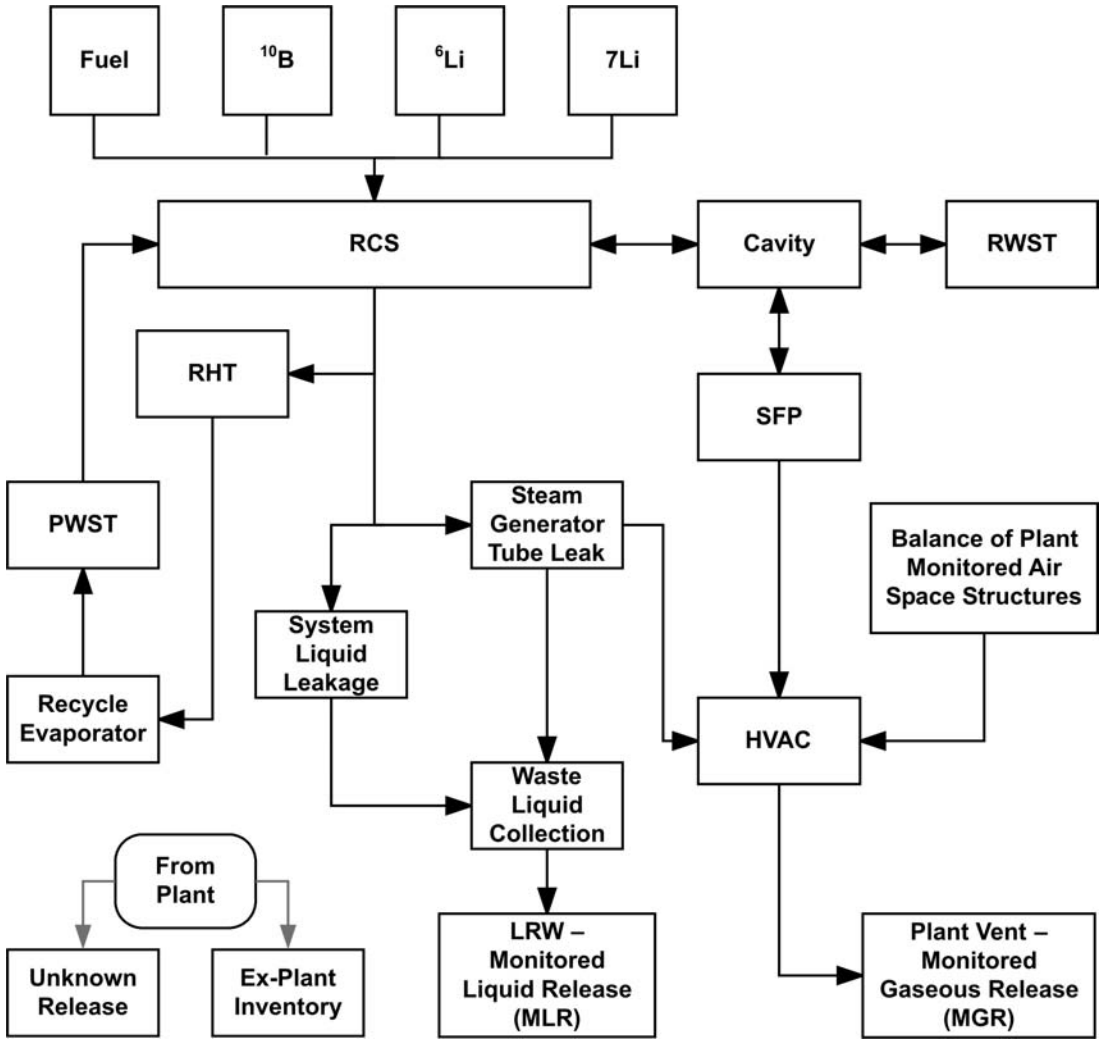
EPRI Tritium Management Model

Project Summary Report

Technical Report



EPRI Tritium Management Model

Project Summary Report

1009903

Final Report, November 2005

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REPORT SUMMARY

While tritium generated by nuclear power plants has insignificant dose impacts to the public, its management can be a significant issue in terms of public relations and perception. This document provides a tool for nuclear power plant decision makers to assess their operating strategies for tritium management.

Background

In 2003, EPRI released an industry document (1008015), which addresses liquid effluent strategy optimization. During that effort, a team, comprised of utility and other industry experts, recognized that tritium control is one area that many stations struggle to manage relative to production, concentration, control, and exposure. The challenge for utilities is to define the optimal holistic or integrated approach that results in regulatory compliance, and therefore appropriate levels of protection to the public, plant workers, and the environment.

Tritium management programs employ concepts such as "as low as reasonably achievable (ALARA)", best management practices (BMP), and internationally, "best available techniques (BAT)". Evolving societal values and advancing techniques and technologies may change the currently acceptable practices. Several stations have adopted unique operational and processing strategies for managing the impact of tritium on plant programs, while others continue to evaluate program improvements.

Objectives

To develop an interactive tritium management tool to assist with program oversight and decision-making processes.

Approach

A team of utility and other industry experts reviewed current performance, technology, issues, and regulatory requirements. Additionally, several stations have adopted unique operational and processing strategies for managing the impact of tritium on plant programs. Based on that collective information, the team developed a template for the tritium management model.

Results

This document summarizes the team's efforts. It includes a detailed outline of the Excel™ based strategy evaluation model, which EPRI will use to develop the final electronic version. It contains overviews of tritium production, management issues, regulations, typical approaches to monitoring, cost factors, and control and management mechanisms. The report also captures relevant issues and considerations to aid users in evaluating, developing, or improving their site-specific tritium management programs.

EPRI Perspective

EPRI developed industry guidance on the management of effluents, including the 2003 document that addresses overall liquid effluent strategies. Additional work focusing on tritium management has also studied a potential removal technology. Although some methods for tritium removal from liquid streams are in development, none are yet effective for removing the low concentrations of tritium present in light water reactor waste streams (1006710). This report, in contrast, provides a framework for plants to evaluate their site-specific operational practices for tritium control, which must meet the needs of various stakeholders such as the public, workers, and regulators. EPRI will continue to validate the Excel model developed in this study for future publication.

Keywords

Tritium
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OVERVIEW

Background

In 2003, EPRI released an industry document that addresses liquid effluents strategy optimization. During that effort, the team comprised of utility and other industry experts, identified and evaluated at length the importance of balancing a site's liquid, solid, and gaseous effluents. Utilities are challenged to define the optimal holistic approach that results in regulatory compliance and hence, the appropriate levels of protection to the public, plant workers, and the environment. Further, the team recognized that tritium control is one area that many stations struggle to manage relative to production, concentration, control, and exposure.

Tritium is a hydrogen atom that has 2 neutrons in the nucleus, in addition to its single proton, giving it an atomic weight near 3. It has a half-life of 12.62 years and emits a very weak beta particle and transforms to stable, non radioactive helium. Although tritium can be a gas, its most common form is in water, because, like non-radioactive hydrogen, radioactive tritium reacts with oxygen to form water. Tritium replaces one of the stable hydrogens in the water molecule, H_2O, and is called tritiated water. Like H_2O, tritiated water is colorless and odorless. Tritium is produced in light water reactors by several mechanisms including ternary fission, soluble boron reactions, soluble lithium reactions, burnable poison materials, and deuterium reactions.

Historically, the dose associated with the discharge of radioactive tritium from commercial nuclear plants is less than one percent of the annual allowable dose to a member of the public in an unrestricted area as governed by 10CFR20.1301.

Tritium management programs employ concepts such As Low As Reasonably Achievable (ALARA) and Best Available Technology (BAT) (as defined in the European Union Integrated Pollution Prevention and Control (IPPC) Directive of 1996). Developing societal values and advancing techniques and technologies may change what is currently regarded as "reasonably achievable" and "best available", therefore ALARA and BAT remain moving targets.

Tritium Strategy Considerations

The following is a brief overview of the key considerations related to tritium management. Additional detail is captured in subsequent sections of this document.

Environmental Stewardship

The nuclear industry continues to develop and implement pollution prevention programs using innovative approaches that in most cases exceed the expectations set by local, state, and federal regulatory requirements. These aggressive goals reduce the environmental impact associated with plant operations and reduce the future liabilities associated with exposure related litigation and decommissioning site remediation. Historically, the exposure associated with U.S. tritium releases is a small fraction of the exposure reported under the guidance of 10CFR20 Appendix I. Based on this information tritium remains an isotope of minimal biological risk or environmental consequence.

Regulatory

Nuclear Regulatory Commission

10 CFR20.1101 subpart (b) requires "The licensee shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)."

Currently, there are no cost effective abatement techniques available to PWR and BWR units for simultaneously reducing tritium activity inventory and effluents. However, to some extent tritium can be managed using operation strategies that determine the optimal release path, minimizing the impact exposure impact to the public, the plant staff, and the environment.

There are several regulations that must be considered when developing a tritium management strategy. 10CFR20.1301 Dose limits for individual members of the public requires that "(a) Each licensee shall conduct operations so that "(1) The total effective dose equivalent to individual members of the public from the licensed operation does not exceed 0.1 Rem (1 mSv) in a year…….".

The regulations also define occupational exposure limits in Part 20.1201 Occupational dose limits for adults. The annual allowable exposure is the more limiting of

The total effective dose equivalent (TEDE) being equal to 5 Rems (0.05 Sv); or

The sum of the deep-dose equivalent (DDE) and the committed effective dose equivalent (CEDE) to any individual organ or tissue other than the lens of the eye being equal to 50 Rems (0.5 Sv).

10CFR50 Appendix I, Sec. II. Guides on design objectives for light-water-cooled nuclear power reactors licensed under 10 CFR Part 50, Section A, requires that "The calculated annual total quantity of all radioactive material above background to be released from each light-water-cooled nuclear power reactor to unrestricted areas will not result in an estimated annual dose or dose commitment from liquid effluents for any individual in an unrestricted area from all pathways of exposure in excess of 3 millirems to the total body or 10 millirems to any organ." The Appendix further states in Section III, Implementation, A.1, that "…Account shall be taken

of the cumulative effect of all sources and pathways within the plant contributing to the particular type of effluent being considered.”.

The regulations are clear that there are specific limits to be considered for both plant staff and the public, and that all sources and pathways need to be considered in design and implementation of effluent exposure management strategies.

Environmental Protection Agency

In the U.S., the Environmental Protection Agency (EPA) is the enacting and governing body for regulatory pollution controls. Those regulations applicable to power reactors as part of the fuel cycle standard are codified in Title 40 Part 190 of the Code of Federal Regulations (CFR). The majority of the federal pollution control laws enacted by U.S. Congress require that associated state laws be pre-empted if they are not at least as protective of the environment as the federal programs. As a result, States and/or local municipalities have enacted their own statutory programs for environmental protection, typically based on federal mandates.

One of the primary national environmental priorities has been to protect and enhance the quality of the nation’s water supplies. The primary law for assuring the quality of drinking water when it reaches consumers is the federal Safe Drinking Water Act of 1974 (SDWA).

The Primary drinking water regulations associated with this Act set *Maximum Contaminant Levels* (MCLs) for biological and chemical contaminants in drinking water. MCLs are numerical standards for the maximum permissible level of a contaminant that is permitted in drinking water delivered by a public water system; the EPA’s MCL for tritium is 20,000 pCi/L.

Additional regulatory discussion is provided in Section 5, “Monitoring”.

Industry and Public Awareness

Industry

Historically, at the majority of U.S. light water reactors, tritium has represented a minimal contribution to worker exposure during routine operations and maintenance. The levels of tritium have been low, and turning over the RCS liquid volume on a routine basis through liquid releases results in an acceptable tritium activity inventory. However, in recent years several developments have impacted the status quo. The two primary factors are:

1. In the 1990’s many stations were attempting to achieve an operating status that included zero liquid activity and/or volumetric discharges. Several industry organizations use liquid effluent mixed fission and activation product activity as a principle plant performance indicator. It is well documented that traditional liquid processing technologies are not effective for removing tritium. Therefore, the combined effect of not discharging and constant tritium generation during operations, resulted in a steady increase in tritium concentrations in the effected plant’s liquid inventory. This has proven to be the case for those stations that operate in a zero or near zero liquid release mode. In addition to facing

challenges related to personnel monitoring, the gaseous effluents from those stations (particularly PWRs) is typically higher.

2. Improvements to analytical equipment, training standards, and sampling practices have led to more accurate quantification of tritium concentrations at low levels.

As a result of these issues, several stations have implemented tritium monitoring programs for plant staff working in the vicinity of open volumes of RCS such as the spent fuel pool.

Public

The industry's focused effort to reduce liquid effluent mixed fission products (MFP) and activation product (AP) activity continues, and at some point mixed fission products may no longer be the major contributors to dose and/or stand out as a negative social factor. Several U.S. sites are currently at or near this site-specific value. This could result in a public perception shift to inconsequential exposure constituents such as tritium, as evidenced at several stations where acute increases in liquid tritium effluents have resulted in a significant resource burden to clarify tritium's minimal impact.

Risk

Health

Tritium readily forms water when exposed to oxygen. Therefore, tritium is almost always found as water, or "tritiated" water. Tritiated water may enter the body by inhalation, ingestion, or absorption through the skin. Because of its relatively short 12 day biological half life, combined with a low beta decay energy of 19 keV maximum, 6 keV average, it is one of the least significant radionuclides produced in power reactors. Once tritium enters the body, it disperses quickly, is uniformly distributed throughout the body and is excreted through urine or lost through respiration and perspiration. Organically bound tritium (tritium that is incorporated in organic compounds) can remain in the body for a longer period.[3] [5]

As with all ionizing radiation, exposure to tritium increases the risk of developing cancer. However, tritium is one of the least dangerous radionuclides because it emits very weak radiation and leaves the body relatively quickly. Since tritium is almost always found as water, it goes directly into soft tissue and organs. The associated dose to the tissue is generally uniform and dependent on the tissue water content.

The minimal impact is further reinforced by the relatively large concentration limits established for tritium in public drinking water. For example, the NRC establishes a value of 1 X E-3 μCuries per milliliter in 10CFR20 Appendix B, Table 2, Column 2. Similarly, in 40CFR141.16 the EPA's Safe Drinking Water Act of 1974 establishes a safe drinking water maximum concentration limit (MCL) of 20,000 pCuries per liter (2 X E-5 μCi/mL). These values are orders of magnitude higher than those for other radionuclides in liquid wastes released from commercial nuclear plants.[4]

Sources

There are several sources for potential exposure associated with tritium from nuclear power plants. Table 1-1 summarizes the principle considerations related to sources, transport mediums and the exposed population.

Table 1-1
Tritium Source Term Impact

Medium	Source(s)	Description	Potentially Impacted Population
Liquid	RCS SFP Liquid waste tanks and sumps Released liquid Leakage/migration to ground water/aquifers	RCS is commingled with refueling water and spent fuel pools during refueling operations. Liquid from systems is transferred or leaks to liquid waste. Liquid waste is processed and released to the environment.	Plant staff – from all but released liquids Public – from released liquids and leakage/migration to ground water/aquifers
Airborne (gaseous)	SFP evaporation Cavity evaporation Leaks Sumps Atmospheric tanks Normal plant venting Containment purge	Evaporative processes transport tritium as an airborne constituent. Plant ventilation processes result in release to the environment. This in turn can fall out onto site property and concentrate in soil, drains, structural concrete, or be reintroduced to the plant via liquid and air intake plenums.	Plant staff – affiliated with work around atmospheric liquid volumes and plant venting processes. Public – plant venting and purge; to a lesser extent evaporation of dilution surface bodies of water such as retention ponds and non-flushing bodies of water.
Solid	Radioactive waste Off-site vendor processing Activation constituents in concrete	Entrained liquids in liquid waste processing media including resins, carbon, filters/septa, and concentrates. Sampled annually for 10CFR61 waste classification analysis. Concrete products exposed to neutron flux have shown to contain tritium. The mechanism is believed to be related to activation of naturally occurring lithium entrained in the concrete raw materials.	Plant staff - processing, packaging, and shipment preparation. Public – minimal to none during waste transport and process vendor effluents. Processing vendor staff - processing, packaging, and shipment preparation at vendor facility.

This summary clearly shows that the sources and their impact can be widespread, potentially affecting all plant staff members and the public. It also has a direct and significant impact on decommissioning efforts and costs. Tritium that is entrained in concrete structures, residing in soils and pavement, or concentrated in subsurface aquifers can present unique and costly challenges during site remediation.

More recently an additional challenge has emerged. As utilities strive to maximize their capacity factors through more efficient outage execution, the volume of at power tasks has increased. This exposes workers to containment atmospheric conditions. Seemingly minor system leakage can result in relatively high concentrations of tritium in the containment structure. This aspect of radiological controls requires careful evaluation and planning to ensure workers do not incur unnecessary or unmonitored exposure as a result of this relatively "new" source term challenge.

Liability and the Legal Arena

American Nuclear Insurers (ANI) provides nuclear liability insurance of US $300 million to each US nuclear power plant. ANI is a joint underwriting association which is a Pool of insurance companies that provides financial protection to the nuclear industry. Through insurance, financial protection is provided to cover the third party nuclear liability exposures of nuclear utilities and other businesses that support nuclear utility operations. This protection covers the operators of nuclear facilities and their suppliers for liability for damages because of bodily injury or property damage caused by the nuclear energy hazard. Insurance losses can be of the catastrophic or non-catastrophic type.

Expenses that might be paid under the nuclear liability policy include the payment of claims that are presented under the policy and the costs of defense of those claims. Often, these claims defense costs are a major portion of the expense of providing insurance to the nuclear industry, and may be reduced considerably when there is clearly-documented evidence of due care and proper operation of the insured facility. Claims alleging third party bodily injury or offsite property damage as a result of the nuclear energy hazard are covered under an insurance policy referred to as the Facility Form Policy.

For the purpose of this EPRI document it is important to note that effluent releases have a direct financial impact on nuclear liability insurance premiums via the Engineering Rating Factor (ERF) program. There is also an indirect financial impact.

Direct Impact - Beginning in 1981, ANI implemented an ERF program for its insurance purposes to monitor and evaluate industry and individual nuclear plant performance based on select engineering plant performance indicators. The program is also used to redistribute a portion of total power reactor nuclear liability insurance premium based on the results of the select engineering performance indicators.

As of December 2003, ANI evaluates twelve areas of plant performance under the Program. Based on aggregate plant performance, a portion of the total nuclear plant liability premium is redistributed. Performance information also plays an important part in the development of insurance risk profiles that support loss control strategies at each nuclear power plant facility.

There are six rating factors used to calculate nuclear liability insurance premium.

1. Reactor Type
2. Reactor Use
3. Reactor Size (Thermal Power Level)
4. Plant Location
5. Containment Type
6. Engineering Rating Factor (ERF)

Each of these six factors is a direct multiplier in the premium computation. While plant operations have very little effect on each of the first five rating factors (i.e., Type, Use, Size, Location, and Containment), plant operations have a substantial impact on the sixth factor – the ERF.

The ERF serves as the mechanism to rate power reactor insureds on a comparative risk basis. The fundamental criteria for the ERF required that total ANI power reactor nuclear liability premium not change as a result of implementation. There are eight broad performance areas of perceived nuclear liability insurance. Each of the performance areas is described in Table 1-2 below. Tritium related performance measures are highlighted solely for ease of identification in this document.

Table 1-2
ANI ERF Performance Areas

Environmental Releases[1] a) Noble Gases b) Airborne Iodine & Particulate **c) <u>Airborne Tritium</u>** d) Waterborne Mixed **e) <u>Waterborne Tritium</u>**	The Environmental Performance Area is comprised of five components accounting for releases of radioactive material in the effluent streams. Effluent releases (airborne & waterborne) represent an increasing level of insurance exposure, which is proportional to the amount of activity (curies) released, the population density and distribution surrounding the insured, and the local environmental uses (drinking water, aquifers, fishing, etc.) of the surrounding properties. The environmental release path can be managed by actions such as proper chemistry and plant environmental(temperature/humidity) controls and by the proper design and operation of radioactive waste processing systems.
Regulatory Performance **NRC Violations**	This sub factor is referred to as the Regulatory Performance Sub factor. The sub factor reflects the ability of the utility to operate within prescribed rules and regulations. Deviations from operational compliance may result in a higher nuclear liability exposure. The NRC Violations component includes only NRC violations that result in a fine that is paid by the utility. The worst performance is weighted 100 times more than the best performance
ANI Liability Recommendations	ANI Liability recommendations that are not accommodated by the insured are candidates for inclusion into the ERF. Recommendations that fall into this category are reviewed and processed by the ANI Recommendation Review Committee for insurance risk significance and consistency.
Significant Events	This data is from the NRC's Performance Indicator Program. Events classified as "significant" include: Degradation of important safety equipment Unexpected plant response to a transient Degradation of fuel integrity, primary coolant pressure boundary, etc. Scrams with complications Unplanned releases of radioactivity Operation outside the limits of technical specifications.

Table 1-2 (continued)
ANI ERF Performance Areas

Radioactive Waste	Radioactive waste shipments represent an insurance exposure to the general population and property while in transit. The exposure is proportional to the volume, activity and distance shipped. Because of reporting inconsistencies, only activity (curies) shipped is included in the ERF.
Safety System Failures	Events or conditions that could prevent the fulfillment of the safety function of structures or systems are included. This data is from the NRC's Performance Indicator Program.
Unplanned Automatic Scrams	This sub factor monitors the number of unplanned automatic scrams that occurred while critical, such as those that resulted from unplanned transients, equipment failures, spurious signals or human error. Also included are those that occurred during the execution of procedures in which there was a chance of a scram occurring, but the occurrence of a scram was not planned. This data is from the NRC's Performance Indicator Program.
Safety System Actuations	This sub factor monitors automatic or manual safety system actuations of the logic or actual equipment of either certain Emergency Core Cooling Systems or in response to an actual low voltage on a vital bus. This data is from the NRC's Performance Indicator Program.

Note 1: Measurement techniques vary by site. Caution should be exercised when performing direct comparisons to "sister" station's effluent performance.

When viewed on a comparative basis, the various factors reflect relative nuclear liability insurance risk. These performance areas are combined using statistical methods to produce a composite ERF value that corresponds to an adjustment of nuclear liability insurance premium based on operational performance. The best performers are eligible to receive a credit of up to 20 percent and the highest insurance risk performers would be assessed a surcharge of up to 30 percent. The ERF is computed on a yearly basis.

Of significance is that nuclear liability insurance premiums may also be impacted by ANI Liability Recommendations which may be offered by ANI Engineers. Any ANI recommendation, including effluent/environmental recommendations, that has not been implemented (i.e., open or pending categories) is subject to rating by the ANI Recommendation Review Committee. Rating in this area is based on insurance risk significance. A recommendation's impact within the ERF can be between approximately $3,000 and $52,000 per recommendation, based on the significance of the recommendation. For a multi-unit site, the impact can be 1.5 times that.

For 2003, the average nuclear liability premium for an operating nuclear reactor site is approximately $725,000. The relative contribution for the aggregate environmental component in the ERF for an average hypothetical nuclear plant site that exhibited best industry performance in all sub factor performance areas, other than environmental, could be in the range of approximately $20,000 to $250,000.

Indirect Impact - There is also the potential of indirect impact on nuclear liability premium due to claims activity. The costs associated with defending nuclear liability claims are factored into overall premium on an actuarial basis.

There is a growing public consciousness of offsite contamination issues, in particular radiological. We note also global risk management experience which suggests that achieving compliance with applicable regulations does not always offer protection from claims alleging bodily injury or offsite contamination caused by the nuclear energy hazard. The judicial arena is very low on the learning curve relative to the scientific basis for Environmental impact factors. As a result there have been several financially significant nuclear liability claims alleging damage caused by a release of radioactive effluents from nuclear facilities. However, this also presents an opportunity for utilities to implement effluent strategies based on defensible decisions. In consideration of this, ANI believes that proactive management of radiological effluents serves to strengthen an insured's ability to demonstrate that reasonable actions have been taken to protect the general public and therefore, justly defend claims.

The term used to describe this proactive concept is risk minimization. In brief, risk minimization utilizes proactive, contemporary, systematic risk minimization principles that are not necessarily regulatory driven, to address the potential or actual release of radioactive materials which may present insurance risk to the public from plant systems, structures or property. Risk minimization also considers the public's perception of risk which often is much more significant than the risk as determined by the release, measurement and computational methodologies used today. For example; we know based on science, that a curie of cobalt-60 presents a markedly more significant biological impact than does a curie of tritium. The public, however, does not differentiate between these isotopes with regard to the level of concern and perception of harm caused by different radioactive constituents that are released from nuclear facilities.

Monitoring

Recent industry literature indicates that a 3300 MWt reactor will produce between 1.7E4 and 2.2E4 Curies of tritium. That range is important to understand when monitoring tritium levels to ensure that the technology and techniques employed produce acceptable results. The technologies, techniques, and protocols for monitoring tritium relative to plant inventory, plant staff, effluents, and the environment are complex and varied. This document is not intended to provide that level of detail, alternate industry resources should be used as references for detailed monitoring information. Fundamentally there are several traditional methods for measuring tritium in gaseous and liquid effluents. Industry experience indicates that the accuracy of those techniques varies by technology and application. For example, the results are impacted by the type of sample (grab or continuous, cold trap, or silica gel), the sample duration (short duration, week, month) and plant operations and evolutions (system venting, containment purging).

Personnel exposure monitoring is required for elevated concentrations of tritium in work areas. This is typically limited to work adjacent to large open bodies of tritiated water (e.g., SFP work) and at power containment entries. The majority of US plants are able to effectively maintain tritium activity at levels that are low enough to preclude worker monitoring.

Based upon the experience at several operating and decommissioning commercial nuclear power stations, negligible release of radionuclides, as well as non-radiological contaminants, to the groundwater at such plants is likely to occur over a plant lifetime. Monitoring wells are the primary tool used to investigate groundwater contamination, and if properly located, installed, and maintained, provide in depth strategy for public protection defense, minimizing the potential for dispersion into public drinking water supplies or recreational areas. Plant managers should engage all stakeholders early and continually throughout the planning and implementation of the groundwater monitoring program, to ensure their understanding, ownership, and acceptance of its findings. Additionally, because of the importance of groundwater analytical data in making decisions regarding the need for groundwater monitoring or remedial action, a robust program of quality assurance and quality control should be implemented.

For all monitoring efforts, plants must carefully evaluate the quality of their program relative to providing the appropriate level of protection to workers, the public and the environment. That effort is supported by a well defined, documented, sampling, analysis, quantification, and regulatory compliant program.

Tritium Reduction Technology

There are several proven and equally as many technologies in varying stages of development for tritium concentration and reduction. However, the technologies in their current state do not lend themselves to use for the relatively minor production rates associated with light water commercial nuclear power operations. This is primarily due to implementation and operating costs and the physical size of the units. Additionally, the processes result in a secondary waste stream with concentrated tritium levels that requires additional processing prior to disposition. Four specific technologies that have been used in either pilot or full scale applications include 1) molecular separation, 2) Vapor Phase Catalytic Exchange (VPCE) followed by Cryogenic Distillation, 3) Bithermal Hydrogen-Water Processing, and 4) Combined Electrolysis Catalytic Exchange. Some variation of the latter three technologies is currently being used or has been demonstrated at DOE sites and Canada's CANDU reactors.

Management of Consequences

Remediation and Decommissioning

Remediation and decommissioning are outside the scope of this project however, the operating, monitoring, and control strategies employed by currently operating units will have a dramatic impact on the efficiency and costs associated with remediation and decommissioning. All operating nuclear power stations will eventually become uneconomic for continued operation, will reach the end of their useful life cycle, and will be decommissioned. Based upon the experience at several operating and decommissioning commercial nuclear power stations, the release of relatively small quantities of radionuclides and non-radiological contaminants to groundwater is likely to occur. One objective of the decommissioning process is to terminate the

plant operating license in accordance with the site release criteria established by the United States Nuclear Regulatory Commission. These site release criteria require that plant-related subsurface contamination be fully characterized. The details of the local hydro geologic features that control contaminant migration must be sufficiently described and understood to demonstrate to the most skeptical stakeholders that the nature and extent of all releases to the groundwater flow domain have been adequately investigated.

Several EPRI and industry references provide a significant amount of information related to remediation and decommissioning and should be consulted for more detailed information.

Project Objective and Approach

Objectives

The primary objective of this project was to develop an interactive tritium management tool to assist with program oversight and decision making processes.

This product is not intended as a tritium management guideline document. It is a platform for communicating with experts and decision makers so they become better informed about the technical implications and feasibility of tritium management options. It provides basic factual information on options for managing and regulating radioactive liquid tritium releases from commercial nuclear power plants during normal operation.

An Excel™ based interactive analytical tool was developed for managing tritium; that model was based on both design basis and operating data as they impact Tritium production, inventory and effluents. The tool is intended for evaluation of actual or proposed program changes. The tool will track and trend data, and can be used to generate graphical displays representing input data analysis.

This project specifically does not address in detail the technologies, techniques and issues related to tritium measurement programs. Additional related reports may be developed as recommended by the utility support team.

Approach

A team of utility and other industry experts reviewed current performance, technologies, issues, and regulatory requirements. Additionally, several stations have adopted unique operational and processing strategies for managing the impact of tritium on plant programs. Based on that collective information, the team developed a template for the tritium management model. Additional, relevant issues and considerations are captured in this report to aid users with evaluating, developing, or improving, their site specific tritium management programs. The model description and details in this document form the basis for the final analytical product. It is expected that variations from those specific descriptions and calculations will occur during the model development process.

Long Term Program Management

Tritium management is a complex process involving several significant elements that directly influence its success. The model and report template are designed specifically for near term strategy development. However, they do support long term program direction analyses and should be used by utilities for that purpose. Several of the considerations are critical to long term success and are annotated as such. Specific examples include fuel type or primary chemistry changes that would impact future tritium production and liquid effluent processing recycle or release strategy changes that affect plant tritium inventory.

Path Forward

Tritium management continues to present opportunities for the majority of stations. Continued research and support in this area is leading to a more holistic site and unified industry endpoint. During this project many utilities expressed a significant level of interest related to sampling, analytical, and reporting methodologies and technologies. The limited data available indicates that although approved and acceptable, sampling and analytical methods and standards could be more standardized across the industry. An industry opportunity does exist related to future research to define an optimal personnel, effluents, and environmental tritium monitoring programs.

2
TRITIUM MANAGEMENT MODEL OVERVIEW

This section of the document provides a generic overview of the model and an example of a specific PWR model. The model is intended to use plant specific information to predict values for production, release, and inventory. Figure 2-1 provides an overview of the modeled analysis process.

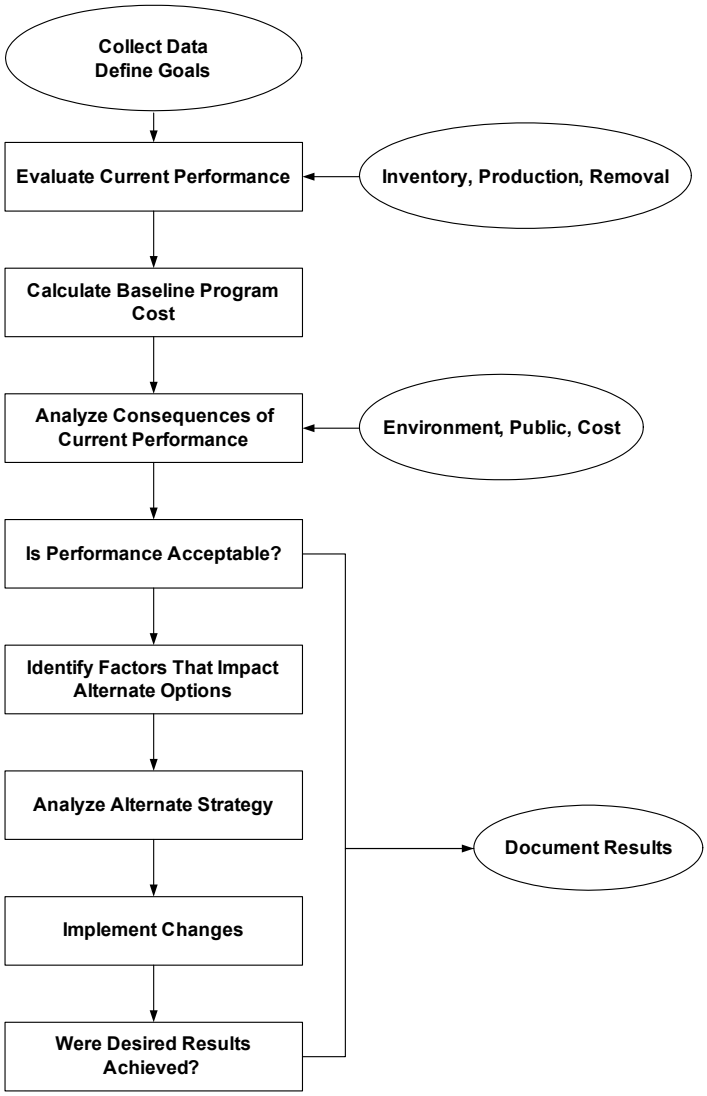

Figure 2-1
Model Use Overview

General Model Overview

The model addresses the major program elements of concern including:

1. Production
2. Removal
3. Inventory

It is recognized that there are other aspects of tritium management that should be included in a comprehensive program analysis. The majority of those considerations are addressed in the text of this document. The environmental inventory and impact were not included in the model.

The model serves two distinct functions.

1. To provide a visual tritium map and sequence for understanding, reviewing, and evaluating tritium effluent strategies.
2. To provide a basis template for the Excel™ based strategy analysis model.

Figure 2-2 through Figure 2-5 represent the basis for the tritium model. They illustrate the four modules of the modeling process.

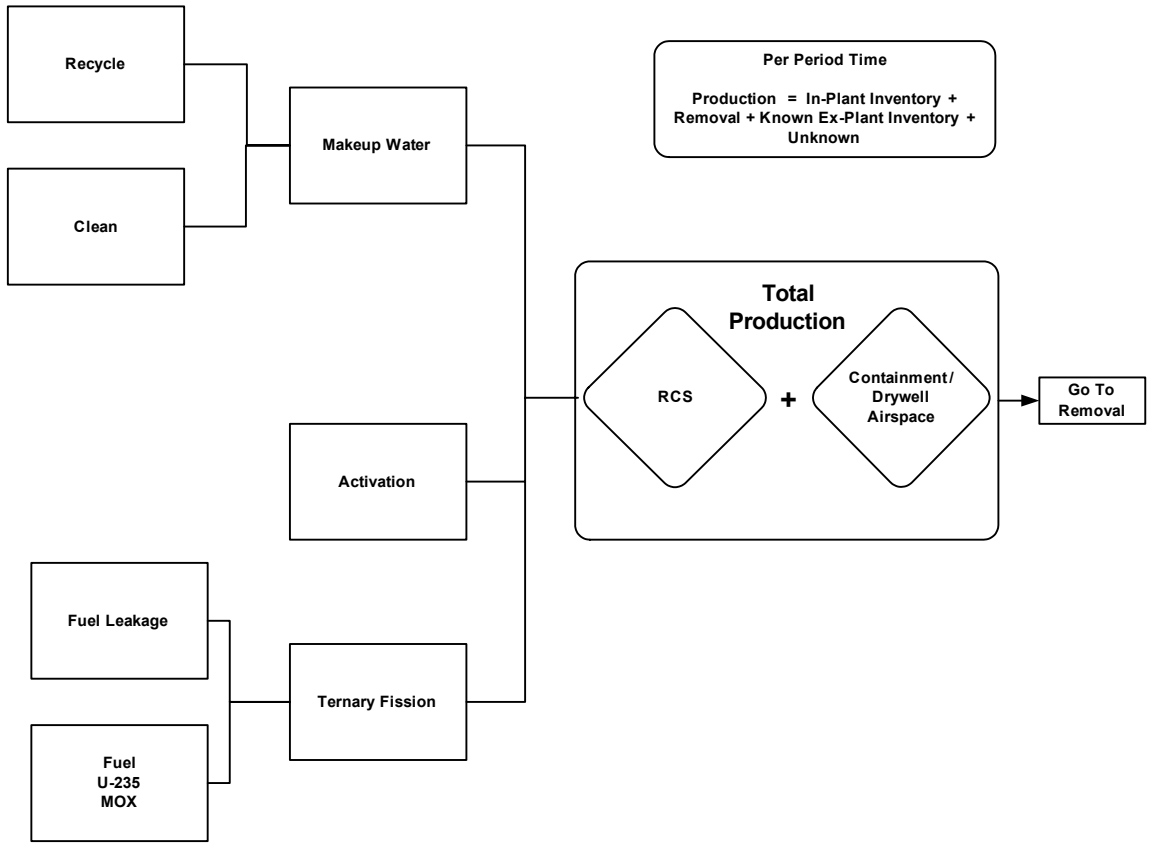

Figure 2-2
Tritium Production Diagram

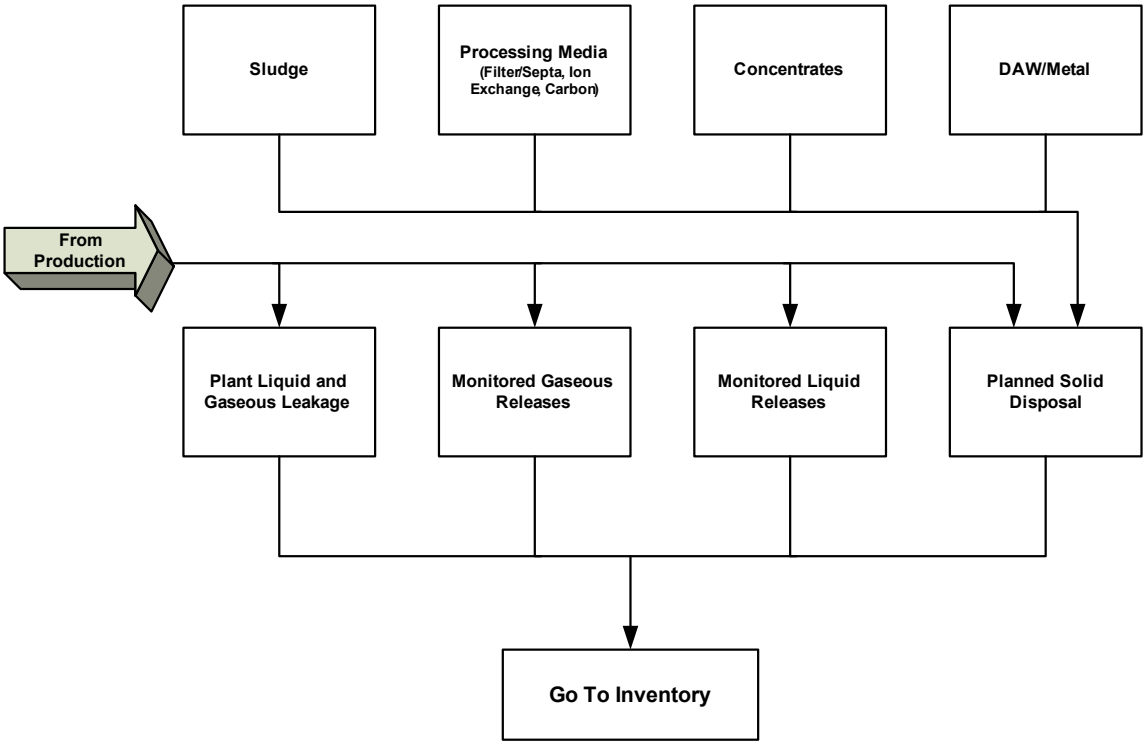

Figure 2-3
Tritium Removal Diagram

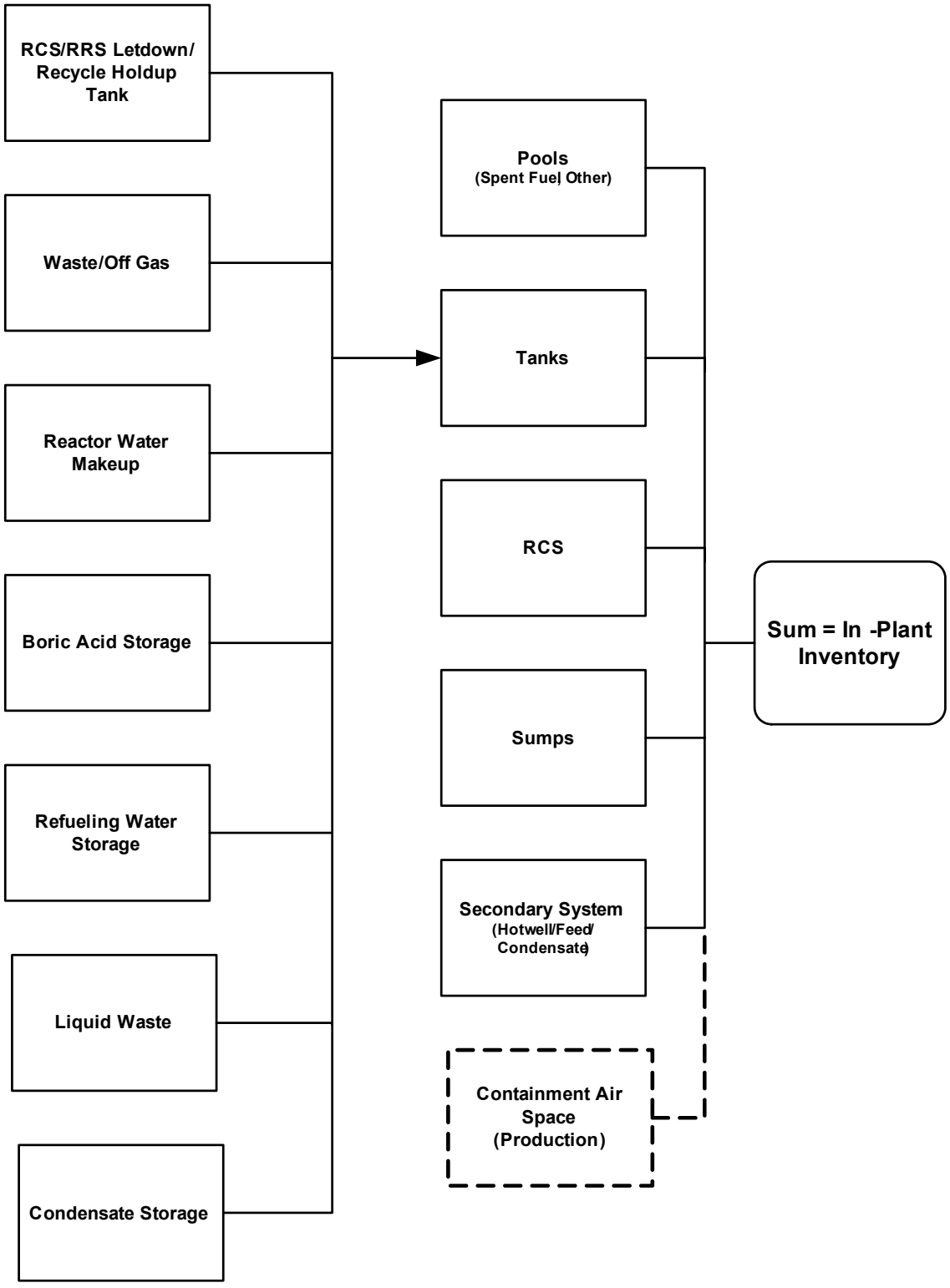

Figure 2-4
Tritium In-Plant Inventory Diagram

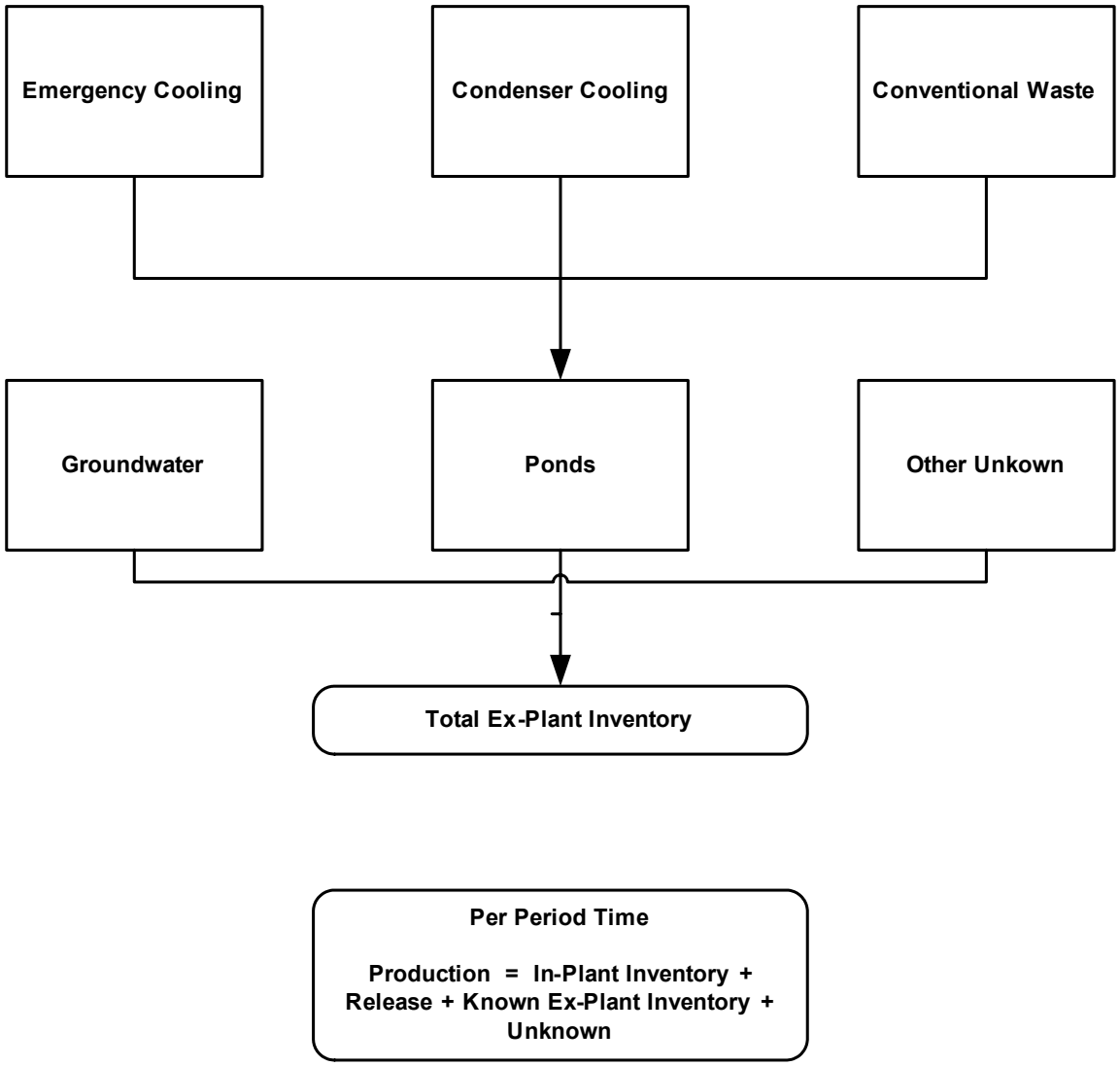

Figure 2-5
Tritium Ex-Plant Inventory Diagram

Detailed information on the analytical model, supporting calculations, and associated program cost and performance considerations are described in detail in Section 7of this report.

3
TRITIUM PRODUCTION

Tritium, ^{3}H or T, is the only significant radioisotope of hydrogen. It has a nucleus consisting of one proton and two neutrons giving it an atomic weight near 3. It decays with a 12.32 year half-life, emits only low energy beta particles at an average energy of 5.69 keV, and transforms to stable, non radioactive helium.[6] Its nuclear characteristics are summarized in Table 3-1.

Table 3-1
Tritium Nuclear Characteristics

Half-Life:	12.32 year
Decay Constant:	1.783 E-9 seconds^{-1}
Decay Mode:	β^- (100%)
Maximum β^- Energy	18.59 keV
Average β^- Energy	5.69 keV
Gamma Radiation	None
Thermal Neutron Cross-Section	0.52 millibarns**
Resonance Neutron Cross-Section	0.23 millibarns**

Source: IAEA, NUDAT2 Nuclear Data Tables

Although tritium can be a gas, its most common form is in water, because, like non-radioactive hydrogen, radioactive tritium reacts with oxygen to form water. Tritium replaces one of the stable hydrogen atoms in the water molecule, H_2O, and is called tritiated water. Like H_2O, tritiated water is colorless and odorless.

Production (General Mechanisms)

Tritium is produced in a light water reactor by ternary fission in the fuel, by neutron reaction with the boron used in control rods or as a chemical shim in the coolant, by neutron reactions with lithium used for pH control, and by neutron reaction with natural occurring deuterium in the form of coolant water molecules. There is a large variation in available literature related to cross-sections. However, resolving these differences is well beyond the scope and intent of this report. A summary of nuclear reactions is provided in Table 3-2.

Table 3-2
Significant Nuclear Reactions

Nuclear Reaction	Target Isotopic Abundance (%)	Neutron Reaction	Cross-Section (barns)
^{1}H (n,γ) ^{2}H	99.99	Thermal	0.332 b (Note 2)
^{2}H (n,γ) ^{3}H	0.0115	Thermal	0.52 mb
^{10}B (n,α) ^{7}Li	19.9	Thermal	3840 b
^{10}B (n,^{3}H) ^{8}Be	19.9	Fast	42 mb
^{10}B (n,2α) ^{3}H	19.9	Fast	45 mb
^{11}B (n,^{3}H) ^{9}Be	80.1	Fast	15 mb
^{6}Li (n,α) ^{3}H	7.6	Thermal	941
^{7}Li (n,nα) ^{3}H	92.4	Fast	330 mb
^{7}Li (n,^{5}He) ^{3}H	92.4	Fast	55 mb
^{235}U (n,fission) ^{3}H	---	Thermal	0.01% of fission rate

Ternary Fission

Ternary fission is the primary production mechanism for tritium in light water reactors. The rate of tritium production and its rate of release from the fuel in terms of µCi/s-MWt are the same for all light water reactors fueled with UO_2 and using zircaloy cladding. A variety of literature (refer to Reference Appendix) provides values for ternary fission tritium yields that range from 8.7 x E-5 to 2.0 E-3 tritium atoms per U-235 fission. It is known that fuel types (high duty, MOX, etc.) will impact this fission yield. However, as stated previously resolving those differences is beyond the scope of this report. IFBA is an "integral fuel burnable absorber" that is coated on the fuel pellet surface. WABA is "wet annular burnable absorber", and is essentially an assembly of burnable poison (BP) rodlets which are annular, thus allowing some coolant flow inside the rodlet. This increases the local moderation of neutrons and absorption capability of the BP. These are two types of poisons that are employed in PWR cores.

Regardless of that production rate, only a very small fraction of this tritium diffuses out of the fuel and cladding into the reactor coolant. Calculation of the tritium production rate agrees with the ANSI/ANS-18.1 design basis BWR concentration of 0.01 µCi/g. This is the primary evidence for a negligible tritium release from the control rods and fuel. Refer to reference 6 for additional detail regarding production rate research and values.

The material used for fuel cladding (stainless steel or Zircaloy) and its integrity determines the quantity of tritium generated. Research of this production mechanism by Westinghouse included measuring the tritium released from Zircaloy clad fuel in an operating PWR over five core cycles. The resultant calculated release rate into the primary coolant via ternary fission in a PWR

is approximately 0.001 Curies per megawatt-day or less. In BWRs (and less frequently in PWRs), increased tritium can be attributed to fuel cladding defects.

Soluble Boron

The predominant soluble boron production mechanism is thermal and fast neutron activation of boron-10. Boron-10 is a naturally occurring isotope and is a very efficient neutron absorber. It is used for chemical shim and reactivity control in PWRs. For this mode of production, tritium generation follows the concentration of boron-10 in the reactor coolant. The concentration of boron in PWR reactor coolant can vary from over 1300 ppm at the beginning of core life to a near zero, core specific concentration near the end of the fuel's useful life. As a result, boron related tritium production will initially be high and then decline over the course of the fuel cycle. This is the primary contributor to tritium inventory in PWRs. Note that the previously discussed ternary fission is the primary tritium production mechanism in a reactor, however, the tritium contribution (release) to reactor coolant is minimized by the zircaloy cladding.

Boron Carbide, B4C, is used in BWR reactor control rods to shape the power distribution and in conjunction with the recirculation flow-rate, control the reactor power. The control rods consist of a set of stainless steel tubes filled with boron carbide, B4C. These tubes are then sheathed in stainless steel in a cruciform array. The tubes are about 65% filled with B4C. The balance of the spaces is used to contain generated gases. There are four fuel assemblies surrounding each control rod. During operation the control rods perform the dual function of power shaping and reactivity control. A typical 3300 MWt reactor has 185 control rods with 84 B4C tubes per control rod for a total of 15,540 B4C tubes. Leaking control rod blades can generate boron that converts to tritium via the reactions below.

Boron is 19.9% Boron-10 and 80.1% Boron-11. Boron-10 has a large thermal neutron cross-section. The principal thermal neutron reaction is $^{10}\mathbf{B(n,\alpha)^{7}Li}$ which has a 3840 barn cross-section. The principal reaction producing tritium is the fast neutron reaction $^{10}\mathbf{B(n,2\alpha)^{3}H}$ and secondly the reaction $^{7}\mathbf{Li\ (n,n\alpha)^{3}H}$ where the Lithium-7 is a result of the $^{10}B(n,\alpha)^{7}Li$ reaction or lithium added to the coolant as LiOH for pH control. The complete reactions are shown in the following equations.

$$^{10}B(n,2\alpha)\rightarrow{}^{3}H$$

$$^{10}B(n,\alpha)\rightarrow{}^{7}Li(N,n\alpha)\rightarrow{}^{3}H$$

The overall formation of tritium from boron-10 is the sum of that produced from both reactions.

Plant Experience

The following information provides a specific analysis completed by one utility to determine the impact burnable poisons, core configuration, and boron concentration has on their PWR unit's tritium production. The analysis was performed using cycle 14 and 15 core design and boron data to determine the impact of reducing the "cycle-averaged" boron concentration by 200 ppm B.

For Unit 1, the nominal cycle-averaged boron concentration was found to be 858.5 ppm B. Assuming no depletion of B-10 over the cycle, the expected tritium production was found to be 46.903 Ci. If depletion of B-10 is addressed as modeled in the Startup and Operational Report (SOR), the expected tritium production was found to be 44.399 Ci. Reducing the boron concentration by 200 ppm B from the nominal cycle-averaged concentration results in a boron concentration of 658.5 ppm B (a reduction in reactor coolant boron concentration of 23.296%). At this concentration, the no depletion model predicts a tritium production of 36.891 Ci (a 21.345% reduction in tritium production). Including depletion in the analysis results in a predicted tritium production of 34.181 Ci (a 23.014% reduction in tritium production).

For Unit 2, the nominal cycle-averaged boron concentration was found to be 829.3 ppm B. Assuming no depletion of B-10 over the cycle, the expected tritium production was found to be 45.910 Ci. The depletion model resulted in a tritium production of 43.441 Ci. Reducing the nominal cycle-averaged concentration by 200 ppm B resulted in a 629.3 ppm B (a reduction in the reactor coolant boron concentration of 24.117%). At this concentration, the no depletion model predicts a tritium production of 35.510 Ci (a 22.652% reduction in tritium production). The depletion model predicts a production of 32.861 Ci (a 24.354% reduction in tritium production).

As can be seen, the reduction in tritium production over cycle is roughly equal to the percent change in reactor coolant boron concentration. However, to achieve such low cycle-averaged boron concentrations requires a much higher IFBA/WABA loading. This would lead to higher enrichments requirements for new fuel and significant fuel costs (1.5 - 4 million dollars). The analysis concluded that quantification of the avoided personnel exposure could be estimated and valuated, it was deemed unlikely that this option would be cost effective when fuel costs per cycle were included. The Reactor Engineering organization recommended that under the current conditions, the boron reduction option should not be pursued. Changes to tritium inventory or personnel exposure significance may dictate the need for a re-evaluation of this option.

Soluble Lithium

Lithium hydroxide is used for pH control in the primary coolant in some PWRs (Li^7OH). The lithium reactions for tritium production are captured in the following equations:

$$^7\text{Li}(n, n\alpha)\rightarrow{}^3\text{H}$$
$$^6\text{Li}(n, \alpha)\rightarrow{}^3\text{H}$$

As the ^{6}Li equation illustrates, controlling the purity of lithium in the primary system to minimize the amount of lithium-6 will reduce the resultant tritium concentration. The purity of lithium is typically specified at 99.9% lithium 7. Demineralizers are used to remove excess lithium-7, reducing the reaction potential. Similarly, the use of high purity Li^7OH (enriched to 99.9% ^{7}Li) will reduce the lithium-6 available for reaction. Conversion to a less expensive, less pure LiOH product (e.g., 98.4%) containing higher concentrations of lithium-6 would result in a 16 fold increase in tritium production associated with this reaction.

Burnable Poisons

The previously discussed boron reactions take place in burnable poison absorbers that contain boron. The amount of generated lithium-7 cannot be controlled, therefore there is a buildup of lithium-7 in the material. Failure of control rod blades is a potential source of increased tritium concentrations.

Heavy Water Reactors (Deuterium)

Heavy water reactors (e.g., CANDU) are impacted by tritium through the two equations below.

$$^{2}H\ (n,\gamma)\ ^{3}H$$

$$^{2}H\ (D,p)\ ^{3}H$$

Due to significant differences related to commercial heavy water reactor tritium production, concentrations, and management and regulatory controls, this document is focused on light water PWR and BWR reactors.

Although light-water reactors have considerably lower deuterium concentrations than those found in heavy water reactors, the activation of deuterium can still serve as a tritium production mechanism in light water reactors. Neutron capture by deuterium in the form of water molecules, HDO, is considered the principal source of tritium in the BWR primary coolant. Calculation of the tritium production rate is complicated by formation of deuterium from coolant hydrogen atoms by the reaction $^{1}H(n,\gamma)^{2}H$ that has a neutron cross-section 0.332 barns. In PWR's, however, this reaction is negligible compared to the tritium formed by neutron capture in the boron added as chemical shim.

Plant Specific Production Factors

Several factors directly impact a unit's tritium production including type of plant, fuel cladding, burnable poison assemblies (BPA), fuel integrity, primary chemistry controls, operating strategies, and reactor power. It is an important part of the process for a station to identify the applicable plant specific production mechanisms using materials such as Technical Specifications, UFSAR, and using data that define plant specific production boundaries. This combined information can then be used to analyze the unit specific production rate.

Based on the previous discussions, it is clear that boron control, lithium purity, and fuel integrity are the three most critical production control variables. Ensuring that these three parameters are accurately monitored, and their performance assessed and management optimized, will help to reduce the production, inventory, and release of tritium activity.

4
INVENTORY AND INVENTORY MANAGEMENT

When evaluating tritium management options, numerous interrelated factors must be considered. Increased tritium concentrations in a plant's liquid inventory can negatively impact site personnel exposure and work practices. Feed and bleed techniques via liquid releases and non-radioactive makeup will reduce that concentration, but the bleed component, liquid release, will affect off-site dose, industry effluent activity performance standings, and potentially liability exposure and/or insurance premiums. Increasing airborne emission's tritium concentration through the use of evaporative techniques will reduce the site liquid borne tritium inventory, but can impact the on-site environment and similar to liquid effluents, will affect off-site exposure considerations. Figure 4-1 through Figure 4-3 compare PWR and BWR gaseous effluents to liquid effluents. Logarithmic trend lines are included to illustrate the general correlation between those effluent streams. The data in Figure 4-1 is sorted by liquid total activity by reactor number going from the lowest liquid effluent value to the highest. The data clearly shows the impact inventory and release options have on effluents activity by stream. As liquid effluents increase, the gaseous values decrease. The data from the first three reactors represents units that operate in a 100% recycle mode and clearly indicate the impact that this strategy has on gaseous release activity.

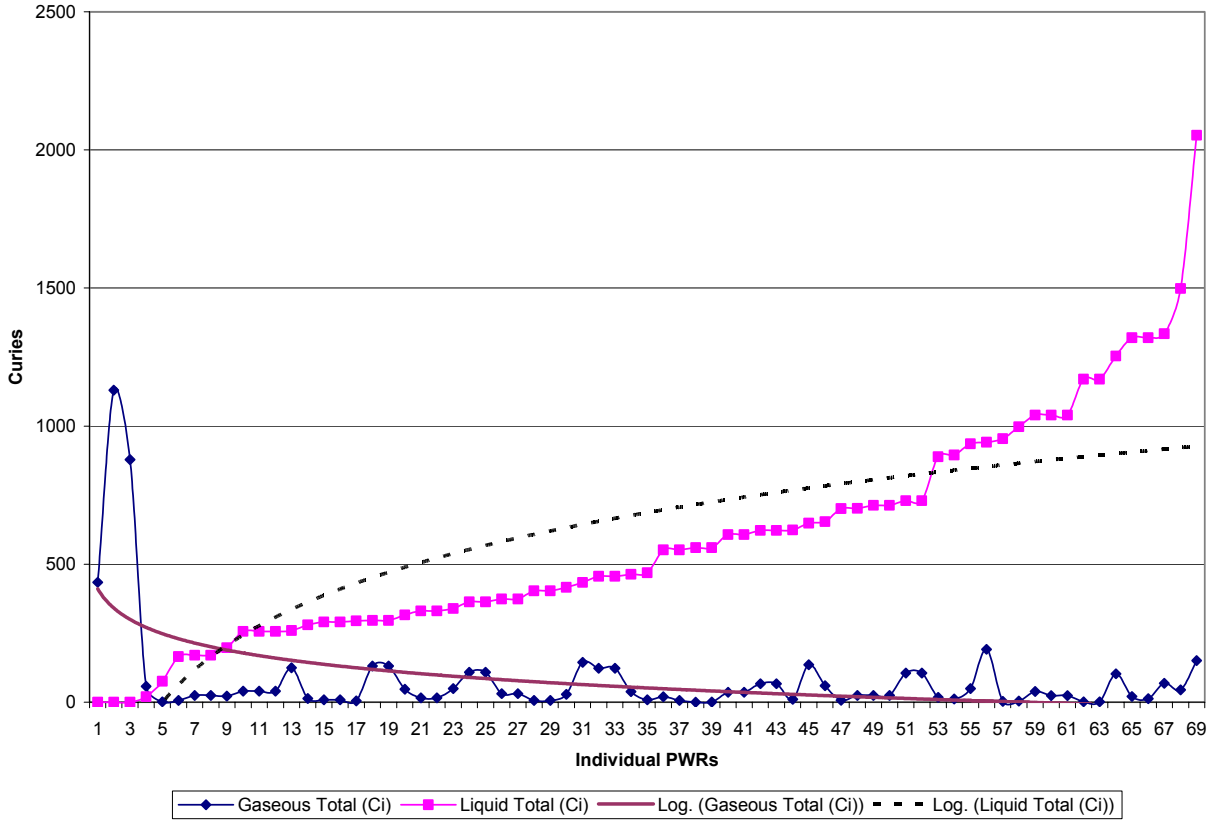

Figure 4-1
US PWR Liquid Versus Gaseous Effluent Tritium Activity – 2003

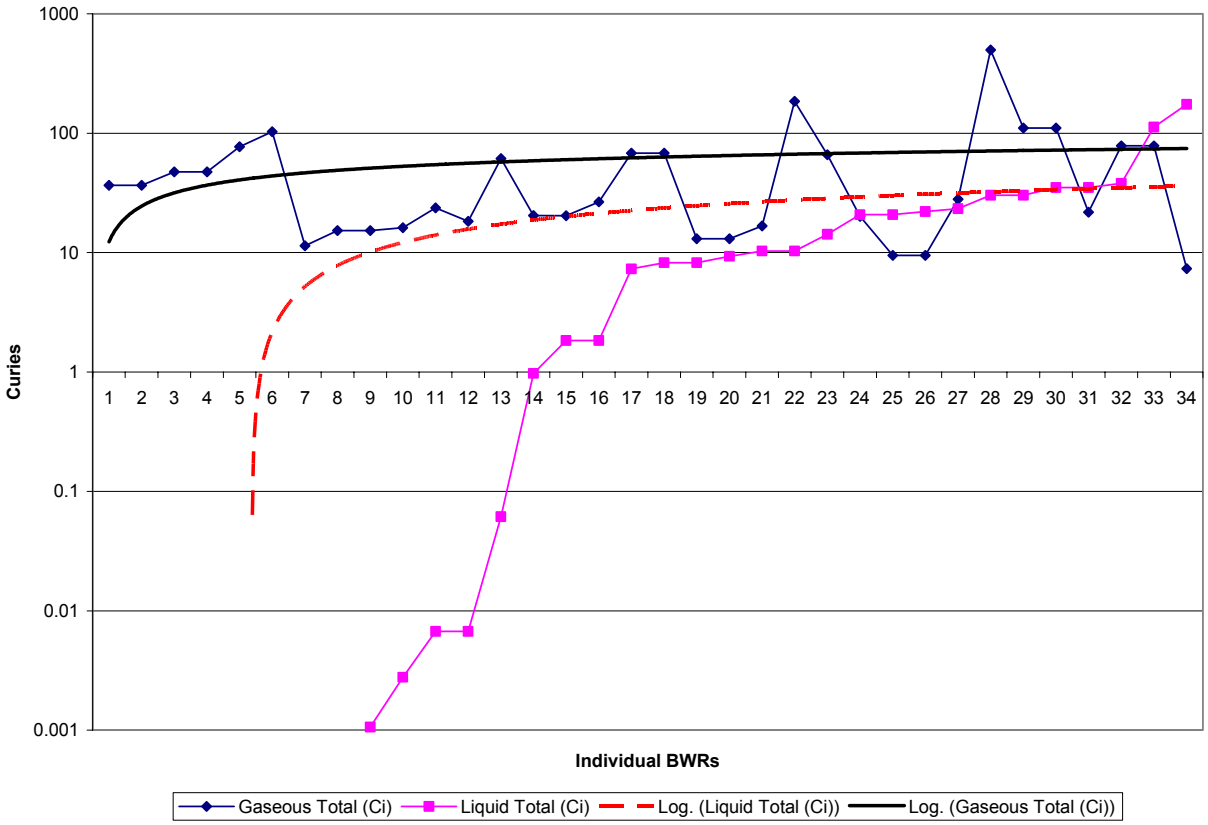

Figure 4-2
US BWR Liquid Versus Gaseous Effluent Tritium Activity – 2003

The BWR data in Figure 4-2 do not result in an equally clear trend, however, the information does illustrate a similar conclusion for several sites. The BWR versus PWR clarity is most likely due to the higher tritium concentrations present at PWRs (higher Li and boron concentrations) and the low volume and relatively low activity of released liquid at BWR stations as compared to PWR effluents. Regardless of the conclusions drawn, this data reinforces the importance of involving Radiological Environmental Technical Specifications (RETS) and Radiological and Environmental Monitoring Program (REMP) expertise in the effluent control and management decision making process.

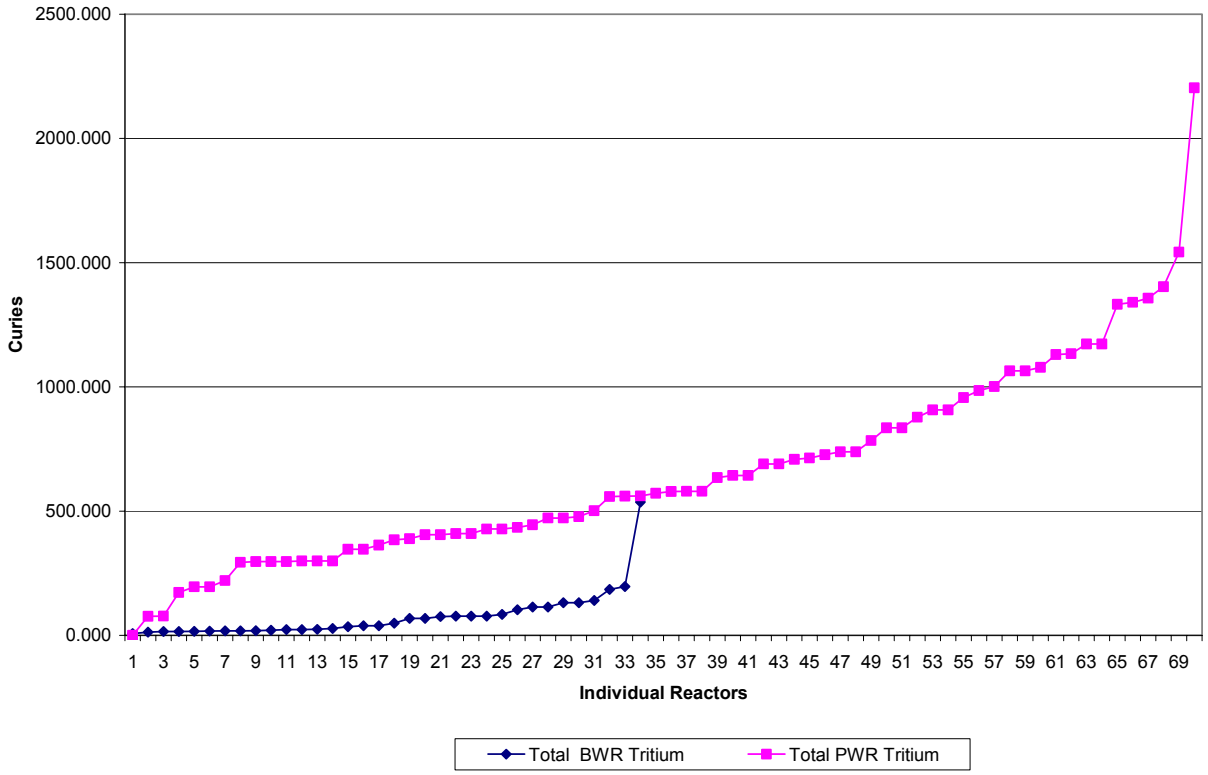

Figure 4-3
Comparison of BWR and PWR 2003 Tritium Effluent Totals (Gaseous and Liquid)

Note: The effluent data in this section was collated from NRC RG 1.21 reported data and was provided by the NATC.

The direct correlation between liquid and gaseous effluent activity is not as clear for the BWR data. It is important to note that gaseous effluent benchmarking analyses are most likely skewed by sampling and analysis techniques. Plant to plant variations in sample tap location, sample collection methodologies, plenum flow rates, collection duration, and laboratory analyses will impact the accuracy of the sample results and subsequent industry benchmarking efforts.

Accumulators

Reactor Coolant System

The most predominant and obvious accumulation medium in both PWR and BWR units is the reactor coolant system (RCS). During both normal plant operations and outages the RCS system communicates with several other plant systems. The extent of the tritiation resulting from that interaction is dependent on several factors including:

- Initial RCS concentration

- Volume of liquid in the receiving body of liquid
- Volume of water transferred to that body of liquid

The predominant system interactions are described in the following text. The RCS tritium concentrations are analyzed on a routine basis and the fixed volume allows relatively easy tritium inventory calculations. This concentrator should be included as the primary source term for the tritium management model.

Water Recycle

Recycling options will vary dramatically by site and reactor type and those variations will directly impact the effect recycling has on tritium inventory. However, regardless of that impact, recycling will impact the plant inventory by reducing the amount of "clean" water dilution. This also helps to maintain RCS tritium at equilibrium concentrations. Several US stations that have long histories of zero liquid volume release, are currently evaluating the impact their elevated tritium inventory has on plant staff exposure and monitoring programs.

Several options should be addressed in water recycle evaluations including processing and/or recycling primary water to:

- RCS makeup tanks
- Refueling water tanks
- Spent fuel pools

As a result of maintenance requirements, operation, maintenance, and energy costs, personnel exposure, and recycled boron quality issues, the majority of US PWR stations have discontinued the use of boron recycle and waste evaporators. This previously recycled liquid is now processed and released. However, several PWRs continue to have success with boron recycle evaporator operation and at least one US PWR operates in a zero liquid volume release mode due to its location in a dry climate that results in an inadequate dilution water source. Similarly, due to the volume of liquid generated, many BWRs do recycle a large portion of the plant's radioactive liquid streams. This is particularly true for the chemically pure and high activity equipment drain wastes. Several BWRs process and release their lower quality, low activity floor drain wastes.

Reactor Cavity, Refueling Water Tanks and Reactor Makeup Water Storage

The reactor cavity and subsequently the RWST are exposed to tritiated liquid during refueling operations. The reactor cavity is configured for direct closed loop flow of liquid from RCS piping, through the reactor vessel. This configuration provides core and fuel assembly cooling during refueling operations, and for PWRs the cooling water is borated to provide shutdown reactivity control. The primary liquid treatment processes employed during this condition are ion exchange and filtration via installed plant purification systems (letdown purification, reactor water cleanup). While such processing techniques are very efficient in removing fission and activation product activity, historical processing technologies have no noticeable impact on coolant tritium removal. Upon completion of refueling operations, the majority of the tritiated

cavity water is pumped back to a RWST. To expedite that cavity draindown process, the liquid is transferred using high flow pumps and treatment is not feasible. Following transfer to the RWST the water is processed for activity reduction using conventional techniques such as filtration and demineralization. However, those processes have a negligible impact on the post-treatment RWST tritium concentrations. The tritium concentration in the RWST and in most instances, reactor cavity is analyzed on a routine basis. The liquid volume is also known, making quantification of the inventory a practical consideration for the model.

Spent Fuel Pool

Similar to the reactor cavity, spent fuel pools are cross connected with the RCS system during refueling outages. The fuel transfer canal provides a direct pathway for tritiated liquid transfer from the RCS/reactor cavity to the spent fuel pool (SFP). In addition to acting as both a large scale sink and source of tritium, the SFP can provide a source of boron resulting from breakdown of borosilicate compounds present in some fuel storage racks. The generated boron is then recycled into the reactor coolant via the transfer canal and reactor cavity, and becomes activated to tritium in the reactor.

The SFP activity is monitored to assess the buildup of tritium over time and to assess the impact on personnel exposure and related monitoring programs. The routinely accessed SFP building houses the largest volume of atmospheric tritiated liquid. Therefore, the SFP area requires careful evaluation and control to effectively manage the tritium action levels and to ensure personnel exposure monitoring is performed in accordance with regulatory requirements. At some stations, the personnel exposure impact assessment resulted in the need to implement personnel tritium monitoring programs during work in that area. The tritium inventory can be calculated based on sample results and pool volume.

Waste Liquid Sumps and Tanks

Tritiated liquid is routed to liquid radwaste (LRW) system sumps and tanks via a host of flowpaths. System draining, component leakage, cavity draindown residual water, and letdown (for process and release) are several of the more common sources. The volumes, concentrations, and dilution factors vary significantly by sump or tank and period of time. The vast majority of sumps and tanks at most stations are not routinely analyzed for tritium, therefore quantifying the impact this accumulation mechanism has on plant inventory is considered of limited value.

Inventory Control

Liquid - Normal Operation

Planned Liquid Release

Planned liquid releases can reduce a plant's tritium inventory. The significance of that option is dependent on the released volume, tritium concentration, and release frequency. The most

common technologies for treating liquid waste prior to release are filtration and demineralization, with a few stations employing advanced membrane systems. All of these processes have a negligible effect on reducing tritium concentrations in the effluent stream, therefore process and release strategies will reduce the plant tritium inventory as tritium is discharged from the plant as a liquid effluent stream.

Unplanned Liquid Release

Unlike planned, monitored releases, there is a less desirable tritium inventory impact factor, unplanned, unmonitored leakage. Leakage from SFP and cavity walls, transfer canals, structural joints, collection and monitoring tanks located outside and exposed to the environment, and outside or below grade radioactive liquid piping are the most predominant sources of leakage. Additionally, several industry events have resulted from short cycling plant effluent gaseous waste by plant HVAC systems. In these events, building supply ventilation systems pulled in airborne tritium activity, routing it across chiller units. The normally non-radioactive condensation was released as unmonitored liquid wastes (Refer to Appendix D for additional detail).

These sources not only impact the in-plant inventory and tritium accountability, but can also result in a significant liability related to surface and groundwater intrusion and dispersion, and decommissioning and site remediation efforts and regulatory acceptable end points. Identified leakage should be considered in tritium management analyses, and similarly, an imbalance between tritium production, inventory, and effluents should also consider this undesirable condition.

Liquid Inventory Management Options

Planned Liquid Releases

As stated previously, processing tritiated liquid waste streams using conventional methods such as filters, demineralizers, advanced membranes, or evaporation is ineffective. Therefore, the concentration of tritium in liquid process system's influent waste is essentially equal to the activity in the effluent waste stream. Based on that premise, releasing processed liquid wastes can be a significant tritium inventory reduction tool.

Figure 4-4 and Figure 4-5 summarize US PWR and BWR 2003 tritium activity releases. The data represents per single unit data from 69 PWR and 34 BWR plants as reported to the NRC in annual Regulatory Guide 1.21 reports.

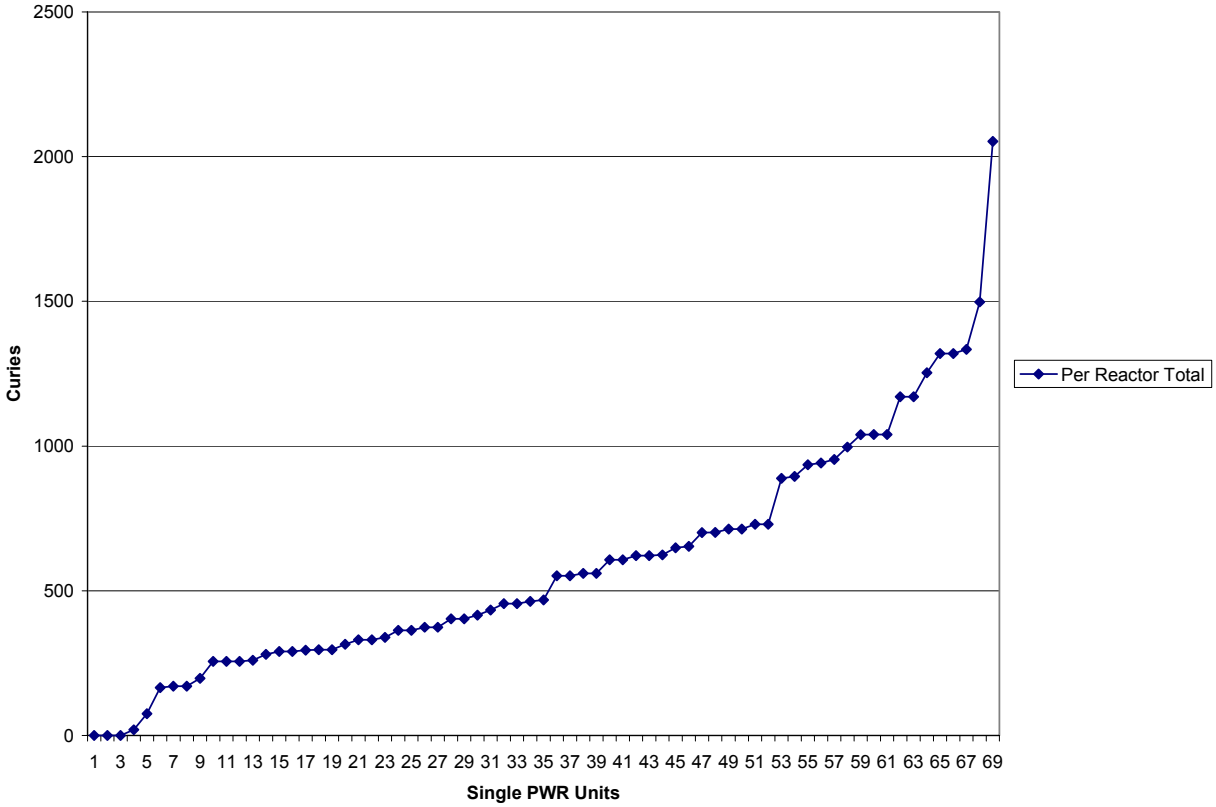

Figure 4-4
US PWR Tritium Released in Liquid Effluents in 2003

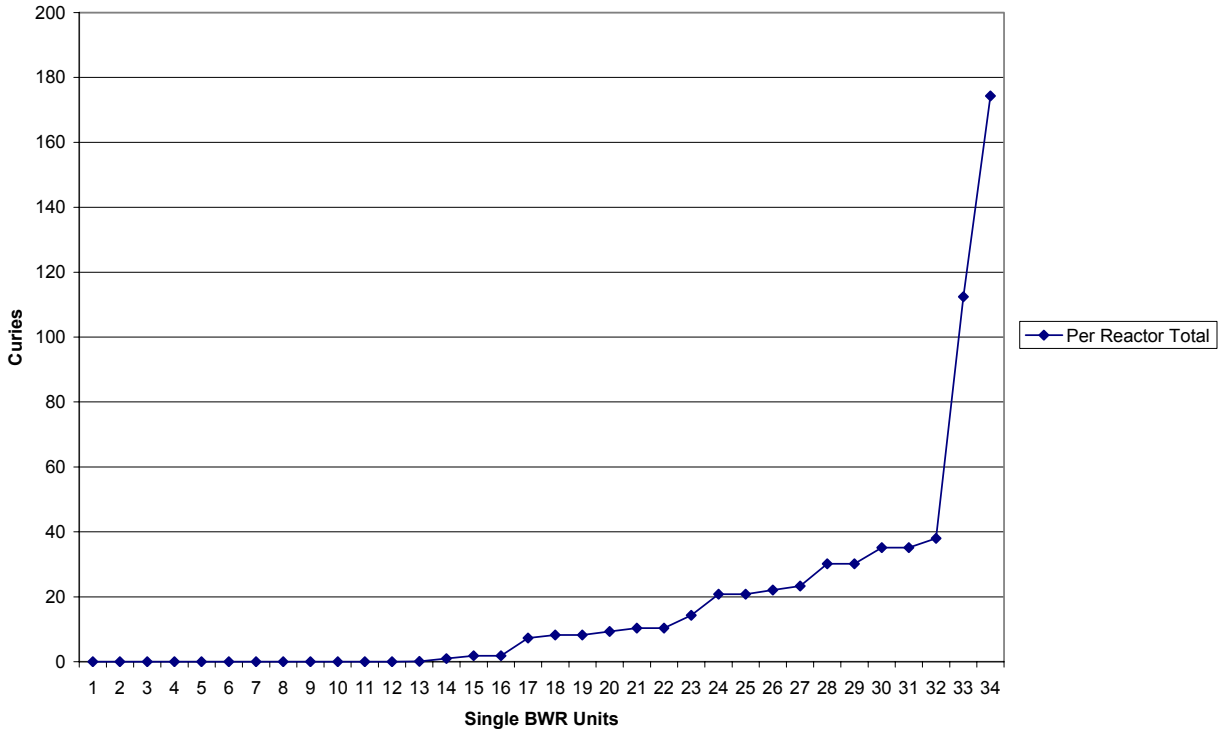

Figure 4-5
US BWR Tritium Released in Liquid Effluents in 2003

This data clearly indicates that PWR liquid releases can have a significant impact on in-plant inventories. The very high PWR released tritium Curie values represent activity that has been successfully removed from the RCS and SFP systems, thus significantly reducing the overall in-plant tritium inventory. The BWR data indicates that the benefit associated with releases is not as significant. However, it is important to remember that for many BWR stations released liquid wastes originate from low activity, low quality floor drain wastes. The significantly higher activity equipment drain wastes are typically recycled. Regardless of the impact liquid release can have on tritium inventory, it should be considered as part of a strategy assessment.

Key Considerations

When evaluating liquid releases as a tritium inventory management option, several key factors warrant careful consideration. Those issues are summarized in the following text.

1. Evaluate the impact on the environmental and public health. Increased tritium **concentrations** in liquid effluents may (will) impact off site exposure calculations.

2. Releasing liquids will reduce the potential for personnel exposure when working near open bodies of water including the SFP, reactor cavity, and major system penetrations (e.g., PWR S/G primary side prior to nozzle dam installation).

3. Liquid releases can reduce the released gaseous activity. This in turn reduces the potential for exposure of unmonitored site personnel due to inadvertent re-introduction of released gaseous tritium into plant HVAC supply intakes.

4. Plant effluent data reported to the NRC is publicly accessible information. A sudden, dramatic increase in liquid effluent activity, regardless of its impact or an associated reduction in gaseous effluents, can have a negative effect related to public perception.

5. Significant increases in liquid effluent tritium activity have a strong potential to result in an ANI premium increase. The ERF process specifically tracks effluent liquid tritium activity as a performance indicator.

6. An increase in tritium concentration (e.g., fuel leakage, increased boron concentration) in process system effluents may require a significant reduction in release system flow rates to ensure compliance with ODCM methodology for maintaining effluent concentration within regulatory limits. Subsequently, this could have had an impact on water management success. This is particularly true during high liquid volume generation periods such as pre and post outage.

7. In the majority of modeled performance, when compared to gaseous effluents liquid releases will reduce the calculated exposure to the public.

Note: The impact on the general public is outside the scope of this document. However, it is important to recognize that the exposure impact is affected by the effluent stream. For example, a river may route liquid effluents downstream, the prevailing wind direction may route gaseous effluents in another direction.

Recycle

Recycling RCS liquid will result in an increase in RCS tritium activity levels up to an equilibrium state, and will affect tritium activity in SFPs, RWSTs and waste collection systems. The three primary management options are 100% recycle, partial recycle (high quality, high activity wastes), and strategic releases. Recycle operations typically include the use of evaporative processes (PWR and BWR) or filter/demineralizers (BWR).

Key Considerations

The following issues should be considered as part of a recycle strategy evaluation.

1. In lieu of transforming to a 100% release option to reduce inventory, developing and implementing a strategic release protocol (bleed and feed) may be effective. This process would be based on optimal concentrations and production, and would dictate when and how much liquid should be released on a periodic basis to achieve the desired results. Radioactively clean makeup water would replace the released, tritiated inventory. For example, a station could release a predetermined volume once per month or calendar quarter.

2. The associated increase in tritium concentrations in plant liquids will result in increased gaseous effluents associated with evaporation. An off-site pathway analysis should be

modeled to identify projected changes and their impact on the environment and public exposure.

3. Elevating tritium concentrations by recycling may result in a need for increased personnel monitoring in areas adjacent to bodies of tritiated liquid. This can result in increased personnel exposure.

   Note: At least one station experienced a significant challenge from workers when work area analyses indicated the need for tritium monitoring. The workers were familiar and "comfortable" with historical external radiation sources, but were uncomfortable with the concept of internal exposure that may impact them differently.

4. If evaporators are used or their use planned, perform a tritium mass balance to determine the impact its operation has on liquid and gaseous (entrainment, carryover) effluent activity.

5. Going from a release scenario to a 100% recycle scenario will by default create a new standard for liquid effluent activity. Deviation from this strategy in the future, may have a negative impact on public perception.

Gaseous - Normal Operation

Monitored gaseous releases are controlled via the plant HVAC system. The tritium concentration in a gaseous waste stream at a given point in time can vary dramatically as a result of:

- Ambient temperature
- Humidity
- Barometric pressure
- Liquid tritium concentration
- Plant operating status and evolutions
- System maintenance and venting
- Ventilation plenum flow rate and local velocity

Pools, Ponds, and Atmospheric Liquids

Evaporation from "open" bodies of tritiated water such as the SFP, reactor cavity pool, plant cooling ponds, and sumps, tanks, and open systems vented to plant buildings' atmosphere are the primary method of introducing tritium into gaseous release paths.

Tank and Component Ventilation

Some tanks and components are designed with ventilation piping hard piped directly to the HVAC system. In some instances the vent path is mandated to reduce the risk associated with hazardous or combustible environments. This controlled path is routed directly to the plant

exhaust plenum eliminating the potential for tritium uptake by the plant staff. In the majority of applications, no pre-release treatment is applied prior to discharge.

During containment purges, a known volume of air with a measured concentration is batch processed directly to the plant exhaust ventilation system. For BWRs a continuous flow from the off gas systems is processed directly to the plant exhaust ventilation system.

Design and Unplanned Leakage

With few exceptions, design leakage is typically routed to collection systems for processing, release, or recycle. That configuration allows for tritium management to the extent practical by the associated system. Evaporation of standing liquids from either design or unplanned leakage can contribute to this effluent stream. Live steam leakage with entrained tritium that is directly captured by ventilation systems can also contribute to gaseous effluent activity. Tritium can also be absorbed by porous base materials that are exposed to the liquid. This can result in long-term challenges related to remediation and decommissioning efforts.

Venting and Draining

Venting and draining systems and components can result in generation of gaseous tritium (and liquid for draining). Major evolutions including reactor head venting and removal, PWR pressurizer and steam generator venting/opening can produce high gaseous tritium activity levels in acute time periods.

Gaseous Inventory Management Options

Gaseous waste streams have a number of factors, techniques, and opportunities that will impact reported effluent tritium activity. Figure 4-6 and Figure 4-7 are based on 2003 gaseous effluents from PWR and BWR reactors respectively.

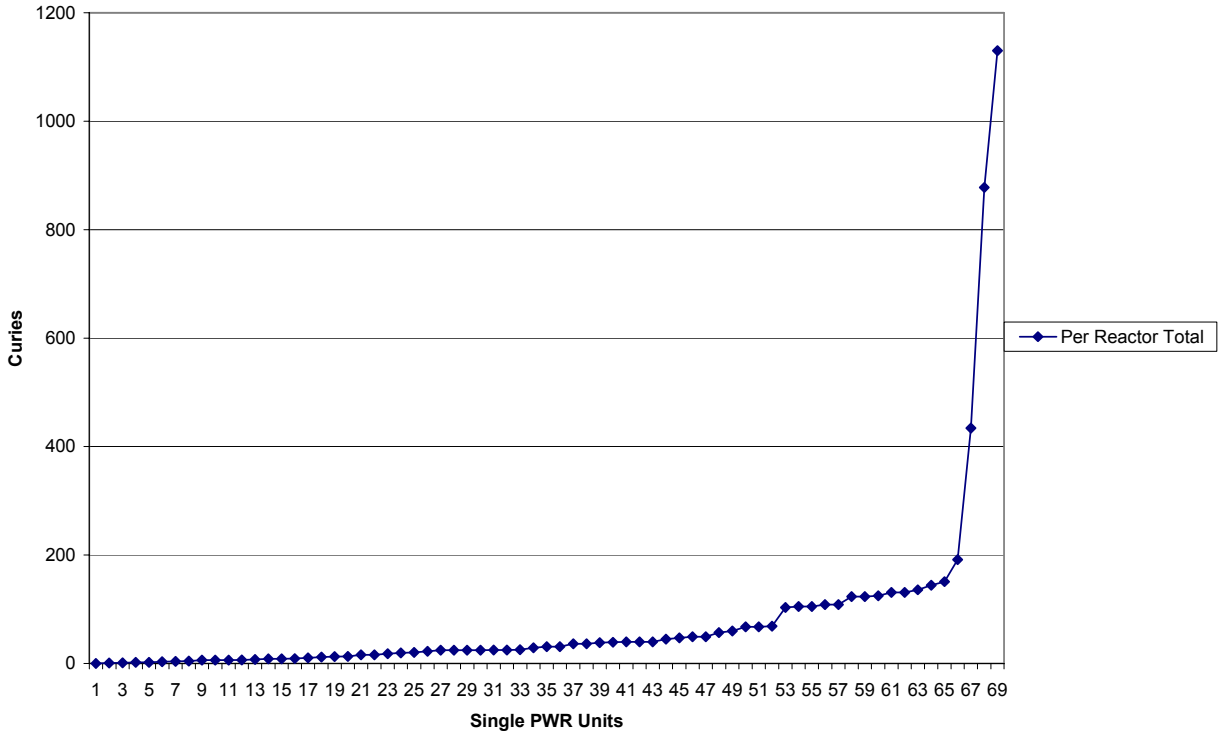

Figure 4-6
US PWR Tritium Released in Gaseous Effluents in 2003

In Figure 4-6, the data for "X" axis PWRs numbered 67, 68 and 69 represent three reactors that are in a 100% recycle mode. By not releasing the activity via liquid pathways, the total tritium inventory for those three units is high, which in turn increases the tritium available for gaseous release via evaporation and venting as evidenced by those high values.

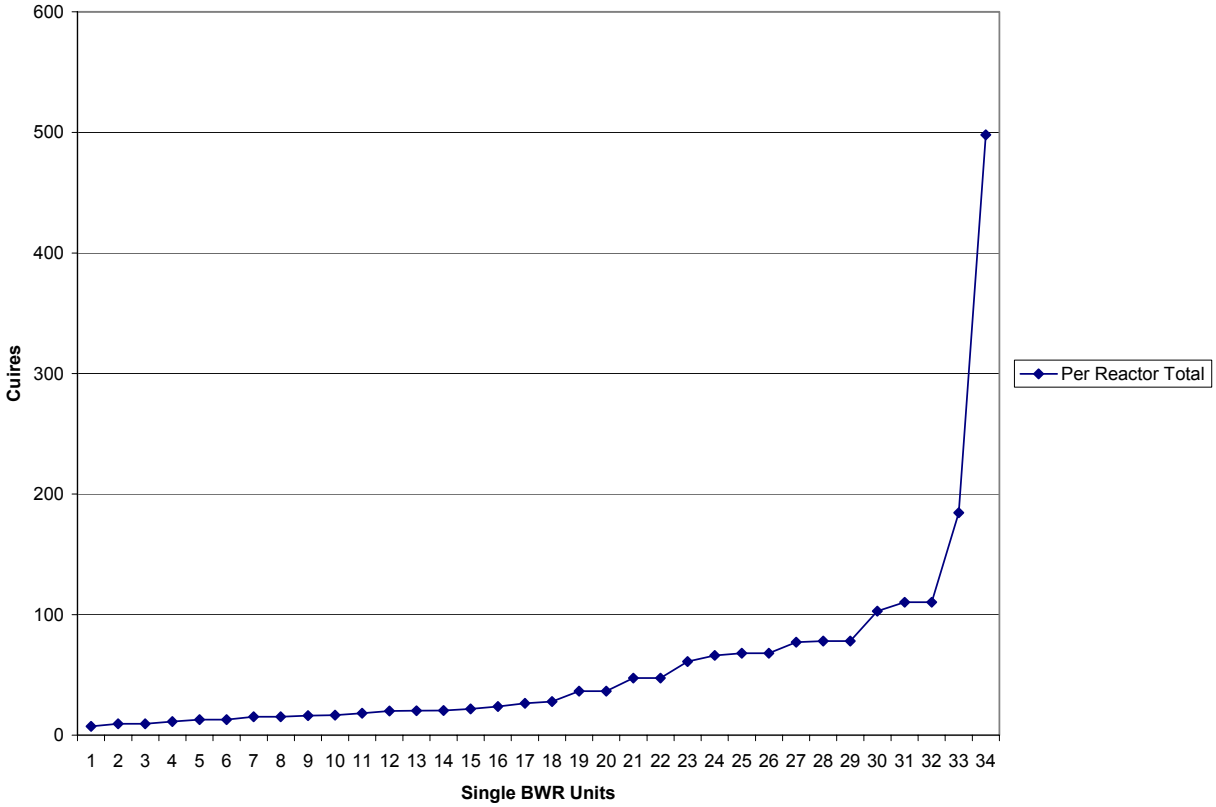

Figure 4-7
US BWR Tritium Released in Gaseous Effluents in 2003

The gaseous effluent tritium from PWRs and BWRs in Figures 4-4 and 4-5 appears to be very high for some plants, particularly the BWRs. The BWR GALE code allots about 0.025 Ci/yr tritium per MW thermal for tritium release. According to that code, the largest reactor site has approximately 10,000 MW thermal which would only yield approximately 250 Ci, which is far less than many of the data reported above. As discussed previously, resolving apparent discrepancies between calculated and reported values is outside the scope of this document.

Pools, Ponds, and Atmospheric Liquids

Large atmospheric bodies of liquid such as the SFP and reactor cavity are temperature controlled to manage the decay heat generated by spent fuel assemblies. Airborne tritium is generated as a result of evaporation of the liquid. The contribution of these sources to gaseous activity is a function of several quantifiable factors including:

- Water temperature
- Building humidity
- Building temperature
- HVAC turnover and removal rate

- Exposed liquid surface area

Several operational opportunities for managing the associated evaporative process exist. They are presented with the assumption that other factors remain constant unless otherwise noted.

- Decreasing the SFP or reactor cavity water temperature will reduce the rate of evaporation, thereby directly reducing the gaseous tritium concentration.
- Increasing the water temperature to reduce the liquid tritium inventory.

Caution: This may lead to increased airborne tritium levels in the vicinity of the open body of water leading to a tritium monitoring program for personnel working in the affected areas.

- Modifying the surrounding building environment including the temperature, humidity, or HVAC turnover rate. The use of heating, cooling, or dehumidifying units may be required.
- Modifying the exposed liquid surface area is not practical for most applications. Opportunities may exist for installing or removing covers or barriers to inhibit or promote the transference of tritium from liquid to gaseous mediums.

Key Considerations

There are several important considerations to evaluate when defining the optimum management strategy for large volume, high activity sources.

1. Changing the operating band for water temperature will require a detailed safety evaluation, and potentially changes to plant documents such as operating procedures, update final safety analysis reports, technical specifications, and training.

2. Reducing airborne gaseous activity concentrations will increase the tritium concentration in the source liquid.

3. Reducing water temperatures may require additional energy and impact operating costs.

4. Increasing water temperature may require additional makeup water.

5. HVAC flow rate and local velocity must be sufficient to capture evaporated tritium and route it directly to exhaust plenums. Insufficient ventilation can result in local deposition/condensation impacting personnel monitoring requirements and/or future remediation and decommissioning efforts.

6. As stated above, transferring a significant amount of tritium to the SFP will result in tritium evaporation and release through the ventilation exhaust. However tritium will also be present in condensation created by the SFP building's air conditioning unit. This converts a planned discrete release of tritium into a continuous low concentration release. For example, if you assume that 50% of the humidity that is condensed is from SFP evaporation, then the release concentration will be roughly 50% of the average SFP tritium concentration.

Tank and Component Ventilation

There are a few options for modifying gaseous tritium inventory via tank and component ventilation. After performing a detailed safety evaluation, several stations have removed liquid to air barrier bladders in storage or effluent release monitoring tanks. Following this modification the effluent gaseous tritium levels may increase due to increased evaporative action. Otherwise modifying a tanks temperature, humidity, or liquid surface area is largely impractical.

The contribution from the containment purge activities can be modified by controlling leakage to the containment atmosphere. The total activity per year will theoretically remain the same regardless of the frequency of purging. This assumes that tritium concentrations are low enough to preclude saturation/equilibrium conditions from occurring.

Key Considerations

1. Some ventilation requirements are related to control of a hazardous or combustible environment.

2. Many sites treat a containment purge similar to a "batch" release using a single sample's activity results. This methodology assumes a constant tritium concentration is maintained in containment during the entire physical purge. However, if a source term is present (leakage, venting, etc.) the containment atmosphere's tritium concentration may not remain constant during a purge.

3. Existing tank heating elements or heat tracing can be used to control the tank temperatures.

4. Agitating a tank's contents will reduce the surface tension and will increase the tritium removal rate.

5. Reducing the gaseous effluents from a tank or closed component will result in an increase in the liquid tritium concentration. This may impact other processes or system's tritium inventory.

Design and Unplanned Leakage

One specific method to control tritium releases via design leakage is to challenge manufacturer recommendations regarding the volume of seal leakage required. Alternatively, many stations have employed advanced dripless mechanical seal packages, eliminating that source. The obvious solution of unplanned leakage is to maintain an effective maintenance program for identifying and repairing identified leaks. Unidentified leakage poses a unique challenge. Known concentrations and distribution patterns for tritium and other radionuclides can be used to fingerprint collected liquid wastes and environmental monitoring programs to assist with identification of leakage sources.

Key Considerations

1. Additional benefits associated with dripless seal package installations may include reduced maintenance requirements, and reduced liquid radwaste generation and/or makeup water requirements.

Venting and Draining

Venting and draining events should be carefully planned and executed to ensure that the resultant gas is captured by design and routed directly to plant effluent systems. Seemingly innocuous draining evolutions may result in significant, sharp increases in effluent gaseous levels. Well defined schedules, vent and drain paths, and implementation plans and cautions can mitigate the impact from these evolutions.

Key Considerations

1. The activity levels may be very high relative to routine levels. The station should be evaluate the impact from, and prepare for, acute increases in plant exhaust activity levels.

2. The exact contribution from a vent or drain path is often difficult to quantify due to inaccuracies related to volume and/or the homogeneity of the liquid or gaseous stream.

3. Uncontrolled draining or venting may result in local levels that result in tritium uptake by workers in the affected area.

General Gaseous Effluent Strategy Issues

Several individual issues can impact gaseous effluent strategies. The key considerations for each of these are captured below.

Key Considerations

The following issues should be considered as part of any gaseous effluent strategy evaluation.

1. Evaluate the impact that the release elevation has on both the on and off site environment.

2. The release elevation may impact recycling effluents back into unmonitored liquid and air intake plenums. Elevated tritium concentrations could impact plant intake plenum air and water quality.

3. Similar to #2 above, consider the impact condensation from a cooling tower may have on recycling effluents back into unmonitored liquid and air intake plenums. For some stations, the cooling tower tritium source may originate from either a gaseous or liquid effluent.

Solid – Normal Operation

Waste Media

Some tritium may be entrained in residual liquid in processing waste including filters, septa, resins, carbon, and concentrates. The tritium activity is quantified for inclusion in waste classification calculations, and is captured on waste shipping manifests. The total tritium activity is typically insignificant relative to other plant inventory sources, however data is available and should be considered as part of an effluents strategy evaluation.

Solid Inventory Management Options

There are few available options for modifying a plant's tritium inventory via solid waste management. More complete dewatering of waste media prior to shipment will result in return of some tritiated liquid to plant liquid waste systems. Similarly, the use of commercially available thermal treatment for final dewatering may drive some tritium to gaseous effluent streams via the plant's HVAC system. Employing off site thermal treatment may permit shipment of waste resins without on-site dewatering, decreasing the plant's tritium inventory. Dry active waste (DAW) should also be considered during the analysis.

None of these management options should result in a significant change to tritium inventory.

Ex-Plant Inventory

The majority of stations in the US have reported the presence of tritium outside their physical plant structures. Examples include cooling ponds, groundwater, cooling towers and structural concrete. That inventory is often very difficult to quantify and therefore is not addressed in the model calculations. However, the consequences associated with that inventory and the point of origin may impact individual site analyses and should be considered as appropriate. Changes to tritium management strategies should be carefully evaluated for their potential impact on ex-plant inventory value and long term exposure, financial and societal impact.

Reduction and Concentration Technologies

Recent advances in tritium concentrating technologies have made their deployment technically feasible. However, those technologies typically require a large capital investment and for U.S. light water reactors cannot be justified based on the relatively low tritium total activity, liquid concentrations, and associated public and occupational exposure. Additionally, the processes all result in a concentrated secondary waste stream for which disposition options are not defined in the U.S.

Combined Electrolysis Catalytic Exchange (DOE)

Combined electrolysis catalytic exchange (CECE) is one of several processes based on use of the hydrogen/water exchange equilibrium reaction that favors formation of HTO when liquid H_2O is contacted with tritiated hydrogen (HT) gas. The reaction is shown below.

$HT\ (g) + H_20\ (l) \leftrightarrow HTO\ (l) + H_2\ (g)$

A catalyst is required for the reaction to proceed at an appreciable rate, and the development of improved hydrophobic catalysts in recent years has been key to commercialization of the process.

The actual process consists of countercurrent gas/liquid exchange columns with packed catalyst beds, an electrolysis cell and a hydrogen/oxygen recombiner. A platinum based solid catalyst is used that has been treated to make it hydrophobic. The water to be treated is added in mid-column and as it flows down, the tritium is transferred from the stream of hydrogen. This produces a liquid that is rich in tritium. Clean water is used to further purify the hydrogen column to levels that are suitable for release. The tritium laden water is electrolytically split into oxygen and tritiated gas. The stream can be captured either as tritiated water or tritiated hydrogen gas. Although tritiated hydrogen gas has a lower dose conversion factor than tritiated water, such tritiated gas in an uncontrolled environment will readily oxidize and be converted to tritiated water vapor. This fact illustrates the challenges associated with tritium management in which the processing technique in essence only changes the tritium effluent release mechanism from that of a liquid stream to a gaseous stream.

This process results in a secondary waste stream making it less than desirable for commercial power plant applications.

Bithermal Hydrogen-Water Process (DOE)

The bithermal process is based on the same reaction as the CECE and uses the same catalysts. However it relies on a recycled stream of hydrogen coupled with dual temperature separation columns. The process consists of cold and hot enriching and stripping columns in a vertical orientation with the hydrogen gas flowing upwards counter to the liquid stream. The upper cold stripper is used to strip tritium from the hydrogen. The tritium free gas is recirculated to the hot stripper column to remove tritium from the waste water to be discharged. The tritiated stream is then captured as a separate entity for disposition.

Similar to CECE, this process also produces an undesirable secondary waste stream, negating its current value to commercial power plants.

CANDU Experience

The design of CANDU reactors results in the generation of large quantities of tritium in the moderator and primary heat transport systems during routine operations. It is estimated that moderator systems account for more than 50% of plant tritium emissions. Recent advances in

removal technology have resulted in the relatively recent construction and operation of the Darlington Station Tritium Removal Facility (DTRF) that is designed to service 20 CANDU reactors. The CANDU tritium recovery liquid hydrogen cooled proprietary process captures and concentrates the activity using variations of the distillation processes described below. The Korean Hydrogen and Nuclear Power agency is constructing a tritium recovery facility that is expected to be completed in 2005 and will service the four CANDU reactors at the Wolsong site.

More recently, Ontario Hydro has developed a smaller, modular tritium removal system designed for use at a single CANDU-6 reactor site. It was deployed at Princeton Plasma Physics Laboratory (PPPL) in N.J. with the captured tritium recycled for experiments and commercial use. It is fundamentally a gaseous helium refrigerated cryogenic distillation process and functions similar to the DOE evaluated technologies previously addressed. The compact units are designed with an approximate footprint of 26' X 33".

Of particular significance is the fact that this process can immobilize the resultant waste on titanium for storage. Ontario Hydro estimates that a typical CANDU-6 removal plant will generate approximately 8 titanium tritide containers (~7" diameter X 39" in length) per year. the Wolsong site is planning on capturing and storing the titanium tritide for reuse in specially designed storage vessels capable of containing 0.5 MegaCi in a 6.5 liter volume. For U.S. plants issues include license limitations on stored waste and activity and long term disposition of the tritiated waste.

Molecular Separation

A media based process that was originally developed by Molecular Separation Inc. (MSI) generated a fair amount of interest within the nuclear industry. At the time of this report, a new group of investors is evaluating commercialization of the process. The original testing, supported by EPRI is summarized in the EPRI report "Evaluation of a Low Level Waste Technology – A Media Based Tritium Removal Process"(1006710). The Tritium Resin Separation (TRS) process is a proprietary method for the preferential removal of tritium from liquids. The process has been shown to selectively adsorb tritiated water (HTO) through the hydration of ions loaded onto a conditioned resin media. Typical adsorption materials include commercial exchange resins such as sulfonated polystyrene/divinylbenzene (cation) resin. Prior to use the resin is pretreated by loading the ion exchange sites with aluminum sulfate to form an Al^{+3} site bonded to at least one sulfonated group in the media structure. Aluminum in this form has a high number of waters of hydration and due to the energy associated with the hydration the resin has a greater affinity for tritiated water (HTO) over light water (HOH). The tritium removal is conducted at near ambient temperatures (87^0 F, 30^0 C) and low pressure (30 psi, 2 bar absolute). Preconditioning is required to remove competing cations from the feed stream. Their presence would adversely affect the process by removing the aluminum ions from the resin media.

Once removed from the wastewater, the captured tritium is released from the media by a stepwise drying process. The first drying stages remove interstitial and adsorbed light water from the media. This water is returned to the inlet stream for reprocessing. The last stage of the process involves subjecting the media to high temperature air (300^0 F, 150^0 C) to completely dehydrate the media and the evaporated, tritiated vapor is condensed and collected. The liquid

removed in this step is elevated in tritium and is ultimately captured for disposal on a molecular sieve.

Tritium removal with the TRS Process has been clearly demonstrated in the test work performed to date. However, the existing data strongly suggests that the commercialization of the process, as it is presently defined, will be challenging. This conclusion is based on the exceedingly low capacity of the media and the need for complete media drying. Both the drying requirement and the low capacity translate into large major hardware capital expenditures.

The EPRI report titled "Evaluation of a Low Level Waste Technology – A Media Based Tritium Removal Process", 1006710, Final Report, January 2002 (Reference 1 of this document) contains additional details related to this technology.

Commercial Tritium Recovery (NSSI)

In 2004, the DOE reported that Nuclear Sources and Services, Inc. (NSSI) of Houston is in the process of starting up the first commercial tritium recovery system. The first applications will be cleanup of tritiated pharmaceutical waste. Full scale processing will determine if the technology can provide cost-effective detritiation required by commercial reactors. This process merits attention from the commercial power sector, but due to its current low throughput design coupled with its fixed location, it may prove to be of limited value for routine tritium reduction. Enhancements to throughput may make this process more viable for campaign type recovery efforts in the future.

5
MONITORING

This document is specifically not intended to describe the best monitoring program attributes or technologies, but rather to provide a methodology for using monitoring results. However, a brief summary of monitoring requirements, standards and technologies is provided for insight only. The referenced technologies and techniques are all considered qualified and acceptable in the U.S.

The primary attributes of a successful monitoring program include the following:

- 100% regulatory compliance.
- On-time, accurate data reporting.
- Key performance indicators defined and effectively communicated to the plant staff.
- Goals established, results tracked and support provided for zero equipment failures
- Proceduralized sampling, analysis, and data management requirements.
- Initial and refresher training provided to the appropriate plant staff.
- Establish Preventative Maintenance program for all equipment.
- Benchmarking required and used to identify opportunities for improvement and/or industry success sharing.

U.S. Requirements

10CFR50 Appendix I, SEC. IV. Guides on technical specifications for limiting conditions for operation for light-water-cooled nuclear power reactors licensed under 10 CFR part 50, B, requires that "The licensee shall establish an appropriate surveillance and monitoring program to:

1. Provide data on quantities of radioactive material released in liquid and gaseous effluents to assure that the provisions of paragraph A of this section are met;

2. Provide data on measurable levels of radiation and radioactive materials in the environment to evaluate the relationship between quantities of radioactive material released in effluents and resultant radiation doses to individuals from principal pathways of exposure; and

3. Identify changes in the use of unrestricted areas (e.g., for agricultural purposes) to permit modifications in monitoring programs for evaluating doses to individuals from principal pathways of exposure."

10CFR20.1301 “Dose limits for individual members of the public”, and 1302 “Compliance with dose limits for individual members of the public” state that:

10CFR20.1301

(a) Each licensee shall conduct operations so that–

> (1) The total effective dose equivalent to individual members of the public from the licensed operation does not exceed 0.1 Rem (1 millisievert) in a year, exclusive of the dose contributions from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released in accordance with §35.75, from voluntary participation in medical research programs, and from the licensee's disposal of radioactive material into sanitary sewerage in accordance with §20.2003, and
>
> (2) The dose in any unrestricted area from external sources, exclusive of the dose contributions from patients administered radioactive material and released in accordance with §35.75, does not exceed 0.002 rem (0.02 millisievert) in any one hour…….”

It further states that:

“(d) In addition to the requirements of this part, a licensee subject to the provisions of EPA’s generally applicable environmental radiation standards in 40 CFR Part 190 shall comply with those standards.

(e) The Commission may impose additional restrictions on radiation levels in unrestricted areas and on the total quantity of radionuclides that a licensee may release in effluents in order to restrict the collective dose.

20.1302

(a) The licensee shall make or cause to be made, as appropriate, surveys of radiation levels in unrestricted and controlled areas and radioactive materials in effluents released to unrestricted and controlled areas to demonstrate compliance with the dose limits for individual members of the public in §20.1301.

(b) A licensee shall show compliance with the annual dose limit in §20.1301 by–

> (1) Demonstrating by measurement or calculation that the total effective dose equivalent to the individual likely to receive the highest dose from the licensed operation does not exceed the annual dose limit; or
>
> (2) Demonstrating that–
>
> > (i) The annual average concentrations of radioactive material released in gaseous and liquid effluents at the boundary of the unrestricted area do not exceed the values specified in table 2 of appendix B to part 20; and

(ii) If an individual were continuously present in an unrestricted area, the dose from external sources would not exceed 0.002 rem (0.02 mSv) in an hour and 0.05 rem (0.5 mSv) in a year.

(c) Upon approval from the Commission, the licensee may adjust the effluent concentration values in appendix B to part 20, table 2, for members of the public, to take into account the actual physical and chemical characteristics of the effluents (e.g., aerosol size distribution, solubility, density, radioactive decay equilibrium, chemical form)."

Table 5-1 contains the regulatory tritium limits for occupational exposure, **effluent concentrations**, and releases to sewers.

Table 5-1
Tritium Exposure Limits 10CFR20 Appendix B

Atomic No.	Radionuclide	Class	Table 1 Occupational Values			**Table 2 Effluent Concentrations**		Table 3 Releases to Sewers
			Col. 1	Col. 2	Col. 3	**Col. 1**	**Col. 2**	
			Oral Ingestion ALI (µCi)	Inhalation		**Air (µCi/ml)**	**Water (µCi/ml)**	Monthly Average Concentration (µCi/ml)
				ALI (µCi)	DAC (µCi/ml)			
1	Hydrogen-3	Water, DAC includes absorption	8E+4	8E+4	2E-5	**1E-7**	**1E-3**	1E-2

In addition to the regulatory requirements, there are several other reasons for monitoring tritium activity. The information can be used to:

- Assess the affect of releases on the environment and the public.
- Identify trends related to plant releases.
- Provide information to regulators, industry organizations, and the public.
- Verify proper functioning of effluent controls and monitoring.
- Assess the affect of unplanned releases.
- Document effluent and environmental performance for litigation defense.
- Provide information for site remediation and decommissioning.

Standards

The American National Standards Institute (ANSI) has published a standard for effluent monitoring that is being evaluated as a foundation for international standards. The standard

establishes specific requirements, including technical characteristics and general test conditions, and gives examples of acceptable methods for, tritium effluent monitors. The standard is ANSI N42.30-2002, "American National Standard for Performance Specification for Tritium Monitors", document # IEC 60761-5 Ed. 2.0 b:2002, titled "Equipment for continuous monitoring of radioactivity in gaseous effluents - Part 5: Specific requirements for tritium monitors".

Technology

Technologies to monitor the quantities of tritium released to the environment are becoming an increasingly important component of effluent management programs. Environmental protection legislation often sets emission limits or minimum environmental quality standards (EQS) which must be achieved to ensure that the application of the selected strategy delivers environmentally acceptable results. Both sampling and analytical technology and techniques can influence the reported activity. This directly impacts the data used by regulatory agencies to establish guidance and limits and to accurately monitor compliance. It also impacts the accuracy of performance standings with industry organization's and as discussed previously, ANI liability premiums.

Gaseous Effluent Monitoring

Gaseous effluents are typically monitored via sampling systems that tap into the plant vent (stack). One example configuration is shown in Figure 5-1, plant specific configurations vary significantly by site.

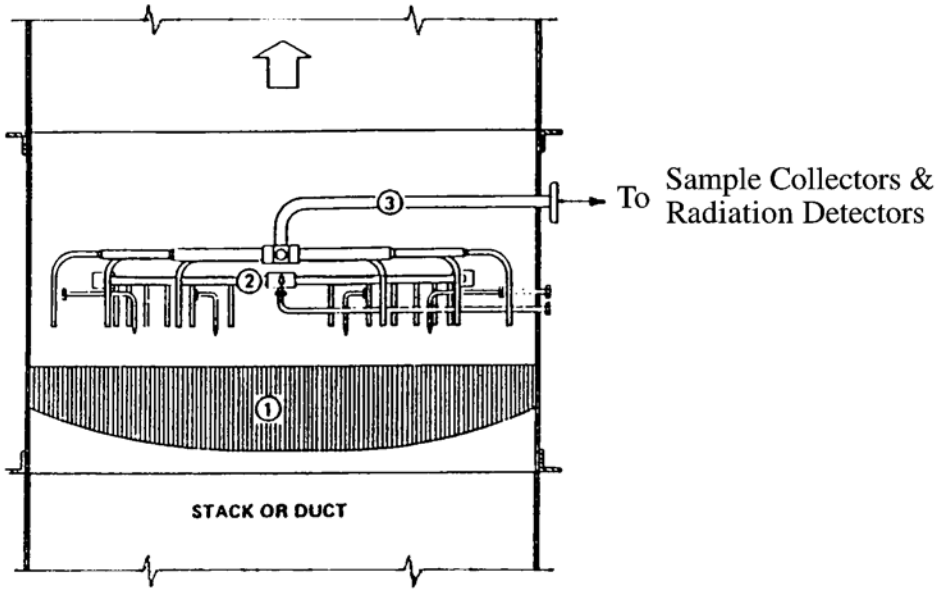

Figure 5-1
Typical Plant Vent Sample Piping Configuration

(Reproduced from RETS/REMP Website)

Sample Collection - Cold Trap - Condensation of Moisture from the Process Stream

The cold trap method for collection of tritium samples utilizes a flow-through collection flask immersed in a dry ice/methanol bath. The flask contains inlet and outlet tubing and wet and dry bulb thermometers. During sampling, the inlet wet and dry bulb air temperature is measured and used to calculate the humidity and moisture content of the sampled air stream. At the end of the collection period, the collection flask is isolated, the frozen water vapor is heated and the resultant water is analyzed for tritium in a laboratory. This technique has the advantage that the liquid sample can be analyzed directly, with a minimum of sample processing and preparation.

The average water vapor in the sample stream gases (plant ventilation) during sample collection is used in the calculation to determine the tritium release rate and the total curies released. Fluctuations in humidity and temperature of the air stream during the sampling evolution can introduce errors into the estimation of water vapor content in the sample stream. This introduces a similar level of error into the final estimate of tritium release. Grab sample collection frequency leads to greater error in the measurement process. Dry ice and methanol present a hazard to the technician and specific sample and analysis training and protective equipment are required.

Desiccant Column- - Adsorption of Moisture from the Process Stream

This method requires a representative, continuous flow side stream for sampling. Columns of desiccant (silica gel or Drierite™) are installed in that sampling stream. At the end of the sampling period (varies by plant), the desiccant is weighed and the total amount of water is calculated. The desiccant is thoroughly mixed and a portion is processed to remove the entrained water. That collected condensation is analyzed for tritium using a liquid scintillation detector. Although the method of continuous sampling captures daily fluctuations in the sample stream moisture content and assumed tritium concentrations, this techniques is more labor intensive than other sampling methods. The desiccant must be dried and weighed prior to installation in the field, and accurately weighed and thoroughly mixed following collection. Samples must be heated and recondensed prior to analysis.

Some product information suggests that the efficiency of desiccants to capture water vapor can be affected by the humidity levels to which they are exposed. Such changes in efficiency as a function of humidity would introduce error into the collection of water onto the desiccant column, and ultimate determination of tritium activity released. Desiccant columns can also be subject to saturation in situations of high humidity levels, long sampling periods, and high sample flow rates. Although color-indicating desiccants can provide a visual indication of the level of saturation, special precautions must be taken to avoid desiccant saturation. This approach may require the use of low air flow rates, or limiting the time the desiccant is exposed to the air stream.

Bubbler - Gas Washing Bottle - Absorption of Moisture from the Process Stream

This sampling method requires a representative side stream of the air stream being measured. The side stream is bubbled through a column of water in a gas washing bottle, which absorbs the tritiated water vapor from the air into the water in the bottle. An aliquot of the water is then collected and analyzed via liquid scintillation counting for tritium content. Airborne tritium concentrations are derived from the total volume of air sampled through the washing bottle. As was the case with the cold trap method of sampling, the bubbler technique of sampling requires minimal processing to collect and analyze a sample.

Although this sampling technique lends itself to both grab sampling and continuous sampling, most industry applications involve short-term grab sampling. While such sampling results may be representative of airborne tritium concentrations during the sampling interval, errors may be introduced by fluctuations in tritium levels between grab sampling intervals. If the bubbler technique is used in a continuous mode, caution must be exercised to prevent sampling too large of a volume of air. Several U.S. plants are operating in the continuous mode. Studies suggest that collection efficiencies of 95% to 99% can be realized for air sample volumes of less than 10,000 liters. Continuous sampling under such circumstances would entail use of low flow rates (tens of milliliters per minute), or frequent sample exchanges to ensure air volume of less than 10,000 liters.

Flow-through Detectors – Direct measurement from the Process Stream

This method of airborne tritium monitoring is somewhat similar to that used in monitoring noble gases at nuclear power facilities. A side stream of the process air is passed though a counting chamber and the decay rate of radioactivity in the chamber is correlated to the airborne concentration. However, since tritium does not emit any gamma photons, and yields only a very low energy beta particle, conventional use of scintillation detectors (e.g., sodium iodide or plastic scintillators) are not applicable to tritium monitoring. Most designs of flow-through tritium monitors involve introducing the side stream of air directly into the ion chamber, and measuring the ionization resulting from the charged particles in the chamber. The process can be sensitive to external gamma radiation, which can yield ionization events that may be attributed to tritium activity. In a similar fashion, noble gases in the sample stream would also produce ionizations in the chamber, resulting in false positive indications. Although background correction detectors, and energy discrimination can reduce some of these erroneous measurements, this complicates the design and increases the cost of such a system.

Another limitation of direct counting is that of sensitivity. Most power plant effluent monitoring programs specify a lower limit of detection (LLD) requirement of 1 X E-6 μCi/mL for tritium in air. All of the various methods involving direct sampling and analysis (cold trap, desiccant, bubbler) can easily reach detection sensitivities as low as 1 X E-8 μCi/mL or even lower, flow through detectors are often incapable of reaching the sensitivity requirement of 1 X E-6 μCi/mL. While such flow-through detectors can be useful in monitoring air where tritium levels are relatively high, they may have limited application in meeting detection requirements in most nuclear power plants.

Personnel Monitoring

Inhaled or ingested Tritium rapidly exchanges with body water and is exhaled or excreted with a 10-day biological half-life. A small fraction of the tritium is incorporated in body tissue resulting in a longer biological half-life.

Occupational exposure must be monitored as appropriate to ensure compliance with the regulatory requirements in Table 5-1 above. For commercial power operations this is typically affiliated with elevated tritium concentrations in SFP and reactor cavity liquids, and during containment entries at power. The latter condition may become more significant as a result of additional at power work being completed to improve plant capacity factors.

Urinalysis is the easiest bioassay method for determining exposure to tritium. Liquid scintillation counting is a quick and relatively inexpensive method for assessing the concentration of tritium in urine. Because tritium is found naturally in most water supplies at very low concentrations, levels in drinking water or worker urinalysis may be measured to determine whether the tritium levels exceed the levels present in the body.

Ground Water Monitoring

Groundwater sampling equipment includes devices used to extract the water from a monitoring well and associated peripheral support equipment, including tubing, generators, instruments for measuring water-quality indicator parameters in the field, and sample bottles. A variety of these pieces of equipment for sampling groundwater are available commercially. The analytical data produced by a groundwater monitoring program must be relied upon to describe the nature and extent of contamination at the site. This data forms the basis for decisions regarding the need for further investigation, monitoring, or remedial action. For this reason, the importance of producing data that meet the objectives of the monitoring program cannot be overstated. Additional detailed information on developing and managing a successful ground water monitoring strategy can be found in the EPRI report “Groundwater Monitoring Guidance for Nuclear Power Plants”, TR- 1011730.

6
RESULTS MANAGEMENT

A station's defined and implemented tritium strategy will result in consequences associated with those efforts. For example, increasing the tritium inventory in a SFP may result in increased localized airborne tritium concentrations. This consequence of the inventory action may require increased personnel monitoring in that area. This section briefly touches on key consequences and related considerations.

Monitoring

Significantly modifying any aspect of tritium management will almost certainly require a change in monitoring frequency, location, or process equipment. Regulations at the local, state, and federal level should be evaluated for compliance and monitoring, documentation, and reporting requirements. Currently used procedures and equipment should be evaluated to ensure they are adequate for both current conditions and estimated deviations from the norm. Occupational exposure considerations may require revising or developing personnel monitoring programs.

Dispersion and the Environment

As stated previously, this document is focused on tritium management up to the point of release from the plant proper. However, one of the most critical consequences of strategy selection and implementation is tritium's impact on exposure to the environment and public sectors. Generally, tritium is introduced to the environment from nuclear plants via two mechanisms, liquid and gaseous (airborne) releases. Liquids are released in accordance with the governing body's release permits taking into account dilution flow, activity concentrations, and the effluent body of water. The dilution factor varies dramatically by station, ranging from non-flushing small lakes and ponds, to small rivers or large salt water bodies (oceans and bays). When evaluating the plant specific impact, it is also critical to evaluate the impact from naturally occurring sources and from other nuclear facilities. At least one U.S. site's tritium monitoring program is impacted by liquid and gaseous (deposition and entrainment in water) effluents from an upstream facility.

Following exposure to oxygen, tritium replaces one of the stable hydrogen atoms in the water molecule, H_2O, resulting in tritiated water or water vapor. Due to tritium's behavior in the atmosphere and the design of most plant's gaseous effluent system, tritium can present challenges related to on-site deposition and concentration. Figure 6-1 illustrates typical dispersion mechanics associated with gaseous/airborne effluents.

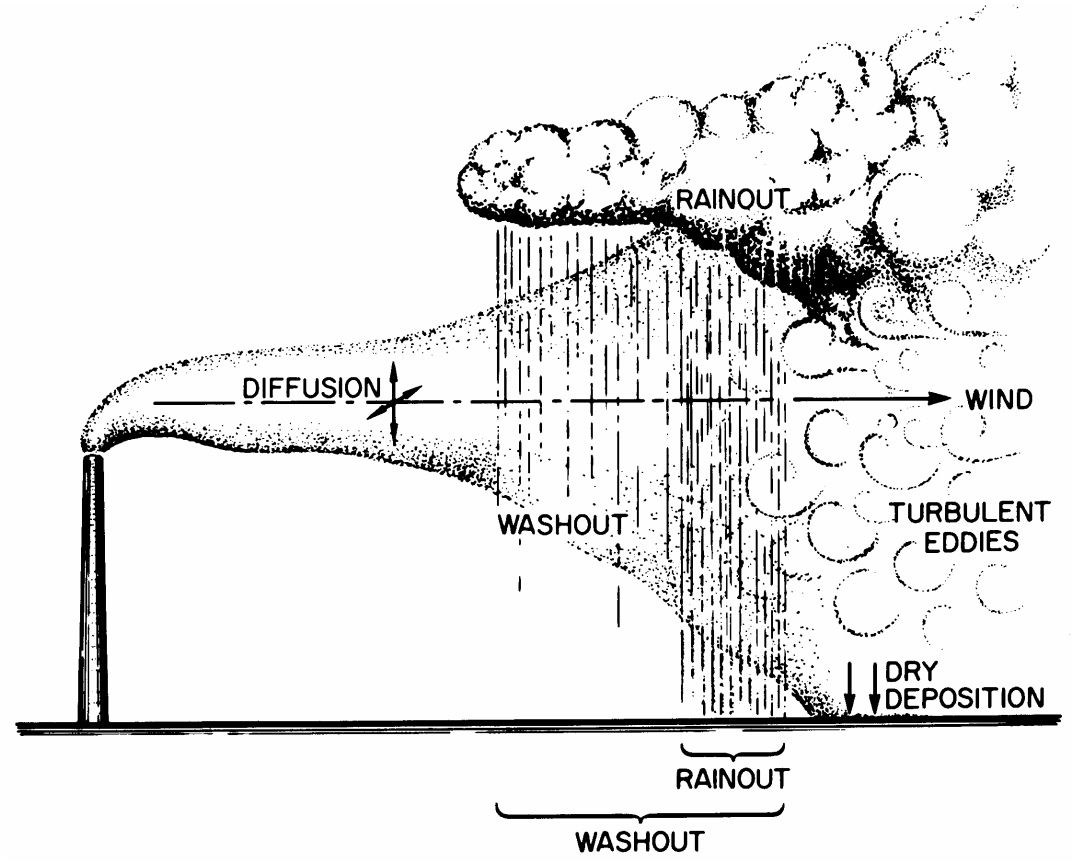

Figure 6-1
Atmospheric Dispersion Model

(Reproduced from RETS/REMP Website)

Figure 6-2 illustrates released activity interactions between typical ecosystem components.

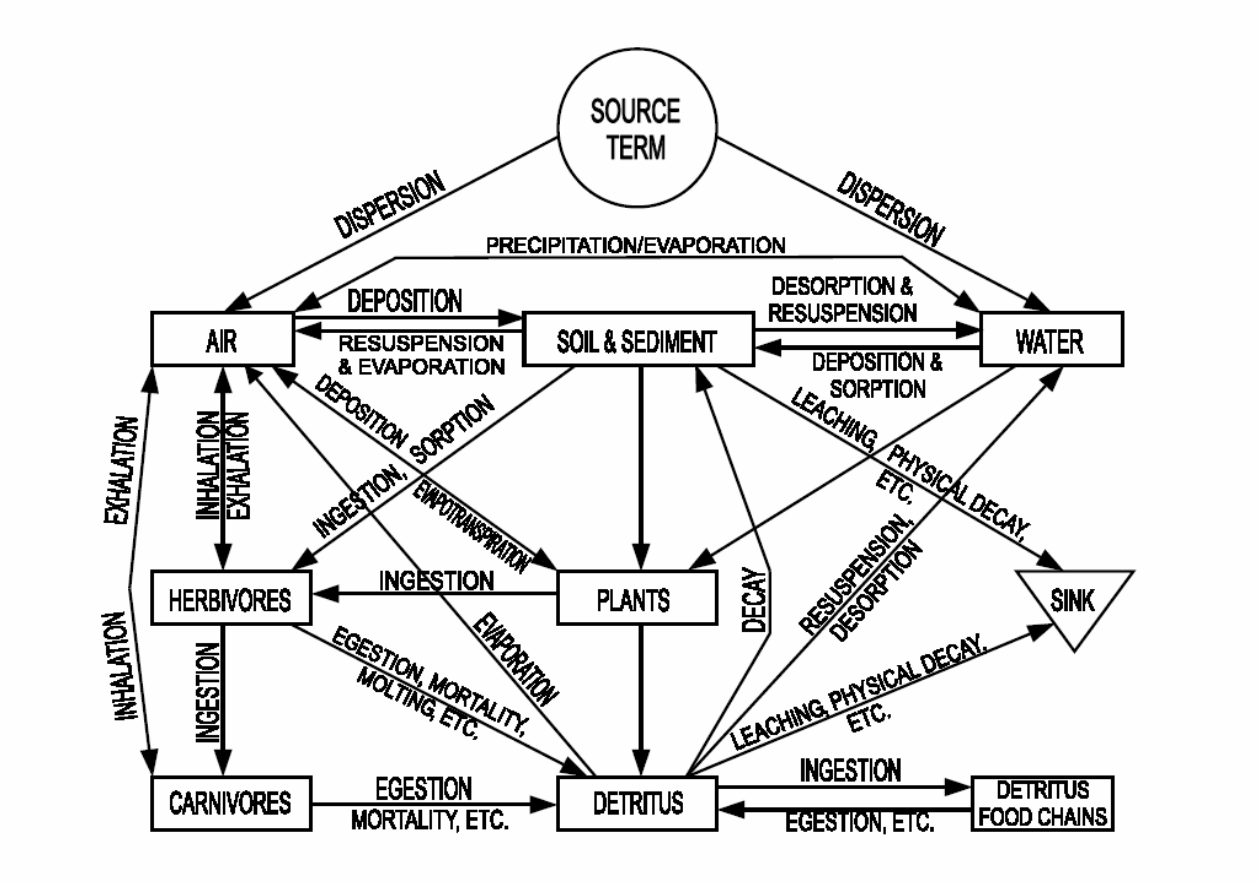

Figure 6-2
Released Activity Principle Ecosystem Components

(Reproduced with permission from Key Solutions)

Changes to management strategies may require a revision to a station's REMP program and current pathway model results. Current and projected levels should be carefully evaluated to ensure results are both desirable and regulatory compliant and that the results from models are defensible

Exposure Impact

From an ALARA viewpoint, the user of this document must be aware of the differences in dose consequences from airborne and liquid releases, and incorporate that into the strategy for how best to manage the effluent streams.

The USNRC occupational limits for tritium are shown in Table 5-1 in terms of Allowed Limits of Intake (ALI), i.e. the annual intake of tritium that would result in a committed effective dose equivalent of 5 Rems. A single uptake of water containing 2.9E-3 TBq (7.8E4 μCi) of tritium results in a dose rate of 5 rem/yr over the first year.[11] This clearly illustrates that power plant effluent tritium concentrations are innocuous from a radiological standpoint.

Remediation and Decommissioning

Based upon the experience at several operating and decommissioning commercial nuclear power stations, release of radionuclides, as well as non-radiological contaminants, to the groundwater at such plants is likely to occur. Final closure of a decommissioned site will demand compliance with the requirements of multiple state and federal regulatory programs. The agencies administering these programs will likely have varying degrees of familiarity with the technical details related to operation of a commercial nuclear power station and to the significance of the types and concentrations of radionuclides that may be measured in the environment in their vicinity.

The Nuclear Regulatory Commission may not be the lead agency that determines the scope of a required groundwater monitoring program. Ultimately, it may be a state regulatory agency or a local citizen's group with limited technical expertise, who influence the scope and magnitude of the monitoring program required. The details of the local hydrogeologic features that control contaminant migration must be sufficiently described and understood to demonstrate to the most skeptical stakeholders that the nature and extent of all releases to the groundwater flow domain have been adequately investigated. Plant managers should engage all stakeholders early and continually throughout the planning and implementation of the groundwater monitoring program, to ensure their understanding and acceptance of its findings.

Investigation and monitoring of releases to groundwater should begin early to avoid delays in achieving objectives for final site closure. Groundwater investigations are best undertaken with an iterative approach that can be expected to require a minimum of three years to complete, in even relatively simple situations. Full characterization of a site of average complexity will likely require more than three years. Development of a comprehensive conceptual site model early on will guide the investigation and focus it in areas requiring the most scrutiny. By so doing, unnecessary effort will be minimized and the time required for all stakeholders to achieve consensus on the results of investigation and the need for further study or corrective action will be shortened.

Monitoring wells are the primary tool used to investigate groundwater contamination. They should be drilled in those locations and depths dictated by an understanding of the site arrived at by development of a conceptual site model. Stratigraphic variations within a groundwater flow regime exert a controlling effect on the pattern of contaminant transport. Therefore, it is important to thoroughly characterize the stratigraphy of a site at which a release of contaminants to the environment has occurred. Such an effort should include investigating the full depth of the geologic section through which local groundwater flow is likely to extend.

Should removal of contaminated soil or other source of impact to groundwater be required, monitoring should continue for at least one to three years following source removal, until contaminant concentrations have reached equilibrium throughout the flow domain. Only then can a reasoned judgment be made regarding the effectiveness of the remedial action.

Because of the importance of groundwater analytical data in making decisions regarding the need for groundwater monitoring or remedial action, a robust program of quality assurance and quality control should be implemented to assess and enhance the reliability and validity of field

and laboratory measurements conducted to support these programs. A site-specific list of constituents of concern for which samples will be analyzed should be carefully screened, with appropriate justification for those constituents included, as well as those excluded. Efforts should be made to statistically evaluate and trend laboratory data in order to understand the limitations and irregularities in analytical results.

Documentation

Industry change management templates stress the importance of documenting all relevant information. This data typically includes:

- The original basis
- Basis for program changes
  - Assumptions, calculations, and known risks and cautions
- Safety analyses
- Projected results
- Actual results
- Monitoring requirements
- Related document changes
- Regulatory compliance

The information should be collated and archived to facilitate easy reference and future retrieval. This quality and level of detail of this data is particularly significant for regulatory reviews, litigation, and site remediation and/or decommissioning.

7
TRITIUM MODEL

This section of the report contains details related to the tritium analysis model. The inputs, calculations and results described in this section are representative of the general concepts and data evaluation logic that will be addressed by the final analytical product. It is planned that the model will be refined based upon plant validation analysis.

Assumptions

The following assumptions are made for developing the model. Several of these assumptions will be applicable to the final product's data collection and input.

- For a given period in a plant's life, the tritium balance is as follows:
  - [Production+Historical Inventory]– Releases (Known and Unmonitored Gaseous, Liquid, and Solid) = Current Plant Inventory
  - Current Plant Inventory = known (Reactor Coolant System, containment/drywell airspace, Spent Fuel Pool, refueling water storage tanks, liquid waste collection tanks, boron recycle tanks) + unknown (sumps, tanks not analyzed for tritium, leakage to plant, leakage out of plant)
- The model's tritium production, inventory and release activity inputs will be based on actual plant data. Therefore the calculations will be per a period of time based on that "snapshot" data at a given moment in time. The current model iteration is based on weekly performance. The current plan is to integrate sufficient flexibility into the final product to facilitate a user defined analysis periodicity.
  - Theoretically, under steady-state conditions the RCS will reach equilibrium. However, in reality, bleed and feed operations, changing primary chemistry conditions (e.g., boron concentration, lithium concentration), fuel leakage and fluctuations in release rates all impact tritium concentrations. Therefore it is not possible that equilibrium will actually be attained and the tritium release rate via all pathways will equal a reactor's production rate.
- Tritium is released via liquid, airborne and solid pathways.
- SFP evaporation is the primary mechanism for generation of gaseous tritium.
- Tritium accumulates in the reactor coolant, SFP, and storage tanks for refueling water (refueling water storage tanks).
- There will be an "unknown" activity variable related to unmonitored releases such as spent fuel pool liner, transfer canal expansion joint, or other structural leaks.

Variables

There are a number of variables which must be considered when analyzing a tritium management strategy:

- Fuel cycle duration
- Reactor output
- Boron concentrations over core life and between plants.
- Letdown volume and rate.
- Boron recycle versus release.
  - Volume of new, non-tritiated makeup water added to the RCS diluting the RCS tritium inventory.
- Sampling and analysis methods and accuracies vary dramatically by site, impacting the accuracy of benchmarking model results.
- Ternary fission contribution to production.
- Core design
  - Fuel types (e.g., high duty, MOX)
  - Boron reduction
  - Burnable poisons
- Containment purges, frequency, and purge rates.
- Temperature of atmospheric liquid volumes (tanks, sumps, SFP, reactor cavity).
- Atmospheric temperature and relative humidity over atmospheric liquid volumes.
- Tritium measurement - sampling and analytical techniques and accuracy.

Supporting Data

Prior to using the model, plant specific data must be collated for reference, input to the model, and for archives. That historical and current information includes the following:

- Effluents - liquid and gaseous effluent reports, release volumes, tritium concentrations
- Reactor engineering – fuel cycle duration, power levels, trends
- Outage management – dates, duration, refueling cavity cross connection to RCS and SFP
- Liquid radwaste management – processing system configurations (all), strategies, and boron recycle system design, cavity liquid disposition following refuel.
- Solid waste management – shipping records, waste volume, tritium concentrations
- Chemistry – RCS boron concentrations, RCS, refueling cavity, SFP, and refueling water storage tank tritium concentrations

- Operations – SFP operating temperature and trends, letdown volumes per operating period
- System engineering – RCS, SFP, cavity, and refueling water storage tank volume.

Development of the Mathematical Model

The foundation of the mathematical model is the standard chemical engineering definition of the mass balance. The mass balances are applied to both water and tritium.

$$\sum \text{Inputs} - \sum \text{Outputs} \pm \text{Generation} = \text{Accumulation} \qquad \text{(Eq. 1)}$$

The control volume is defined as the plant reactor coolant volume plus the static containment/drywell airspace. Each of these terms is developed as a rate with units in pCi/sec; however, inventory is stored as mass. Equation 1 is applied repeatedly to the total system volume and the individual unit operations for both liquid volume and tritium.

Total Coolant Tritium Balance

The tritium mass balance for the coolant is defined using Inputs, Outputs, Generation and Accumulation.

Inputs

The input to the primary coolant is the make-up water, which is typically assumed to have no influent tritium. However, there are two known cases where the zero influent assumption is invalid: 1) plants that recycle liquid processing effluent - tritium is re-injected into the makeup volume, 2) rare situations where a plant is downstream of a river from another plant, and uses purified make-up water from that source.

Outputs

There are three effluent streams considered: the gaseous release, the liquid release, and unknown effluents.

- The liquid effluent is perhaps the best characterized because there are relatively accurate assessments of the volumes of liquid radwaste with known concentrations of tritium.
- The gaseous effluent, although measurable, is more difficult to quantify because of the variations in stack flow, sampling, and analytical techniques.
- Unidentified, unmonitored releases are quantified as liquid or gaseous releases to the atmosphere and/or groundwater or through other unmonitored pathways.

Generation

Tritium is assumed to be generated in the core. PWR and BWR generation term descriptions differ; however, they are similar in form.

Tritium has a half life of approximately 12 years. For this model, it is assumed that the decay of tritium is negligible.

For a PWR, the generation is divided into five different sources according to a Westinghouse source term reference for a four-loop, 4100 MWt plant (Source: personal communication with STP staff).

Table 7-1
Example tritium generation values

Tritium Source	*Value (Ci)*
Tritium in coolant from Boron	1020
Tritium in coolant from Lithium	245
Tritium in coolant from Deuterium	6
Tritium in Coolant from Fission	313.5
Tritium in Coolant from IFBA	72.3
Total Tritium	1656.8

Primary chemistry data were provided by South Texas Project for Unit 1, Cycle 11 and 12. Assuming concentration dependent generation terms for boron and lithium and constant generation for fission, and IFBA, the data were used to estimate the following generation constants (deuterium was neglected).

NOTE: These values do not necessarily apply generically to any PWR plant; they are a function of many parameters including core design, chemistry, and fuel performance.

Table 7-2
Estimated generation rates for tritium using STP-1 Cycle 11 data

Tritium Generation Rates	
Boron Rate (Ci/ppm/min)	1.60E-06
Lithium Rate (Ci/ppm/min)	1.30E-04
Fission Rate (Ci/min)	3.00E-04
IFBA Rate (Ci/min)	5.00E-05

Accumulation (Inventory)

The time dependent accumulation terms are the most complicated section of the model. The total system inventory is defined as the sum of the individual unit operation accumulations. These terms are defined the following sections.

Specific Plant Operations/Inventories

A specific generation, inventory and release path model for tritium was developed for an operating PWR and is illustrated in Figure 3-6. This model is similar in concept to the previous models, but is more specific in its definition of plant operations and evolutions that impact tritium management. A similar BWR template is included in the final model product.

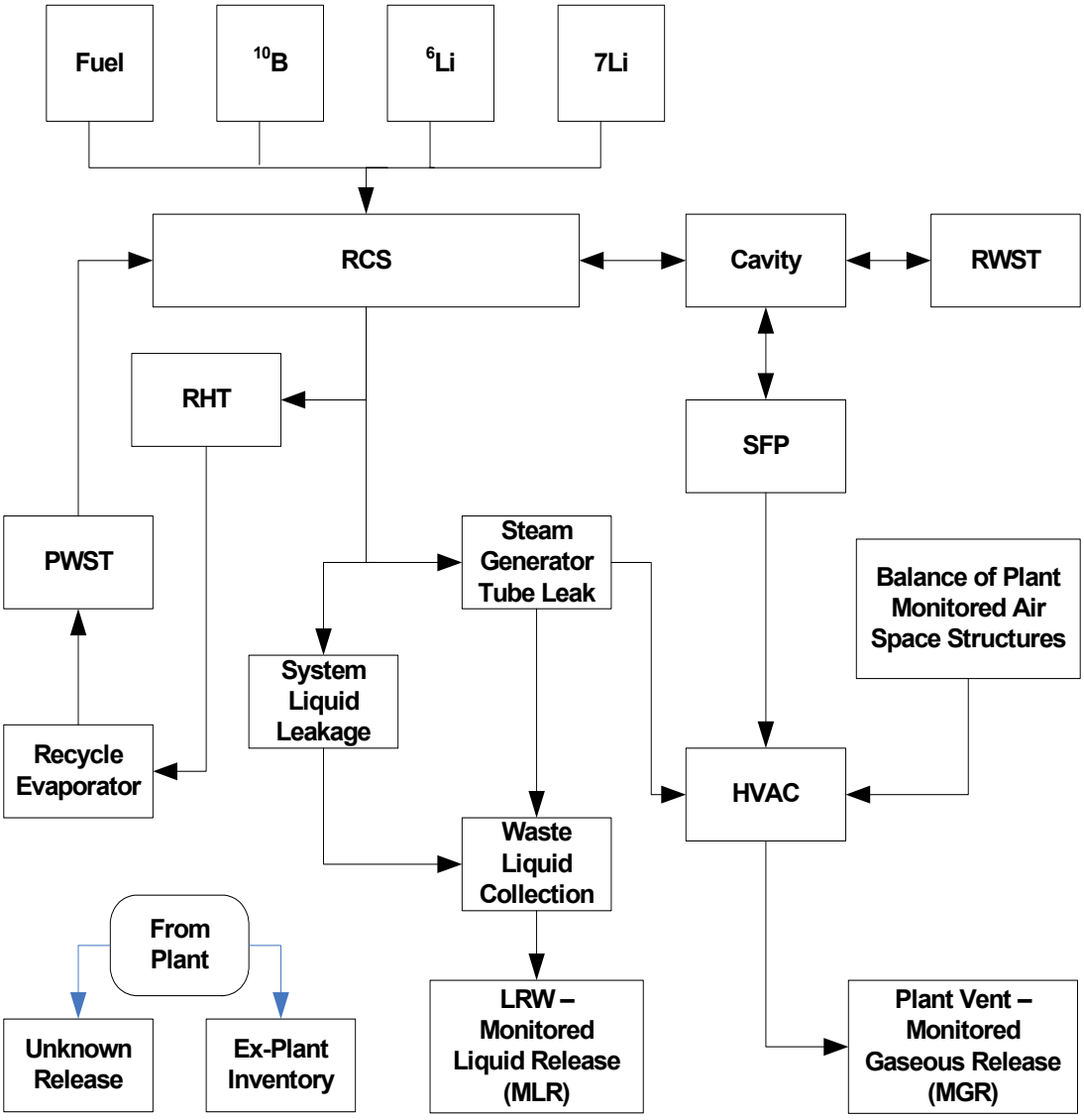

Figure 7-1
Example schematic of tritium flow path for a PWR

Not only must the total system mass balance be satisfied, but also the mass balance for individual unit operations/evolutions must be satisfied. This required the development of a system of accumulation equations that are solved simultaneously. The accumulation equations are derived below in Table 7-3.

Note that the generation terms are not listed because they are zero except for the RCS system.

In the equations, the following variables are used. Subscripts will denote input, i, output, o, or the system name, e.g. RCS for reactor coolant system.

F = Water flow rate (L/s)
C = Concentration (pCi/L)
V = Volume (L)

Volume is calculated using the water mass and density at the given temperature. The density is found from the following correlation.

$$SG = \left[\frac{1 + 0.134248SS_2 - 3946263x10^{-3} SS_1}{3.1975 - 0.3151548SS_2 - 1.203374x10^{-3} SS_1 + 7.48908x10^{-13} SS_1^4} \right]^{1/2}$$

Where

SS1=374.11-T
SS2=$SS_1^{1/3}$
T = temperature in Degrees Celsius

The mass balances are written generally. During various phases of the cycle, there are terms that will be zero, or flow rates and concentrations that will remain constant. In many situations, the exit stream concentrations (those with a negative sign) will equal the concentration of the inventory volume, which assumes the inventory is perfectly mixed (similar to Constant Stirred-Tank Reactor models).

Table 7-3
Unit operation mass balances for tritium model

Unit Operation	Inputs	Outputs	Accumulation Equation
Reactor Coolant System (RCS)	Primary Water Storage Tank (PWST) Refuel Water Storage Tank (RWST) Boric Acid Storage Tank (BAST)	Letdown/Recycle Hold-up Tank (RHUT) Spent Fuel Pool (SFP) Refuel Water Storage Tank (RWST)	$\frac{\Delta(V_{RCS}C_{RCS})}{\Delta t} = F_{PWST}C_{PWST} + F_{RWST,i}C_{RWST} + F_{BAST}C_{BAST} - F_{RWST,o}C_{RCS} - F_{SFP,o}C_{RCS} - F_{RHUT}C_{RCS} + R_{H_3Gen}$
Primary Water Storage Tank (PWST)	Make-up System (MU) Recycle Holdup Tank	RCS	$\frac{\Delta(V_{PWST}C_{PWST})}{\Delta t} = F_{MU}C_{MU} + F_{RHUT}C_{RHUT} - F_{RCS}C_{PWST}$
Recycle Hold-up Tank (RHUT)	RCS	Liquid Radwaste (LRW), PWST,	$\frac{\Delta(V_{RHUT}C_{RHUT})}{\Delta t} = F_{RCS}C_{RCS} - F_{LRW}C_{RHUT} - F_{PWST}C_{RHUT}$
Spent Fuel Pool (SFP)	RCS	SFP HVAC, RWST	$\frac{\Delta(V_{SFP}C_{SFP})}{\Delta t} = F_{RCS}C_{RCS} - F_{HVAC}C_{SFP} - F_{PWST}C_{SFP}$
Refuel Water Storage Tank (RWST)	SFP	RCS	$\frac{\Delta(V_{RWST}C_{RWST})}{\Delta t} = F_{SFP}C_{SFP} - F_{RCS}C_{RWST}$
Spent Fuel Pool HVAC	SFP	Monitored Gas Release (MGR)	$\frac{\Delta(V_{HVAC}C_{HVAC})}{\Delta t} = F_{SFP}C_{SFP} - F_{MGR}C_{HVAC}$
Liquid Radwaste (LRW)	RHUT	Monitored Liquid Release (MLR)	$\frac{\Delta(V_{LRW}C_{LRW})}{\Delta t} = F_{RHUT}C_{RHUT} - F_{MLR}C_{LRW}$

The expansion of the equations for application in a spreadsheet was relatively straightforward. First, the water balance was solved for the unit operation. Using the primary water storage tank as an example, let $V_{PWST,1}$ be the initial volume of the PWST before an operation and

$V_{PWST,2}$ be the final volume after an operation. The final volume is solved by applying the water balance

$$\frac{\Delta(V_{PWST})}{\Delta t} = F_{MU} + F_{RHUT} - F_{RCS}$$

$$V_{PWST,2} = V_{PWST,1} + \Delta t(F_{MU} + F_{RHUT} - F_{RCS})$$

Next, the concentration is solved by using the final volume calculated above.

$$\frac{\Delta(V_{PWST}C_{PWST})}{\Delta t} = F_{MU}C_{MU} + F_{RHUT}C_{RHUT} - F_{RCS}C_{RCS}$$

$$C_{PWST,2} = \frac{V_{PWST,1}C_{PWST,1} + \Delta t(F_{MU}C_{MU} + F_{RHUT}C_{RHUT} - F_{RCS}C_{RCS})}{V_{PWST,2}}$$

Spent Fuel Pool Evaporation

Several methods for calculating the evaporation rate based on the dry-bulb temperature, wet-bulb temperature, pool temperature and air velocity are available. The following equations are taken from several references; most notably the ASHRAE Handbook. This data is fed into the model's gaseous effluent determination. An option is provided for bulk SFP gaseous contributions in lieu of data collection for evaporation calculations.

The mass of water evaporated is found from the following equation;

$$Q_m = A(x_1 - x_2)a_e$$

where,

Q_m = mass of water evaporated (kg/s)
A = the surface area (m^2)
x_1 = the specific humidity directly above the pool (kg H_2O/kg air)
x_2 = the specific humidity of the room (kg H_2O/kg air)
a_e = the evaporation constant (kg/m^2s)

The evaporation constant is dependent on the velocity of the air above the pool.

$$a_e = \frac{(25 + 19v)}{3600}$$

where,

v = air velocity (m/s)

The absolute humidity is typically found from the psychometric chart; however, these cannot be applied in a computer algorithm. Instead, the absolute humidity is calculated by using the relationships between saturation pressure and relative humidity.

The relative humidity, Rh, is defined as the ratio of the partial pressure of water (P_{steam}) and the saturation pressure of water (P_{sat}) at a given temperature.

$$R_h = \frac{P_{steam}}{P_{sat}}$$

Both the partial pressure of water and the saturation pressure are related to the absolute humidity using the relations below.

$$P_{steam} = \left(\frac{P_{atm}}{P_{sat}}\right)x$$

$$P_{sat} = \left(\frac{R_{air}}{R_{steam}} + x\right)$$

R_{air} and R_{steam} are the specific gas constants for air and steam; the ratio is a constant at 0.622. Inserting these definitions into the relative humidity expression yields,

$$R_h = \frac{P_{steam}}{P_{sat}} = \frac{\left(\frac{P_{atm}}{P_{sat}}\right)x}{(0.622 + x)}$$

Solving for x gives an expression that requires the saturation pressure and relative humidity.

$$x = \frac{0.622R_h}{\frac{P_{atm}}{P_{sat}} - R_h}$$

The saturation pressure can be found from the following correlation.

$$P_{sat} = 610.710701 + 44.4293573T + 1.41696846T^2 + 0.0274759545T^3 +$$
$$2.61145937e-4T^4 + 2.85993708E-6T^5$$

where P_{sat} is in Pascals.

The relative humidity of the air directly above the pool is assumed to be 100%, and the ambient relative humidity from the local weather can be used for the relative humidity.

The saturation pressure of the pool surface is found from the temperature of the surface water of the pool. The temperature of the surface water is slightly cooler than the bulk temperature because of energy loss due to evaporation. The following simple correlation can be used to estimate the pool surface temperature

$$T_{surface} = T_{pool} - \frac{\left(T_{pool} - T_{wetbulb}\right)}{8}$$

Other methods are quickly derived for using the wet-bulb temperature to calculate the absolute humidity if needed.

Table 7-4 summarizes the mathematical model inputs and considerations that are based on current plant performance. The inputs will vary based on the user defined analytical frequency (period between inputs). The mathematical output is used in conjunction with Table 7-5 (balance of the model content) to assess current performance, program cost, options for improvement, and long term strategies.

The user is encouraged to review this report in its entirety prior to developing site specific inputs. This will help to ensure all nuances or limitations are addressed during the process. The default volume, flowrate, activity, and monetary units for input and display will be English Customary. The tool provides a metric conversion option for display. The default cost unit is $ US; other currencies can be input. Calculations are done in the kilogram/meters/minutes unit base.

Note: Table 7-4 and Table 7-5 each require a significant amount of information for completion. Industry experience clearly shows that most of that information is readily available from a variety of site sources. The intent is to provide a methodology for an accurate, comprehensive evaluation. Following performance of an initial detailed analysis, the volume of data should be reviewed and tailored (reduced) as required to meet specific site/utility needs for subsequent analyses.

Table 7-4
Mathematical Tritium Model Input Summary

Current Performance	
Parameter	**Units – Liquid (Gaseous)**
Power Data	
Analysis based on:	
o Annual performance	
o Fuel cycle performance	
Fuel cycle duration	day, week, month, year (Defined by plant based on preferred analysis period)
Plant operational period per fuel cycle	Effective Full Power Days (EFPD)
Generation	
Boron concentration (PWR)	
Lithium concentration (PWR)	
Initial, Known Inventory - For each inventory space (e.g., RCS, tank, containment, etc.)	
Volume	Gallons (cubic feet)
Tritium concentration	pCi/L (pCi/m3)
Temperature	
Water SG	
Volume (calculated)	L (m3)
Water Mass (calculated	kg
Tritium concentration (calculated)	pCi/kg
Tritium activity (calculated)	pCi
Inventory Management	
Normal operations	
Bleed and feed operations	
RCS/RRS draining	
Cavity flood-up	
RCSRRS and Cavity and SFP cross tie during refuel	
Refill RCS/RRS	

Table 7-4 (continued)
Mathematical Tritium Model Input Summary

SFP Evaporation (calculated or plant data)	
Known plant rate	Ci/period of time
Calculated rate	
Troom	Dry bulb temperature (°C)
Tdewpoint	Dew point (°C)
Tpool	Bulk pool temperature (°C)
Twetbulb	Wet bulb temperature (°C)
Relative Humidity	of room
Pressure	Bar
Pool surface area	m^2
Avg air velocity	m/s
Monitored Liquid Release (LRW System, Turbine Building)	
Liquid releases	
Monitored Gaseous Release (HVAC)	
Continuous release	
Containment purge	
SFP evaporation data	
Gaseous release volume	SCF plant vent
Gaseous release activity	Ci
Monitored Solid "Release"	
Solid waste volume	ft3
Solid waste activity	Ci
Performance Based Production Calculation	
Reduction +	Ci
Inventory =	Ci
Tritium Production	Ci
Unknown – calculated value	
Design Production – In-Plant Inventory – Release – Known Ex-Plant Inventory = Unknown (unmonitored)	

After the production, removal and inventory have been defined using the mathematical model, the considerations in Table 7-5 are used as a template for analyzing the balance of the tritium management strategy. The table represents a systematic approach for evaluating the plant's current performance relative to its cost efficiency, industry expectations, and potential alternative management strategies.

Table 7-5
Balance of Tritium Management Model

Parameter	Description/Notes
Baseline Cost ($US)	
	All cost factors will be summed to define a total program cost. Long term strategy consideration
Administrative	
Environmental management	
REMP/RETS & Off-Site Dose Calculation Manual (ODCM)	
Occupational exposure (site staff)	
Site effluents	
Contracted support services (includes off-site analytical, technical, decommissioning program support, coordination)	
Travel to workshops, seminars and industry meetings	
Labor	
Sampling and analysis	
Procedure development and maintenance	
Repair maintenance and preventative maintenance	
Routine operability testing	
Personnel monitoring	
Recordkeeping	
Equipment and consumables	
Consumables – silica gel, filter paper, laboratory supplies, standards, etc.	
Fixed sampling and monitoring	
Portable sampling and monitoring	
Land and water transportation	

Table 7-5 (continued)
Balance of Tritium Management Model

Training	
Contracted support	
Support technicians	
Plant staff/management	
Capital costs	
New equipment	
Well installation	
Modifications	
Post installation testing	
Monitoring	
ANI premium performance penalty (+)or benefit (-)	
Avoided Litigation Benefit (-)	
Exposure ($ per Person Rem)	
Effluent processing	
Liquid	
Media, system operations, contracted processing, sampling and analysis	
Gaseous	
Filters, operations, changeout, sampling and analysis	
Solid	
Packages, shipment preparation, shipping, disposal	
Site remediation and/or decommissioning	
Monitoring	
Remediation	
Energy costs	
Changes that modify energy requirements (e.g., reducing SFP temperature, dehumidifying units, etc.)	
Unusual event support	
Other miscellaneous	
Total Program Cost	

Table 7-5 (continued)
Balance of Tritium Management Model

Current Performance Consequence Analysis	
Per Unit Goals	Per period of time, Long term strategy consideration
Liquid release Ci	
Airborne release Ci	
Gap Analysis - Benchmark Current Performance	
Review current performance and trends	Long term strategy consideration
Regulatory	
EPRI	
ANI	
INPO	
ISOE/NATC	
Other	
Pathway Analysis (Gaseous, Liquid, Solid)	
Compare pathway analysis results to model & design predictions for consistency	
Determine reason for discrepancies for each effluent stream	
Effluent values vs. pathway impact	
a) high – but acceptable	
b) high – requires investigation	
c) high – requires reduction	
Cost	
Evaluate baseline costs for current strategy	
Intangible and Soft Issues	Long term strategy considerations
Level of regulatory oversight	Proposed changes to modeling and regulatory requirements are long term strategy considerations
Public relations and perception	
Worker acceptance of monitoring and protection practices related to exposure	
Industry organization perception and acceptance	

Table 7-5 (continued)
Balance of Tritium Management Model

Acceptability Determination	
Performance options	
Evaluate: benchmark, site specific consequences, investigation results, costs to determine acceptability of results	
Satisfactory	Document results
Unsatisfactory	Document results
Change Evaluation Factors	
Inventory Impact Factors	
Production rate	
Liquid volumes	
Tritiated liquid temperature	
Ambient air temperature	
Humidity relative humidity?, dew point?	
Liquid body surface area	
Liquid agitation	
Heating, Ventilation, Air Conditioning	Flow rates, flow vectors (sweep paths)
Releases	
Makeup water	
Production Impact Factors	
Reactor power	Long term strategy considerations
Fuel type	Long term strategy considerations
Fuel integrity	
Lithium purity	
Delithiation	
Boron concentration	
Operating duration	Long term strategy considerations
Change Analysis	
For Abnormal Results	
Perform source analysis of abnormal results	Evaluate all impact factors
Identify plant specific sources per pathway	

Table 7-5 (continued)
Balance of Tritium Management Model

For Improvement Opportunities	
Identify potential improvement opportunities	
Identify plant specific sources per pathway	
For All Changes	
Define all options	
Define new goals for all options	To be used for success measurement
Change applicable parameters in model and analyze results	
Prioritize	
Define most viable option(s)	
Plan Implementation	
Define plan for viable option(s)	Using impact factors and industry experience
Define revised goals	To be used for success measurement
Approval	
Final Impact Analysis	
Sensitivity and Decision Validation	
Cost benefit for each option	
Review model results	
Perform pathway analysis	
Review actual performance	
Define intangibles, soft issues, factors, benefits	
Document and archive results	

At this point, the evaluation process is considered complete.

A
REFERENCES

1. EPRI, TR 1006710, *Evaluation of a Low Level Waste Technology – A Media Based Tritium Removal Process* (January 2002).

2. Foster, A. R., & Wright, Jr., R. L, *Basic Nuclear Engineering – Second Edition* (Boston, 1978).

3. NUREG/CR-3332, ORNL 5968, *USNRC Radiological Assessment, A Textbook on Environmental Dose Analysis* (1983).

4. Code of Federal Regulation, Title 10, Part 50, Appendix I (10CFR50 Appendix I), *Numerical Guides for the Design Objectives and Limiting Conditions for Operation to Meet the Criteria, As Low As Is Reasonably Achievable for Radioactive Material in Light Water Cooled Nuclear Power Reactor Effluents*.

5. Merril Eisenbud and Thomas Gesell, *Environmental Radioactivity* (San Diego, 1997).

6. NWT, A Review of Tritium in Light Water Reactors, NWT 721 (June 2005).

7. EPRI, *Investigation of Tritium Releases from Beaver Valley Power Station* (December 1997).

8. DOE, *DOE/RL-2004-11, 2004 Evaluation of Tritium Removal and Mitigation Technologies for Wastewater Treatment,* (February 2004).

9. International Atomic Energy Agency, Safety Reports Series No. 19, *Generic Models for use in Assessing the Impact of Discharges of Radioactive Substances to the Environment* (Vienna, 2001).

10. Ronald L. Kathren, *Radioactivity in the Environment: Sources, Distribution and Surveillance* (New York, 1984).

11. Phillips, J.E., Easterly, C.E., "*Sources of Tritium*," Nuclear Safety, 22, pp 612-626, 1981.

12. F. Ward Whicker and Vincent Schultz, *Radioecology: Nuclear Energy and the Environment* (Boca Raton, 1982).

13. IAEA Technical Report Series No. 421, *Management of Waste Containing Tritium and Carbon-14* (2004)

14. Chien C. Lin, National Academy Press, Nuclear Science Series, NAS-NS-3119, *Radiochemistry in Nuclear Power Reactors* (1996)

15. American Nuclear Society, 1980, *American National Standard of Radionuclide Transport in Groundwater for Nuclear Power Sites*, ANSI/ANS-2.17-1980, American Nuclear Society, Grand Park, Illinois.

16. Federal Guidance Report 11, "*Concentration and Dose Conversion Factors for Inhalation, Submersion and Ingestion*", September 1988.

17. Glasstone, S., Jordan, W.H., *Nuclear Power and its Environmental Effects, American Nuclear Society*, 1980

18. Title 40 Part 190 of the Code of Federal Regulations

19. EPRI, TR-1011730, Groundwater Monitoring Guidance for Nuclear Power Plants, 2004

B
RESOURCES

The following information is provided for general reference only. Contact information is subject to change.

Websites (alphabetical listing)

ANI	http://www.amnucins.com/
DOE	http://www.energy.gov/
EPA	http://www.epa.gov/radiation/radionuclides/tritium.htm
EPRI	http://www.epri.com/
Health Physics Society	http://www.hps.org/
IAEA	http://www.iaea.or.at/programmes/a2/
INPO	http://www.eh.doe.gov/inpo/
NATC/ISOE	http://hps.ne.uiuc.edu/
NEI	http://www.nei.org/
NRC	http://www.nrc.gov/
RETS/REMP	www.rets-remp.org
WANO	http://www.wano.org.uk/
Waste Management Symposium	http://www.wmsym.org/

Workshops and Conferences

Organization	Frequency	Information Source
RETS/REMP	Annual	Website
EPRI LLW	Annual	Website
EPRI Radiation Exposure Technology and ISOE ALARA Symposium	Annual	Website

C
PLANT EXPERIENCES

The following are examples of tritium related Operating Experiences. They emphasize the impact tritium management and decision making processes have on long-term plant monitoring, remediation, and costs.

Ground Water Experience 1

Effluent Line Leak

At a nuclear plant in the mid 1990s, a pressure test was performed on the Radwaste Effluent Line (a small diameter concrete-lined steel pipe). The line did not hold pressure, and it was assumed to have leaked low levels of tritium and other radionuclides into the subsurface. The Effluent Line, which is buried within the plant backfill, is used to routinely discharge low-level radioactive wastewater into the plant's cooling water canal system.

The potential for off-site release of radionuclides via the ground water was subsequently assessed by utility technical staff and a hydrogeological consultant. Tritium was identified as the only radionuclide present in the Radwaste Effluent Line with significant mobility. The assessment concluded there was no potential for an off-site release above 10CFR20 limits.

A site ground water assessment was conducted which involved sampling of shallow piezometers and monitoring wells. The presence of tritium was confirmed in two shallow monitoring wells constructed in the plant backfill at its eastern-most edge. The study concluded that tritium from the leak was confined to the plant backfill, and is expected to slowly move with the ground water in the backfill to the cooling canal, as there is a positive hydraulic gradient from the surrounding natural soils to the plant backfill and from the plant backfill to the canal.

Vertical migration of tritium from the plant backfill to deep aquifers was also considered as a potential contaminant pathway based on the observed hydraulic gradients. Based on these previous studies, is has been concluded that there is no potential off-site exposure pathway for tritium released from the Radwaste Effluent Line that could present a hazard to public health and safety or the environment. The current ground water monitoring program for tritium in the vicinity of the plant backfill is considered adequate to confirm this conclusion. The leak was identified as part of the plant’s decommissioning files and American Nuclear Insurers continues to monitor the situation with interest.

Ground Water Experience 2

Holding Pond

A several dozen acre holding pond at a BWR temporarily holds storm water and other drainage waters. Water from the pond is periodically released to the cooling canal as a means of level control. Such releases are monitored and are considered "off-site releases".

The pond routinely receives wastewater collected by the plant's storm drain collection system, which collects wastewater from outside areas and inside building areas throughout the plant. Tritium enters the storm wastewater system via the air coolers located in the Turbine Building. A side effect of this process is that the water spray in the air coolers collects tritium from the air inside the Turbine Building. Water that overflows from the air coolers discharges to a storm drain collection basin, and is eventually conveyed to the holding pond. The average tritium concentration in the pond surface water is on the order of E-5 μCi/cc. This activity is well below the 10CFR20 limit for effluent discharge of 1E-3 μCi/cc without any dilution.

In mid 1990s, an evaluation of the impact of a potential release to the groundwater from the holding pond was conducted as part of an overall site environmental risk assessment. While concluding that the probability of such an occurrence was high since water in the holding pond is maintained at an elevated level (compared to the water table in the surrounding soils) and its bottom is unlined, the evaluation also concluded that the environmental impact would be low and would not pose a threat to public health. Periodic samples of groundwater, from wells near the holding pond, are evaluated for the presence of tritium. Although no tritium has been detected in the groundwater, American Nuclear Insurers continues to have interest in following this issue.

Ground Water Experience 3

Spent Fuel Pool Leakage

PWRs are currently investigating and mitigating tritium identified in groundwater at the sites that originated from spent fuel pool leakage. Additional details are not available at the present time.

Surface Water Experience 1

Lake Concentration

A PWR discharges radioactive liquid effluents into a lake which turns over fairly slowly. The liquid disposal facilities are designed such that discharge of plant effluents are minimized and in accordance with applicable regulations. Because of tritium's chemical and physical similarities to hydrogen it can replace a hydrogen atom in a water molecule. Therefore, normal wastewater treatment techniques (ion exchange or evaporation) cannot separate the tritium from the water in the plant.

Consequently, during periods of low rainfall, the tritium concentration of the lake would increase due to continued input of tritium (accumulation) coincident with low lake turnover.

Tritium concentrations in the lake are closely monitored and are maintained well below tritium drinking water standards. However, the plant must plan when it makes liquid effluent releases and sometimes waits for optimum lake level conditions for releases. The plant has successfully minimized tritium concentrations in the lake by recycling and restricting releases of tritium to periods of high rainfall. This sometimes places challenges on managing water inventories at the plant. American Nuclear Insurers follows this issue with interest.

Plant Drains Experience 1

Ventilation Inlet Plenum Drains Concentration

In this case tritium was detected in the turbine building supply ventilation plenum drains. Air coming into that building is cooled via chilled water. The condensate from these drains is routed to storm drains during operation in hot, humid weather. The subsequent investigation determined that a small amount of gaseous effluent from the plant exhaust vents were recycled back to the turbine building ventilation supply plenums. The low levels of tritium activity in the effluents were then condensed in the drains resulting in a release of tritium to the environment.

Plant Drains Experience 2

Executive Building Air Conditioning Condensate

A BWR's air conditioner condensate originating in an administrative builiding was routed to plant storm drains. The HVAC system concentrated plant effluent tritium in that condensate stream which resulted in elevated tritium levels in the storm drain system. Additional detail is not available at the present time.

HVAC Experience 1

Sewage Treatment Plant

On July 08, 2004, tritium was detected during routine monthly surveillance of sewage treatment plant effluent. Liquid radwaste release permits were prepared to account for the activity discharged, and a moratorium was placed on sludge shipments from the sewage treatment plant. No sludge was released from the site with detectable tritium activity. The tritium results were verified and a sampling program was initiated to identify the source(s). Ground monitoring wells were sampled but no tritium was detected. An evaluation of the tritium discharged in routine gaseous releases from the site indicated that there was a low probability the source could be attributed to

normal plant vent stack effluents. All inputs to the sewage treatment plant were identified and sampled. Condensate was collected from many air conditioning units on site. The highest concentration of tritium (6.3E-5 μCi/ml or 2300 Bq/kg) was identified in the condensate from the air conditioner servicing the first floor of the security building.

Lower levels of tritium were detected on the condensate from the air conditioners servicing other areas of the security building. The flow rate of the air conditioner's condensate was measured and a calculation indicated the tritium expected in the sewage treatment plant effluent would be 1.3E-6 μCi/ml. The actual level identified in the routine monthly surveillance was 1.3E-6 μCi/ml. Over the next several days tritium was monitored and found to vary in an inverse proportional relationship with the volume of uncontaminated input to the sewage treatment plant.

A search of the records of radioactive sources indicated the Sentex explosive detectors on the first floor of the security building contained a tritium source in a titanium foil of the electron capture detector. The literature accompanying the explosive detector indicated tritium would be carried out of the explosive detector with the exhaust carrier gases, venting to the local ventilation.

The emissions from explosive detectors containing radioactive material are governed by 10CFR31.5, "Certain detecting, measuring, gauging, or controlling devices and certain devices for producing light or an ionizing atmosphere." Subparagraph (c)(10) of that regulation specifies such emissions "shall be exempt from the - requirements of parts 19, 20, and 21 of this chapter."

The tritium in the liquid discharged from the sewage treatment plant was reported in a manner similar to reporting of material discharged from operation of the reactor.

The appearance of tritium in the liquid discharged from the sewage treatment plant effluent at Calvert Cliffs is expected to be seasonal, provided the operation of the Sentex explosive detectors remains unchanged.

HVAC Experience 2

Spent Fuel Building Exhaust

The NRC determined that a PWR did not account for all tritium activity in the spent fuel pool exhaust area. This resulted in an NRC violation. Additional detail is not available at the present time.

Decommissioning Experience 1

Concrete Shielding Contamination

Contractors undertaking decommissioning of a shut down nuclear power plant performed tritium analysis on concrete taken from a number of borings in the containment building. Unusually high concentrations of tritium were detected in the concrete, in areas where the concrete had never been exposed to tritium-bearing water. Although diffusion of tritiated water vapor into the concrete may have accounted for some of the observed tritium, high tritium levels deep in the concrete indicated other potential contamination mechanisms. Chemical analysis of the concrete matrix led the contractors to conclude that naturally-occurring lithium and boron in the concrete matrix may have become activated and converted to tritium by the high neutron flux. Regardless of the exact formation mechanism, the high levels of tritium dispersed throughout the concrete resulted in much of it having to be treated as radioactive waste.

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