/buried-pipes-tritium.html
- NRC requires power reactor licensees to report annually on releases of radionuclides (including tritium). Reports for the last 5 years are available at: http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-info.html

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NRC Experiences in Reviewing Abnormal Releases to Ground Water

- Earlier reports are available in NRC's Agency-wide Documents Access and Management System (ADAMS) at: http://www.nrc.gov/reading-rm/adams.html
- NRC maintains a list of reactor sites with radioactive material in ground water originating from significant spills or leaks that can be viewed at:
  http://www.nrc.gov/reactors/operating/ops-experience/tritium/sites-grndwtr-contam.html

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New Relevant Industry-Consensus Guidance

ANSI/ANS-2.17-2010, "*Evaluation of Subsurface Radionuclide Transport at Commercial Nuclear Power Plants*," American Nuclear Society, La Grange Park, IL, 60526, USA
(approved 12/23/2010) available for purchase at:
http://www.new.ans.org/store/i_240281

CSA Standard N288.4-10 "Environmental monitoring programs at Class I nuclear facilities and uranium mines and mills," Mississauga, Ontario, Canada L4W 5N6
(published May 2010) available for purchase at:
http://www.ShopCSA.ca

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