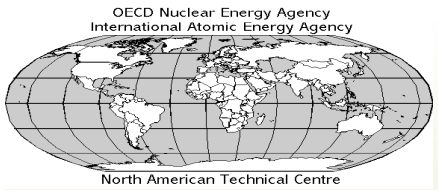
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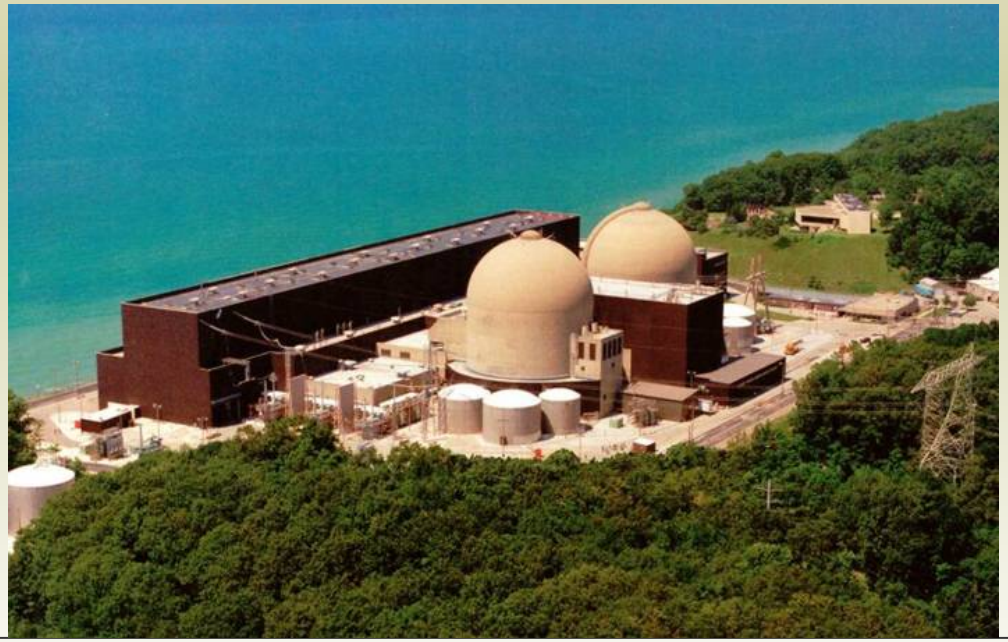
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# Tritium Releases from Nuclear Power Plants

**Jason T. Harris, Ph.D.**
Department of Nuclear Engineering and Health Physics

Idaho State University
North American Technical Center

July 24, 2012



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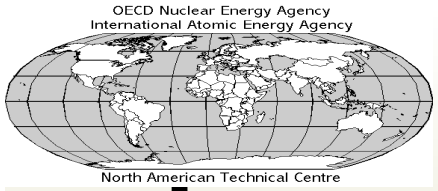
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# Presentation Outline

- Introduction
- Public Exposure (Regulatory Criteria)
- Tritium Production and Releases
- Unplanned Releases
  - Braidwood, Indian Point
- Industry Actions
- Tritium Deposition
  - Recapture Behavior Study



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# Introduction

- Commercial Nuclear Power Plants (NPPs) produce gaseous, liquid, and solid wastes during normal operations as a result of the beneficial electricity produced (~20% US electricity)
- Radioactive waste treatment systems are used by these plants to assure radioactivity levels are ALARA (As Low As Reasonably Achievable) and below the limits required by governmental regulations
- Although the radioactivity levels released by NPPs can be quite low (effluents), they can still have environmental impacts on man, fauna, and flora
- Tritium is one of the major radionuclides released

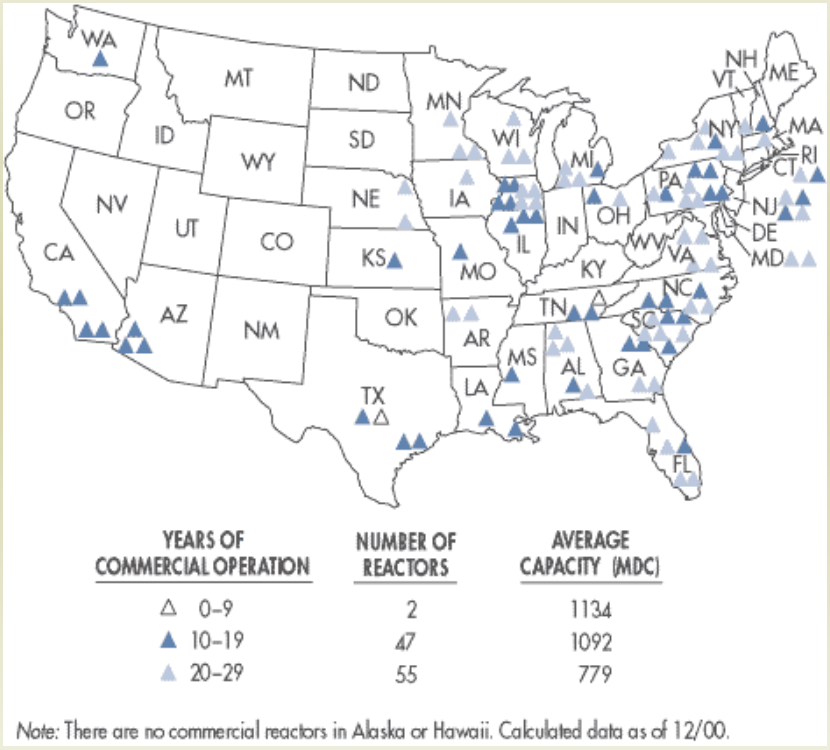
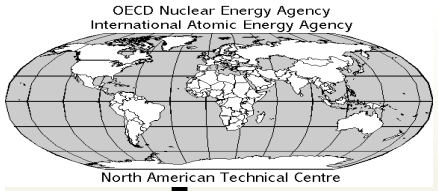



**Figure 1**: U.S. Commercial Nuclear Power Plant Map (104 operating, 69 PWR, 35 BWR, 65 sites)



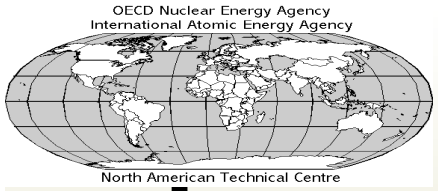

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# Public Exposure (1/1)

## Regulatory Criteria for Releases

- Radiation protection regulations based upon recommendations by ICRP and NCRP
- U.S. regulations concerning nuclear power plant releases

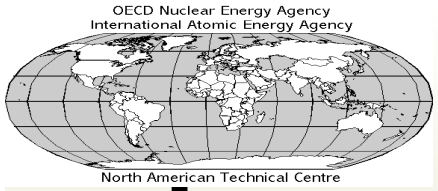
| US Regulatory Body | Regulation | Explanation |
|---|---|---|
| USEPA | 40 CFR 190<br>(public doses)<br>**(CHANGE COMING with GW protection)** | 1 mSv/y (0.1 rem/y) effective dose equivalent<br>0.025 mSv/y (25 mrem/y) whole body dose<br>0.075 mSv/y (75 mrem/y) thyroid dose<br>0.025 mSv/y (25 mrem/y) all other organ dose |
| USNRC | 10 CFR 20 | 1 mSv/y (0.1 rem/y) effective dose equivalent |
| | 10 CFR 50<br>**(CHANGE COMING)** | NPP operations, technical specs. on effluents (Appendix I – numerical guides) |
| | NUREG-0133 | Radiological effluent technical specs. |
| | Reg. Guide 1.109, 1.111, 1.112, 1.21 (recently updated), 4.1 (recently updated), 4.2, 4.8 | Effluent and Solid Waste Release calcs.<br><br>Environmental monitoring programs |
| | NUREG-0016, 0017 | BWR and PWR effluent calcs. (computer codes) |




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# Tritium Production and Releases (1/9)

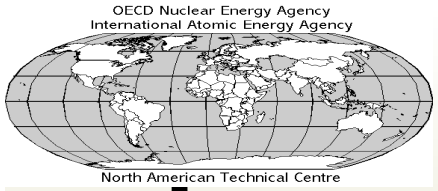
- Tritium is hydrogen with two neutrons in addition to its one proton. Chemically it reacts as hydrogen.
- Tritium (H-3) is produced primarily from neutron capture by boron (B-10) in a PWR.
- Boric acid is added to PWR reactor coolant system (RCS) as a soluble reactivity control.
- Boron (enriched in B-10) is used in PWR fuel assemblies as a burnable poison.
- Approximately 70-90% of the total tritium in PWR reactor coolant is produced in the coolant by the soluble boric acid.
- The remaining 10-30% is produced by ternary fission, B-10 burnable poisons, Li-6 neutron capture, and deuterium activation.
- BWR tritium production is significantly lower than PWR due to absence of boric acid in the coolant.




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# Tritium Production and Releases (2/9)

- **Tritium production has increased**
  - Total boron has increased :
    - Early core designs used other poisons
    - Most PWR's have extended their refueling cycle to 24 months
    - Longer cycles require higher initial boron concentration in reactor coolant
    - Core power uprates require more boron
  - Increased boron caused increased tritium production




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# Tritium Production and Releases (3/9)

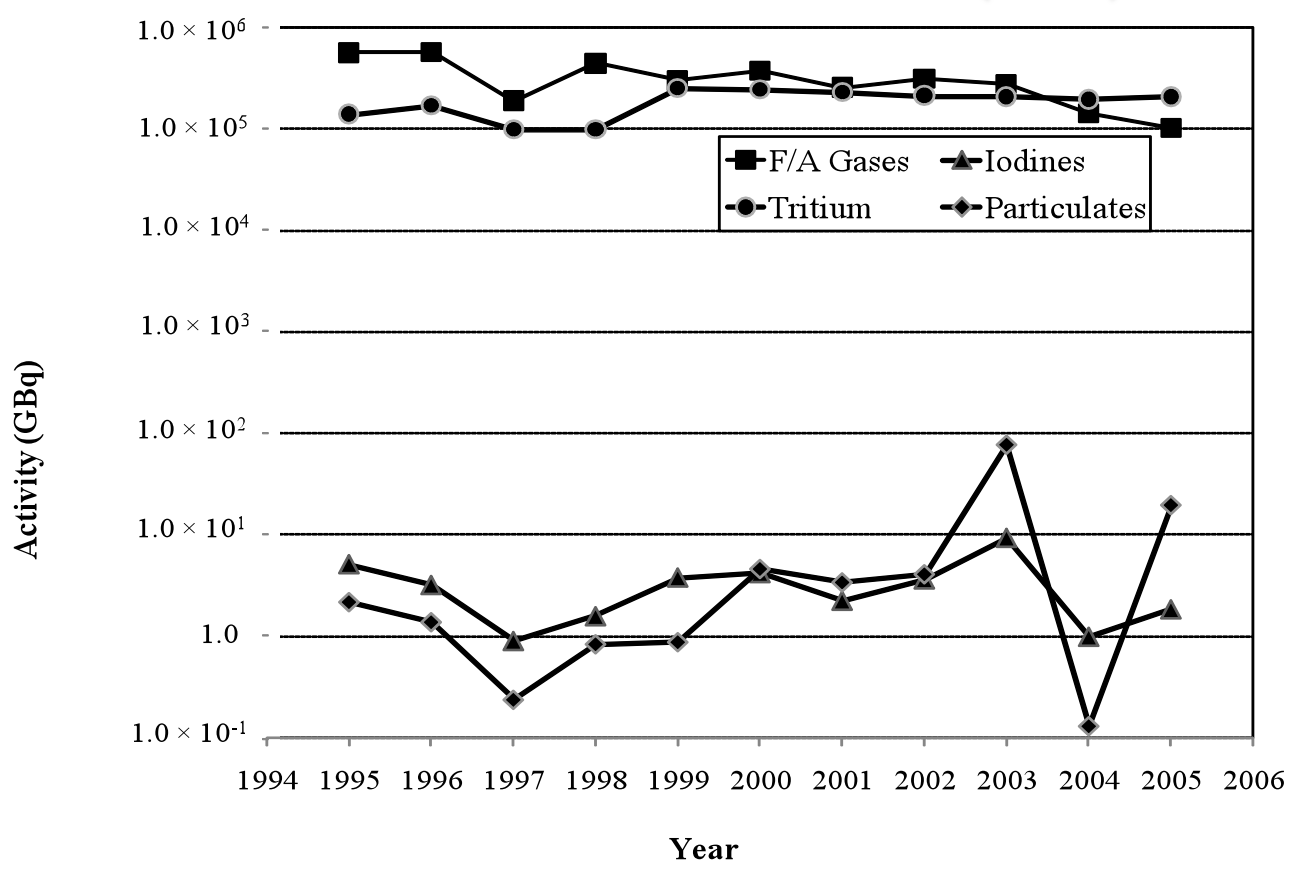
- Spent Fuel Pool Inventory increases with plant age
  - Tritium builds up in the SFP due to mixing with reactor coolant during refueling.
  - 12.4 year half-life causes SFP inventory to build up over time.
  - Additional factors:
    - Mid-cycle plant shutdowns when RCS tritium inventory is highest will transfer more tritium
    - Fuel cladding defects will allow more tritium transfer from fuel than diffusion alone
- Spent Fuel Pool Releases
  - This general design criteria drives the evaporation rate (H-3 release rate) as it is routed to the routine plant ventilation.
  - The majority of H-3 released to the atmosphere is from the SFP.
    - The dose consequence is low – around 1x $10^{-3}$ mR

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# Tritium Production and Releases (4/9)



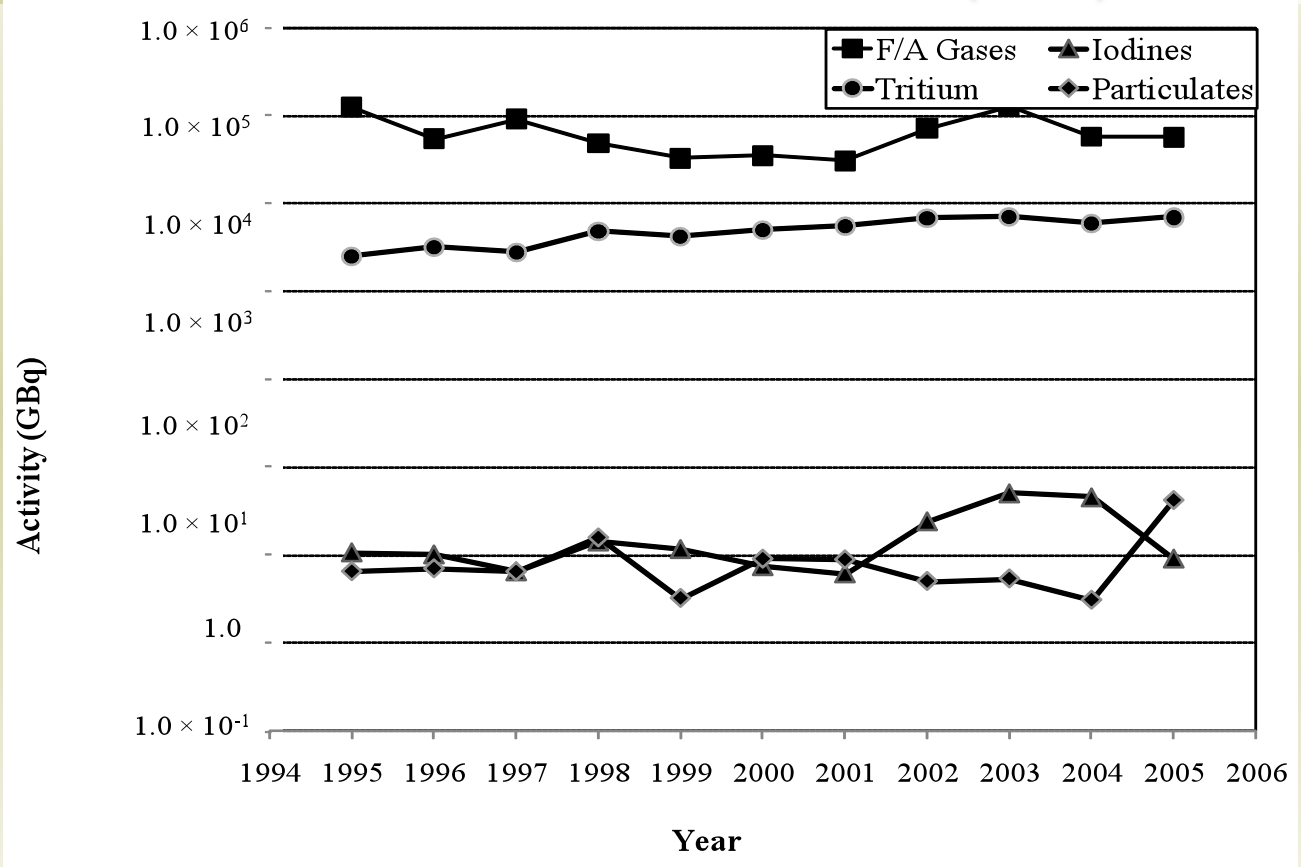

Variation of radionuclide activity released in gaseous effluents from PWR plants.

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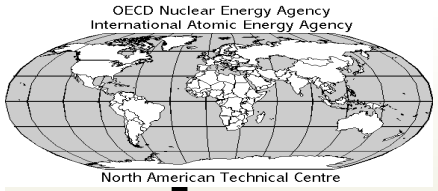
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# Tritium Production and Releases (5/9)




Variation of radionuclide activity released in gaseous effluents from BWR plants.




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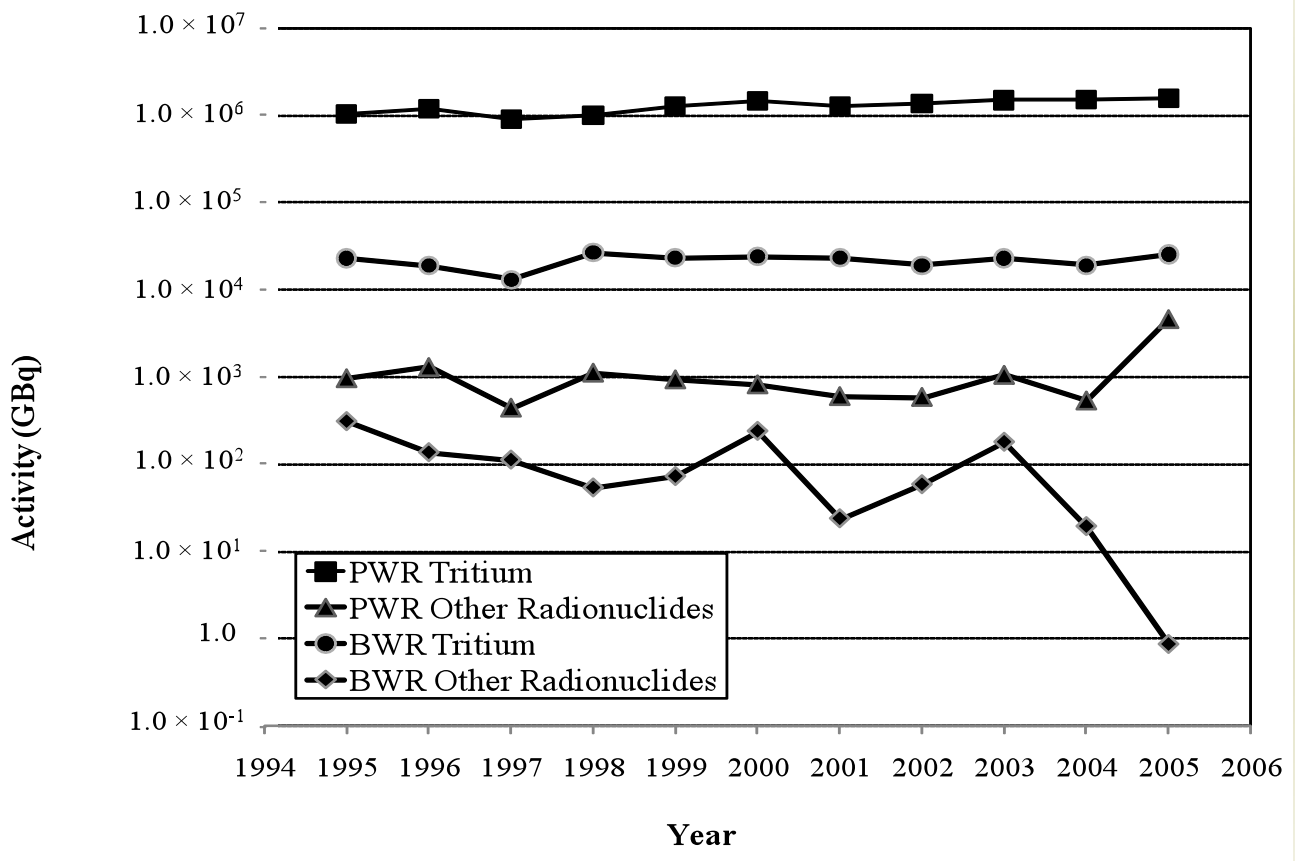
# Tritium Production and Releases (6/9)

- **Liquid Tritium releases**
  - Processing of liquid waste – Reactor letdown, system leakage, etc. – uses ion exchange which does not treat tritium since it exists primarily as HTO – chemically it is water.
  - New tritium removal processes are not widely discussed or considered in our industry (yet).
  - Liquid effluent dose consequence is low – typically $10^{-5}$ rem ($10^{-4}$ mSv) for plants with a drinking water pathway, $10^{-10}$ rem ($10^{-9}$ mSv) otherwise.
  - Recent AP report says tritium has leaked from 48 of the 65 U.S. sites

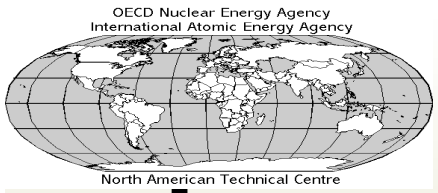
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# Tritium Production and Releases (7/9)




Variation of radionuclide activity released in liquid effluents from PWR and BWR plants



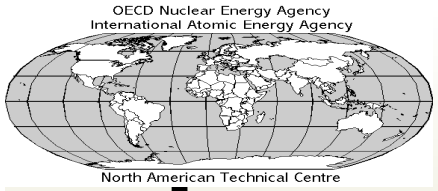

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# Tritium Production and Releases (8/9)

- **Trend Detection**
  - Mann-Kendall Non-Parametric Test Statistic

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right)$$

  - Results
    - Gaseous PWR F/A Gases – decreasing trend
    - **Liquid PWR Tritium– increasing trend**
    - **Gaseous BWR Tritium – increasing trend**
    - Liquid BWR Other Radionuclides – decreasing trend
    - Gaseous Total F/A Gases – decreasing trend
    - Liquid Total Other Radionuclides – increasing trend
    - All other categories – no trend




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# Tritium Production and Releases (9/9)

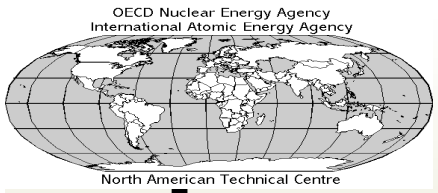
| | | | Effective Dose (mSv) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Gaseous Releases | | | | Liquid Releases | | |
| Year | Electrical Energy Produced (GW) [a] | U.S. Population ($\times 10^4$) [b] | F/A Gases | Total Iodine | **Tritium** | Particulates | **Tritium** | Other Radionuclides | Total |
| 1995 | 77.1 | 266,557 | $8.36 \times 10^{-8}$ | $1.95 \times 10^{-10}$ | **$1.68 \times 10^{-8}$** | $1.28 \times 10^{-9}$ | **$2.93 \times 10^{-8}$** | $2.90 \times 10^{-8}$ | $1.60 \times 10^{-7}$ |
| 1996 | 77.3 | 269,667 | $7.79 \times 10^{-8}$ | $2.75 \times 10^{-10}$ | **$1.31 \times 10^{-8}$** | $1.10 \times 10^{-9}$ | **$3.18 \times 10^{-8}$** | $2.89 \times 10^{-8}$ | $1.53 \times 10^{-7}$ |
| 1997 | 71.9 | 272,912 | $1.08 \times 10^{-7}$ | $1.29 \times 10^{-10}$ | **$1.90 \times 10^{-8}$** | $1.47 \times 10^{-9}$ | **$2.71 \times 10^{-8}$** | $1.22 \times 10^{-8}$ | $1.68 \times 10^{-7}$ |
| 1998 | 74.9 | 276,115 | $1.38 \times 10^{-8}$ | $2.80 \times 10^{-10}$ | **$1.46 \times 10^{-8}$** | $2.66 \times 10^{-9}$ | **$2.68 \times 10^{-8}$** | $1.37 \times 10^{-8}$ | $7.19 \times 10^{-8}$ |
| 1999 | 82.3 | 279,295 | $7.00 \times 10^{-9}$ | $1.75 \times 10^{-10}$ | **$1.57 \times 10^{-8}$** | $3.06 \times 10^{-10}$ | **$2.83 \times 10^{-8}$** | $1.10 \times 10^{-8}$ | $6.24 \times 10^{-8}$ |
| 2000 | 85.2 | 282,402 | $7.98 \times 10^{-9}$ | $1.80 \times 10^{-10}$ | **$1.48 \times 10^{-8}$** | $1.08 \times 10^{-9}$ | **$3.05 \times 10^{-8}$** | $1.07 \times 10^{-8}$ | $6.53 \times 10^{-8}$ |
| 2001 | 87.8 | 285,329 | $5.58 \times 10^{-9}$ | $9.21 \times 10^{-11}$ | **$1.50 \times 10^{-8}$** | $8.57 \times 10^{-10}$ | **$2.54 \times 10^{-8}$** | $7.97 \times 10^{-9}$ | $5.49 \times 10^{-8}$ |
| 2002 | 88.6 | 288,173 | $8.42 \times 10^{-9}$ | $1.95 \times 10^{-10}$ | **$1.73 \times 10^{-8}$** | $6.62 \times 10^{-10}$ | **$2.70 \times 10^{-8}$** | $1.96 \times 10^{-8}$ | $7.32 \times 10^{-8}$ |
| 2003 | 87.0 | 291,028 | $1.44 \times 10^{-8}$ | $3.79 \times 10^{-10}$ | **$1.51 \times 10^{-8}$** | $3.04 \times 10^{-9}$ | **$2.87 \times 10^{-8}$** | $1.15 \times 10^{-8}$ | $7.30 \times 10^{-8}$ |
| 2004 | 88.1 | 293,907 | $6.94 \times 10^{-9}$ | $2.67 \times 10^{-10}$ | **$1.39 \times 10^{-8}$** | $2.07 \times 10^{-10}$ | **$2.64 \times 10^{-8}$** | $6.38 \times 10^{-9}$ | $5.42 \times 10^{-8}$ |
| 2005 | 88.6 | 298,025 | $7.43 \times 10^{-9}$ | $9.70 \times 10^{-11}$ | **$1.58 \times 10^{-8}$** | $5.07 \times 10^{-9}$ | **$2.75 \times 10^{-8}$** | $7.55 \times 10^{-8}$ | $1.31 \times 10^{-7}$ |

[a] U.S. NRC 2006a

[b] U.S. Census Bureau 2006

Average effective doses received by members of the public in the U.S. from commercial nuclear power plant radiological effluent releases.

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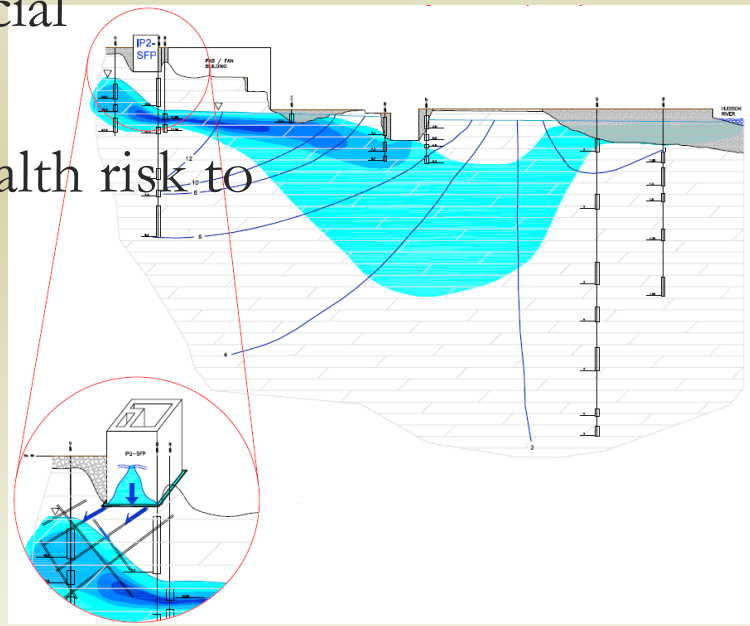


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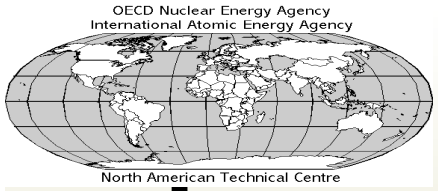
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# Unplanned Releases (1/1)

- Numerous unplanned radioactive material releases over the past several years have led to stepped up actions by the industry, regulator, and special interest groups (2005-present)
- The releases (mostly tritium) pose little health risk to human life
- Groundwater Contamination Events
  - Vermont Yankee, Harris, Sequoyah
  - Oyster Creek, **Indian Point, Braidwood**
  - Callaway, Dresden, Byron
  - Palo Verde, Quad Cities



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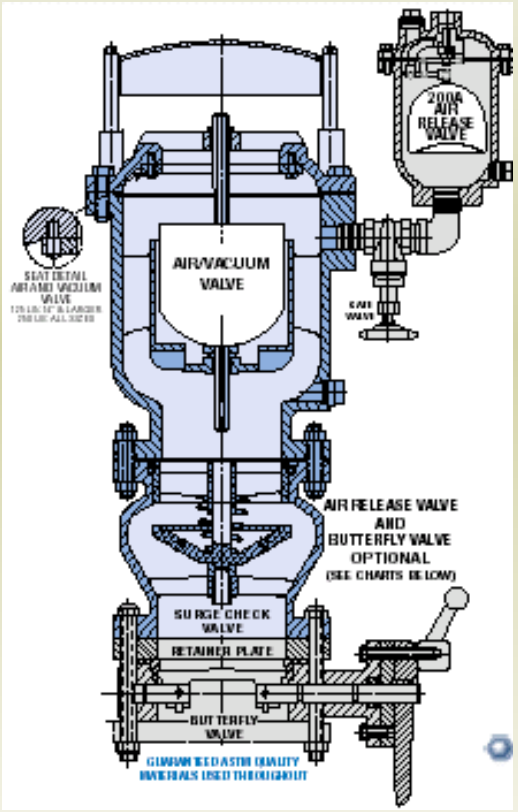


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# Braidwood (1/6)

- 2 unit PWR plant on 4500 acre site with 2500 acre cooling lake
- Circulating water system transfers heat to cooling lake
  - Continuous make-up and blowdown between cooling lake and Kankakee River
- Vacuum breakers (VB) used in blowdown line
  - Release air to allow fill at high points
  - Admit air for protection against siphoning and column separation transients
- Blowdown line used for periodic discharges of liquid radioactive waste
  - Circulating water blowdown flowrate: 10,000 to 25,000 gpm
  - Tritium - principal radionuclide
  - Before November 2005, discharges 2 to 3 times per week

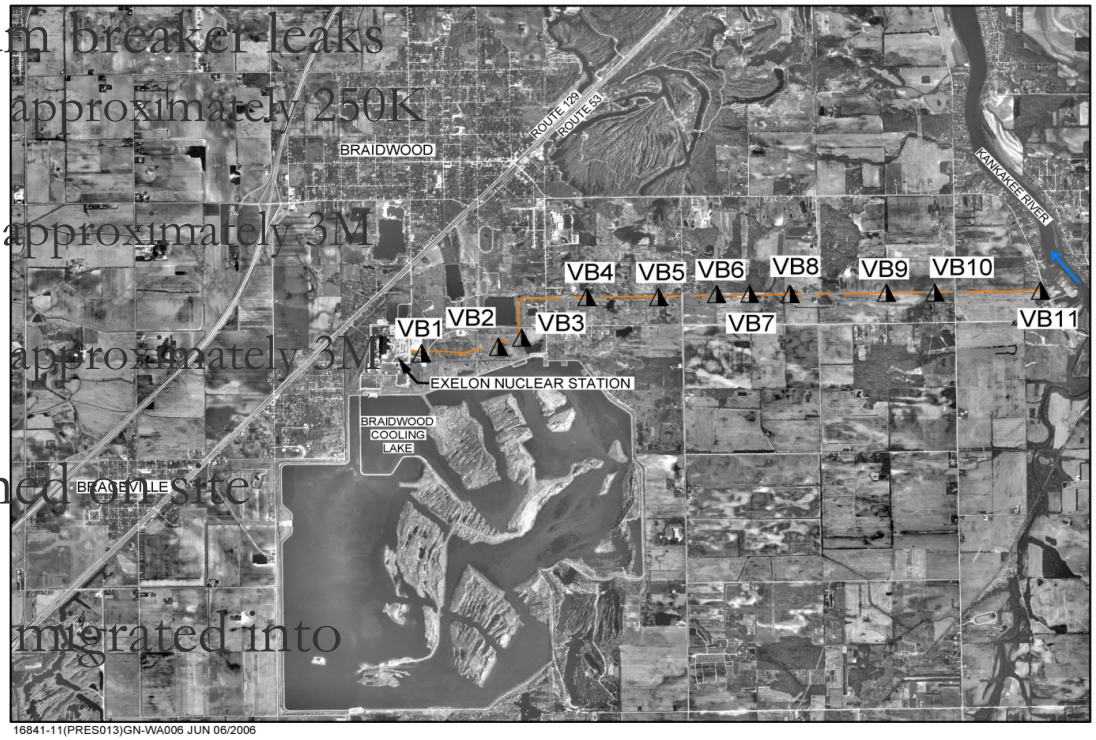


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# Braidwood (2/6)

- **Groundwater Contamination**
  - Three significant vacuum breaker leaks
    - VB-1: November 1996, approximately 250K gallons
    - VB-3: December 1998, approximately 3M gallons
    - VB-2: November 2000, approximately 3M gallons
  - Surface releases contained on site property
  - Water from these spills migrated into groundwater

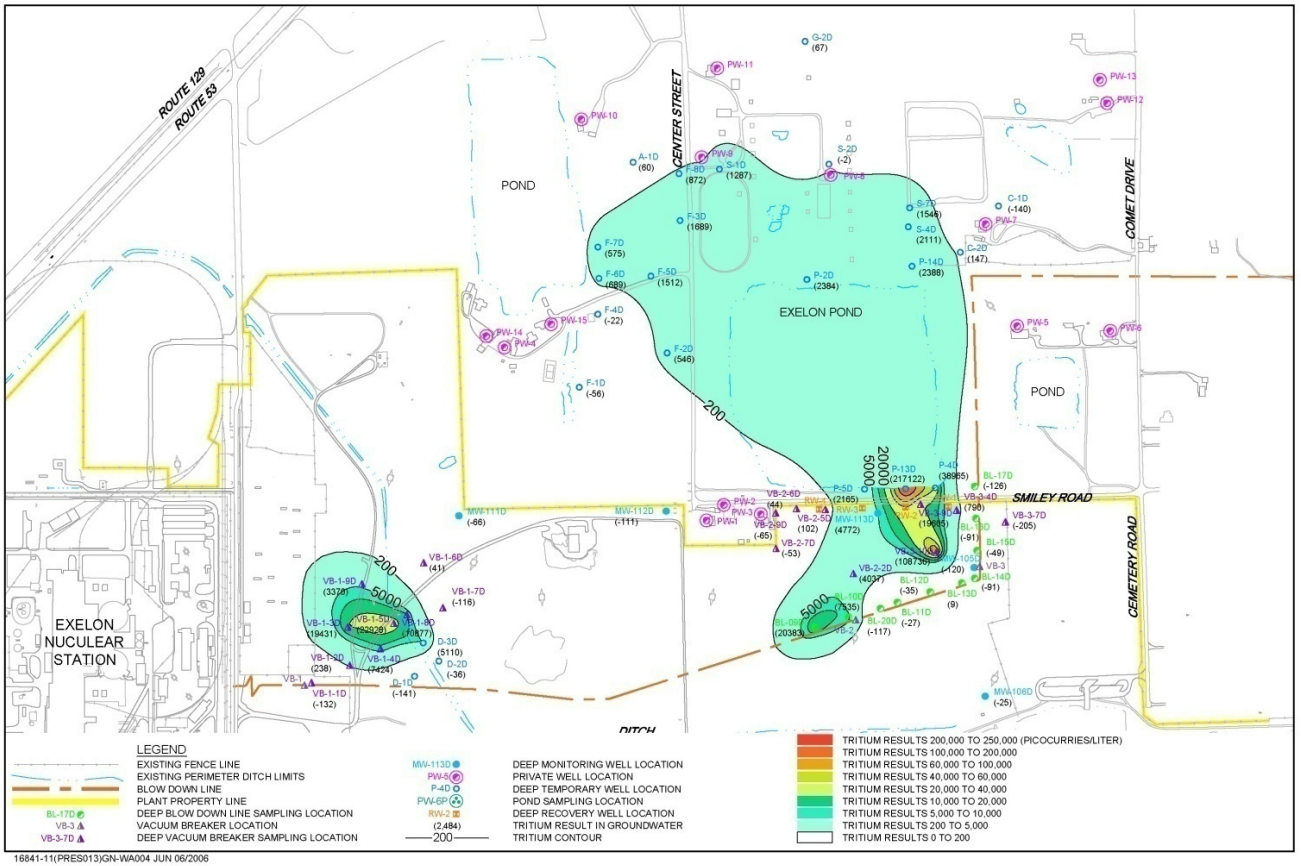


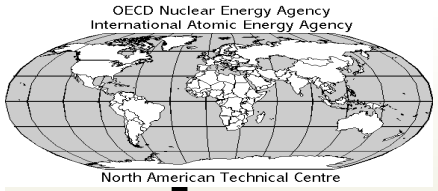
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# Braidwood (3/6)

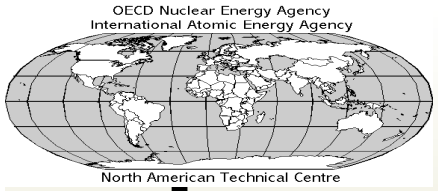





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# Braidwood (4/6)

- **Causes**
  - Variable spill response
    - 1996 and 1998 spills treated as water spills; no sampling or cleanup
    - 2000 spill was sampled and cleaned up; no consideration of impact on groundwater
  - Root cause - lack of integrated procedural guidance
    - Environmental spill response procedures not intended for radioactive spills
    - Radiological documentation procedure does not consider impacts on groundwater, hydrology, groundwater regulations
  - Lack of management oversight
  - Limited communication with officials




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# Braidwood (5/6)

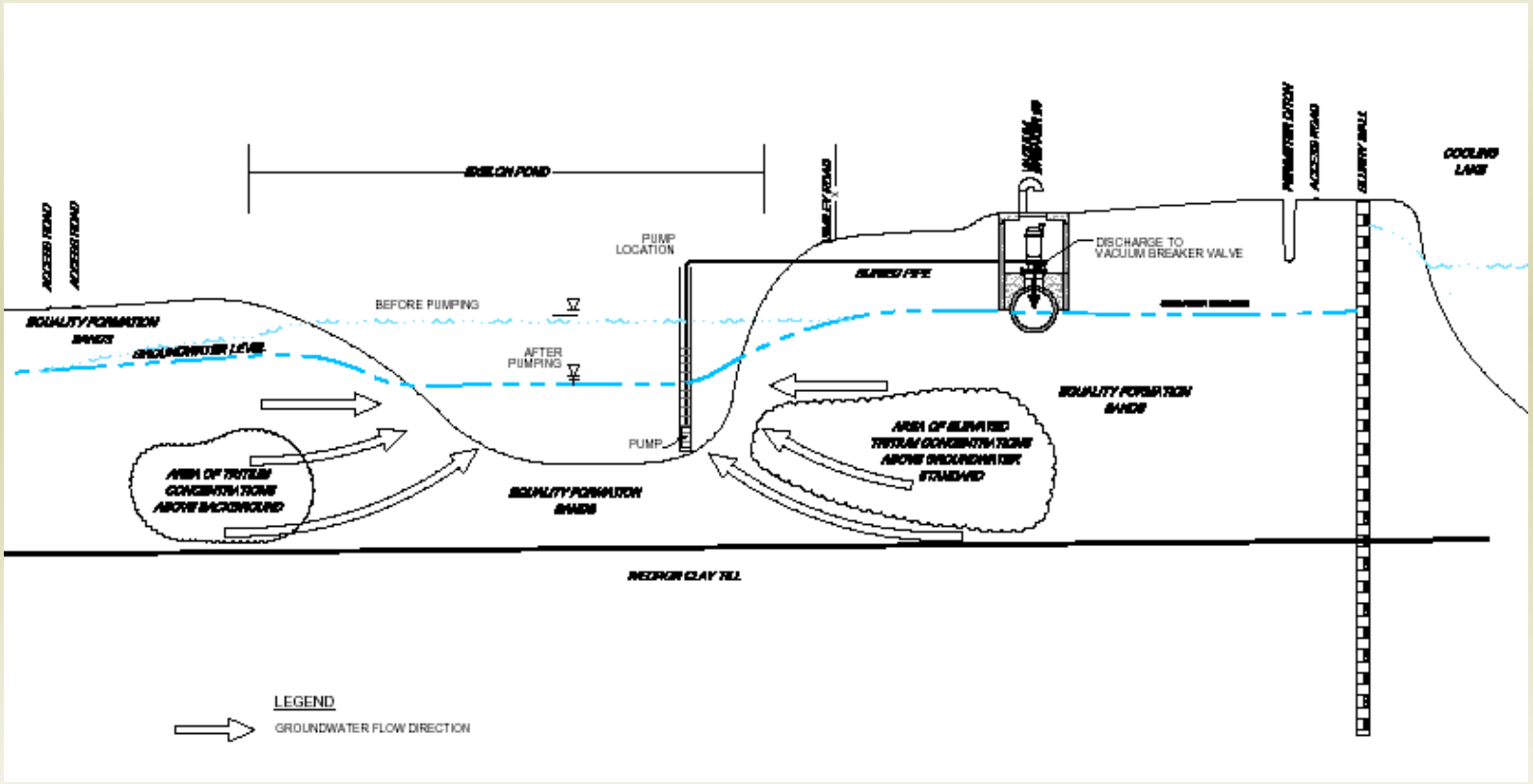
- **Corrective actions**
  - Comprehensive assessment of offsite dose
    - Bounding dose determined to be 0.16 mrem/yr
  - Preliminary injunction order negotiated with State
  - Remediation activities
    - Migration control plans
    - Groundwater management zone corrective action plans
    - Minimize impairment of groundwater
    - Multiple public outreach initiatives
    - Reporting "unlicensed releases"
    - Private well sampling program
    - Bottled water distribution program
    - Tritium production/release enhancements

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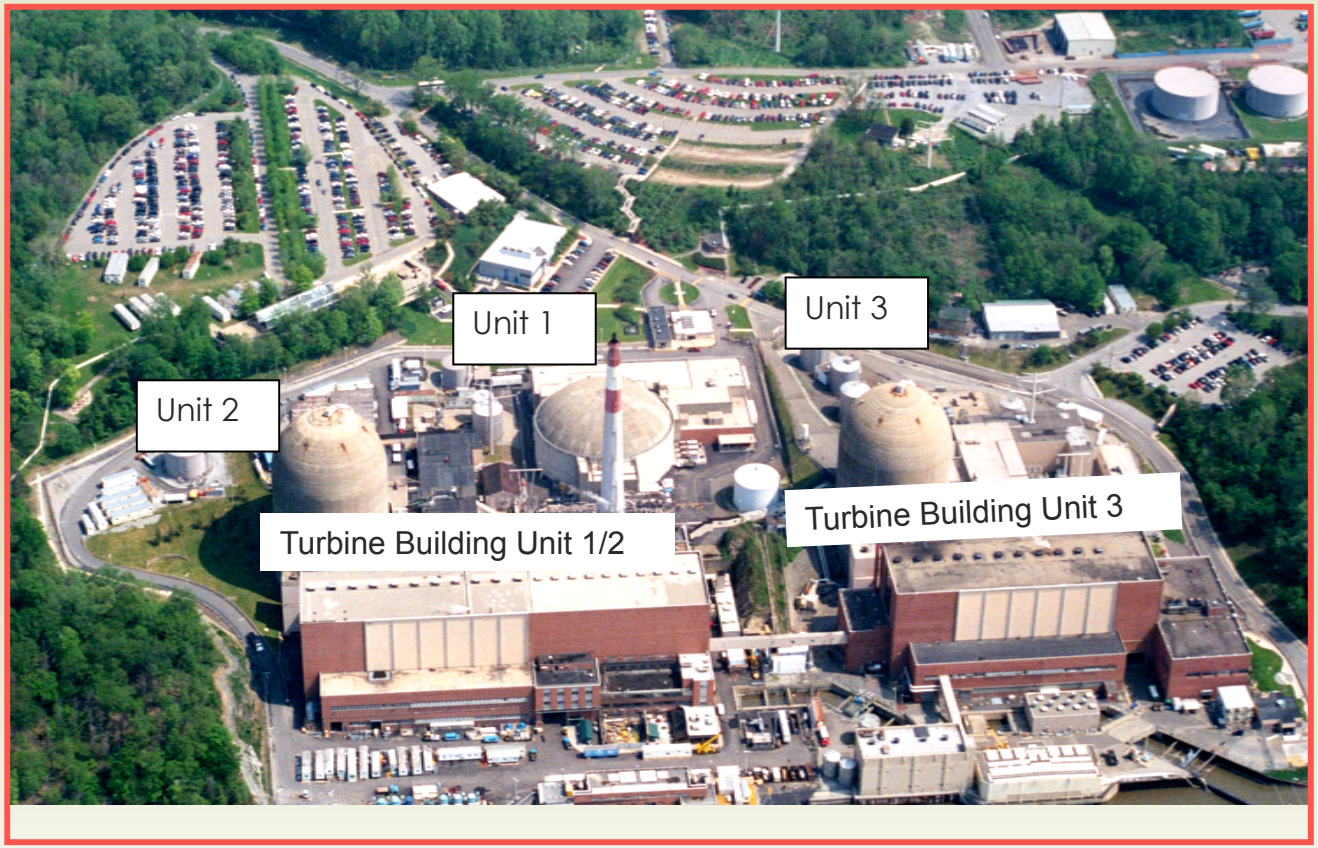
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# Braidwood (6/6)



# Indian Point (1/7)

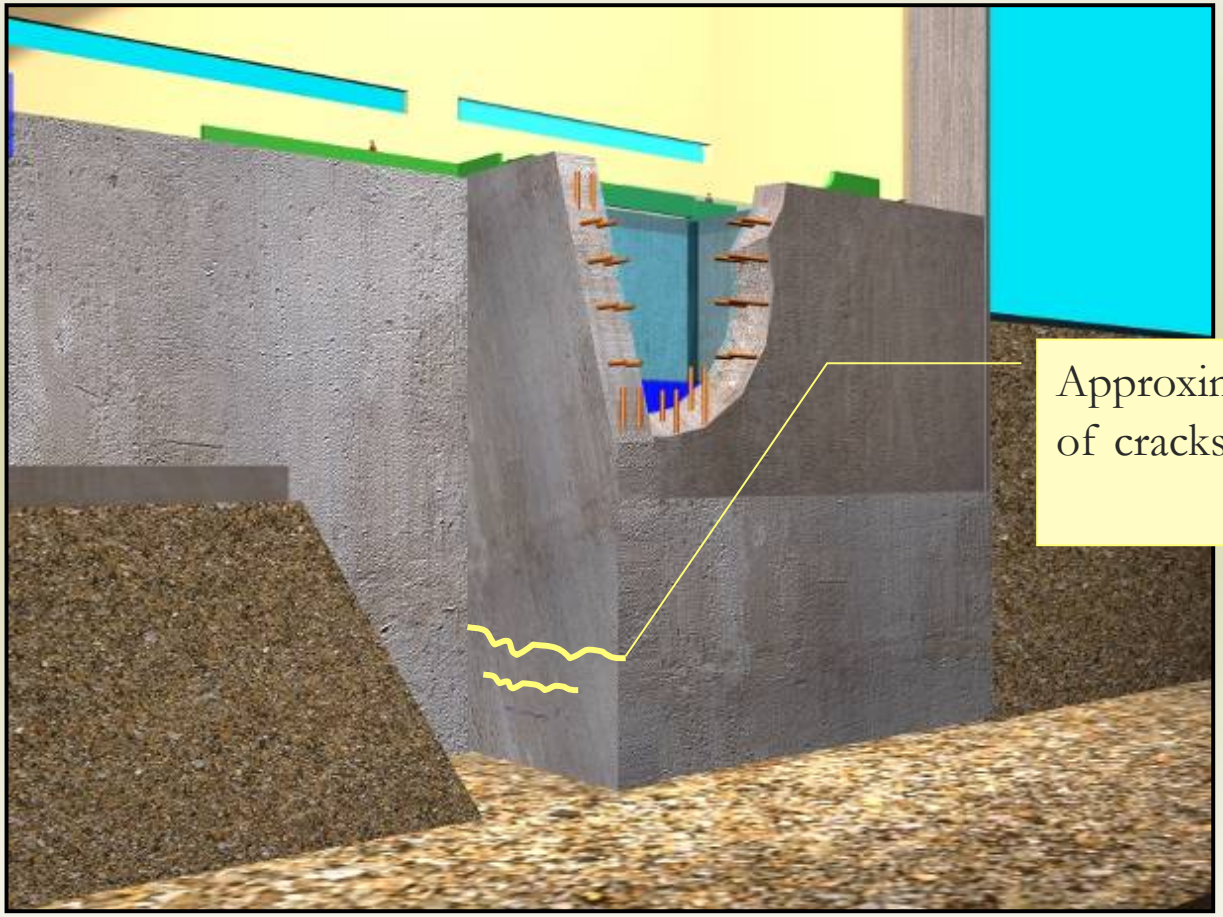
- 3 unit PWR plant located in Buchanan, New York that sits on the east bank of the Hudson River (24 miles north of New York City)

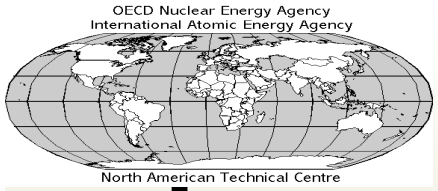


# Indian Point (2/7)

- Hairline settlement cracks identified in Fuel Storage Building wall during excavation for new gantry crane
  - Moisture in crack tested for radioactivity
  - Radionuclides characteristic of spent fuel pool identified in sample
  - Leakage collected, sampled, and trended
  - Permanent leak collection box designed and installed
  - Intermittent leakage
- Tested existing wells on site for radioactivity- Tritium detected
- Tested off-site wells and water supplies for radioactivity—none detected

# Indian Point (3/7)






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# Indian Point (4/7)

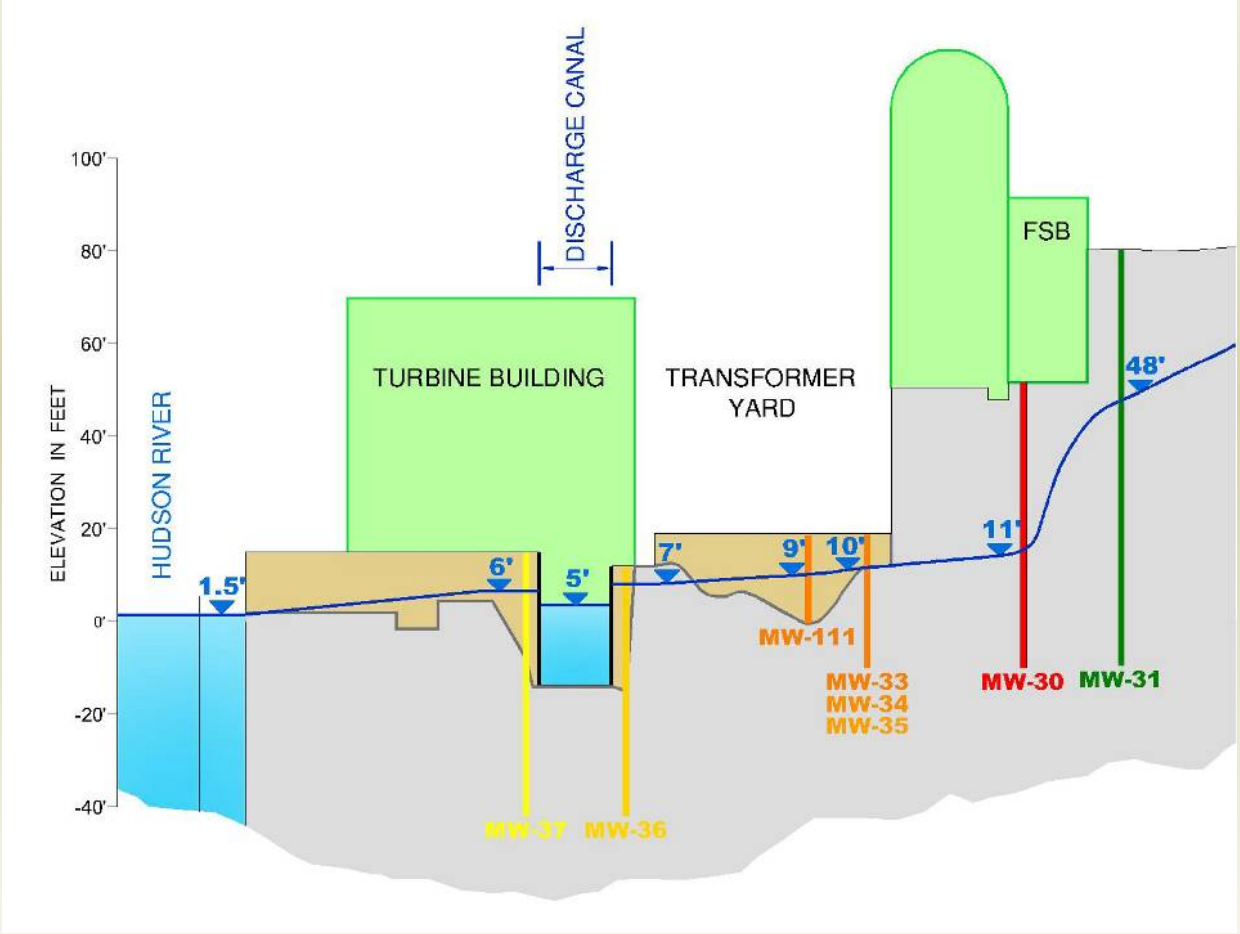
- **Investigation team assembled**
  - Identify Leak Sources
  - Evaluate Potential Risk to Public
  - Identify Leak Sources
  - Determine Current Nature and Extent of Ground Water Contamination
  - Assess Future Impacts
  - Evaluate Need for Ground Water Remediation
  - Implement Long-term GW Monitoring Program

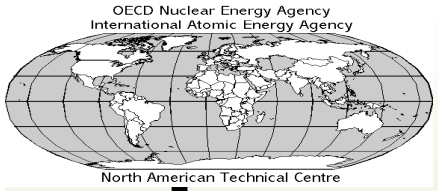
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# Indian Point (5/7)



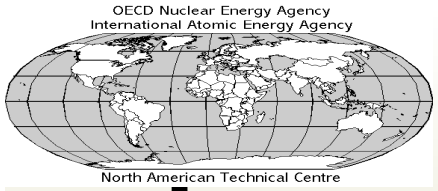



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# Indian Point (6/7)

- **Phases of action**
  - Installed 9 new wells to determine groundwater characteristics and Tritium concentrations around IP2
  - Found H-3 Up to 600,000 pCi/L adjacent to U2 SFP (MW-30)
  - Pool of H-3 found under Transformer Yard, Up to 200,000 pCi/L (MW-111)
  - H-3 Plume extends westward to discharge canal, up to 30,000 pCi/L (MW-37)

  - Installation of additional 14 wells (+12 wells)
  - IP Unit 1 and 3 portions of the site
  - Site boundary locations
  - Storm drains, river sediment and fish
  - Addition of Sr-90 and Gamma emitters analyses (from IP1 SFP leak in 1990s)
  - Conducted split sample program with NRC and DEC




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# Indian Point (7/7)

- **Current Actions**
  - Assess GW flow and contaminant migration
  - SFP inspected and repaired
  - Tritium and Sr-90 characterization
  - Implement remediation and long term monitoring program
- **Results**
  - Water movement on site has been influenced by past construction activities
  - Groundwater flow is generally from north to west and south toward Hudson River
  - Some contaminants are migrating around or under the discharge canal
  - No impact from groundwater or river pathway

# Industry Actions (1/1)

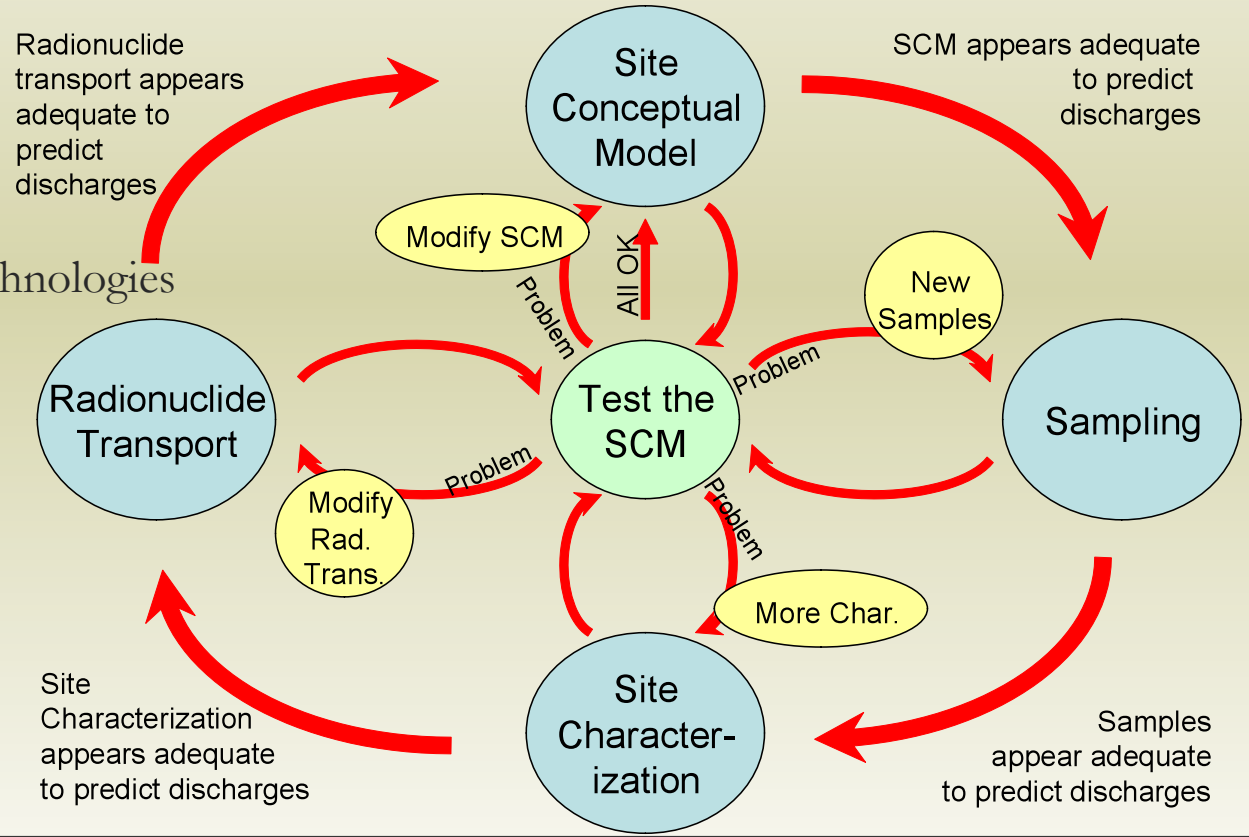
- **EPRI, NEI**
  - Groundwater Protection
    - Evaluation of systems, structures, components, and work practices
    - Site hydrology
    - Groundwater monitoring
    - Grade Approach
    - Remediation
    - Many sites have incorporated groundwater monitoring as part of their REMP, especially for offsite wells
    - EPRI - Currently working on revision of Groundwater Guidelines; GW Protection 1015118, Remediation 1021104
  - Tritium
    - Atmospheric deposition
    - In plant tritium and water management
    - Precipitation washout

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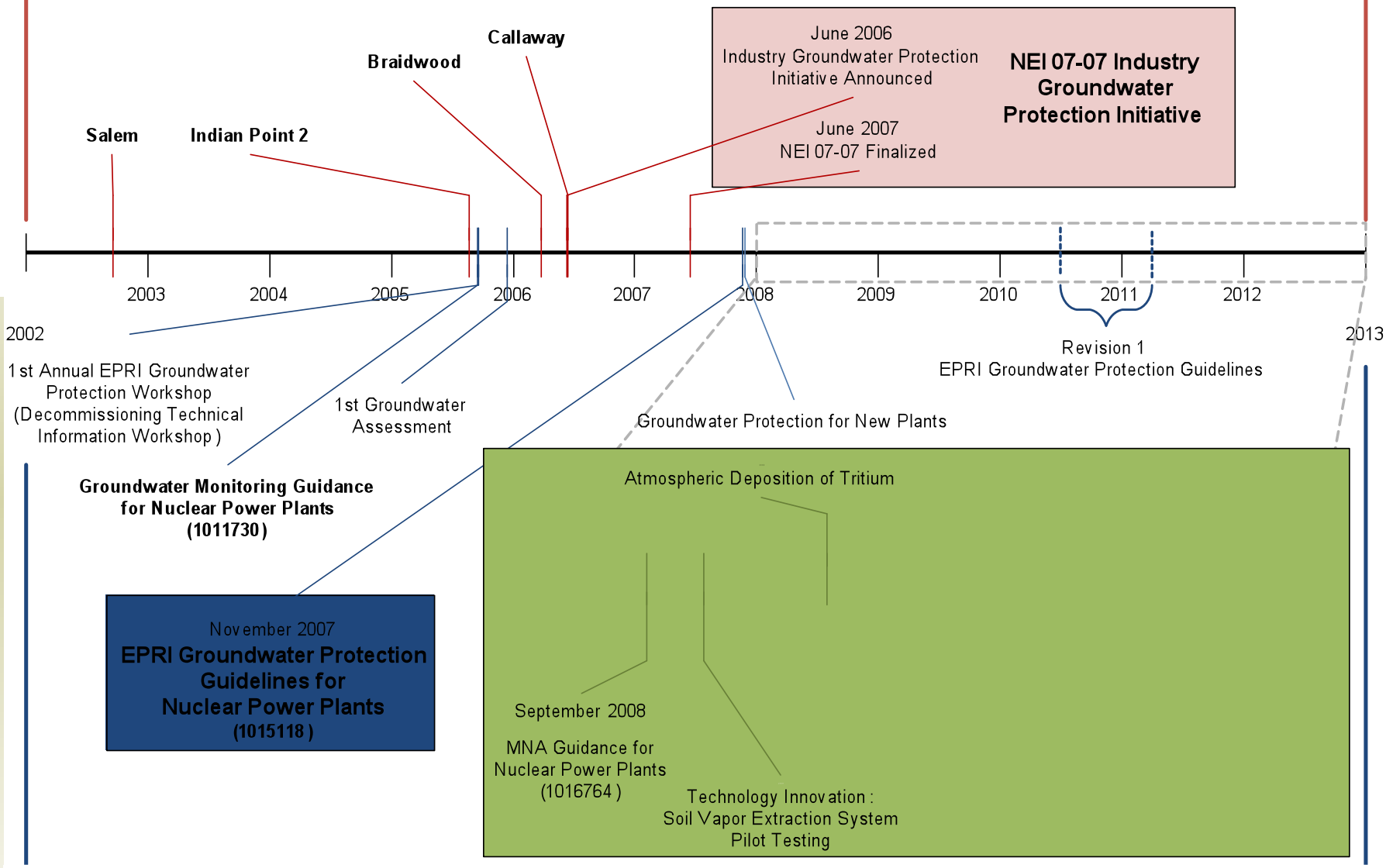
# Groundwater Protection Initiative (1/2)

## Basic Steps for GW Monitoring

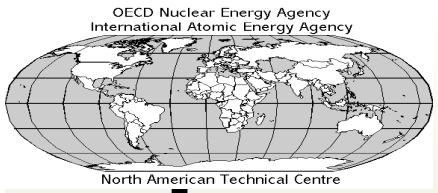



Advanced Technologies

# Nuclear Industry Groundwater Events



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# Tritium Deposition (1/1)

- Problem- tritium released to the atmosphere and "recaptured"
  - Atmospheric removal rain washout, condensation and snow scavenging
- Can calculate washout factor (highly variable)

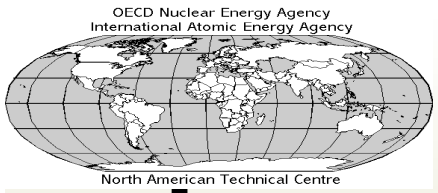
$$\Lambda = \frac{\omega}{\chi_0 \times H_{\text{eff}}},$$

$\Lambda$ = washout coefficient ($s^{-1}$);
$\omega$ = tritium deposition rate (Bq $m^{-2}$ $s^{-1}$);
$\chi_0$= atmospheric tritium concentration at ground level (Bq $m^{-3}$); and
*H*eff = effective height (m)

- Tritium retention and release from concrete (fast and slow process)
- Problem with new pathways



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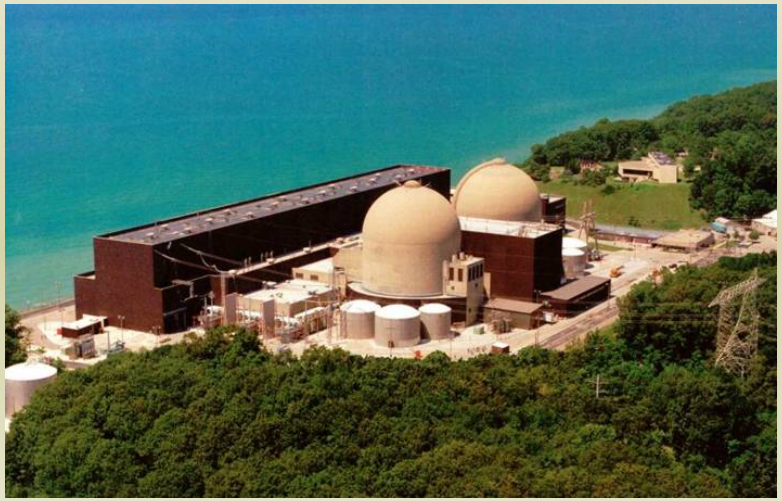


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# Tritium Recapture Behavior Study (1/7)

- **Background**
  - Increased regulatory vigilance regarding tritium releases
  - Asked to investigate elevated tritium findings at Cook Nuclear Plant
  - Unplanned releases may lead to public and occupational exposures
  - Supporting/refuting analysis developed to validate hypothesis that the source of elevated tritium levels is from downwash and air conditioning condensate

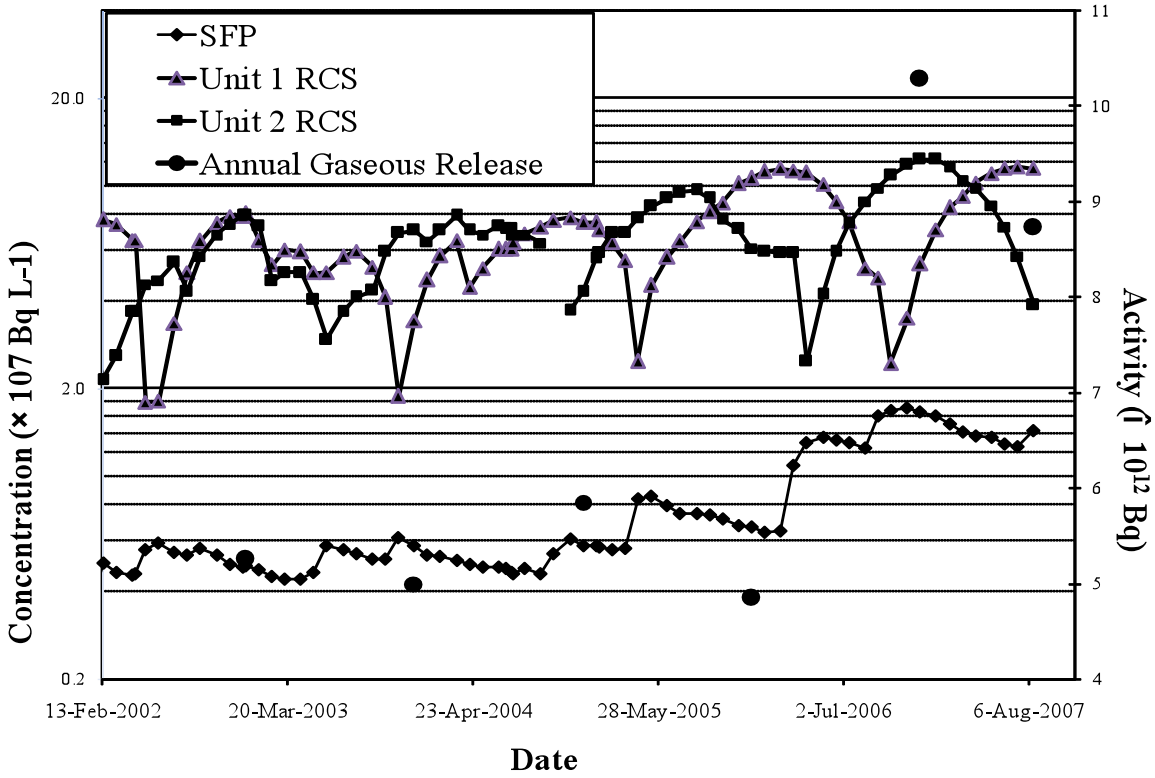


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# Tritium Recapture Behavior Study (2/7)




Comparison of tritium concentration in the Cook Nuclear Plant spent fuel pool and reactor coolant systems with the gaseous tritium activity release

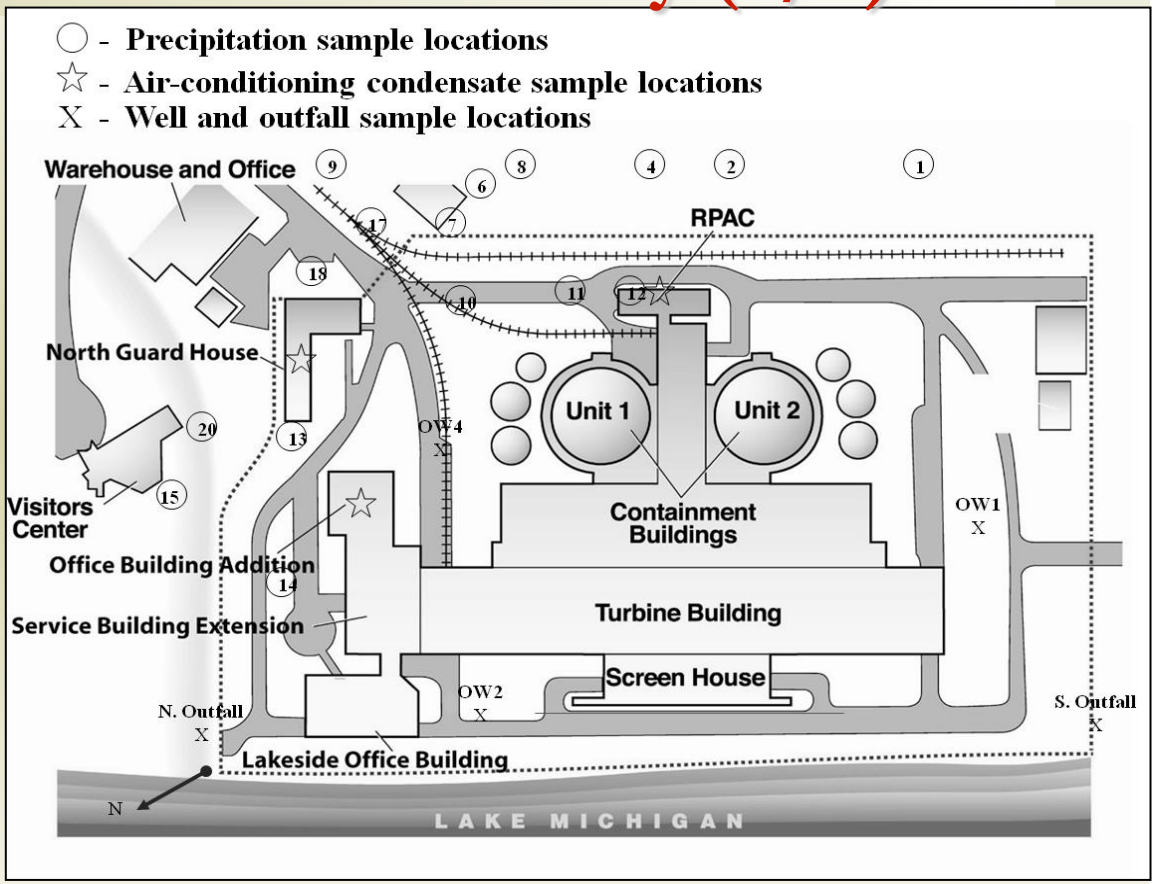
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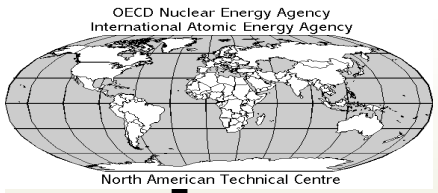
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# Tritium Recapture Behavior Study (3/7)

- **Pathway Hypothesis**
  - AC condensate from RPAC, Guard House and OBA
  - Downwash from station vents during rain
- **Comprehensive sampling program**
  - Precipitation (rainwater) - washout
  - Condensate
  - Well and outfall (storm water)
  - Analyses performed with LSC




Sample locations for rainwater, air-conditioning condensate, outfall and well water within and in the vicinity of the Protected Area at Cook Nuclear Plant



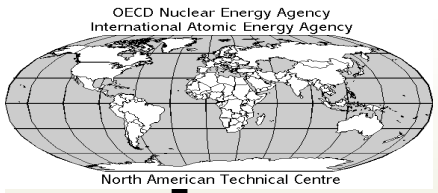

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# Tritium Recapture Behavior Study (4/7)

Maximum tritium concentrations for all rainfall, air-conditioning condensate and surface and well water sample locations at Cook Nuclear Plant

| Sample Location | Maximum $^{3}H$ concentration (Bq $L^{-1}$) |
|---|---|
| Rainfall | |
| 1 | <33.9 |
| 2 | 36.7 |
| 3-5 | <33.9 |
| 6 | 55.5 |
| 7 | 141.7 |
| 8 | 38.11 |
| 9 | 124.7 |
| 10 | 133.9 |
| 11 | 73.6 |
| 12 | 67.3 |
| 13 | 228.7 |
| 14 | 153.9 |
| 15 | 37.4 |
| 16 | <33.9 |
| 17 | 315.6 |
| 18 | 168.7 |
| 19-23 | <33.9 |
| 24 | 71.8 |
| 25-32 | <33.9 |
| Surface/Well Water | |
| OW1 | <33.9 |
| OW2 | 75.9 |
| OW4 | <33.9 |
| S. outfall | 101.8 |
| N. outfall | 654.9 |
| HVAC Condensate | |
| OBA | 1198.8 |
| N. Guard House | 1147.0 |
| RPAC | 536.5 |

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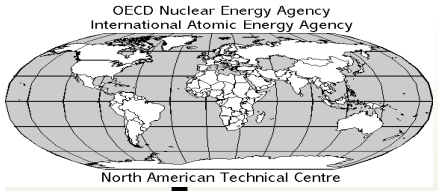
# Tritium Recapture Behavior Study (5/7)

| Sample Location | $H_{eff}$ (m) | ω ± S.D. ($\times 10^3$ Bq m$^{-2}$ s$^{-1}$) | Λ ($\times 10^5$ s$^{-1}$) |
|---|---|---|---|
| 2 | 400 | 19.5 ± 12.1 | 14.6 ± 12.4 |
| 6 | 400 | 7.21 ± 7.99 | 4.68 ± 4.91 |
| 7 | 400 | 9.19 ± 2.16 | 5.71 ± 2.88 |
| 8 | 257 | 13.8 ± 4.31 | 10.9 ± 3.63 |
| 9 | 242 | 13.4 ± 5.06 | 10.9 ± 3.62 |
| 10 | 400 | 19.5 ± 12.1 | 14.6 ± 12.4 |
| 11 | 400 | 7.99 ± 0.36 | 4.91 ± 2.25 |
| 12 | 259 | 11.3 ± 0.50 | 8.86 ± 1.41 |
| 13 | 237 | 13.7 ± 7.09 | 11.4 ± 5.00 |
| 14 | 442 | 9.36 ± 4.44 | 5.65 ± 4.39 |
| 15 | 251 | 3.06 ± 0.00[a] | 2.44 ± 0.00[a] |
| 17 | 336 | 19.2 ± 18.8 | 13.9 ± 13.3 |
| 18 | 379 | 14.4 ± 12.0 | 10.4 ± 10.6 |
| 18a | 387 | 15.1 ± 10.4 | 11.5 ± 12.3 |
| 24 | 259 | 10.1 ± 3.30 | 7.68 ± 0.99 |
| | | Mean value | 9.70 ± 8.40 |

[a]Only one sample taken at this location

Washout coefficients calculated for the Cook Nuclear Plant

Same order of magnitude as other studies (Touyana and Oonishi 1997)



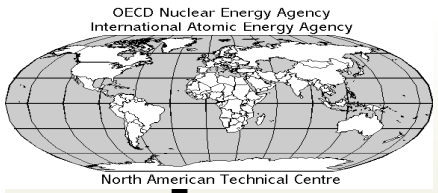

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# Tritium Recapture Behavior Study (6/7)

| Sample Location & Type | Concentration (Bq $L^{-1}$) | Target Organ | Dose (mSv) | 10 CFR 50 Limit (mSv) | Percent Limit (%) |
|---|---|---|---|---|---|
| OBA AC condensate | 1198.8 | Total Body | $1.05 \times 10^{-10}$ | $1.5 \times 10^{-2}$ | $7.0 \times 10^{-7}$ |
| | | Liver | $1.05 \times 10^{-10}$ | $5.0 \times 10^{-2}$ | $2.1 \times 10^{-7}$ |
| N. guard house AC condensate | 1147.0 | Total Body | $1.01 \times 10^{-10}$ | $1.5 \times 10^{-2}$ | $6.7 \times 10^{-7}$ |
| | | Liver | $1.01 \times 10^{-10}$ | $5.0 \times 10^{-2}$ | $2.0 \times 10^{-7}$ |
| N. outfall water | 654.9 | Total Body | $5.74 \times 10^{-11}$ | $1.5 \times 10^{-2}$ | $3.8 \times 10^{-7}$ |
| | | Liver | $5.74 \times 10^{-11}$ | $5.0 \times 10^{-2}$ | $1.2 \times 10^{-7}$ |
| RPAC AC condensate | 536.5 | Total Body | $4.67 \times 10^{-11}$ | $1.5 \times 10^{-2}$ | $3.1 \times 10^{-7}$ |
| | | Liver | $4.67 \times 10^{-11}$ | $5.0 \times 10^{-2}$ | $9.3 \times 10^{-8}$ |
| OBA AC condensate | 421.8 | Total Body | $3.67 \times 10^{-11}$ | $1.5 \times 10^{-2}$ | $2.5 \times 10^{-7}$ |
| | | Liver | $3.67 \times 10^{-11}$ | $5.0 \times 10^{-2}$ | $7.3 \times 10^{-8}$ |
| Rain sample #17 | 315.6 | Total Body | $2.75 \times 10^{-11}$ | $1.5 \times 10^{-2}$ | $1.8 \times 10^{-7}$ |
| | | Liver | $2.75 \times 10^{-11}$ | $5.0 \times 10^{-2}$ | $5.5 \times 10^{-8}$ |

Maximum annual individual doses at locations with the highest tritium concentrations (calculated with MIDAS software)

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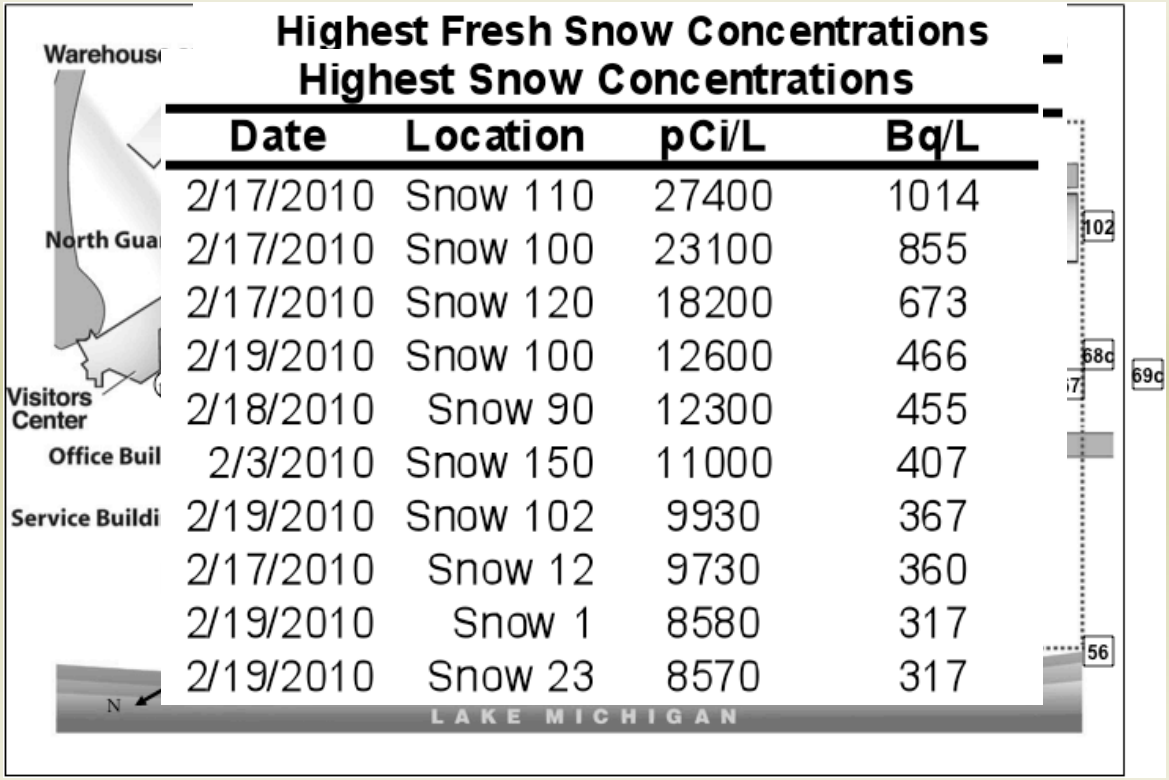


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# Tritium Recapture Behavior Study (7/7)

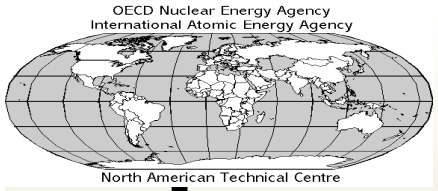
- **Snow study (Hinchcliffe, 201)**
  - Washout coefficients 2.04 x $10^{-5}$ $s^{-1}$ for rain and 1.30 x $10^{-5}$ $s^{-1}$ for fresh snow
  - Rain and Snow washout showed a statistical difference
  - Meteorological Conditions require annual and long term studies of washout and recapture
  - Snow presents unique problems
  - "Old" snow (piles) had higher activities compared to "fresh" snow




**Highest Fresh Snow Concentrations**
**Highest Snow Concentrations**

| Date | Location | pCi/L | Bq/L |
|---|---|---|---|
| 2/17/2010 | Snow 110 | 27400 | 1014 |
| 2/17/2010 | Snow 100 | 23100 | 855 |
| 2/17/2010 | Snow 120 | 18200 | 673 |
| 2/19/2010 | Snow 100 | 12600 | 466 |
| 2/18/2010 | Snow 90 | 12300 | 455 |
| 2/3/2010 | Snow 150 | 11000 | 407 |
| 2/19/2010 | Snow 102 | 9930 | 367 |
| 2/17/2010 | Snow 12 | 9730 | 360 |
| 2/19/2010 | Snow 1 | 8580 | 317 |
| 2/19/2010 | Snow 23 | 8570 | 317 |

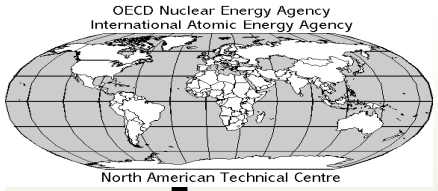
Sample locations for precipitation (circles) and snow (squares) within and in the vicinity of the Protected Area at Cook Nuclear Plant




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# Acknowledgements


- David Miller, University of Illinois and Cook NPP
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# Questions?

## Thank You!