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2019 TECHNICAL REPORT

# Methodology for the Evaluation of Used Oil for Radiological Contamination

## Focusing on Hard-to-Detect Radionuclides, Tritium, and Carbon-14

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## *Focusing on Hard-to-Detect Radionuclides, Tritium, and Carbon-14*

All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

YES NO

EPRI Project Manager
D. Perkins

EPRI ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue
Palo Alto, CA 94304-1338
USA

PO Box 10412
Palo Alto, CA 94303-0813
USA

800.313.3774
650.855.2121

askepri@epri.com

www.epri.com

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THE FOLLOWING ORGANIZATIONS, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

**DW James Consulting, LLC**

**CN Associates, Inc.**



**NOTE**

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DW James Consulting, LLC
855 Village Center Drive, #330
North Oaks, MN 55127

Principal Investigators
W. Doolittle
T. Kalinowski

CN Associates, Inc.
P.O. Box 959
Harvard, MA 01451

Principal Investigators
R. Cardarelli
G. Oliver
K. Sejkora

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# Abstract

Used oil that is generated during the normal operations of a nuclear power plant has the potential to be radiologically contaminated. To appropriately disposition the used oil, regulations in the United States require licensees to conduct a reasonable survey of the oil to determine if it is contaminated with radionuclides. This includes a reasonable survey for both gamma and non-gamma-emitting radionuclides. The U.S. Nuclear Regulatory Commission (NRC) staff have expressed concerns that a survey approach that focuses on screening only for the presence of gamma-emitting radionuclides may not account for the presence of beta-emitting radionuclides such as tritium and carbon-14 or other hard-to-detect radionuclides—and that this approach may not, by itself, constitute a reasonable survey for the presence of beta-emitting radionuclides such as tritium and carbon-14.

EPRI has conducted research to review, identify, and develop a technical basis for a reasonable survey for the free release of used oils. This includes the review of the U.S. Code of Federal Regulations, regulatory guidance, site-specific nuclear power plant practices, and laboratory capabilities to address the U.S. regulator concern. Where applicable, other data sets from outside the United States were included. The results of this work can be applied at nuclear power stations in the development of site-specific free-release guidance on used oils.

**Keywords**
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# Product Title: Methodology for the Evaluation of Used Oil for Radiological Contamination: Focusing on Hard-to-Detect Radionuclides, Tritium, and Carbon-14

**PRIMARY AUDIENCE:** Nuclear power plant technical staff and radiation protection managers responsible for free release of materials from the nuclear power plant station

**SECONDARY AUDIENCE:** Nuclear power plant technical staff responsible for the management of radioactive waste and system engineers responsible for the management of lubricating oil systems and analyses

## KEY RESEARCH QUESTION

Nuclear power plants release materials based on defined limits established by regulatory bodies. In the United States, regulations allow for the release of materials from nuclear power plants only after a reasonable survey indicates no detectable radioactivity. Determination of whether materials contain licensed, radioactive materials is made by radiation protection staff through various methods, including survey with radiation detection instrument, by sample and analysis, and/or process knowledge. The objective of this research is to establish a technical basis for the reasonable survey of used oil to determine its suitability for free release.

## RESEARCH OVERVIEW

This research was conducted by reviewing existing regulatory guidance and standards, the performance of an industry survey to identify used oil sources, the quantity of used oil generated, analyses performed on used oils for free release, detection limits associated with oil analyses, industry data on used oil sampling, and historical shipment records.

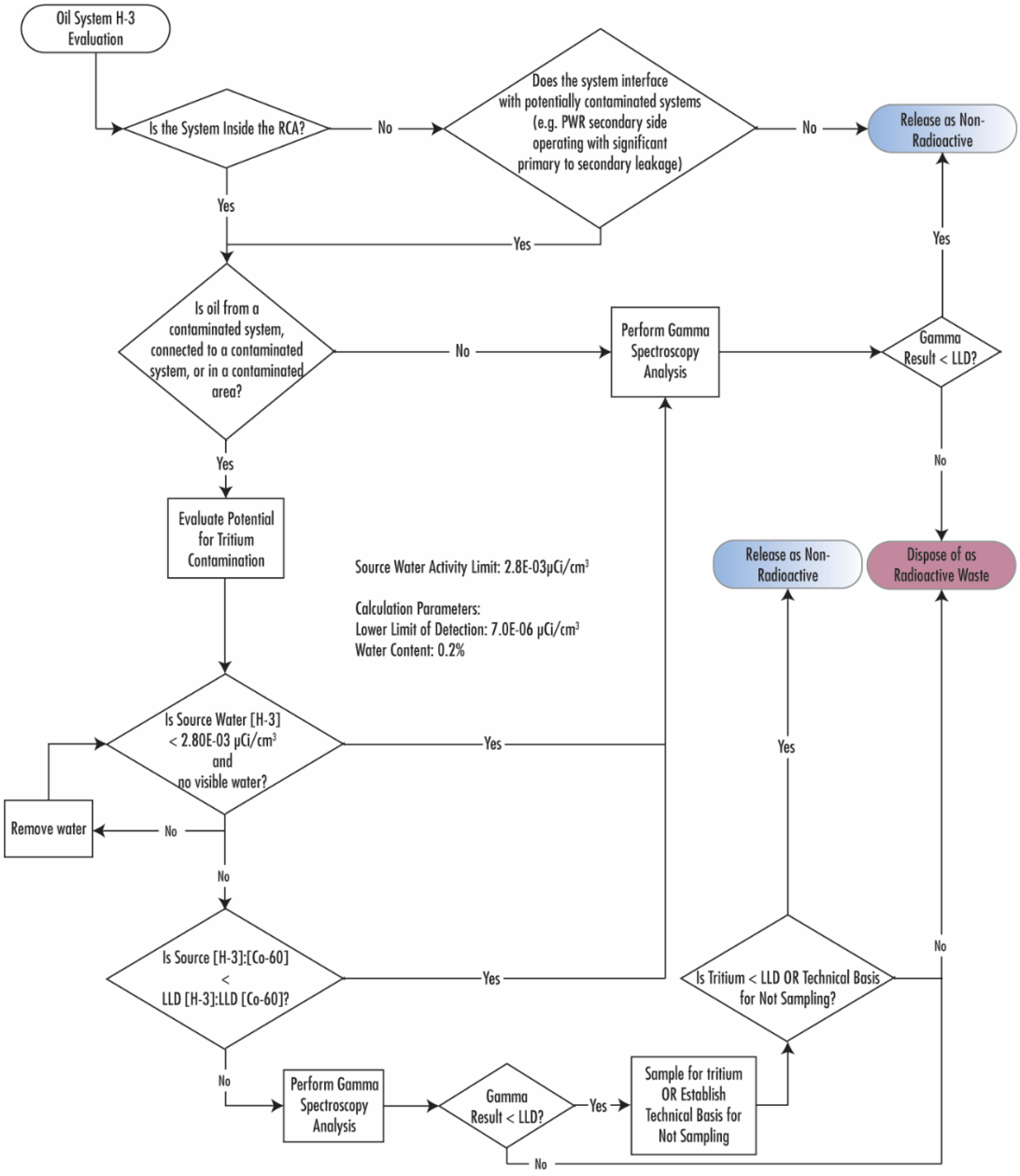
## KEY FINDINGS

- In U.S. regulations, there is no defined lower limit of activity (clearance level) that can be released from regulatory control; the radioactivity must be non-detectable. Surveys are required before any material can be released from regulatory control by the licensee. The surveys must be “reasonable under the circumstances” and use the “operational state-of-the-art” (state of art) for the method used.
    - Surveys can include the use of process knowledge and relationships among radionuclides to establish presence and concentration. The use of these kinds of assessments should be readily explained by the licensee and, ideally, documented for inspection and future reference.
    - Environmental lower limit of detection (LLD) values can be used for isotopes that are identified in NUREG 1301 and NUREG 1302. Because there are no environmental LLDs established for carbon-14 and the environmental LLD for tritium is related to water rather than oil, a reasonable detection level for tritium and carbon-14 in oil under 10 CFR § 20.1501 would be the laboratory capability. EPRI defined the state-of-art laboratory LLDs of 7.00E-06 µCi/cm$^3$ (259 Bq/L) for tritium in oil and 5.00E-06 µCi/cm$^3$ (185 Bq/L) for carbon-14 in oil for screening methodology described in this report based on the information provided by the two most commonly used laboratories in the United States. It should be noted that the actual LLD achieved when a sample is sent for analysis may be different. Plants may choose to use a different LLD for tritium in oil; this report provides the methodology to derive site-specific

screening factors if a different LLD is used. Table 2-1 in Section 2.2 of this report lists other typical detection levels for other hard-to-detect (HTD) radionuclides.

- EPRI developed a process by which plant staff can optimize their site-specific survey processes to ensure that reasonable surveys are conducted while optimizing operational cost. In some cases, survey of the oil for gamma-emitting radionuclides is sufficient to determine that the HTD radionuclides are not present—that is, in some cases, if HTD radionuclides are present in the oil, gamma-emitting radionuclides would also be detectable.
    - Using the state-of-art LLD defined in this report, oil associated with both BWR and PWR reactor coolant systems (RCSs) is not expected to have detectable levels of carbon-14 if the water content in the oil is ≤0.2%. See Section 4.4.2 for the technical basis behind this conclusion.
    - HTD radionuclides other than carbon-14 and tritium are considered in Section 4.5. This research concludes that the most likely method of contamination of oil with HTD radionuclides (for example, iron-55 and nickel-63) is through cross-contamination during maintenance activities—including change-out of oil in plant equipment or through direct contact with contaminated water. In either case, it can be demonstrated that the ratios of the HTDs relative to gamma emitters is such that gamma emitters would be detected if these HTDs are present.
    - Tritium presence requires additional consideration because of the unique physical properties, including the ability to be present as a gas or vapor and its relative abundance compared to gamma-emitting radionuclides and may require additional analysis.
- The technical basis for the development of this used oil evaluation methodology for tritium and carbon-14 contamination is the subject of Section 4 of this report. The decision-making processes are summarized in the flow chart below. Key conclusions of this research include the following:
    - Tritium (and carbon-14) from natural background should not be present above the detection levels in typical oil samples if petroleum-based (vs. bio-based) oils are used, considering the state-of-art defined LLDs in this report. If plants shift to bio-based oils or synthetic oils, this assumption should be reevaluated.
    - Although there is potential to generate tritium (and carbon-14) from direct neutron activation of the oil, these activation processes are not expected to lead to detectable levels in used oil, considering the laboratory LLDs in this report.
    - Tritium (and carbon-14) contamination of oil as a result of atmospheric diffusion is not likely in ventilated areas of the plant. However, there are instances in which atmospheric contamination is credible and should be considered when dispositioning used oil. Contamination by atmospheric diffusion is most likely in PWR containments, poorly ventilated areas of the plant, and in the close physical proximity of off-gas systems. Site-specific evaluations need to be performed to determine if these conditions exist.
    - Based on survey data provided to EPRI and using an analytical LLD of 7.00E-06 µCi/cm3 (259 Bq/L) for tritium in oil and a dissolved water content of ≤0.2%, some BWRs **would not** have the potential to create oil contaminated with tritium above the analytical LLD when gamma emitters are not detected.
    - Based on the survey results for PWRs, oils that come into contact (direct and indirect) with the RCS are likely to require additional sampling for tritium in the absence of detectable gamma-emitting radionuclides or the application of other site-specific factors and process knowledge to rule out the need for additional sampling. It should be noted that the source water activity for oils within the radiologically controlled area (RCA) is based on reactor coolant activity, is conservative, and may not be valid for all systems within the RCA. Evaluation of site-specific

systems may reveal that oil interfaces with component cooling water or other systems not related or connected to the RCS typically have much lower tritium activity.




- Oil segregation in conjunction with site-specific data and process knowledge can be used to determine the proper disposition of used oil. Segregation processes that keep oil known to not be contaminated segregated from oil that is potentially contaminated can be effectively used to minimize the need for additional sampling. For oil that is potentially contaminated, plants may choose to sample this oil prior to free release rather than develop a more complicated program that would use process knowledge to eliminate the need for sampling of some of this oil. If this option is chosen by the plant, composite sampling of similar oils might be used to reduce the number of samples required. Sampling of oil from different systems may over time provide data that help determine how to best use composite sampling.

## WHY THIS MATTERS

Nuclear power plants generate used oils from various systems in RCAs that can be potentially contaminated. These lubricating oils can present challenges to the ability of analytical laboratories to consistently detect some radionuclides at very low concentrations. The development of technically based used oil sampling and analysis methodology ensures that used oil is monitored and free-released consistent with regulatory requirements and that licensed materials are controlled appropriately.

## HOW TO APPLY RESULTS

The results of this work provide plant staff with the technical basis to develop and enhance site-specific procedures for evaluating used oils considering HTD radionuclides. The first step is to perform a site assessment of used oil procedures considering the information provided in this research. The second step is for each site to review the assessment findings, identify opportunities for improvement, and address these in a site-specific action plan and procedure revisions for a more enhanced overall used oil release evaluation methodology. Though this material is based on a review of U.S. regulatory standards, the research may provide opportunities for global members to check site-specific procedures for enhancement opportunities. The need for this research in countries that have clearance levels for radioactive materials may be limited.

## LEARNING AND ENGAGEMENT OPPORTUNITIES

- Nuclear power plant technical staff and radiation protection managers responsible for radioactive material control and release may benefit from attending future meetings and workshops where this topic may be discussed, such as the Nuclear Energy Institute (NEI) Radiological Environmental and Effluents Workshop (REEW), Condition-Based Maintenance User Groups, Lubricating Oil System Engineer Workshops, and the Institute of Nuclear Power Operations (INPO) Radiation Protection Manager and Chemistry Manager Workshops.
- Nuclear power plant maintenance staff may be interested in this research to address lubricating oil system analysis programs and vendor limitations related to handling radioactive materials.

**EPRI CONTACT:** David Perkins, Senior Technical Executive, dperkins@epri.com

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**Electric Power Research Institute**
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

# Unit Conversions

The *Methodology for the Evaluation of Used Oil for Radiological Contamination* reports data primarily in micro-curies per cubic centimeter with becquerel per liter captured in parentheticals. The following equations capture the major unit conversions.

Micro-curies per cubic centimeter to pico-curies per liter:

$$A\ \frac{pCi}{L} = A\ \frac{\mu Ci}{cm^3}\ x\ 10^6\ \frac{pCi}{\mu Ci}\ x\ 1000\ \frac{cm^3}{L}$$

Micro-curies per cubic centimeter to becquerel per liter:

$$A\ \frac{Bq}{L} = A\ \frac{\mu Ci}{cm^3}\ x\ 37{,}000\ \frac{Bq}{\mu Ci}\ x\ 1000\ \frac{cm^3}{L}$$

Pico-curies per gram to becquerel per liter: laboratory results were reported in μCi/g.

$$A\ \frac{Bq}{L} = A\ \frac{pCi}{gram}\ x\ 0.037\ \frac{Bq}{pCi}\ x\ 1000\ \frac{gram}{L}$$

Section 4 discusses the use of densities and notes that densities of oil for the subject materials range from 0.85 g/cm$^3$ to 1.16 g/cm$^3$ and that, based on these data, a density correction is not considered necessary.

# Acronyms

Acronyms are commonly used to abbreviate frequently used terms in reports and communications in the industry. The terms are defined below.

| Acronym | Terminology |
|---|---|
| α | alpha symbol |
| ASTM | American Society of Testing and Materials |
| ANSI | American National Standards Institute |
| BWR | boiling water reactor |
| Ci | curie |
| γ | gamma symbol |
| Gal/yr | gallon per year |
| GBq/ $GW_{th}$-yr | giga-becquerel per thermal giga-watts produced per year |
| $GW_{th}$-yr | thermal giga-watts produced per year |
| HPPOS | health Physics Positions |
| HTD | hard to detect |
| L/yr | liter per year |
| LLD | lower limit of detection |
| NPP | nuclear power plant |
| NRC | U.S. Nuclear Regulatory Commission |
| $n/cm^2$ | neutron per square centimeter |
| ρ | proton symbol |
| pCi/L | pico-curie per liter |
| PWR | pressurized water reactor |
| REMP | Radiological Environmental Monitoring Program |
| RCA | radiologically controlled area |
| RCS | reactor coolant system |
| $\mu Ci/cm^3$ | micro-curie per cubic centimeter |
| μCi/g | micro-curie per gram |
| η | neutron symbol |

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# Section 1: Background and History

## 1.1 Introduction

The use of petroleum oils for lubrication is common in nuclear power plant equipment. Used oil is typically controlled as a special waste once it is removed from equipment during routine maintenance. This report evaluates the potential for the presence of hard to detect (HTD) radionuclides including tritium {$^{3}H$} and carbon-14 {$^{14}C$} in used oil and provides a technical basis for the reasonable survey of used oil to determine if it is radiologically contaminated. Failure to perform an adequate survey constitutes a violation of NRC requirements.

Several mechanisms that can potentially result in radioactive contamination of oil in nuclear plant systems were considered. These contamination mechanisms include neutron activation, contact with process fluids that are contaminated, contact with contamination in the vicinity of the equipment, and diffusion from the atmosphere of the equipment vicinity:

- Neutron activation of oil is only possible within the BWR drywell or PWR containment building where there is sufficient neutron flux to cause activation. A calculation can demonstrate the bounding level of activity expected from neutron activation of oil within these areas.
- Contact of the oil with radioactive liquid is possible during equipment operation or within plant systems such as water sumps. Contamination levels of oil due to contact with contaminated system liquids can be demonstrated by calculation based on contamination levels in plant systems.
- Cross contamination of the oil can occur during maintenance activities within areas with surface contamination present. The contaminated tools or equipment used during oil change or sampling processes that contact the oil could transfer contamination to the oil. In these scenarios, the radionuclide distribution of the contamination of the oil is expected to be similar to that observed in routine waste stream analyses for compliance with Title 10 of the Code of Federal Regulations Part 61 (10 CFR § 61). [1]
- For contamination transfer to oil by atmospheric diffusion, the contaminant level can be calculated based on expected airborne radionuclide concentrations.

A survey is required for removal of equipment or materials (including used oil) from the plant radiologically controlled area (RCA). [2] For flowable materials such as used oil, a surface evaluation (frisking) is not considered to be sufficient. For small volumes, the analysis would consist of a bulk assay of the material. For

large volumes, this analysis may be performed on a representative sample of the bulk material.

An additional consideration for used oil is whether water is present within the oil. Though oil and water do not mix well due to the chemical characteristics of oil and water, water can still enter oil systems via system leakage, atmospheric contamination, and system contamination during maintenance activities. [3] The reactor coolant has the highest tritium concentrations outside of the fuel, and these potential reactor coolant and oil system interactions present the highest source for tritium and other radionuclide contamination.

Water and oil are not miscible[1] but some quantity of non-visible water may still be present in oils that also contain detergents or other emulgators. Water can exist in oil in three forms. Dissolved water is the natural state and is typically an extremely small concentration and difficult to detect with the eye. Free water occurs once the saturation point is reached and the water separates from the oil. Emulsified water is water concentrations above the saturation point that is held in suspension due to agitation or mixing. [4] Decanting the free water from used oil prior to analyses for radioactivity is a typical water removal process.

One approach that has been used by some plants to survey oil for release is to perform a bulk assay of the oil using gamma spectroscopy analysis. If gamma emitting radionuclides are detected, then the used oil is controlled as radioactive waste. If there is no detectible gamma radioactivity, then some sites allow the oil to be free-released. This would include off site processing for incineration or recycling without the constraints imposed on radioactive waste. This approach makes the assumption that HTD radionuclides are not present if gamma emitting radionuclides are not detected. This practice is based on the relationships of the HTD radionuclides to the gamma emitters as defined by other sample data. [5]

The EPRI research conducted as part of this study indicates that it would be prudent for the industry to establish a clear technical basis for evaluating oil intended for release from licensed control for non-gamma emitting radionuclides. This technical basis would include using process knowledge to determine when sampling and analysis for non-gamma radionuclides in used oil is warranted. The objective of this work is to establish that technical basis. Wholesale sampling of all oil for non-gamma emitting radionuclides can be unnecessarily resource intensive. Calculations of potential activity levels in oil based on concentrations in plant systems and in the atmosphere can be used to determine when sampling is necessary. If the highest potential concentration of the non-gamma emitting radionuclides is below the LLD achieved for the analysis, then additional sampling would not be warranted.

This report frames the current state of evaluating used oil for release and includes a discussion of available sampling and analysis technologies based on the industry survey, guidance for applying process knowledge, and applicable scaling factors

[1] The ability to form a homogenous mixture.

that may be used for evaluating HTD radioactive contaminants in oil. Data, operating experiences, and other information were collected from scientific literature (e.g. industry standards, regulatory guides, journal articles, etc.) and nuclear power plant personnel in the U.S. and South Africa. This information is used to provide a framework for implementing technically sound approaches for evaluating oil for the presence of tritium and carbon-14 and other HTD radionuclides.

The key findings and observations captured in this document are found in **bold text**.

## 1.2 Evaluation and Methodology

A survey was distributed to EPRI members and replies were received from members in the United States and South Africa. Data on current plant practices were collected, including:

- The use of process knowledge to inform decisions to sample and analyze oil,
- Methods for sampling and analysis of oil (including technologies used and lower limits of detection),
- Free release of oil,
- Disposal of oil,
- Use of off-site processors,
- Amount of used oil generated, and others.

In addition to the survey, follow-up interviews were conducted with various industry individuals to confirm industry practices and their bases where questions arose during the review.

The regulatory review was conducted to determine NRC regulatory requirements related to surveys of used oil for release from licensed control including applicable LLDs and the potential use of process knowledge in performance of a survey. In addition to the review of regulations, guidance documents were reviewed, and additional discussions were conducted with NRC staff to ensure a complete understanding of the issue and NRC concerns.

Discussions were also conducted with the commercial radiological laboratories to determine their analytical methodologies, capabilities, and limitations for the analysis of used oil.

Previous EPRI reports and other publications were reviewed to collect and evaluate information as it pertains to understanding the radiological materials in the used oil and used oil and water mixtures. These reports also provide insights into the process of how oil becomes contaminated.

Data from laboratory analyses of both clean and used oil samples and historical shipment records were also reviewed to provide empirical evidence.

# Section 2: United States Regulatory Requirements

## 2.1 Overview

In the United States, the regulations related to potentially radiologically contaminated used oil from nuclear power plants is addressed by the United States Nuclear Regulatory Commission.

## 2.2 US Nuclear Regulatory Commission Regulations and Guidance

The NRC has established regulatory requirements in Title 10 of the Code of Federal Regulations Part 20 (10 CFR § 20) "*Standards for Protection against Radiation*" and 10 CFR § 61 "*Licensing Requirements for Land Disposal of Radioactive Waste*". The sections of these regulations that applies to the management of radiologically contaminated used oil or potentially contaminated used oil include:

- 10 CFR § 20.15001 "*Surveys and Monitoring*" establishes requirements for radiological surveys that are "reasonable under the circumstances to evaluate the magnitude and extent of radiation levels, concentrations or quantities of residual radioactivity, and the potential radiological hazards of the radiation levels and residual radioactivity detected". Surveys are defined in 10 CFR § 20.1003 as "*…an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present*". [2]

  **Assessments of radioactivity that include the use of process knowledge therefore meet the definition of a survey.**

The NRC has also issued various other documents that provide advisory information or regulatory guidance that affect the management of contaminated materials including used oil. The following **H**ealth **P**hysics **Pos**itions (HPPOS) are included for reference and reviewed as part of the research work. Inspection Manual Chapter (IMC) 0303 notes that HPPOS are not intended to be used to interpret regulations but to provide clarification and summaries of the positions. [6] They do however provide insight into this technical basis.

- Health Physics Position 073 (HPPOS 073), *Surveys of Waste from Nuclear Facilities before Disposal,* [7]: In 1981, the NRC issued Inspection and Enforcement Circular (IE) 81-07, *Control of Radioactivitely Contaminated Material,* [8] that provided guidance on the control of radioactively contaminated material and identified the extent licensees should survey for contamination. It indicates that surveys should be made with methods for detecting very low levels of radioactivity to discriminate between materials that are contaminated and those that can be disposed of as clean waste.

  > "The survey methods should provide licensees with reasonable assurance that licensed material is not released from their control." [8]

  HPPOS 073 was intended to account for activity in materials that were aggregated prior to release to detect any accumulation of detectable activity that would have been missed by surface survey techniques. The use of gamma spectroscopy by itself as the final evaluation was considered adequate to perform this final evaluation.

- Health Physics Position 072 (HPPOS 072), *Guide on How Hard You Have to Look as Part of Radioactive Contamination Control Program,* reiterates that NRC regulations do not provide for "de minimis" activities and that the guidance in IE 81-07 was to provide acceptable limits of detection for portable survey equipment. While laboratory equipment is capable of much lower levels of detection, their use is not practical in all situations. The disposal of material with any detectable radioactivity is more appropriately handled through the authorization process described in 10 CFR § 20 2002. [9]

- Health Physics Position 221 (HPPOS 221), *Lower Limit of Detection (LLD) for Potentially Contaminated Oil,* [10] provides guidance specific to potentially contaminated oil that is consistent with the guidance for release of other materials. The HPPOS states that:

  > "For cases in which no release of radioactive material is authorized, the appropriate lower limit of detection (LLD) is the 'operational state of the art' value used for laboratory measurements of environmental samples. This is the LLD value given in the standard Radiological Effluent Technical Specifications for environmental samples[2]." [11] [12]

[2] Note: The LLD being referenced here is the LLD for Radiological Environmental Monitoring Program (REMP) samples not the effluent LLDs.

HPPOS 221 further notes that when no LLD is identified, "the appropriate LLD is the *operational state of art* value used for laboratory measurements of environmental samples" and requires additional action by plant staff to identify and document the LLD and basis for selection The HPPOS 221 provides examples of environmental LLDs for Co-58, Co-60, and Cs-134 that are consistent with environmental water samples analysis LLDs provided in NUREG 1301 and 1302, but NUREG 1301 and 1302 do not provide any oil analysis LLDs. [11] [12] The regulations applicable to nuclear power reactor licensees do not provide for the release of materials that are known to be radioactively contaminated at any level.

The previous discussion focused the requirements and LLDs around tritium and carbon-14 in used oil and the need to perform an adequate radiological survey for release from licensed control, but there may be other hard to detect radionuclides in the oil. The NRC has established regulatory requirements in the Code of Federal Regulations 10 CFR § 61 "*Licensing Requirements for Land Disposal of Radioactive Waste*". [1] 10 CFR § 61.55 "*Waste Classification*" defines a waste classification system for shallow land disposal of radioactive waste. The regulation was written to implement the Low Level Waste Policy Act of 1980 (and as amended in 1985). [13]

The *NRC Branch Technical Position on Radioactive Waste Classification* describes methodologies that can be used to determine the presence and concentrations of radionuclides in radioactive waste. The use of process knowledge and establishment of correlations among radionuclides to determine the activity of hard-to-detect radionuclides is discussed. [14]

Similar to tritium and carbon-14, there are no environmental or effluent LLDs for the HTD radionuclides identified in 10 CFR § 61.55. Any detection of licensed material[3], regardless of the level detected, means that the material is radiologically contaminated and not suitable for release from licensed control. For HTD radionuclides the analyses are typically performed by vendor laboratories. The list of the HTD radionuclides and typical detection levels in oil or water is included in Table 2-1 with other radionuclides listed for comparison (Co-60, Cs-137, and Pu-239). These detection levels are based on laboratory reports obtained during this project. [15]

[3] Licensed material is defined as "Source material, byproduct material, or special nuclear material that is received, possessed, used, transferred, or disposed of under a general license or specific license issued by the NRC or Agreement States." [35]

*Table 2-1*
*Detection Levels for Hard to Detect Radionuclides and Key Radionuclides**

| Nuclide | Typical Detection Level (µCi/cc) | Typical Detection Level (Bq/L) |
|---|---|---|
| Co-60* | 3E-08 | 1.11 |
| Fe-55 | 3E-06 | 111 |
| Ni-63 | 3E-07 | 11.1 |
| Sr-90 | 3E-07 | 11.1 |
| Tc-99 | 2E-06 | 74 |
| I-129 | 2E-07 | 7.4 |
| Cs-137* | 2E-08 | 0.74 |
| Pu-239* | 4E-08 | 1.48 |
| Pu-238 | 1E-07 | 3.7 |
| Pu-241 | 5E-06 | 185 |
| Am-241 | 6E-08 | 2.22 |
| Cm-242 | 3E-08 | 1.11 |
| Cm-243 | 6E-08 | 2.22 |

The review of U.S. Nuclear Regulatory Commission regulations and guidance clearly establishes the expectations for the release of material from regulatory control. These can be summarized as follows:

1. There is no defined lower limit to activity that can be released from regulatory control. The radioactivity must be "non-detectable".
2. Surveys are required before any material can be released from regulatory control by a licensee. *Surveys must be "reasonable under the circumstances" and use the "operational state-of-the-art" for the method used.*
3. Surveys can include the use of process knowledge and relationships among radionuclides to establish presence and concentration. The use of these kinds of assessments *should be readily explained by the licensee and, ideally, documented for inspection and future reference*.
4. Environmental LLD's can be used as the basis for how hard to look for isotopes that are identified in NUREG 1301 and NUREG 1302 [11] [12] Because an environmental LLD for carbon-14 is not defined and the environmental LLD listed for tritium is for water and sediments and are not reasonably applicable for analysis of tritium in oil. Therefore, it is appropriate to consider the "*operational state of the art*" laboratory capabilities as a reasonable detection level for tritium and carbon-14 in oil under 10 CFR § 20.1501.

## 2.3 Laboratory Lower Limit of Detection considering U.S. NRC Regulations and Other Guidance

Plant X provided analysis data for samples of new, petroleum based oil analyzed using liquid scintillation counting (LSC) and shown in Table 2-2. The liquid scintillation counting for the tritium in oil samples was limited to 15 minutes resulting in much higher LLDs than the EPRI methodology is considering.

**Variations in Counting Equipment and LLDs**

The LLD achieved by liquid scintillation counters can vary depending on background fluctuations, chemiluminescence, static electricity, color quenching, and chemical quenching.

A common method for oil analysis includes the flashing of the oil sample into a vapor mixture that is collected and passed through a condenser resulting in a distillate. The oil sample size for these analyses is typically limited to ≤0.5 ml, which can be a limiting factor in the LLD determination. This distillate is collected and added to a sample vial with the liquid scintillation cocktail for counting.

*Table 2-2*
*New Oil Sample Data*

| Oil Type | Description | Sample number | Tritium (µCi/cm³, Bq/L) * | Carbon-14 (µCi/cm³, Bq/L) * |
|---|---|---|---|---|
| New Turbine Oil (Petroleum) | DTE 732 | 458073003 | <6.68E-05, <2.472E+03 | <1.04E-05, <3.85E+02 |
| New Turbine Oil (Petroleum) | Mobile Heavy Medium | 458073004 | <5.92E-05, <2.19E+03 | <9.53E-06, <3.53E+02 |
| New Turbine Oil (Petroleum) | Mobile Extra Heavy | 458073005 | <5.04E-05, <1.86E+03 | <1.13E-05, <4.18E+02 |
| New (synthetic, silicone) | Sullair 24KJ | 458073008 | <6.01E-05, <2.22E+03 | <1.02E-05, <3.77E+02 |
| New Chiller Oil (Petroleum-synthetic) | DTE 26 | 458073010 | <6.33E-05, <2.34E+03 | <9.33E-06, <3.45E+02 |
| 18-1867 (synthetic, phosphate) | Fyrquel New | 458073006 | <5.22E-05, <1.93E+03 | <8.93E-06, <3.30E+02 |

*Laboratory results were reported in µCi/g. Oil densities for the subject materials range from 0.85 g/cm³ to 1.16 g/cm³ [16] [17] [18] [19]. A density correction is not considered necessary for purposes of comparing the detection limits.

The NRC Staff has communicated general expectations for reasonable surveys for the release of oil in several public presentations and meetings in 2018 and 2019. Example LLDs ***(not criteria)*** for used oil were provided as follows based on NRC review of vendor laboratory information: [20]

- Tritium in Oil 1.00E-05 µCi/ml (370 Bq/L)
- Carbon-14 in Oil 5.00E-06 µCi/ml (185 Bq/L)

The example LLD's identified by the NRC are LLD's for oil analysis will vary between oil type, oil samples and different laboratory methodologies. Laboratory LLD will depend on the type of oil and condition of the oil where higher LLDs

may be calculated for used oil samples. It is noted that the actual LLD in an oil sample can be significantly higher as observed in the laboratory data provided for this report. [15] It is also noted that regardless of the actual LLD achieved, the laboratory capability for the specific analyte would define the "*state of the art.*"

**Lower Limit of Detection**

The lower limit of detection (LLDs) defined in this report are based on commercial laboratory feedback for a reasonable analysis considering oil condition, methodology, and counting requirements.

Since there are no environmental LLDs established for carbon-14 and the environmental LLD for tritium is related to drinking water rather than used oil, EPRI concluded the appropriate LLD is defined by the laboratory capability "*state of art*" and the analysis provided by the vendor laboratories and the associated LLDs are "*surveys reasonable under the circumstances*" in accordance with NRC regulations and guidance. [20] The key observations of the review are shown below.

**The release of used oil from regulatory control must be predicated on a reasonable survey or assessment sufficient to show the isotopes are not detectable at the laboratory capability (*operational state of art*), as discussed above.**

**Regulations clearly note; there is no lower limit on activity defined that exempts waste from regulation. [1] [13]**

**An environmental LLD for carbon-14 is not defined and the environmental LLDs listed are for water and sediments and are not reasonably applicable for analysis of tritium in oil. Therefore, it is appropriate to consider the "*operational state of the art*" laboratory capabilities.**

**Based upon interviews with commonly used laboratories (Appendix F and G) [21] [22] and input/presentations from NRC staff, EPRI believes that 7,000 pCi/L (259 Bq/L) for tritium and 5,000 pCi/L (185 Bq/L) for C-14 meets the "*operational state of art*" for the screening purposed of this methodology.**

# Section 3: Origin of Tritium and Carbon-14 in Nuclear Power Plants

## 3.1 Introduction

Tritium and carbon-14 are present in various systems within a nuclear power plant due to nuclear interactions such as fission and various activation processes. Although tritium and carbon-14 can also arise from natural processes such as cosmic particle interactions in the atmosphere, the anticipated concentrations would likely be below the detection capabilities used by most power plants. Anticipated background levels of tritium and carbon-14 in used oil resulting from natural production is discussed in Section 4 of this report.

## 3.2 Production of Tritium and Carbon-14 in BWRs and PWRs

The largest tritium source is produced by ternary fission and contained within the fuel cladding in both boiling water reactors (BWRs) and pressurized water reactor (PWRs) nuclear fuel. In both BWRs and PWRs, tritium is produced by neutron activation of the boron used in boron-carbide control rods and from the neutron activation of the natural occurring hydrogen-2 (deuterium) in the coolant water molecules. In PWRs, tritium is produced by neutron activation of the boron used as a chemical shim, and lithium used for pH control in the reactor coolant system (RCS).[4] [23]

There is the potential to generate tritium from neutron activation of oil used in nuclear plant equipment. Oil is approximately 14% hydrogen by weight with naturally occurring hydrogen consisting of 99.99% hydrogen-1 with the remainder being hydrogen-2 (deuterium). Tritium is produced from hydrogen-1 by a two-step thermal neutron activation process. (Table 3-1) There is a competing fast neutron reaction with hydrogen-2 producing hydrogen-1 that consumes some of the hydrogen-2 (H-2 (n,2n) H-1). (Section 4.2)

Carbon-14 is produced in the reactor environment by neutron activation of oxygen and nitrogen in the PWR and BWR RCS [24]. Production of carbon-14 from nitrogen is only of importance in PWRs as nitrogen is not present in

[4] Site specific terminology may refer to the primary coolant or reactor coolant. For the purposes of this report, references to reactor coolant are the same as primary coolant and the reports uses the acronym, RCS for both BWR and PWR coolant. In case of differences between PWR and BWR, the acronyms BWR, PWR, or both will proceed the RCS acronym.

significant concentrations in BWR reactor water. Carbon-14 production from neutron activation of carbon and nitrogen directly in oil in plant equipment is also possible. (Table 3-1)

*Table 3-1*
*Potential Tritium and Carbon-14 Neutron Activation Reactions*

| Tritium | Carbon-14 |
|---|---|
| B-10 (n, H-3) Be-8 | O-17 (n, α) C-14 |
| Li-3 (n, α) H-3 | N-14 (n, p) C-14 |
| H-2 (n, γ) H-3 | C-13 (n, γ) C-14 |
| H-1 (n, γ) H-2 | |
| H-2 (n,2 n) H-1 | |

## 3.3 Anticipated Concentrations of Tritium and Carbon-14 in the RCS

The highest tritium concentrations outside of the nuclear fuel cladding are associated with the BWR and PWR RCS because of the tritium production associated with these systems. Tritium concentrations in reactor coolant vary dependent on reactor type because of the differences in chemical shims, water make up rates, and other chemical species between the BWR and PWR RCS. Nuclear power plants routinely monitor the tritium levels in the RCS and based on responses to the EPRI questionnaire:

- BWR RCS concentrations ranged from 3E-4 μCi/cm$^3$ (0.01 MBq/L) to 5E-2 μCi/cm$^3$ (1.85 MBq/L).
- PWR RCS concentrations are several orders of magnitude higher, with tritium concentration ranging from 8E-1 μCi/cm$^3$ (29.60 MBq/L) to 4E+0 μCi/cm$^3$ (148 MBq/L).

The BWR and PWR RCS are not routinely analyzed for carbon-14. Carbon-14 production is estimated to be about 5.1 Ci/GW$_{th}$-yr (188.7 GBq/GW$_{th}$-yr). in BWRs, and 3.9 Ci/GW$_{th}$-yr (144.3 GBq/GW$_{th}$-yr) in PWRs. The chemical forms of carbon-14 in BWRs are carbon monoxide and carbon dioxide, of which 95% to 99% is removed by the off-gas system. In PWRs, carbon-14 is present in organic molecules such as methane, methanol, formaldehyde, and formic acid due to the reducing environment of the RCS. For PWRs, it is estimated that 90% to 98% of the carbon-14 is removed in the waste gas system. [25] EPRI data established RCS carbon-14 levels as a maximum of approximately 4E-06 μCi/cm$^3$ (1.5E-04 Bq/L) for the BWR and 8E-04 μCi/cm$^3$ (2.96E-02 Bq/L) for a PWR [24]. None of the plants responding to the EPRI questionnaire indicated that they have analyzed for carbon-14 in any of their plant systems on a routine basis. Oil waste sample data provided to EPRI as part of this study indicates that carbon-14 concentrations are consistently below the analysis LLD.

# Section 4: Process Knowledge and Oil Contamination Mechanisms

## 4.1 Introduction

There are five basic mechanisms for oil to become contaminated with radioactive material that were considered in this work.

- Incorporation of naturally occurring radioactive materials in the oil.
- Neutron activation.
- Diffusion of radioisotopes from atmospheric gases, vapor or aerosols.
- Contact with another contaminated liquid (e.g., water).
- Introduction of radioactive material from the surroundings during maintenance activities (contamination).

## 4.2 New Oil and Natural Background of Tritium and Carbon-14

Tritium (half-life of 12.3 years) and carbon-14 (half-life of 5,730 years) are present as naturally occurring radionuclides as a result of cosmic ray interaction in the upper atmosphere. Such atmospheric tritium and carbon-14 are available for incorporation into organic molecules during photosynthesis. Other radionuclides that are prevalent in nuclear power plant waste are not naturally occurring.

Petroleum-based oils are geologically old, and any tritium and carbon-14 captured within the hydrocarbon chain would have decayed to non-detectable levels by today. In petroleum based oils, the carbon is older than 50,000 years and is considered to no longer contain carbon-14. These materials are sometimes referred to as radio-carbon dead [26], [27], [28].

Bio-based oils are made from more recent organic material and may contain tritium or carbon-14 from natural sources. The expected concentration of tritium in bio-based oil would be 5.00E-09 to 9.00E-09 μCi/cm$^3$ (1.85E-01 to 3.33E-01 Bq/L) based on typical levels of tritium present in the atmosphere. Such concentrations would be below the laboratory LLDs identified in Appendix F and Appendix G of 5.0E-06 to 8.0E-06 μCi/cm$^3$ (185 to 296 Bq/L.).

The carbon-14 concentration in natural carbon is 6.1E-06 μCi/cm$^3$ (2.26E+02 Bq/L) [25]. This would correspond to a baseline concentration of carbon-14 in

**Future Application of Bio-based Oils**

The use of synthetic oils, or even bio-based oils, may warrant additional consideration for background contamination and should be reviewed by Radiation Protection and System Engineering prior to usage.

bio-oil of 3.60E-06 μCi/cm$^3$ to 4.90E-06 μCi/cm$^3$ (133 to 181 Bq/L). This concentration of carbon-14 is in the range of the LLDs identified in Appendix F and Appendix G of 5.00E-06 μCi/cm$^3$ (185 Bq/L) and may be detectable. Blended petroleum and bio-oil products are expected to contain carbon-14 at concentrations below the detection level due to dilution by the petroleum-based fraction.

The bulk majority of the oil products used at nuclear power plants (e.g., lubricating oil, cooling oil, hydraulic and insulating fluids, machining and cutting oils, fuel oils, etc.) are petroleum based products and fall into the American Petroleum Institute (API) Group 1, Group 2 or Group 3 classifications. Over the years, these oils have become more refined and the industry has seen a transition from the original API Group 1 oil (petroleum based) composition to more refined Group 2 or 3. API Group IV and V transitions to the polyalphaolefins[5] (synthetic base oils) [29]. The nuclear power plant industry is currently not using bio-based lubricating oils in systems, but has started evaluating the application of synthetic oils.

**This evaluation assumes that the industry continues to use petroleum based oils. If the industry were to transition to bio-based oils, this assumption may be revisited. However, the assumption of no contribution of tritium and carbon-14 from natural background sources is conservative if this transition were to occur. Plants may do periodic sampling of new oil to verify or update these assumptions.**

## 4.3 Tritium and Carbon-14 due to Neutron Activation of Oil

The neutron activation of elements in oil to tritium and carbon-14 is possible because oil is an organic compound consisting of hydrogen and carbon (hydrocarbon) with trace impurities and other chemical additives. The neutron activation reactions of interest are summarized in Table 3-1. Because naturally occurring hydrogen consists of 99.99 % abundance hydrogen-1 with the remainder being hydrogen-2 (deuterium) much of the neutron activation of hydrogen to tritium requires two steps. In addition, the competing reaction of deuterium to hydrogen-1 actually has a larger fast neutron cross section than the reaction that produces tritium. These factors decrease the expected activation of hydrogen to tritium. For carbon-14, naturally occurring carbon-13 has an abundance of 1.1% and the neutron cross section for production of carbon-14 from carbon-13 is quite low. This results in the majority of the carbon-14 production resulting from the activation of nitrogen (less than 0.1% of the carbon-14 is produced from activation of carbon-13).

A neutron activation calculation was performed using the ORIGEN[6] program to estimate the tritium and carbon-14 content in oil due to neutron activation. [30]

[5] Polyalphaolefins is a commonly used term for synthetic hydrocarbons that may be used in some plant systems or components.

[6] ORIGEN is a software code developed by Oak Ridge National Laboratories (ORNL) to perform decay, depletion, activation, and emission calculations.

For this calculation, oil was modeled as 86% carbon and 14% hydrogen by weight. An estimated neutron fluence was based on a value of 2.6E+07 n/cm$^2$ per second at the external surface of the bioshield at the center of the core. This value was adjusted to 1.5E+06 n/cm$^2$ per second based on the neutron flux at the vessel flange. A service period of six years was assumed for the oil with no adjustment for periods of reactor power derate or outages. Information on lubricating oil was used to establish the nitrogen content of oil as 50 ppm. [31] Using this assumed neutron flux and service history resulted in a calculated tritium concentration of 7.1E-09 µCi/cm$^3$ (0.26 Bq/L) and a carbon-14 concentration of 6.3E-09 µCi/cm$^3$ (0.23 Bq/L) in oil. (Table 4-1)

*Table 4-1*
*Tritium and Carbon-14 Production from Neutron Activation*

| Nuclide | Laboratory LLD, µCi/cm$^3$ (Bq/L) | Concentration from Neutron Activation, µCi/cm$^3$ (Bq/L) |
|---|---|---|
| Tritium | 7.00E-06 (259) | 7.1E-09 (2.63E-01) |
| Carbon-14 | 5.0E-06 (185) | 6.3E-09 (2.33E-01) |

These calculated values are well below the detection levels for tritium and carbon-14 of 7.0E-06 µCi/cm$^3$ (259 Bq/L) and 5.0E-06 µCi/ cm$^3$ (185 Bq/L), respectively.

**While there is the potential to generate tritium and carbon-14 from direct neutron activation of oil, this activation is not expected to lead to detectable levels in used oil.**

## 4.4 Tritium and Carbon-14 Contamination of Oil Due to Diffusion in a Contaminated Atmosphere and Ventilation Concerns

For plant systems that are in areas of the nuclear power plant that have airborne radioactivity, it is possible for tritium or carbon-14 to diffuse into the lubricating oil if the system is vented to the atmosphere. This phenomenon is limited to areas of the nuclear power plant that have significant airborne radioactivity levels such as the BWR drywell and reactor building and the PWR containment building and fuel building in the vicinity of the spent fuel pool. Personnel access to these areas is controlled and if the level of airborne activity approaches these assumed levels additional radiological controls are required. The diffusion process from the atmosphere to the oil is dependent on temperature and pressure and is slow at atmospheric pressure and temperature. A calculation was performed to establish expected tritium and carbon-14 levels associated with exposure of oil to airborne radioactivity. The calculation using Henry's Law requires the partial pressures of the gases of interest to be known in both the atmosphere and the other medium (oil). Since these are highly variable based on the type of oil and various temperatures and pressures, the calculation conservatively assumed that the concentration in the oil would equal the concentration in the air. There is no

mechanism for tritium or carbon-14 to concentrate in the oil. The calculation assumes airborne radioactivity levels of ten percent of a derived air concentration (DAC) for tritium and one percent of the DAC for carbon-14 and that the oil will be at equilibrium concentration with the airborne activity concentration. (Table 4-2)

*Table 4-2*
*Oil Contamination from Airborne Tritium and Carbon-14*

| Nuclide | DAC, µCi/ cm³ (Bq/L) | Airborne concentration, µCi/ cm³ (Bq/L) | Oil radioactivity concentration, µCi/ cm³ (Bq/L) | Laboratory LLD, µCi/cm³ (Bq/L) |
|---|---|---|---|---|
| Tritium | 2E-05 (7.4E+02) | 2E-06 (7.4E+01) | 2E-06 (74) | 7.00E-06 (259) |
| Carbon-14 | 9E-05 (3.33E+03) | 9E-07 (33.3) | 9E-07 (33.3) | 5.0E-06 (185) |

Nuclear power plants do not routinely count air samples for carbon-14 and carbon-14 is not expected to be present in air outside of the off-gas systems at significant levels. (Table 4-2) This calculation demonstrates that carbon-14 is not expected to be present at detectable levels in used oil due to diffusion from airborne carbon-14.

The calculated oil concentration for tritium is also below the detection level. (Table 4-2) This calculation demonstrates that tritium is not expected to diffuse into oil when plant areas are maintained in a ventilated condition. If plant areas are not ventilated and airborne tritium levels exceed ten percent of the DAC, tritium may diffuse from the atmosphere into the oil in plant equipment.

**The key observation considering the DAC assumptions for this report, is that tritium and carbon-14 contamination of oil due to atmospheric diffusion is not likely in ventilated areas of the plant.**

**Tritium and carbon-14 contamination of oil due to atmospheric diffusion is credible in the PWR containment and fuel building due to the higher RCS source term and less likely in the BWR drywell and reactor building.**

**Plant staff should review plant specific atmospheric tritium and carbon-14 concentrations to the LLDs to evaluate the potential for atmospheric contamination using Table 4-2 as an example.**

## 4.5 Tritium and Carbon-14 Contamination of Oil Due to Contact with Contaminated Liquid

### *4.5.1 Tritium*

The highest tritium concentration in the nuclear power plant environment is in the BWR or PWR RCS. There have been instances of detectable tritium in the BWR turbine cooling water and the PWR secondary system, but the concentrations in these systems are expected, if present at all, to be significantly lower than RCS concentrations. The diffusion of tritium through heat exchanger materials (BWR condenser or PWR steam generator) is most likely when the tritium is present as hydrogen ($H_2$). This will only be possible for the BWR or PWR RCS because this is the only system in which tritium may be present as diatomic hydrogen. Tritium would be available for interacting with secondary lubricating oil systems after diffusion from the BWR or PWR RCS. Tritium is typically present in the form of water molecules (HTO) in nuclear plant systems.

Oil and water do not mix well, and visible water can easily be separated from the oil, taking the tritium with the water. Oil can naturally contain trace dissolved water or some water that is emulsified within the oil which, in turn, potentially contains the tritium contaminant. Concentrations of tritium in other plant systems are lower than the RCS due to dilution, evaporation and radioactive decay.

A calculation was performed to estimate the level of tritium expected in oil if the oil has been in direct contact with contaminated aqueous liquid, assuming a water content (%) between 0.05 to 0.2 and RCS and PWR secondary coolant tritium levels. The level of tritium in oil will be dependent on the amount of water in the oil. Most NPPs limit the water content of oil to ensure that the oil performs its intended lubricating function and minimize the likelihood of damage to plant equipment. A typical dissolved water concentration in turbine lubricating oil is 500 ppm to 1000 ppm (0.05 to 0.1%). [4] In the EPRI survey, some sites reported action levels for dissolved water concentration as high as 2000 ppm (0.20%). Site specific values may have been adopted by plant maintenance and engineering programs based on vendor and site specific operating experiences depending on the specific plant components.

Based on the data supplied in the EPRI survey, Equation 4-1 is used to calculate the estimated oil tritium content using the source tritium range and dissolved water content range considering the different sources (BWR RCS, PWR RCS, and PWR secondary coolant) and documented in Table 4-3 with the following assumptions:

- The water content source is from the reactor coolant or PWR secondary coolant and conservative in nature.

- The water content for the calculations is based on a maximum water content of 0.2%.
- Water content is limited by the equipment vendor specifications, ASTM, and EPRI guidance and system equipment and components (turbine lubricating oil, hydraulic controls, large motors, and other oil lubricated systems) are operated within normal operating parameters.

Staff should review the assumptions from this work and use site specific values for these calculations based on a simple dilution calculation (Equation 4-1).

$$A_{Oil} = A_{Source\ Water}\ x\ WF_{Oil} \qquad \textit{Eq. 4-1}$$

Where:

$A_{Oil}$ = Tritium activity in oil, μCi/cm$^3$

$A_{Source\ Water}$ = Source water tritium activity, μCi/cm$^3$

$WF_{Oil}$ = Water fraction of oil

Figure 4-1 was developed using Equation 4-1 to estimate the activity in oils based on varying source water activities and water content in the oil. Using Figure 4-1, PWRs systems have the highest potential for tritium contamination in oil due to the higher RCS tritium concentrations. Some of the BWRs operating with higher levels of tritium have the potential for tritium contamination while the estimated PWR secondary system oil concentrations are below detection levels based on the secondary tritium concentrations of 7.1E-6 and 1.6E-4 μCi/cm$^3$ (262.7 – 5920 Bq/L). The limiting factor related to PWRs secondary side tritium concentration is when operating with known primary-to-secondary leakage across steam generator tubes where secondary side activity may exceed 1.75E-03 μCi/cm$^3$ (6.47E+04 Bq/L)[7].

[7] The activity of the PWR secondary coolant is dependent on the primary-to-secondary leak rate, RCS tritium and secondary makeup rates. The EPRI report *Steam Generator Management Program: PWR Primary-to-Secondary Leak Guidelines—Revision 4* provides additional details. [36]

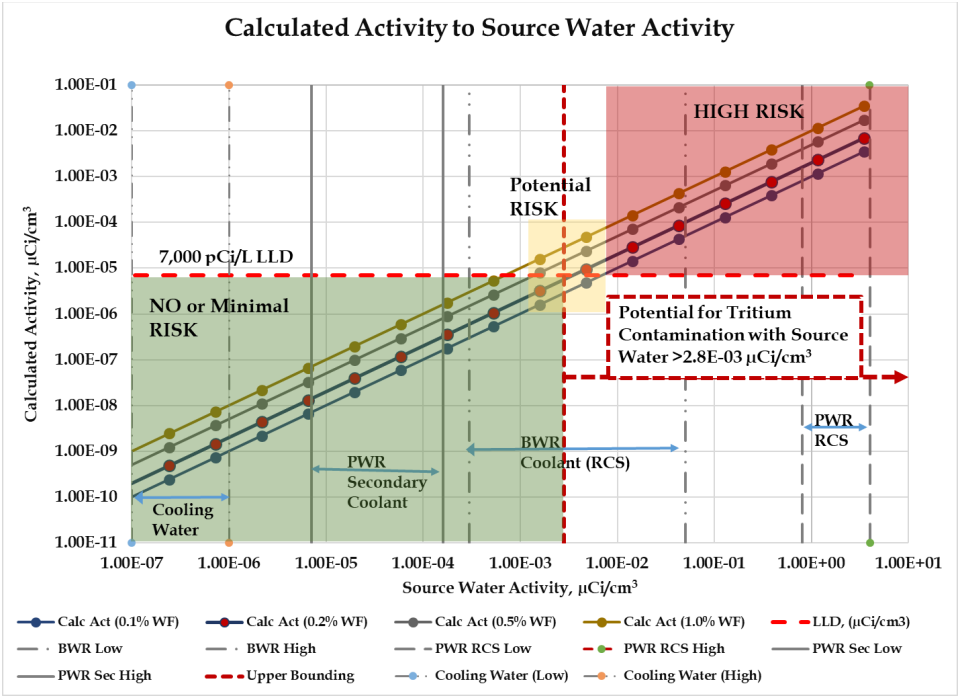


*Figure 4-1*
*Source Water to Calculated Activity in Oil based on Water Content*

The results of this calculation can be compared to the analytical *state of art* LLD of 7E-06 µCi/ cm³ (259 Bq/L) and presented in Table 4-3.

*Table 4-3*
*Tritium Contamination Due to Contact with Contaminated Liquid*

| Plant Type and System | Tritium, µCi/ cm³, (Bq/L) | Water Content (%) | Oil Tritium Content, µCi/ cm³, (Bq/L) |
|---|---|---|---|
| BWR RCS | 3E-04 – 5E-02 (1.11E+04 – 1.85E+06) | 0.05 - 0.2 | 1.5E-07 – 1.0E-04 (5.55 – 3700) |
| PWR RCS | 8E-01 – 4E+00 (2.96E+07 – 1.48E+08) | 0.05 – 0.2 | 4.0E-04 – 8.0E-03 (1.48E+04 – 2.96E+05) |
| PWR Secondary Coolant | 7.1E-06 – 1.6E-04 (262.7 – 5920) | 0.05 - 0.2 | 3.55E-09 - 3.2E-07 (0.13 – 11.84) |

Figure 4-1 identified a screening value of 2.80E-03 µCi/cc (1.04E+05 Bq/L)) assuming a water content of 0.2% and a "*state of art*" LLD of 7E-06 µCi/cc (259 Bq/L) with a margin of 80%. For plants that have different LLDs and/or water content limitations, Equation 4-2 may be used to calculate the screening value

considering the plant specific limits. Appendix C provides additional information on determining site specific screening values.

$$A_{Threshold} = \frac{A_{LLD}}{\left(\frac{WF}{100}\right)} \; x \; 0.8 \qquad \textit{Eq. 4-2}$$

Where:

$A_{Threshold}$ = Source water tritium activity threshold, µCi/cm$^3$

$A_{LLD}$ = Site defined LLD, µCi/cm$^3$

$WF_{Oil}$ = Water fraction of oil

Figure 4-2 provides a simple comparison chart on how different LLDs can impact the screening criteria using Equation 4-2.

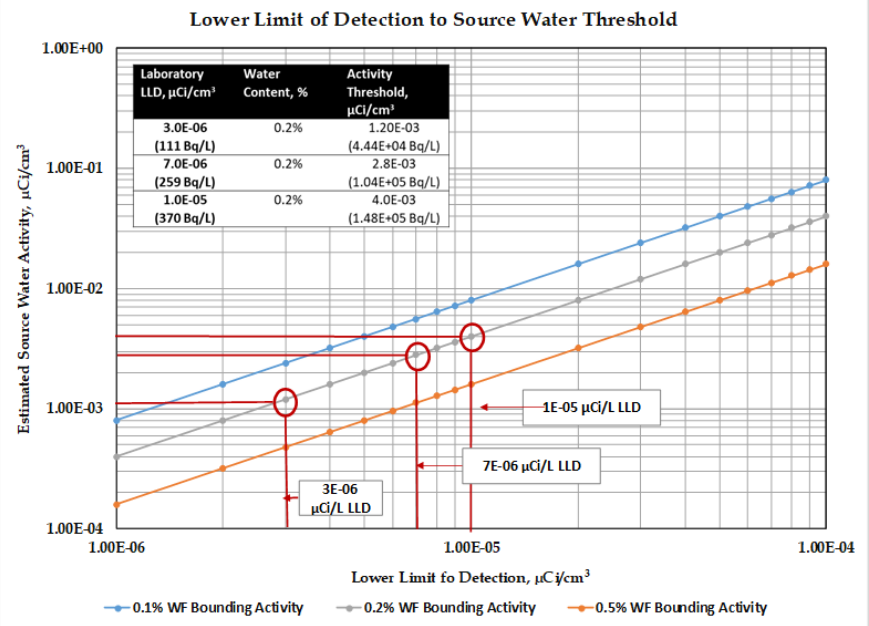


*Figure 4-2*
*Comparison of LLD Changes to Flow Chart Screening Activity*

Key observations from Table 4-3 using the activity and dissolved water content ranges listed.

1. **EPRI calculated the upper limit of RCS tritium concentration that would result in less than detectible tritium concentrations in oil. A simple concentration-volume dilution calculation was applied, assuming a water fraction in oil of ≤0.2% and a reasonable *state of art* laboratory LLD results in an upper limit of RCS tritium of 2.80E-03 (1.05E+05 Bq/L).**[8]
2. **Where water content of the oil is 0.2% and RCS tritium concentrations are >2.80E-03 (>1.04E+05 Bq/L), tritium may be present in the absence of detectable gamma emitters. Additional sample analysis to determine if tritium is present is likely warranted.**
3. **Based on survey data provided to EPRI and using an analytical LLD of 7E-06 µCi/ cm$^3$ (259 Bq/L), the calculation demonstrates that for systems with tritium concentrations <2.80E-03 (<1.04E+05 Bq/L) in the relevant plant systems with the dissolved water content within the identified ranges, some BWR's would <u>not</u> create oil contaminated with tritium above the analytical LLD, but PWRs likely would have additional samples due to the higher RCS tritium, but not for the systems associated with the PWR secondary coolant. (Figure 4-1)**
4. **Oil generated within the radiologically controlled area may not directly interface with reactor coolant system water but may interface with other systems with lower activity water similar to PWR secondary coolant and a site specific system analysis is required to make this determination.**

As part of the consideration of tritium content in oil, a decision flow chart was developed as shown in Figure 4-3 using the *state of art* LLD (7E-06 µCi/ cm$^3$ (259 Bq/L)) to calculate the source water activity screening value.

**Activity Screening Value**

The EPRI work assumes a reasonable *state of art* laboratory LLD for tritium in oil of 7E-06 µCi/cm$^3$ (259 Bq/L) and calculated the screening value with Equation 4-2. Appendix C provides an example on how to calculate the activity screening value using plant specific values.

[8] Staff should define site specific LLD's and water content based on maintenance records and calculate site specific values documenting the technical basis for the LLD's and water content

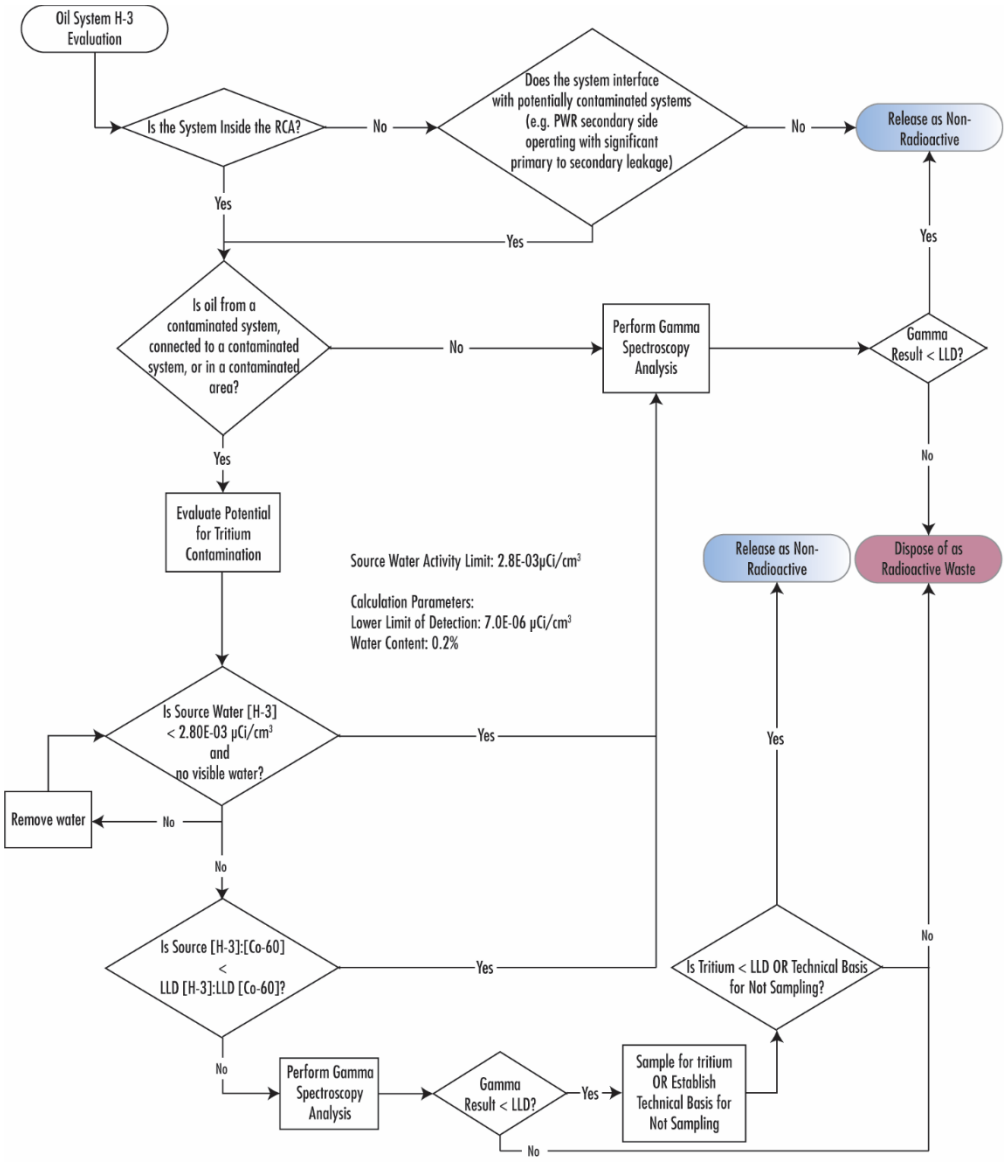


*Figure 4-3*
*Tritium Analysis Decision Matrix*

This flow chart shown in Figure 4-3 is a tool to assist station personnel in applying the methodology described in this report to determine when additional sampling is prudent in the absence any detectable gamma-emitting radionuclides.

The flow chart is based on the practice of analyzing used oil samples for gamma emitting radionuclides and the expected relative abundance of tritium and cobalt-60. Under very conservative assumptions, for some BWRs it is expected that the presence of detectable tritium would be accompanied by the presence of detectable levels of gamma emitting radionuclides (cobalt-60 or cesium-137). The determination of whether to sample for tritium in the absence of detected gamma emitters is driven by a high source water tritium level (>2.80E-03 uCi/cc

(<1.04E+05 Bq/L)) or the ratio of source water tritium to cobalt-60 being higher than the ratio of the LLDs for tritium to cobalt-60 in oil.

Based on survey results, for PWRs, oils that come into contact with the RCS are likely to require additional sampling for tritium in the absence of detectable gamma emitting radionuclides or the application of other site-specific factors and process knowledge to rule out the need for additional sampling.

Figure 4-3 allows for station personnel to develop a site-specific process and using Figure 4-3 to aid in the development of a site specific technical basis for the process knowledge application capturing the basic steps discussed below.

1. Identify plant oil systems that interface with contaminated and potentially contaminated systems within the radiologically controlled area. This flow chart assumes that the oil is segregated by system and/or components to properly evaluate the tritium sample requirements or for the application of a site specific technical basis that exempts oil from tritium analysis.
    a. Assumptions should include an evaluation of the water fraction (dissolved water content) allowed for normal operations in the oil systems and understanding the source water activity ranges.
    b. The EPRI methodology has identified that 7.0E-06 uCi/cc as the *state of art* for detection of tritium in oil in optimal conditions. See Appendix F and Appendix G for laboratory documentation establishing this limit. When an oil sample is sent to a laboratory for analysis, the actual LLD may be different as indicated by the sample results documented in the Appendices. Appendix C provides the methodology needed if the site desires to use a different LLD.
2. For systems outside the radiologically controlled area (RCA), the answer is straight forward. If the oil system does not interface with a contaminated system, the system is exempt, and oils should be discharged as non-radioactive per site procedures. An example is transformer oil systems.
3. For systems inside the RCA or for systems that did meet Step 2 above, the questions are:
    a. Is the oil from a contaminated system, is the oil in a system connected to a contaminated system, or is the oil in a contaminated area? If no, perform a gamma analysis and if gamma emitters are not detected, the oil is disposed of as non-radioactive waste, if gamma emitters are detected, the oil is disposed of as radioactive waste.
    b. If the answer to the question above is yes, then the oil must be evaluated for potential tritium contamination.

**Source Water**

The assumption that the source of tritium contamination is reactor coolant is based on the fact that oil originates in the radiologically controlled areas is conservative but may not be valid.

Evaluation of site specific systems may reveal that oil interfaces with component cooling water or other systems not related or connected to the reactor coolant system. It is expected that the tritium concentration in these systems are much lower than reactor coolant system and should not have detectable tritium.

4. Evaluate for potential tritium contamination:
   a. If the **source water** tritium is <2.8E-03 µCi/cm$^3$ (<1.04E+05 Bq/L) ***and*** there is no visible water in the oil, then the concentration of tritium in the dissolved water of the oil will not be detectable at the current *state of art* technologies. Perform a gamma analysis and if no detectable gamma emitters are present, the oil can be disposed of as non-radioactive waste.

      If detectable gamma emitters are present, the oil is disposed of as radioactive waste.

   b. If the source tritium water is >2.8E-03 µCi/cm$^3$ (>1.04E+05 Bq/L) ***OR*** there is visible water;

      i. Remove the water and repeat step 4 OR

      ii. Proceed to Step 5.

5. If the ratio of tritium to cobalt-60 in the source water tritium is less than the ratio of the tritium LLD to the cobalt-60 LLD, then cobalt-60 will be detected before tritium can be detected at the current *state of art*.
   a. If Yes, perform a gamma analysis and if no detectable gamma emitters are present, the oil can be disposed of as non-radioactive waste.

      If detectable gamma emitters are present, the oil is disposed of as radioactive waste.

   b. If No, then additional screening is necessary. Proceed to Step 6.

6. Either ***analyze the oil*** for tritium OR ***establish and document*** a technical basis discussing the plant specific conditions as to why analysis for tritium is not required.
   a. If tritium is detected, the oil is disposed of as radioactive waste.

   b. If tritium is not detected or a technical basis exists that exempts the oil sample from tritium analyses, the oil may be released as non-radioactive waste.

### *4.5.2 Carbon-14*

For systems contaminated with carbon-14 due to contact with contaminated liquid, as discussed in the tritium section above (Section 4.4.1), the carbon-14 content in oil would be bounded by the carbon-14 content in the system liquid. The BWR and PWR RCS are expected to contain the highest carbon-14 levels. Using Equation 4-1, a calculation was performed based on the oil not containing visible water and limiting the water content in the oil to from 0.05% to 0.2% as described above with the results captured in Table 4-4.

*Table 4-4*
*Cabon-14 Contamination Due to Contact with Contaminated Liquid*

| Plant type and system | Carbon-14, µCi/ cm³*, (Bq/L) | Oil water content (%) | Oil Carbon-14 content, µCi/ cm³ (Bq/L) | LLD, µCi/ cm³ (Bq/L) |
|---|---|---|---|---|
| BWR RCS | 4E-06, (148) | 0.05-0.2% | 2E-09-8E-09, (7.4E-02 - 3E-01) | 5.0E-06 (185) |
| PWR RCS | 8E-04, (29,600) | 0.05-0.2% | 4E-07-1.6E-06, (14.8 - 59.2) | 5.0E-06 (185) |

*Calculated values from EPRI report [24]

The results of this calculation can be compared to the analytical LLD of 5E-06 µCi/ cm³ (185 Bq/L).

**This calculation demonstrates that the oil associated with the PWR and BWR RCS is not expected to have detectible carbon-14 if the assumptions described above for water content in oil and RCS carbon-14 levels are less than or equal to the values identified in** Table 4-4**.**

As with the discussion for tritium contamination due to contact of oil with a contaminated liquid, the reactor coolant case is the limiting activity source because other plant systems are expected to contain lower concentrations of carbon-14.

## 4.6 Contamination of Oil with Hard to Detect Radionuclides other than Tritium and Carbon-14

Tritium and carbon-14 are not the only HTD radionuclides that may be present in oil. In order to address the issue of adequate surveys for used oil, this section considers other hard to detect (HTD) radionuclides. These radionuclides are routinely measured in waste samples from nuclear power plant for demonstration of compliance with Title 10 Code of Federal Regulations 10 CFR § 61. [1] Nuclear Power Plants (NPPs) have extensive data available for assessment of waste HTD radionuclide content.

**Contamination of oil with HTD radionuclides (e.g., iron-55 and nickel-63) other than tritium and carbon-14 is not likely from diffusion from airborne contaminates because these radionuclides are expected to be present as particulates.**

These HTD radionuclides are likely to be present in the PWR and BWR RCS. Work in the NPP RCA may result in contamination of plant areas and contaminated tools and equipment that may include HTD radionuclides.

**However, the most likely method of contamination of oil with HTD radionuclides (e.g., iron-55 and nickel-63) is through cross contamination during maintenance activities including change out of oil in plant equipment or**

**via direct contact with contaminated water. In either case it can be demonstrated that the ratios of the HTDs relative to gamma emitters is such that gamma emitters would be detected if the HTDs are present.**

Nearly all HTD radionuclides scale reliably to cobalt-60 with the exception of technetium-99 and iodine-129. When the data for a radionuclide of interest and a key radionuclide are compiled for the waste streams at a NPP, the scaling factor can be computed as a geometric mean of the data set. The associated dispersion (computed as the standard deviation of the geometric men) provides a measure of the variability in the data set. A regression analysis can be performed on the data set as a measure of the statistical robustness of the correlation between the concentrations of the two radionuclides. [32] These data can be plotted to provide a visual representation of the data. Example plots are provided in Figure 4-4 for iron-55 scaled to cobalt-60 and in Figure 4-5 for nickel-63 scaled to cobalt-60. Note: each plant should develop site specific plots related to the specific radionuclides. The scaling factors from this data set are consistent with and bounded by the values included in Table 4-5. The regression plots include the slopes of 0.905 for the iron-55 plot and 0.843 for the nickel-63 plot. These values are both equivalent to a slope of one at the 95 percent confidence level. This demonstrates that the correlation of the nuclides is supported by statistical analysis. Similar plots can be generated for other radionuclides of interest.

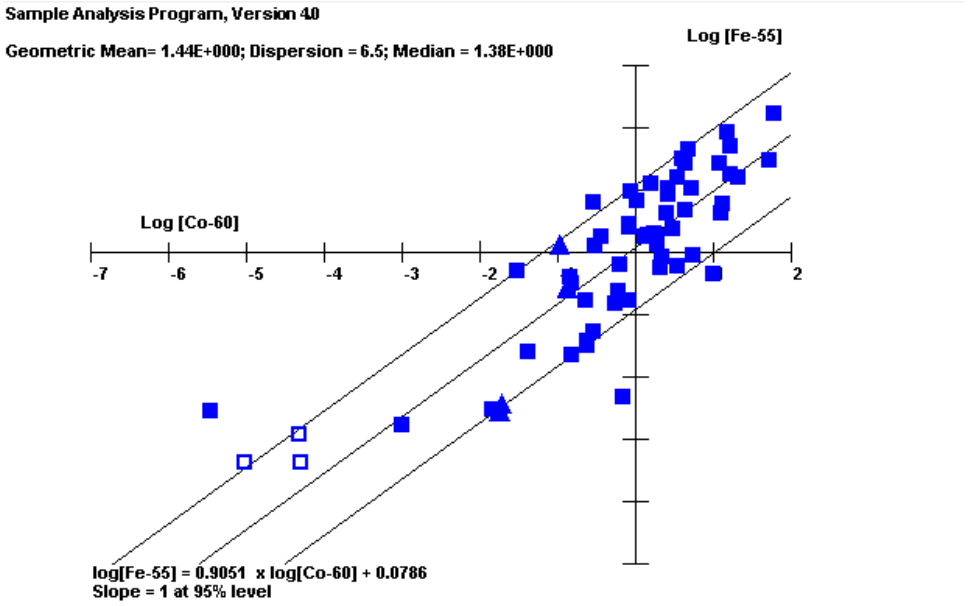


*Figure 4-4*
*Regression Plot for Iron-55 Scaled to Cobalt-60*

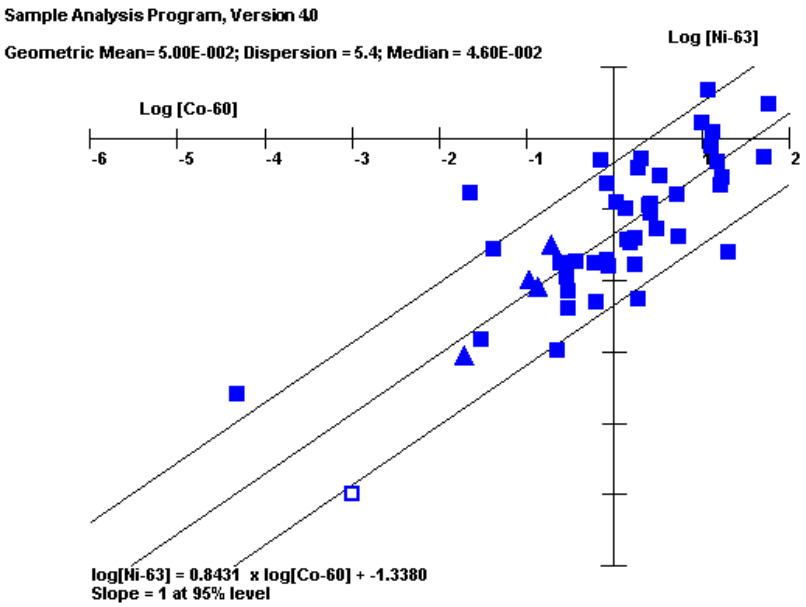


*Figure 4-5*
*Regression Plot for Nickel-63 Scaled to Cobalt-60*

This is demonstrated in Table 4-5 for nuclides that are typically reported by NPPs. This table includes the typical scaling factors for the radionuclides and the typical detection level for these radionuclides in waste samples. The scaling factors are used with the cobalt detection level to calculate the concentration of the HTD radionuclides with cobalt-60 at the environmental detection level.

**The calculated concentrations of the HTD nuclides are less than the reported detection levels for the HTD radionuclides. As such, if Co-60 is not present at detectible levels, then the HTD nuclides will not be present at detectible levels.**

*NOTE: Table 4-5 is an example table only and should be used by plant staff for plant specific scaling factors. Plant staff should generate the data based on plant specific information.*

*Table 4-5*
*Example Hard to Detect Radionuclide Data*

| Nuclide | Typical scaling factor | Typical Detection level, μCi/cm³ (Bq/L) |
|---|---|---|
| Co-60 | 1 | 3E-08 (1.11) |
| Fe-55 | 3 | 3E-06 (111) |
| Ni-63 | 0.5 | 3E-07 (11.1) |
| Sr-90 | 3E-03 | 3E-07 (11.1) |
| Tc-99 | 3E-05 | 2E-06 (74) |
| I-129 | 3E-06 | 2E-07 (7.4) |
| Cs-137 | NS | 2E-08 (0.74) |
| Pu-239 | 3E-06 | 4E-08 (1.48) |
| Pu-238* | 0.9 | 1E-07 (3.7) |
| Pu-241* | 1.5E+02 | 5E-06 (185) |
| Am-241* | 0.8 | 6E-08 (2.22) |
| Cm-242* | 1.4 | 3E-08 (1.11) |
| Cm-243* | 1.1 | 6E-08 (2.22) |

* Scaled to Pu-239.

Additional information related to the HTD radionuclide content of used oil samples from nuclear power plants is discussed in Section 4.6.

## 4.7 Oil Segregation and Composite Sampling

The methodology described in this report can be supplemented by an effective oil segregation program. This methodology should be utilized to identify oils at risk of containing detectable levels of tritium in the absence of gamma emitting radionuclides. An effective oil segregation program should ensure that these oils are not mixed with oils that could contain detectable levels of tritium when gamma emitting radionuclides are not detected.

At a minimum, oils generated outside the RCA should be kept separate from oils generated inside the RCA. Application of process knowledge to determine RCA systems that actually have interfaces with reactor coolant and which do not can be utilized to further improve segregation practices and thereby reduce the amount of required sampling.

For oil that may contain tritium when gamma is not detected, composite samples may be utilized to optimize the amount of off-site analysis that is required.

If a nuclear plant has routinely performed sampling of used oil, the existing data may be sufficient to justify current practices for used oil segregation. Periodic sampling is prudent for nuclear plants that have not sampled used oil in the past to verify the technical basis for the evaluation for HTD radionuclides in used oil.

**The use of process knowledge with a strict method of control of oil segregation will minimize the need for sampling. Based on the data provided and analyzed for this report some sampling of used oil is appropriate (needed).**

# Section 5: References and Bibliography

## 5.1 References

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# Appendix A: Member Survey Data Analyses

In April 2018, EPRI forwarded a questionnaire to the nuclear industry seeking information related to the management and disposition of used oil at nuclear power plants including survey and radiological analyses techniques used. A copy of that questionnaire is included as Appendix B of this report. A total of nine BWRs and fifteen PWRs provided responses to the EPRI questionnaire. The EPRI questionnaire includes questions to assess the quantities of used oil generation, identify current industry practices related to oil analysis, and establish current industry methodologies to disposition used oil. The participant plants were assigned a code for inclusion in this report. The reported oil generation quantities are summarized in Table A-1 by plant ID.[9]

The responses to the EPRI survey were interpreted to establish the volumes provided in Table A-1 for comparison between utilities. Some notes about the data formatting.

- Volumes reported in cubic feet or liters were converted to gallons.
- Volumes reported over multiple year intervals were converted to annual generation rates.
- For volumes reported as ranges a mid-range value was assigned.

The EPRI survey responses indicated that the potential for tritium and/or carbon-14 activity in used oil is determined based on the water content as determined by ASTM/ANSI analyses of oil quality. One large utility conservatively assumes a water content of 1% in used oil for scaling tritium activity in used oil. Another utility indicated that they assumed a water content of 0.1% and applied scaling factors based on that.

Responses to the EPRI questionnaire provided some information on the concentrations of gamma emitters and tritium in water from plant systems and in used oil.

[9] The oil densities for the expected power plant lubricating oils range from 0.85 g/cm$^3$ to 1.16 g/cm$^3$. [16] [17] [18] [19] A density correction is not considered necessary for purposes of comparing the detection limits.

- BWRs cobalt-60 concentrations in the water ranged from 2E-03 µCi/cm$^3$ (7.4E+04 Bq/L) to6E-02 µCi/cm$^3$ (2.22E+06 Bq/L).
- BWR tritium concentrations ranged from <3E-04 µCi/cm$^3$ (1.11E+04 Bq/L) to 5E-02 µCi/cm$^3$ (1.85E+06 Bq/L).
- Cobalt-60 concentrations in used oils ranged from 4E-09 µCi/cm$^3$ (0.148 Bq/L) to 7E-06 µCi/cm$^3$ (259 Bq/L).
- BWR tritium in used oils was typically not detectable.

Responses from PWRs included similar data.

- Cobalt-60 concentrations in water from plant systems ranging from 3E-05 µCi/cm$^3$ (1.11E+03 Bq/L) to 5E-02 µCi/cm$^3$ (1.85E+06 Bq/L).
- Tritium concentrations ranged from 8E-01 µCi/cm$^3$ (2.96E+7 Bq/L) to 4E+00 µCi/cm$^3$ (1.48E+8 Bq/L).
- Cobalt-60 concentrations in used oils ranged from <1E-08 µCi/cm$^3$ (0.37 Bq/L) to 1E-05 µCi/cm$^3$ (370 Bq/L).
- Tritium in used oils ranged from non-detectable to 1E-05 µCi/cm$^3$ (370 Bq/L).

These results from both BWRs and PWRs represent reduction of four to eight orders of magnitude in the transfer of tritium from water to used oil.

The survey requested volumes to be reported by equipment systems with the volumes to be reported as “considered clean”, “retained as waste” or “treated as potentially contaminated”. Most utilities did not report data by plant system so a single used oil volume was determined for each of the three categories included in Table A-2. This was done to facilitate comparison between the plants.

*Table A-1*
*EPRI Survey Response Oil Generation Rate Summary*

| Plant ID | NSSS Design | Potentially Contaminated, gal/yr (L/yr) | Dispositioned as Contaminated, gal/yr (L/yr) | Turbine Building or Not Potentially Contaminated, gal/yr (L/yr) |
|---|---|---|---|---|
| Plant A | PWR | 295 (1116.6) | 215 (813.8) | NS |
| Plant B | PWR | 500 (1892.5) | 500 (1892.5) | 1500 (5678) |
| Plant C | PWR | 50 (189) | 50 (189) | 6239 (23,614) |
| Plant D | PWR | 100 (378) | 100 (378) | 8300 (31415) |
| Plant E | BWR | 5000 (18,925) | 3100 (11,733) | 2000 (7570) |
| Plant F | PWR | | 110 (416) | |
| Plant G | BWR | | 90 (340.6) | |
| Plant H | PWR | 110 (416) | 110 (416) | |
| Plant I | PWR | 250 (946) | 250 (946) | |
| Plant J | PWR | | 800 (3028) | <200 (<757) |
| Plant K | PWR | 1400 (5299) | 550 (2081) | |
| Plant L | PWR | 1950 (7381) | 330 (1249) | 2600 (9841) |

*Table A-1 (continued)*
*EPRI Survey Response Oil Generation Rate Summary*

| Plant ID | NSSS Design | Potentially Contaminated, gal/yr (L/yr) | Dispositioned as Contaminated, gal/yr (L/yr) | Turbine Building or Not Potentially Contaminated, gal/yr (L/yr) |
|---|---|---|---|---|
| Plant M | PWR | 2200 (8327) | 1600 (6056) | 600 (2271) |
| Plant N | BWR | 1650 (6245) | 550 (2081) | |
| Plant O | PWR | 750 (2349) | 400 (1514) | 1000 (3785) |
| Plant P | BWR | | 30 (113.6) | |
| Plant Q | PWR | 5200 (19,682) | 2200 (8327) | 2350 (8895) |
| Plant R | BWR | | 9500 (35,958) | |
| Plant S | BWR | 1400 (5299) | 1400 (5299) | 3500 (13,247) |
| Plant T | BWR | 1550 (5867) | 1550 (5867) | |
| Plant U | PWR | 31,500 (119,227) | 1500 (5678) | 30,000 (113,550) |
| Plant V | PWR | 51,700 (195,685) | 1700 (6435) | 50,000 (189,250) |
| Plant W | PWR | 54 (204.4) | 54 (204.4) | 1900 (7192) |

The EPRI survey included a set of categories for how plants disposition used oil and distinctions were to be provided for systems considered to be free of radioactivity or designated as contaminated. This question was intended to determine the degree to which process knowledge was being applied by the industry and to determine if practices were in place for segregation of used oil as part of the used oil evaluation process. A second inquiry was included for the type of used oil analysis performed prior to the release of used oil.

The utility respondents did not interpret these categorization processes consistently. Most utilities categorize oil from equipment as clean, contaminated or potentially contaminated. Gamma spectroscopy analysis was the most common used oil evaluation practice for release. In several instances, used oil from outside the RCA is not further analyzed. Used oil was only analyzed for tritium in some limited cases and if water was visible in the oil, the water was decanted and analyzed for tritium. It was noted that some of the utilities noted that they do not release oil from the RCA.

*Table A-2*
*EPRI Survey Response Application of Process Knowledge*

| Plant ID | Identify Clean Systems | Release Without Analysis | Systems Treated as Radwaste | Analyze for Gamma Emitters | Analyze for H-3 or Carbon-14 |
|---|---|---|---|---|---|
| Plant A | | | Yes | Yes | |
| Plant B | Yes | Yes | | Yes | No |
| Plant C | Yes | | | Yes | H-3 |
| Plant D | | | | Yes | H-3 |
| Plant E | Yes | Yes | Yes | Yes | H-3 |
| Plant F | Yes | Yes | | | |
| Plant G | Yes | | Yes | | |
| Plant H | Yes | Yes | Yes | Yes | |
| Plant I | Yes | Yes | Yes | Yes | |
| Plant J | Yes | Yes | Yes | Yes | |
| Plant K | Yes | Yes | Yes | Yes | H-3 |
| Plant L | Yes | Yes | | Yes | |
| Plant M | Yes | Yes | | Yes | |
| Plant N | Yes | Yes | | Yes | |
| Plant O | Yes | Yes | Yes | Yes | |
| Plant P | Yes | Yes | | Yes | |
| Plant Q | Yes | Yes | Yes | Yes | |
| Plant R | Yes | | Yes | | |
| Plant S | Yes | Yes | Yes | Yes | |
| Plant T | | | Yes | | |
| Plant U | Yes | Yes | Yes | Yes | |
| Plant V | Yes | | | Yes | H-3 |
| Plant W | Yes | | Yes | Yes | |

As can be seen from Table A-2, the analysis for tritium is rarely performed and analysis for carbon-14 is not reported. The survey noted that the most common disposition for used oil is incineration at a radioactive waste processor. Tritium and carbon-14 are typically calculated using scaling factors consistent with existing station and industry practices for processing radioactive waste.

The analytical sensitivity specified is typically from the radiological effluent procedure or the offsite dose calculation manual. Typical LLDs noted on the surveys are listed in Table A-3 as reported by Plant L and Plant B

*Table A-3*
*Analytical LLDS for Oil Sample Analysis*

| Nuclide | Plant L Lower limit of detection (LLD), µCi/mL (Bq/L) | Plant B Lower limit of detection (LLD), µCi/mL (Bq/L) |
|---|---|---|
| Mn-54 | 5E-07 (18) | 1.5E-8 (0.555) |
| Fe-59 | 5E-07 (18) | 3.0E-8 (1.11) |
| Co-58 | 5E-07 (18) | 1.5E-8 (0.555) |
| Co-60 | 5E-07 (18) | 1.5E-8 (0.555) |
| Zn-65 | 5E-07 (18) | 3.0E-8 (1.11) |
| Zr-95 | 5E-07 (18) | 3.0E-8 (1.11) |
| Nb-95 | 5E-07 (18) | 1.5E-8 (0.555) |
| I-131 | 5E-07 (18) | NE |
| Cs-134 | 5E-07 (18) | 1.5E-8 (0.555) |
| Cs-137 | 5E-07 (18) | 1.8E-8 (0.555) |
| Ba-140 | NE* | 6.0E-8 (2.22) |
| La-140 | NE | 1.5E-8 (0.555) |

*NE – not evaluated

These LLDs have been established for liquid effluents and are typically applied for flowable materials released from the RCA. There are no LLDs established specifically for tritium and carbon-14 in oil and some plants responded that a tritium concentration LLD was based on the drinking water LLDs. Carbon-14 is not included in the liquid effluent analysis and reporting process so there is no LLD for carbon-14. [33] The analytical sensitivity in oil samples was reported by utility B based on information from an analytical vendor as 3500 pCi/L (129.5 Bq/L) for tritium and 8000 pCi/L (296 Bq/L) for carbon-14. This analytical vendor also reported that extended count times could be used to achieve LLDs of 3000 pCi/L (111 Bq/L) and 3500 pCi/L (129.5 Bq/L) for tritium and carbon-14 respectively.

For the BWRs responding to the EPRI survey, the annual volumes of contaminated used oils ranged from 31 gal/yr (117 L/yr) to 9,500 gal/yr (35,957

L/yr) with a median volume of 1400 gal/yr (5299 L/yr). Many of the BWR plants did not specify oil volumes by plant system. BWR systems that were listed included turbine lubricating oil, radioactive used oil separators, radioactive waste sumps, oil skimmers, electro-hydraulic (EH) oils, hydraulic fluids and cutting and machining oil from maintenance shops. The maximum volume of contaminated oil identified by a BWR as originating from a single system was 7,000 gal/yr (26,495 L/yr) of turbine lubricating oil. Figure A-1 provides a plot showing the distribution of the BWR data.

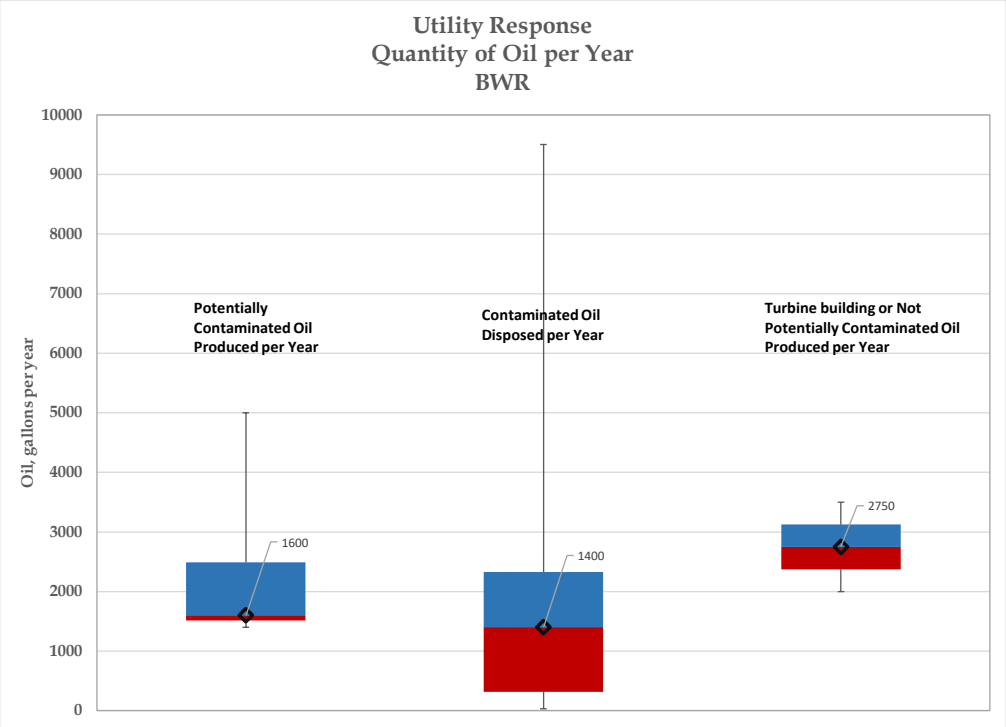



*Figure A-1*
*Survey Responses – BWR*

All eight of the BWRs which responded to the EPRI survey indicated that they analyze used oil onsite for gamma-emitting radionuclides. The detection sensitivities correspond to the free-release LLDs for surveying environmental samples collected as part of the Radiological Environmental Monitoring Program (REMP).

Responses from PWRs indicated annual volumes of contaminated used oils ranging from 50 gal/yr (189 L/yr) to 2,244 gal/yr (8494 L/yr), with a median volume of 365 gal/yr (1381.5 L/yr). As with the BWREs, many of the PWR responses did not include information on the plant system. The PWR systems that were listed included reactor coolant pump motors, charging pump motors, radioactive used oil separators, radioactive waste sumps, oil skimmers and snubber fluids. The maximum volume of contaminated oil associated with a PWR system was 1,628 gal/yr (6162 L/yr) for the reactor coolant pumps. Most PWR plants responding to the survey consider their secondary side as not

containing contaminated oil. Figure A-2 provides an overview of the PWR survey responses.

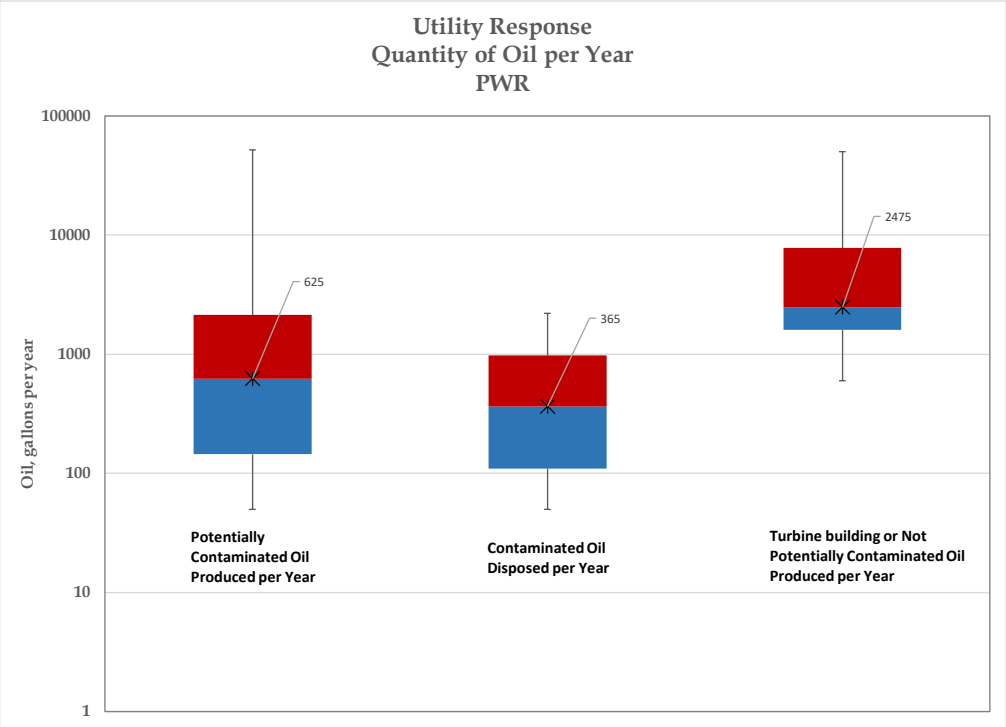



*Figure A-2*
*Survey Response Distribution - PWR*

Eleven of the fifteen PWRs also responded that used oil is analyzed onsite to the REMP LLDs. One nuclear power plant outside of the United States indicated that used oil was analyzed to a detection sensitivity of 500 pCi/L (5E-07 $\mu Ci/cm^3$, 18 Bq/L), a level which in the USA would correspond to the LLDs used for surveying radioactive liquid effluents. One PWR indicated using an LLD that corresponded to 1/100th (e.g., 1%) of the concentration limits specified in the NRC Branch Technical Position for classification of Class A radioactive waste. [14]

None of the licensees responding to the survey indicated that routine surveys for tritium and carbon-14 were applied on every sample of used oil. Eight licensees from a large multi-site utility, including both BWRs and PWRs, indicated a standard practice of submitting a biennial representative sample of used oil to a vendor laboratory for analysis of tritium and carbon-14. The LLDs achieved by the vendor lab were typically in the range of 5,000 pCi/L (5E-06 µCi/mL, 185 Bq/L) for tritium and 7,000 pCi/L (7E-06 µCi/mL, 259 Bq/L)) for carbon-14.

The CANDU Owners Group (COG) reported practices used in Canada regarding tritium and carbon-14 in used oil. [34] Due to the much higher concentrations of tritium and carbon in the heavy-water environment of CANDU reactors, these nuclides are often detected in used oil. Based on their

studies, concentrations of tritium and carbon-14 in used oil were highly dependent on the water content of the oil. Significant reductions in concentrations of tritium and carbon-14 were achieved by removing the water from the oil and through the use of vacuum degasification. Much of the tritium in the used oil was associated with the hydroxyl group of the oil additives, rather than the oil hydrocarbon chain and was dependent on the amount of time the oil was in contact with the water.

Some responses indicated that licensees use scaling factors to determine the activity of HTD radionuclides from the detected gamma activity. One large multi-site utility and three single-site utilities scale carbon-14 activity in used oil to cobalt-60 activity. Two single-site utilities scale tritium activity to cesium-137 activity and scale carbon-14 to cobalt-60. No basis was provided for using different gamma emitters as key nuclides for tritium and carbon-14.

# Appendix B: Member Survey

**EPRI Member Survey**
**Tritium and Carbon-14 in Nuclear Power Plant Used Oil**

Plant Name: _____
Name of Person Providing Response: _____
Reactor Type: PWR: _____BWR: _____PHWR: _____
Phone # and Email for EPRI Follow-Up: _____

## GENERATION OF USED OIL

This section of the questionnaire is designed to obtain information regarding where used oil is generated in the nuclear power plant (NPP) and approximate volumes generated per year. Please provide a general description of where (in which systems and components) oil is used at your nuclear power plants. The following are examples systems – please add systems from your own plant/plant type (either PWR, BWR, PHWR, etc.)

| Major System/Oil Source | Total Used Oil Volume Generated volume/year | Radiologically Contaminated Oil Volume Generated volume/year | Oil from These Sources Are Considered as Non-Contaminated |
|---|---|---|---|
| Turbine System Lubricating Oil | | | |
| Other Large Component Lubricating Oil (List on open rows below) | | | |
| | | | |
| | | | |
| Oil Skimmers | | | |
| Oil Clarifier Waste | | | |
| Rad Used Oily Waste Separators, and Sump Oils | | | |
| Cutting, Machining, or Maintenance Shop Oils/ Oily Waste, etc. | | | |
| Hydraulic Oils/Fluids – Main Turbine, Other Control Systems (List on open rows below) | | | |
| | | | |

| Major System/Oil Source | Total Used Oil Volume Generated volume/year | Radiologically Contaminated Oil Volume Generated volume/year | Oil from These Sources Are Considered as Non-Contaminated |
|---|---|---|---|
| | | | |
| Waste Fuel Oil, Fuel Oil Tank Sludge, Fuel Oil Tank Bottom Water | | | |
| Waste Heating Oil, Heating Oil Tank Sludge, Heating Oil Tank Bottom Water | | | |
| Other (Describe): | | | |
| | | | |
| | | | |

Does your plant have active efforts to segregate used oil by use or from specific system components to avoid the mixing of non-contaminated oils with those that may be contaminated? Yes: _____No: _____

If "Yes" to the above question, please provide additional details on systems, control methods, procedures, etc.

_____
_____
_____

## APPLICATION OF PROCESS KNOWLEDGE TO CHARACTERIZE USED OIL

This section of the questionnaire is designed to obtain information used to evaluate/characterize used oil based on knowledge of the process/system which generated the used oil.

Do you use process/system knowledge to (**check all that apply**)?

___ Determine which used oils do not need to be analyzed for radionuclides?

___ Determine which oils are not contaminated and can be released (without analysis)?

___ Determine which oils are contaminated and cannot be released (without analysis)?

___ Determine which used oils need to be analyzed for gamma-emitting radionuclides?

___ Determine which used oils need to be analyzed for tritium and/or carbon-14?

Please provide the technical bases behind any process/system knowledge used to determine the need to evaluate the contamination status of used oil from various systems. Please provide applicable procedures used to determine the need to evaluate used oil for contamination. (Provide attachments as required.)

_____
_____
_____

## EVALUATION OF USED OIL FOR PRESENCE OF RADIOACTIVE MATERIAL

This section of the questionnaire is designed to obtain information on analyses your plant performs on used oil to determine whether or not radioactivity generated by the nuclear power plant is present in the material.

Do you perform radiological analyses on used/used oil for (**check all that apply**)?

___ Gamma-emitting radionuclides

___ Tritium

___ Carbon-14

If you analyze used oil for ***gamma-emitting radionuclides***, what methodology do you use?

___ In-house counting-room HPGe gamma spectrometer

___ Contract laboratory, if so provide name of laboratory: _____

What LLDs do you apply for analyzing for gamma-emitting radionuclides in oil?

| Nuclide | LLD[10] – uCi/mL or uCi/g (or Bq/ml or Bq/g), or NE (not established) |
|---|---|
| Mn-54 | |
| Fe-59 | |
| Co-58 | |
| Co-60 | |
| Zn-65 | |
| Zr-95 | |
| Nb-95 | |
| I-131 | |
| Cs-134 | |
| Cs-137 | |
| Ba-140 | |
| La-140 | |
| Other – specify: | |
| Gross Activity | |

Please provide the technical basis behind LLDs used for analysis for gamma-emitting radionuclides (Attach documents as required):

_____

[10] LLD – Lower Limit of Detection

If you analyze used oil for ***tritium and/or carbon-14***, what methodology do you use?

___ In-house liquid scintillation of the oil

___ In-house other method (provide information in comments section)

___ Contract lab liquid scintillation of the oil

___ Contract lab pyrolysis or oxidation of the oil and then liquid scintillation of the resulting "combustion products"

___ Contract lab other method _____

If you analyze used oil onsite or through a contract laboratory for ***tritium and/or carbon-14***, what LLD do you use or request for analyzing for tritium and/or carbon-14 in oil or other basis for the analysis?

_____

If you analyze used oil onsite or through a contract laboratory for tritium and/or carbon-14, do you perform the analyses on the bulk oil sample, or do you perform any sample preparation steps such as filtration, separation of oil and water fractions, etc.? Please provide details on how the analysis is performed.

_____

_____

If you analyze used oil onsite or through a contract laboratory for tritium and/or carbon-14, how many samples do you analyze per year:

Number of samples analyzed on-site: _____

Number of samples analyzed through contract laboratory: _____

If you analyze used oil for both gamma-emitting radionuclides and tritium and/or carbon-14, do you have information on used oils that contain detectable radioactivity that (**check all that apply for the same oil samples**):

___ Contain detectable gamma radionuclides with no tritium and/or carbon-14?

___ Contain detectable gamma radionuclides and detectable tritium and/or carbon-14?

___ Contain detectable tritium and/or carbon-14 with no detectable gamma radionuclides?

Please provide information on the known maximum historical concentrations (uCi/mL or Bq/mL) of radioactivity detected in various ***coolant*** streams for the following radionuclides:

| Radionuclide | PWR Primary Coolant | PWR Secondary Coolant | BWR Reactor Water | BWR Condensate |
|---|---|---|---|---|
| Co-60 | | | | |
| Cs-137 | | | | |
| Other diagnostic gamma-emitters - specify | | | | |
| | | | | |
| | | | | |
| H-3 | | | | |
| CARBON-14 | | | | |

Please provide information on the maximum historical concentrations (uCi/mL or Bq/mL) of radioactivity detected in ***oils*** associated with various coolant streams for the following radionuclides:

| Radionuclide | Used oil from PWR Primary Coolant Systems | Used oil from PWR Secondary Coolant Systems | Used oil from BWR Reactor Water Systems | Used oil from BWR Condensate Systems |
|---|---|---|---|---|
| Co-60 | | | | |
| Cs-137 | | | | |
| Other diagnostic gamma-emitters - specify | | | | |
| | | | | |
| | | | | |
| | | | | |
| H-3 | | | | |
| CARBON-14 | | | | |

Please provide used oil radionuclide analysis data (gammas, tritium, and/or carbon-14) from the last one to three years. Email to Karen Kim (kkim@epri.com.)

However; should you believe that you have information that would be of high value older than 1-3 years, use you best judgement when providing this information.

## APPLICATION OF CORRELATION OR SCALING FACTORS

This section of the questionnaire is designed to obtain information on correlation factors or scaling factors that your plant may employ to infer the presence and/or activity levels of tritium and/or carbon-14 in used oil based on the presence of detectable plant-related gamma-emitting radioactivity.

Do you use any correlation factors to ***determine the presence of*** tritium or carbon-14 in used oil (i.e., use the detection of gamma-emitting radionuclides as the key.)? Yes: _____ No: _____

If "Yes" to the above question, please provide any correlation factor used to evaluate used oil, as well as procedures and the technical basis supporting these.

_____
_____
_____

Do you use any scaling factors to **d*etermine the magnitude*** of tritium or carbon-14 in used oil (i.e., use the activity level of gamma radionuclides in the oil to estimate the activity level of tritium or carbon-14 in the oil.)? Yes: _____ No: _____

If "Yes" to the above question, please provide any scaling factor used to evaluate used oil, as well as procedures and the technical basis supporting these.

_____
_____
_____

## DISPOSITION OF USED OIL

This section of the questionnaire is designed to obtain information on how used oil is dispositioned following its characterization as radiologically clean or contaminated.

How do you disposition your used/used oil (check all that apply)?

___ Radiologically clean used oil is released to waste processor for incineration.

___ Radiologically clean used oil is released to waste processor for recycling.

___ Radiologically contaminated used oil is sent to waste processor for incineration (radioactive effluents are accounted for.)

___ Radiologically contaminated used oil is sent to a used oil re-processor for recycling

___ Radiologically clean oil is sent for disposal as hazardous waste

___ Radiologically contaminated oil is sent for disposal as ***mixed*** hazardous waste

___ Other (please provide details)

_____

Please provide procedures associated with the management/disposition of used oil.

EPRI Contacts: David Perkins (dperkins@epri.com) or Karen Kim (kkim@epri.com). April 2018

# Appendix C: Determination of Site Specific Source Water Activity Limit

The Used Oil report methodology is based on a simple concentration-volume dilution calculation (C1V1 = C2V2) using the water fraction methodology. The fundamental assumption for the analysis is that the highest source of $^{3}H$, $^{14}C$, and other hard-to-detect radionuclides is the reactor coolant and the water fraction in the oil is limited to industry guidance and best practices. The flow chart documented in Figure 4-3 references two main screening criteria; the source water activity limit (threshold) and the ratio of [H-3] to [Co-60] to the ratio of LLD[H-3] to LLD[Co-60] ratio.

Appendix C provides additional insight and an example for site specific values.

The methodology requires an understanding of the following factors to calculate with site specific values.

1. Site specific LLD and the basis for the LLD. The LLD may be limited based on feedback from commercial laboratories, plant commitments, or other evaluations.
2. System equipment operating limits – turbines, value hydraulic controls, and other oil based systems have specifications related to the amount of water allowed for equipment reliability and vary based on the equipment, vendor specifications, ASTM guidance, and EPRI guidance. In the most general terms, the amount of water in oil is limited to ≤0.2% (2000 ppm) and ≤0.1% (1000 ppm) for turbines.
3. Source Water Activity – In most cases, the reactor coolant system is the highest and limiting activity for calculations. One common exception is related to the pressurized water reactor (PWR) main turbine lubricating oil system where the limiting concentration is the secondary coolant $^{3}H$ from steam generator (SG) diffusion or primary-to-secondary leakage.

Table C-1 provides a simple template documenting the data required for the calculation using a LLD of 1E-05 µCi/cm$^3$ (370 Bq/L).

*Table C-1*
*Plant Specific Variables*

| Variable | Value | Units | Comments |
|---|---|---|---|
| Lower Limit of Detection | 1E-05 (370 Bq/L) | µCi/cm$^3$ | Demonstration LLD only |
| Water Content | 0.1 | % | Demonstration LLD only |
| Margin Factor | 80 | % | Consistent with ***Used Oil*** Report |

## C.1 Screening Activity Calculation

Using the information in Table C-1 and Equation C-1 (Equation 4-2 from the report) allows the site to calculate the upper source water activity limit.

$$A_{Upper\ Activity\ (Threshold)} = \frac{A_{LLD}}{\left(\frac{WF}{100}\right)}\ x\ 0.8$$

$$8\ x\ 10^{-03}\ \frac{\mu Ci}{cm^3}\ (2.96x10^{+5}\ \frac{Bq}{L}) = \frac{1\ x\ 10^{-05}}{\left(\frac{0.1}{100}\right)}\ x\ 0.8 \qquad \textit{Eq. C-1}$$

Where:

$A_{\text{Upper Activity (threshold)}}$ = Source water tritium activity threshold, µCi/cm$^3$

$A_{LLD}$ = Site defined LLD, µCi/cm$^3$

$WF_{Oil}$ = Water fraction of oil

The updated source water upper activity limit is 8E-03 µCi/cm$^3$ (2.96E+05 Bq/L) and this value would be applied in the report flow chart as shown in the figure below.

## C.2 Tritium to Co-60 Ratio

The tritium ratio evaluation is to evaluate if tritium can be present without the presence of other gamma emitters. The general equation is shown in Equation C-2.

$$\textit{Is the source water activity ratio of } \frac{[H-3]}{[Co-60]} > \frac{LLD\,[H-3]}{LLD\,[Co-60]} \qquad \textit{Eq. C-2}$$

Where:

[H-3] = Source water tritium activity

[Co-60] = Source water Co-60 activity

LLD[H-3] = Site specific defined tritium LLD.

LLD[Co-60] = Site specific defined tritium LLD.

Table C-2 provides a simple table with the variables used for the calculation.

*Table C-2*
*Plant Specific Variables*

| Variable | Value | Units | Comments |
|---|---|---|---|
| LLD [H-3] | 3E-06 (111) | µCi/cm$^3$ (Bq/L) | Based on the non-drinking water LLD |
| LLD [Co-60] | 1.5E-08 (0.555) | µCi/cm$^3$ (Bq/L) | Based on the environmental LLD |
| [H-3] | 2.6 (9.62E+07) | µCi/cm$^3$ (Bq/L) | Example PWR tritium |
| [Co-60] | 1E-03 (3.7E+04) | µCi/cm$^3$ (Bq/L) | Example PWR tritium |

Using Equation C-3, the calculated ratio is greater than the LLD ratios.

$$\frac{2.6}{1\,x\,10^{-03}} > \frac{3\,x\,10^{-06}}{1.5\,x\,10^{-08}}$$

$$2600 > 200 \qquad \textit{Eq. C-3}$$

Using the calculated data, the original Figure 4-3 can be updated based on site specific conditions as identified in the example and shown in Figure C-1.

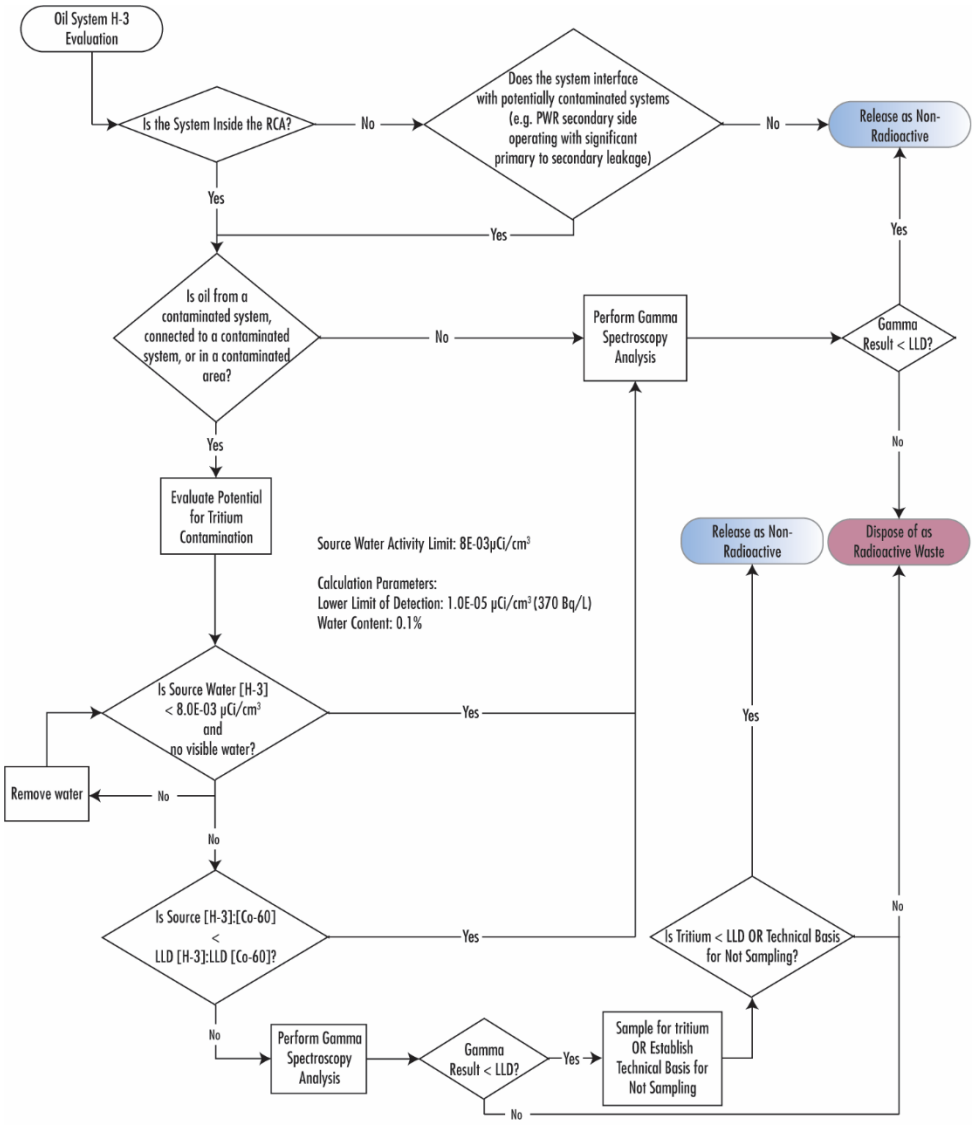



*Figure C-1*
*Updated Used Oil Evaluation Flow Chart*

# Appendix D: Radiochemical Analysis Results for Used Oil Samples

Several plants and two analytical laboratories provided analytical results reported for used oil analysis. These results are summarized in Table D-1 through Table D-8 and Table D-10 through Table D-16. The information in Table D-1 through Table D-5 are focused on tritium and carbon-14. The data in Table D-6 through Table D-8 include data on additional HTD radionuclides. The information in Table D-9 is a summary of analytical details for a subgroup of samples. The sample data are grouped based on where the data was received from and what radionuclides were reported. Overall the data is limited with a total of 191 samples reported. These samples were all reported to be oil or oil and water mixtures however the system of origin was not identified nor was disposition reported as released from license control or disposed of as radwaste. Values reported as picocuries per liter (pCi/L) were converted to micro-curies per cubic centimeter ($\mu Ci/cm^3$).

Appendix E has the data converted to Becquerel per liter (Bq/L)

The data included in Table D-1 were received during the performance of the EPRI used oil survey and provided to DW James Consulting by EPRI. Results were limited to tritium and carbon-14 activity levels except for two samples from one utility which included cobalt-60 activity.

*Table D-1*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID/Utility ID | Sample Date | Sample Number | H-3 (µCi/cc) | C-14 (if other specify) (µCi/cc) |
|---|---|---|---|---|
| Utility D | 6/24/2017 | 62417-2 | <3.80E-06 | |
| Utility D | 6/24/2017 | 62417-3 | <4.03E-06 | |
| Utility D | 6/24/2017 | 62417-4 | 5.65E-05 | |
| Utility D | 7/5/2017 | 170629-1 | <2.25E-06 | |
| Utility D | 7/5/2017 | 170629-2 | <2.27E-06 | |
| Utility D | 7/5/2017 | 170629-3 | <2.42E-06 | |
| Utility D | 7/5/2017 | 170629-4 | <2.25E-06 | |
| Utility D | 7/5/2017 | 170629-5 | <2.51E-06 | |
| Utility D | 7/5/2017 | 170629-6 | <2.20E-06 | |
| Utility D | 7/5/2017 | 170629-7 | 3.90E-06 | |
| Utility D | 7/5/2017 | 170629-8 | 4.53E-06 | |
| Utility D | 7/5/2017 | 170629-9 | <2.45E-06 | |
| Utility D | 7/5/2017 | 170629-10 | 4.96E-06 | |
| Utility D | 7/13/2017 | 30283 | <2.33E-06 | |
| Utility D | 7/13/2017 | 30348 | <2.21E-06 | |
| Utility D | 7/13/2017 | 30472 | <2.84E-06 | |
| Utility D | 7/13/2017 | 30473 | <2.44E-06 | |
| Utility D | 7/13/2017 | 11233 | <2.26E-06 | |
| Utility D | 7/13/2017 | 30282 | <2.29E-06 | |
| Utility D | 7/13/2017 | 30281 | <2.22E-06 | |
| Utility D | 7/13/2017 | 30290 | <2.06E-06 | |
| Utility D | 7/13/2017 | 30344 | <2.28E-06 | |
| Utility D | 7/20/2017 | 30475 | <3.14E-06 | |

*Table D-1 (continued)*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID/Utility ID | Sample Date | Sample Number | H-3 (µCi/cc) | C-14 (if other specify) (µCi/cc) |
|---|---|---|---|---|
| Utility D | 7/20/2017 | 30270 | <3.85E-06 | |
| Utility D | 7/20/2017 | 30271 | <3.78E-06 | |
| Utility D | 7/20/2017 | 30272 | <3.66E-06 | |
| Utility D | 7/20/2017 | 30278 | <4.07E-06 | |
| Utility D | 7/20/2017 | 31223 | <3.64E-06 | |
| Utility D | 7/20/2017 | 31226 | <3.62E-06 | |
| Utility D | 7/20/2017 | 31227 | <3.52E-06 | |
| Utility D | 7/20/2017 | 12705 | <3.67E-06 | |
| Utility D | 7/20/2017 | 31127 | <3.99E-06 | |
| Utility D | 7/20/2017 | 30573 | <3.20E-06 | |
| Utility D | 7/20/2017 | 30570 | <3.20E-06 | |
| Utility D | 7/20/2017 | 30572 | <3.47E-06 | |
| Utility D | 7/20/2017 | 30353 | 6.37E-06 | |
| Utility D | 8/17/2017 | 30364 | <2.08E-06 | |
| Utility D | 8/17/2017 | 30496 | <2.41E-06 | |
| Utility D | 8/17/2017 | 30575 | <2.39E-06 | |
| Utility D | 8/17/2017 | 30363 | <2.15E-06 | |
| Utility D | 8/17/2017 | 31220 | <2.23E-06 | |
| Utility D | 8/17/2017 | 30591 | 2.18E-06 | |
| Utility D | 8/17/2017 | 30599 | 1.68E-06 | |
| Utility D | 8/17/2017 | 30588 | <2.18E-06 | |
| Utility D | 9/11/2017 | 30497 | <2.65E-06 | |
| Utility D | 9/11/2017 | 30379 | <2.26E-06 | |

*Table D-1 (continued)*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID/Utility ID | Sample Date | Sample Number | H-3 (µCi/cc) | C-14 (if other specify) (µCi/cc) |
|---|---|---|---|---|
| Utility D | 9/11/2017 | 30586 | <2.01E-06 | |
| Utility D | 9/11/2017 | 31196 | 2.46E-06 | |
| Utility D | 9/11/2017 | 31199 | <2.15E-06 | |
| Utility D | 9/11/2017 | 30585 | <2.22E-06 | |
| Utility D | 9/11/2017 | 31128 | 3.73E-06 | |
| Utility D | 9/11/2017 | 30587 | 3.20E-06 | |
| Utility D | 10/5/2017 | 30583 | <2.56E-06 | |
| Utility D | 10/6/2017 | 30582 | <3.00E-06 | |
| Utility D | 10/7/2017 | 30581 | <3.25E-06 | |
| Utility D | 10/8/2017 | 30584 | <3.10E-06 | |
| Utility D | 9/21/2017 | 30590 | <3.01E-06 | |
| Utility D | 9/22/2017 | 30365 | <2.99E-06 | |
| Utility D | 9/232017 | 30589 | <3.69E-06 | |
| Utility D | 9/24/2017 | 31209 | <2.78E-06 | |
| Utility D | 9/28/2017 | 30593 | <3.55E-06 | |
| Utility D | 9/28/2017 | 30598 | <3.43E-06 | |
| Utility D | 9/28/2017 | 30592 | <3.54E-06 | |
| Utility D | 9/28/2017 | 10605 | <3.33E-06 | |
| Utility D | 10/18/2017 | 31217 | <3.31E-06 | |
| Utility D | 10/18/2017 | 31218 | <3.37E-06 | |
| Utility D | 10/18/2017 | 30574 | <3.31E-06 | |
| Utility D | 10/18/2017 | 31219 | <3.18E-06 | |

*Table D-1 (continued)*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID/Utility ID | Sample Date | Sample Number | H-3 (µCi/cc) | C-14 (if other specify) (µCi/cc) |
|---|---|---|---|---|
| Plant D | 9/20/2016 | 20-Sep-16-400080 | | 3.30E-07 (Co-60) |
| Plant D | 9/9/2014 | 9-Sep-14-00012 | | 4.01E-07 (Co-60) |
| Plant E | 2/10/2016 | 391399001 | <1.88E-03 | <2.01E-04 |
| Plant E | 1/30/2017 | 416063001 | <2.63E-04 | <1.94E-05 |
| Plant F | 4/25/2017 | 422979001 | <5.10E-04 | <1.70E-04 |
| Plant K | 1/6/2018 | 441020001 | <9.18E-07 | |
| Plant K | 1/6/2018 | 441020002 | <1.72E-06 | |
| Plant K | 1/6/2018 | 441020003 | <9.20E-07 | |
| Plant K | 1/6/2018 | 441020004 | <8.95E-07 | |
| Plant X | | 458073001 | <1.69E-04 | <9.94E-06 |
| Plant X | | 458073002 | <1.40E-04 | <1.09E-05 |
| Plant X | | 458073009 | <5.70E-05 | <1.04E-05 |
| Plant X | | 4580730011 | <8.49E-05 | <1.07E-05 |
| Plant X | | 4580730012 | <6.24E-05 | <1.02E-05 |
| Plant X | | 458073007 | <6.27E-05 | <9.86E-06 |

The data reported in Table D-1 are based on vendor analyses with the exception of the samples from Plant D which are onsite gamma spectroscopy results.

Vendor analytical data for several oil samples were included with 10 CFR § 61 data provided by Plant R to DW James Consulting, LLC. These data are summarized in Table D-2.

*Table D-2*
*Oil Sample Analytical Data*

| Sample number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) | C-14 (µCi/cc) |
|---|---|---|---|---|---|
| L14128-4 | 10/27/2000 | | | <4.00E-04 | <6.00E-04 |
| L17493-4 | 1/22/2002 | | | 1.90E-06 | <3.20E-07 |
| L20398-3 | 11/8/2002 | <7.50E-08 | 1.58E-07 | 1.78E-06 | <1.30E-06 |
| L23143-4 | 2/9/2004 | 1.57E-08 | <3.54E-08 | <6.06E-07 | <3.80E-07 |
| L25262-3 | 2/15/2005 | 6.35E-08 | <2.56E-08 | <1.47E-06 | <2.33E-07 |
| L27963-4 | 12/7/2005 | 1.13E-07 | <5.87E-08 | <1.16E-06 | <2.31E-07 |
| L32070-4 | 5/16/2007 | 1.33E-06 | 1.60E-07 | 5.09E-05 | <7.81E-07 |
| L35293-1 | 5/19/2008 | 5.85E-05 | 2.32E-06 | 1.84E-04 | <3.73E-07 |
| L38060-4 | 3/17/2009 | 3.08E-08 | <4.33E-09 | 6.56E-06 | <1.00E-06 |
| L39278-1 | 7/22/2009 | 5.29E-07 | <1.42E-07 | <1.39E-06 | <1.09E-06 |
| L41655-1 | 3/11/2010 | <2.81E-08 | <2.04E-08 | <1.29E-06 | <1.06E-06 |
| L43806-6 | 9/27/2010 | <8.59E-08 | <6.44E-08 | <2.37E-06 | <3.34E-06 |
| L48409-5 | 6/15/2011 | <1.17E-07 | <8.51E-08 | <1.14E-06 | <1.07E-06 |

Additional analytical data for used oil samples from three plants was provided to DW James Consulting, LLC by an analytical vendor. These data are summarized in Table D-3.

*Table D-3*
*Used Oil Analytical Data*

| Plant ID | Sample Number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) | C-14 (µCi/cc) |
|---|---|---|---|---|---|---|
| Plant S | L52006-1 | 8/8/2012 | 8.01E-07 | <9.79E-08 | <3.47E-06 | <1.03E-06 |
| Plant S | L52006-2 | 8/8/2012 | <2.07E-08 | <3.67E-08 | <3.56E-06 | <2.18E-06 |
| Plant S | L52006-3 | 8/2/2012 | <2.49E-07 | <2.63E-07 | <3.00E-06 | <1.17E-06 |
| Plant S | L52006-4 | 8/2/2012 | <4.24E-07 | <3.64E-07 | <3.51E-06 | <9.38E-07 |
| Plant S | L52006-5 | 9/5/2012 | <6.36E-08 | <7.30E-08 | <3.45E-06 | <1.34E-06 |
| Plant M | L55985-1 | 8/30/2013 | <9.37E-08 | <1.02E-07 | <2.98E-06 | <7.85E-07 |
| Plant M | L55985-2 | 9/4/2013 | <6.29E-08 | <9.01E-08 | <2.94E-06 | <7.09E-07 |
| Plant R | L59979-1 | 8/8/2014 | 2.14E-08 | <5.42E-09 | <3.44E-06 | <6.81E-07 |
| Plant R | L67977-1 | 3/18/2016 | <1.20E-07 | <7.53E-08 | <3.94E-06 | <1.70E-06 |
| Plant R | L69419-1 | 8/19/2016 | 6.11E-08 | <3.45E-08 | <3.17E-06 | <5.88E-07 |
| Plant R | L74935-1 | 10/2/2017 | 2.31E-08 | <1.35E-08 | <6.43E-06 | <2.93E-06 |
| Plant R | L78300-1 | 7/9/2018 | 4.47E-07 | <4.04E-09 | <3.65E-06 | 7.17E-06 |
| Plant R | L79094-1 | 9/5/2018 | 3.96E-07 | <1.18E-07 | <2.35E-06 | <4.53E-06 |
| Plant R | L79095-1 | 9/7/2018 | <4.07E-07 | <4.11E-07 | <2.39E-06 | <2.10E-06 |

Review of this analytical data is performed with the intent of establishing that the analysis of oil for gamma emitters is sufficient to demonstrate whether oil will have detectable levels of tritium or carbon-14. The activity content is expected to be low because oil containing systems are typically sealed. In the case of vented systems that contain oil, there is little mixing with the ambient atmosphere. This leaves diffusion as the method for radioactive contamination of oil. There is no mechanism for tritium or carbon-14 to increase in concentration in oil. The diffusion of tritium and carbon-14 in oil is predicted to be slow due to the relatively low pressure and temperature of the oil system compared to the temperatures and pressures required to drive diffusion at a significant rate. The analytical results confirm these expected low activity levels in contaminated oil.

For data in Table D-1 pertaining to tritium and carbon-14 the analytical results do not identify whether gamma emitters were detected. The data for plant D are reported cobalt-60 activity levels and do not include analytical results for tritium or carbon-14. Only 10 samples of 68 total samples from utility D reported detectable levels of tritium. These samples were not analyzed for carbon-14 or gamma emitters. Information on the associated system and whether the oil had detectable levels of gamma emitting radionuclides was not provided. This makes this data of little use since there is also no process knowledge regarding the system from which the samples originated or if the used oil was segregated to minimize cross contamination. The lack of analytical data for gamma emitters limits the usefulness of the data in making conclusions about the suitability of gamma analyses as sufficient to predict the presence of tritium of carbon-14 in oil.

In Table D-2 and Table D-3 data from three plants are presented for a total of 27 samples. In Table D-3, 3 gamma emitters are detected for each sample that contained a detectable level of tritium. No samples contained detectable activity level for carbon-14. In Table D-2, gamma emitters were detected for six samples including the one sample with detectable levels of carbon-14. None of these samples had activity levels of tritium above the detection limit.

Additional data were received from a second analytical vendor and Plant X. The results are summarized in Table D-4. A total of 31 samples were submitted from seven plants.

*Table D-4*
*Used Oil Sample Analytical Data*

| Plant | Sample number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) | C-14 (µCi/cc) |
|---|---|---|---|---|---|---|
| Plant Y | 326128003 | 5/29/2013 | 8.24E-06 | 2.88E-07 | <2.39E-06 | <4.10E-05 |
| Plant E | 413758001 | 1/16/2017 | 6.04E-07 | <2.91E-07 | <1.89E-04 | <2.42E-05 |
| Plant E | 413758002 | 1/16/2017 | <2.58E-07 | 4.55E-07 | <1.57E-04 | <6.65E-06 |
| Plant E | 413758003 | 1/16/2017 | <6.14E-07 | <5.40E-07 | <2.14E-04 | <3.47E-05 |
| Plant E | 413758004 | 1/17/2017 | <2.31E-07 | <1.83E-07 | <1.92E-04 | <3.01E-05 |
| Plant E | 413758005 | 1/17/2017 | <3.71E-07 | <2.94E-07 | <1.57E-04 | <2.77E-05 |
| Plant E | 413758006 | 1/17/2017 | 6.68E-07 | <2.55E-07 | <2.21E-04 | <1.42E-05 |
| Plant E | 413758007 | 1/17/2017 | <1.40E-07 | <2.44E-07 | <1.93E-04 | <3.05E-05 |
| Plant E | 413758009 | 1/17/2017 | <3.11E-07 | 3.75E-07 | <1.62E-04 | <1.66E-05 |
| Plant E | 413758011 | 1/17/2017 | <2.26E-07 | <1.85E-07 | <2.17E-04 | <6.52E-06 |
| Plant E | 413758012 | 1/17/2017 | <4.04E-07 | <3.51E-07 | <1.37E-04 | <3.47E-05 |
| Plant E | 413758013 | 1/17/2017 | <2.44E-07 | <3.03E-07 | <1.67E-04 | <2.79E-05 |
| Plant E | 413758014 | 1/17/2017 | 8.90E-07 | <2.16E-07 | <2.30E-04 | <3.30E-05 |
| Plant E | 413758015 | 1/18/2017 | <2.51E-07 | <2.06E-07 | <9.00E-05 | <1.46E-05 |
| Plant E | 413758016 | 1/18/2017 | <3.52E-07 | <2.75E-07 | <1.99E-04 | <2.45E-05 |
| Plant E | 413758017 | 1/18/2017 | <2.09E-07 | <2.61E-07 | <1.95E-04 | <1.90E-05 |
| Plant E | 413758018 | 1/18/2017 | <3.36E-07 | <4.36E-07 | <1.93E-04 | <3.30E-05 |
| Plant E | 413758019 | 1/19/2017 | <3.89E-07 | <2.79E-07 | <1.50E-04 | <2.51E-05 |
| Plant E | 416063001 | 2/10/2017 | 2.02E-07 | <9.65E-09 | <2.63E-04 | <1.94E-05 |
| Plant Z | 417526001 | 3/1/2017 | 4.39E-08 | 1.89E-07 | 1.95E-04 | <5.74E-06 |
| Plant AA | 418401001 | 3/14/2017 | | | 2.21E-06 | |
| Plant AA | 418401002 | 3/14/2017 | | | 1.54E-06 | |
| Plant AA | 418401003 | 3/14/2017 | | | 1.02E-06 | |

*Table D-4 (continued)*
*Used Oil Sample Analytical Data*

| Plant | Sample number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) | C-14 (µCi/cc) |
|---|---|---|---|---|---|---|
| Plant AA | 418401004 | 3/14/2017 | | | 2.52E-06 | |
| Plant AA | 418401005 | 3/14/2017 | | | 1.87E-06 | |
| Utility D | 421527003 | 4/28/2017 | <8.95E-08 | 3.88E-07 | <4.43E-04 | <9.06E-05 |
| Plant F | 422979001 | 5/12/2017 | <1.02E-08 | 3.63E-08 | <5.10E-04 | <1.70E-04 |
| Plant E | 429742001 | 8/7/2017 | 6.88E-06 | <8.42E-08 | <3.51E-03 | <1.35E-04 |
| Utility D | 450526005 | 5/21/2018 | <3.51E-08 | 3.99E-07 | <7.80E-04 | <6.95E-05 |
| Plant X | 458073001 | | 8.29E-07 | | <1.69E-04 | <9.94E-06 |
| Plant X | 458073002 | | 3.27E-08 | | <1.40E-04 | <1.09E-05 |

The results from plant AA included only data on tritium with no information on plant system of origin or oil disposition. In the remaining 24 samples tritium was above the reported detection level in a single sample. Cobalt-60 and cesium-137 were detected in several samples and both were above the detection level in the sample with a detectable level of tritium.

Additional data was received from the analytical vendor that provided the data in Table D-2 and is summarized in Table D-5. This data was not linked to a specific nuclear plant. The samples that were included in Table D-1 are not repeated here.

*Table D-5*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) |
|---|---|---|---|---|
| L65879-1 | 11/21/2015 | <3.48E-09 | <3.58E-09 | |
| L71672-1 | 2/9/2017 | <3.03E-09 | <3.34E-09 | <3.96E-06 |
| L71672-2 | 2/9/2017 | <3.19E-09 | <3.06E-09 | <3.96E-06 |
| L72829-1 | 5/4/2017 | | | <4.11E-06 |
| L72829-2 | 5/4/2017 | | | <3.77E-06 |
| L72829-3 | 5/4/2017 | | | <4.03E-06 |
| L72829-4 | 5/4/2017 | | | <3.63E-06 |
| L72829-5 | 5/4/2017 | | | <3.44E-06 |
| L72829-6 | 5/4/2017 | | | <4.79E-06 |
| L72829-7 | 5/4/2017 | | | <4.30E-06 |
| L72829-8 | 5/11/2017 | | | <3.60E-06 |
| L72829-9 | 5/11/2017 | | | <4.82E-06 |
| L73110-1 | 5/25/2017 | | | 2.63E-05 |
| L73110-2 | 5/25/2017 | | | <3.33E-06 |
| L73110-3 | 5/25/2017 | | | 5.98E-06 |
| L73110-4 | 5/25/2017 | | | <3.65E-06 |
| L73110-5 | 5/25/2017 | | | 2.91E-05 |
| L76914-1 | 3/15/2018 | | | <4.42E-06 |
| L76914-2 | 2/15/2018 | | | <4.05E-06 |
| L76914-3 | 2/15/2018 | | | <4.35E-06 |
| L76914-4 | 2/15/2018 | | | <4.04E-06 |

*Table D-5 (continued)*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) |
|---|---|---|---|---|
| L76914-5 | 2/15/2018 | | | <4.75E-06 |
| L76914-6 | 3/15/2018 | | | <4.58E-06 |
| L76914-7 | 3/15/2018 | | | <4.76E-06 |
| L78805-1 | 7/18/2018 | | | <4.67E-06 |
| L78805-2 | 7/18/2018 | | | <4.73E-06 |
| L78805-3 | 7/18/2018 | | | <4.81E-06 |
| L78805-4 | 7/18/2018 | | | <4.71E-06 |
| L78805-5 | 8/10/2018 | | | <3.54E-06 |
| L78805-6 | 8/10/2018 | | | <3.72E-06 |
| L78805-7 | 8/10/2018 | | | <3.72E-06 |
| L78805-8 | 8/10/2018 | | | <3.68E-06 |
| L79334-1 | 9/18/2018 | | | <2.72E-06 |
| L79334-2 | 9/18/2018 | | | <2.70E-06 |
| L79334-3 | 9/18/2018 | | | <2.73E-06 |
| L79334-4 | 9/18/2018 | | | <2.70E-06 |
| L79334-5 | 9/18/2018 | | | <2.71E-06 |
| L79334-6 | 9/18/2018 | | | <2.67E-06 |
| L79334-7 | 9/18/2018 | | | <2.68E-06 |
| L79334-8 | 9/18/2018 | | | <2.67E-06 |
| L79334-9 | 9/18/2018 | | | <2.71E-06 |
| L79334-10 | 9/18/2018 | | | <2.66E-06 |
| L79334-11 | 9/18/2018 | | | <2.72E-06 |
| L79334-12 | 9/18/2018 | | | <2.73E-06 |

*Table D-5 (continued)*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (µCi/cc) | Cs-137 (µCi/cc) | H-3 (µCi/cc) |
|---|---|---|---|---|
| L79334-13 | 9/18/2018 | | | <2.70E-06 |
| L79334-14 | 9/18/2018 | | | <2.66E-06 |
| L79334-15 | 9/18/2018 | | | <2.73E-06 |
| L79334-16 | 9/18/2018 | | | <2.66E-06 |
| L79334-17 | 9/18/2018 | | | <2.66E-06 |
| L79334-18 | 9/18/2018 | | | <2.72E-06 |
| L79334-19 | 9/18/2018 | | | <2.72E-06 |
| L79334-20 | 9/18/2018 | | | <2.66E-06 |

Several of the samples reported in this data set had been included in Table D-1 and are not repeated in Table D-5. Of the 52 samples summarized in Table D-5 three had results reported for gamma emitting radionuclides (one of these had no tritium reported). Of the remaining 49 samples, three had detectable levels of tritium. No gamma activity or detection levels were reported for these 49 samples. These results do confirm the tritium and gamma emitter detection levels discussed in section 2.

Data for hard to detect (HTD) radionuclide content in oil was obtained from Plant R personnel for the samples reported in Table D-2. These data are summarized in Table D-6 through Table D-8.

*Table D-6*
*Used Oil Sample HTD Radionuclide Activity*

| Sample Number | L14128-4 (µCi/cc) | L17493-4 (µCi/cc) | L20398-3 (µCi/cc) | L23143-4 (µCi/cc) | L25262-3 (µCi/cc) |
|---|---|---|---|---|---|
| **Date** | **10/27/2000** | **1/22/2002** | **11/8/2002** | **2/9/2004** | **2/15/2005** |
| H-3 | <4.00E-04 | 1.90E-06 | 1.78E-06 | <6.06E-07 | <1.47E-06 |
| C-14 | <6.00E-04 | <3.20E-07 | <1.30E-06 | <3.80E-07 | <2.33E-07 |
| Fe-55 | <8.00E-05 | <3.82E-06 | <3.46E-06 | <4.01E-06 | <6.11E-06 |
| Co-60 | | | <7.50E-08 | 1.57E-08 | 6.35E-08 |
| Ni-63 | <2.00E-04 | <3.20E-07 | 4.43E-07 | <2.26E-07 | <3.08E-07 |
| Sr-90 | <9.00E-05 | <2.30E-07 | 1.76E-07 | <1.75E-07 | <1.03E-07 |
| Tc-99 | <3.00E-03 | <2.85E-07 | <1.06E-06 | <8.65E-07 | <9.46E-07 |
| I-129 | <4.00E-05 | <9.64E-8 | <3.70E-07 | <1.50E-07 | <1.29E-07 |
| Cs-137 | | | 1.58E-07 | <3.54E-08 | <2.56E-08 |
| Pu-238 | <1.00E-06 | <3.70E-09 | <3.04E-09 | <1.92E-09 | <2.79E-9 |
| Pu-239 | <1.00E-06 | <2.90E-09 | <3.04E-09 | <1.75E-09 | <2.19E-09 |
| Am-241 | <2.00E-06 | <3.20E-09 | <7.17E-09 | <6.26E-09 | 1.45E-09 |
| Pu-241 | <2.00E-04 | <4.30E-07 | <4.05E-07 | <2.45E-07 | <2.48E-07 |
| Cm-242 | <2.00E-06 | <2.60E-09 | <1.55E-09 | <2.26E-09 | 9.68E-10 |
| Cm-243 | <1.00E-06 | 8.70E-09 | <1.08E-08 | <3.58E-09 | 7.23E-10 |

*Table D-7*
*Used Oil Sample HTD Radionuclide Activity*

| Sample Number | L27963-4 (µCi/cc) | L32070-4 (µCi/cc) | L35293-1 (µCi/cc) | L38060-4 (µCi/cc) |
|---|---|---|---|---|
| **Date** | **12/7/2005** | **5/16/2007** | **5/19/2008** | **3/17/2009** |
| H-3 | <1.16E-06 | 5.09E-05 | 1.84E-04 | 6.56E-06 |
| C-14 | <2.31E-07 | <7.81E-07 | <3.73E-07 | <1.00E-06 |
| Fe-55 | <6.15E-06 | <6.89E-06 | <2.59E-06 | <3.71E-06 |
| Co-60 | 1.13E-07 | 1.33E-06 | 5.85E-05 | 3.08E-08 |
| Ni-63 | <2.86E-07 | <2.50E-07 | <2.21E-07 | <2.75E-07 |
| Sr-90 | <1.32E-07 | <1.48E-07 | <2.39E-07 | <2.35E-07 |
| Tc-99 | <6.25E-07 | <3.96E-06 | <1.76E-06 | <1.38E-06 |
| I-129 | <4.28E-07 | <3.32E-07 | <1.10E-07 | <3.40E-07 |
| Cs-137 | <5.87E-08 | 1.60E-07 | 2.32E-06 | <4.33E-09 |
| Pu-238 | <5.25E-09 | <3.88E-09 | <8.62E-08 | <1.97E-09 |
| Pu-239 | <3.03E-09 | <3.25E-09 | <2.19E-08 | <1.40E-09 |
| Am-241 | <2.56E-08 | <5.63E-09 | <3.55E-08 | <2.72E-09 |
| Pu-241 | <7.46E-07 | <2.57E-07 | <8.20E-06 | <7.73E-07 |
| Cm-242 | <1.68E-08 | <3.01E-09 | <2.68E-08 | 2.47E-09 |
| Cm-243 | <1.90E-08 | <2.78E-09 | <6.46E-08 | <1.35E-09 |

*Table D-8*
*Used Oil Sample HTD Radionuclide Activity*

| Sample Number | L39278-1 (µCi/cc) | L41655-1 (µCi/cc) | L43806-6 (µCi/cc) | L48409-5 (µCi/cc) |
|---|---|---|---|---|
| **Date** | **7/22/2009** | **3/11/2010** | **9/27/2010** | **6/15/2011** |
| H-3 | <1.39E-06 | <1.29E-06 | <2.37E-06 | <1.14E-06 |
| C-14 | <1.09E-06 | <1.06E-06 | <3.34E-06 | <1.07E-06 |
| Fe-55 | <8.89E-06 | <3.20E-06 | <2.60E-06 | <8.68E-06 |
| Co-60 | 5.29E-07 | <2.81E-08 | <8.59E-08 | <1.17E-07 |
| Ni-63 | <4.49E-07 | <2.36E-07 | <4.77E-07 | 5.07E-07 |
| Sr-90 | <5.10E-08 | <3.18E-07 | <1.59E-07 | <3.32E-07 |
| Tc-99 | <1.38E-06 | <1.55E-06 | <1.30E-06 | <1.31E-06 |
| I-129 | <9.71E-07 | <1.88E-07 | <3.37E-07 | <2.35E-07 |
| Cs-137 | <1.42E-07 | <2.04E-08 | <6.44E-08 | <8.51E-08 |
| Pu-238 | <2.18E-08 | <1.12E-07 | <7.80E-09 | <7.3E-09 |
| Pu-239 | <1.26E-08 | <4.12E-08 | <1.10E-08 | <3.65E-09 |
| Am-241 | <3.90E-08 | <6.33E-08 | <7.26E-09 | <1.27E-08 |
| Pu-241 | <6.30E-06 | <5.35E-06 | <1.39E-06 | <4.94E-07 |
| Cm-242 | 9.98E-09 | <3.18E-08 | <2.44E-09 | 8.10E-09 |
| Cm-243 | <2.73E-08 | <5.40E-08 | <2.82E-09 | <9.99E-09 |

These sample results demonstrate that the radioactivity level in oil is very low. Detected levels of radioactivity are very near the detection levels.

Details of the analytical results for several of the oil samples are presented in Table D-9 for the samples in Table D-6 through Table D-8. This table includes the reported LLD and error for several detected levels of radioactivity for oil samples. This analysis of analytical data is presented to emphasize the low levels of radioactivity that is detected and the high error levels associated with sample results in this activity range.

*Table D-9*
*Sample Result Analytical Details*

| Sample Number | Radionuclide | Reported Activity (µCi/cc) | Error | LLD (µCi/cc) |
|---|---|---|---|---|
| L17493-4 | H-3 | 1.90E-06 | 6.00E-07 | NR |
| L17493-4 | Cm-243 | 8.70E-09 | 5.50E-09 | NR |
| L25262-3 | Am-241 | 1.45E-09 | 1.33E-09 | 1.16E-09 |
| L25262-3 | Cm-242 | 9.68E-10 | 9.71E-10 | 3.55E-10 |
| L25262-3 | Cm-243 | 7.23E-10 | 8.36E-10 | 3.55E-10 |
| L38060-4 | H-3 | 6.56E-06 | 6.56E-06 | 1.15E-06 |
| L38060-4 | Cm-242 | 2.47E-09 | 2.22E-09 | 7.23E-10 |
| L39278-1 | Cm-242 | 9.98E-09 | 1.41E-08 | 7.32E-09 |
| L48409-5 | Ni-63 | 5.07E-07 | 2.96E-07 | 4.39E-07 |
| L48409-5 | Cm-242 | 8.10E-09 | 6.44E-09 | 5.97E-09 |

Sample L48409-5 is unique in that for the remaining samples gamma emitters were detected with these HTD nuclides. The values reported were for nickel-63 and curium-242. These results are not considered to be valid positive analytical results. For sample L48409-5 the reported activity was 15 and 36 percent greater than the MDA for the nickel-63 and curium-242 respectively. The error was 58 and 80 percent of the reported values for nickel-63 and curium-242 respectively. These error values are in excess of typical analytical acceptance criteria. These results are not significantly different from the MDA for sample L48409-5.

For the remaining samples the other reported results are for TRU radionuclides and for tritium. The error for the radionuclide measurements are from 92 to 116 percent of the reported result and the MDA is exceeded by as little as 16 percent. For the reported tritium result in sample L38060-4 the error is 100 percent of the reported result.

Data for HTD radionuclide content in oil samples from several plants was obtained for samples reported in Table D-3 from an analytical vendor. These results are summarized in Table D-10 and Table D-11.

*Table D-10*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant S | Plant S | Plant S | Plant S | Plant S | Plant M |
|---|---|---|---|---|---|---|
| **Sample number** | **L52006-1** | **L52006-2** | **L52006-3** | **L52006-4** | **L52006-5** | **L55985-1** |
| **Date** | **8/8/2012** | **8/8/2012** | **8/2/2012** | **8/2/2012** | **9/5/2012** | **8/30/2013** |
| H-3 (µCi/cc) | <3.47E-06 | <3.56E-06 | <3.00E-06 | <3.51E-06 | <3.45E-06 | <2.98E-06 |
| C-14 (µCi/cc) | <1.03E-06 | <2.18E-06 | <1.17E-06 | <9.38E-07 | <1.34E-06 | <7.85E-07 |
| Fe-55 (µCi/cc) | <8.73E-06 | <7.63E-06 | <7.11E-06 | <6.46E-06 | <5.83E-06 | <1.91E-05 |
| Co-60 (µCi/cc) | 8.01E-07 | <2.07E-08 | <2.49E-07 | <4.24E-07 | <6.36E-08 | <9.37E-08 |
| Ni-63 (µCi/cc) | <6.51E-07 | <6.49E-07 | <6.70E-07 | <6.48E-07 | <6.51E-07 | <3.98E-06 |
| Sr-90 (µCi/cc) | <2.56E-07 | <3.09E-07 | <2.82E-07 | <2.61E-07 | <2.75E-07 | <2.78E-06 |
| Tc-99 (µCi/cc) | <1.27E-07 | <1.27E-06 | <1.26E-06 | <1.83E-06 | <1.27E-07 | <1.61E-06 |
| I-129 (µCi/cc) | <1.36E-07 | <2.57E-07 | <1.46E-07 | <1.04E-07 | <1.30E-07 | <1.08E-06 |
| Cs-137 (µCi/cc) | <9.79E-08 | <3.67E-08 | <2.63E-07 | <3.64E-07 | <7.30E-08 | <1.02E-07 |
| Pu-238 (µCi/cc) | <1.67E-08 | <1.53E-08 | <2.62E-08 | <2.65E-08 | <1.71E-08 | <3.85E-08 |
| Pu-239 (µCi/cc) | <1.83E-08 | <2.16E-08 | <2.37E-08 | <2.54E-08 | <1.53E-08 | <2.91E-08 |
| Am-241 (µCi/cc) | <2.89E-08 | <1.19E-08 | <5.31E-08 | <2.61E-08 | <3.44E-08 | <2.51E-08 |
| Pu-241 (µCi/cc) | <2.22E-06 | <2.13E-06 | <2.32E-06 | <2.05E-06 | <2.44E-06 | <1.30E-06 |
| Cm-242 (µCi/cc) | <1.92E-08 | <1.44E-08 | <3.32E-08 | <3.65E-08 | <1.47E-08 | <1.96E-08 |
| Cm-243 (µCi/cc) | <2.79E-08 | <1.86E-08 | <6.04E-08 | <5.53E-08 | <2.17E-08 | <1.76E-08 |

*Table D-11*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant M | Plant R | Plant R | Plant R | Plant R | Plant R |
|---|---|---|---|---|---|---|
| **Sample Number** | **L55985-2** | **L59979-1** | **L67977-1** | **L69419-1** | **L74935-1** | **L78300-1** |
| **Date** | **9/4/2013** | **8/8/2014** | **3/18/2016** | **8/19/2016** | **10/2/2017** | **7/9/2018** |
| H-3 (µCi/cc) | <2.94E-06 | <3.44E-06 | <3.94E-06 | <3.17E-06 | <6.43E-06 | <3.65E-06 |
| C-14 (µCi/cc) | <7.09E-07 | <6.81E-07 | <1.70E-06 | <5.88E-07 | <2.93E-06 | 7.17E-06 |
| Fe-55 (µCi/cc) | <2.15E-05 | <3.82E-06 | <3.54E-05 | <4.64E-05 | <1.93E-05 | <1.15E-04 |
| Co-60 (µCi/cc) | <6.29E-08 | 2.14E-08 | <1.20E-07 | 6.11E-08 | 2.31E-08 | 4.47E-07 |
| Ni-63 (µCi/cc) | <3.98E-06 | 8.64E-07 | <1.41E-06 | <5.01E-07 | <4.50E-06 | <5.84E-06 |
| Sr-90 (µCi/cc) | <2.34E-06 | <1.79E-06 | <1.84E-06 | <2.17E-08 | <1.32E-06 | <2.80E-06 |
| Tc-99 (µCi/cc) | <1.61E-06 | <1.60E-06 | <2.11E-06 | <1.58E-06 | <1.52E-06 | <1.58E-06 |
| I-129 (µCi/cc) | <2.08E-06 | <1.70E-06 | <1.74E-07 | <3.21E-06 | <6.65E-06 | <5.78E-06 |
| Cs-137 (µCi/cc) | <9.01E-08 | <5.42E-09 | <7.53E-08 | <3.45E-08 | <1.35E-08 | <4.04E-09 |
| Pu-238 (µCi/cc) | <1.22E-08 | <2.38E-07 | <7.39E-09 | <4.49E-07 | <1.43E-08 | <1.08E-07 |
| Pu-239 (µCi/cc) | <3.66E-08 | <1.19E-07 | <1.01E-08 | <3.39E-07 | <2.09E-08 | <5.61E-08 |
| Am-241 (µCi/cc) | <2.89E-08 | <2.42E-07 | <2.01E-08 | <1.54E-07 | <9.39E-09 | <1.26E-07 |
| Pu-241 (µCi/cc) | <1.44E-06 | <2.02E-06 | <1.02E-06 | <6.36E-05 | <1.38E-06 | <8.16E-06 |
| Cm-242 (µCi/cc) | <1.84E-08 | <1.43E-07 | <1.32E-08 | <1.82E-07 | <6.16E-09 | <6.93E-08 |
| Cm-243 (µCi/cc) | <1.65E-08 | <2.69E-07 | <1.62E-08 | <2.76E-07 | <1.53E-08 | <9.16E-08 |

For the sample data reported in Table D-10 and Table D-11 detectable activity concentrations were reported for very few radionuclides. Out of a total of 12 samples, cobalt-60 had a detectable level of activity in five samples, nickel-63 was detected in one sample and carbon-14 was detected in one sample. Cobalt-60 was detected for the samples in which carbon-14 and nickel-63 were detected. Tritium was not detected in any of the samples.

The data obtained from the second analytical vendor included all the HTD radionuclides for the 29 samples included in Table D-4. These data are included in Table D-12 through Table D-16.

*Table D-12*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant Y | Plant E | Plant E | Plant E | Plant E | Plant E |
|---|---|---|---|---|---|---|
| **Sample number** | **326128003** | **413758001** | **413758002** | **413758003** | **413758004** | **413758005** |
| **Date** | **5/29/2013** | **1/16/2017** | **1/16/2017** | **1/16/2017** | **1/17/2017** | **1/17/2017** |
| H-3 (µCi/cc) | <2.39E-06 | <1.89E-04 | <1.57E-04 | <2.14E-04 | <1.92E-04 | <1.57E-04 |
| C-14 (µCi/cc) | <4.10E-05 | <2.42E-05 | <6.65E-06 | <3.47E-05 | <3.01E-05 | <2.77E-05 |
| Fe-55 (µCi/cc) | <6.81E-03 | <3.03E-03 | <2.88E-03 | <3.10E-03 | <3.04E-03 | <2.76E-03 |
| Co-60 (µCi/cc) | 8.24E-06 | 6.04E-07 | <2.58E-07 | <6.14E-07 | <2.31E-07 | <3.71E-07 |
| Ni-63 (µCi/cc) | <3.23E-03 | <1.06E-03 | <1.20E-03 | <1.25E-03 | <1.07E-03 | <1.13E-03 |
| Sr-90 (µCi/cc) | <1.75E-04 | <5.32E-05 | <5.41E-05 | <5.66E-05 | <5.50E-05 | <5.47E-05 |
| Tc-99 (µCi/cc) | <3.25E-04 | <3.15E-04 | <2.07E-04 | <3.22E-04 | <5.65E-04 | <3.70E-04 |
| I-129 (µCi/cc) | <5.27E-07 | <3.39E-07 | <2.20E-07 | <2.88E-07 | <2.51E-07 | <2.61E-07 |
| Cs-137 (µCi/cc) | 2.88E-07 | <2.91E-07 | 4.55E-07 | <5.40E-07 | <1.83E-07 | <2.94E-07 |
| Pu-238 (µCi/cc) | <4.45E-07 | <1.57E-06 | <8.47E-07 | <4.91E-07 | <8.23E-07 | <6.06E-07 |
| Pu-239 (µCi/cc) | <4.44E-07 | <1.07E-06 | <7.00E-07 | <5.94E-07 | <7.91E-07 | <5.59E-07 |
| Pu-241 (µCi/cc) | <9.66E-05 | <1.09E-04 | <1.12E-04 | <8.81E-05 | <1.02E-04 | <9.91E-05 |
| Am-241 (µCi/cc) | <3.30E-07 | <7.45E-07 | <3.33E-07 | <8.14E-07 | <6.05E-07 | <9.80E-07 |
| Cm-242 (µCi/cc) | <2.31E-07 | <4.09E-07 | <4.03E-07 | <3.35E-07 | <3.79E-07 | <3.85E-07 |
| Cm-243 (µCi/cc) | <3.26E-07 | <1.06E-06 | <4.62E-07 | <5.43E-07 | <5.60E-07 | <5.35E-07 |

*Table D-13*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant E | Plant E | Plant E | Plant E | Plant E | Plant E |
|---|---|---|---|---|---|---|
| **Sample number** | **413758006** | **413758007** | **413758009** | **413758011** | **413758012** | **413758013** |
| **Date** | **1/17/2017** | **1/17/2017** | **1/17/2017** | **1/17/2017** | **1/17/2017** | **1/17/2017** |
| H-3 (µCi/cc) | <2.21E-04 | <1.93E-04 | <1.62E-04 | <2.17E-04 | <1.37E-04 | <1.67E-04 |
| C-14 (µCi/cc) | <1.42E-05 | <3.05E-05 | <1.66E-05 | <6.52E-06 | <3.47E-05 | <2.79E-05 |
| Fe-55 (µCi/cc) | <2.88E-03 | <2.62E-03 | <2.53E-03 | <2.53E-03 | <2.51E-03 | <2.76E-03 |
| Co-60 (µCi/cc) | 6.68E-07 | <1.40E-07 | <3.11E-07 | <2.26E-07 | <4.04E-07 | <2.44E-07 |
| Ni-63 (µCi/cc) | <1.05E-03 | <1.08E-03 | <1.14E-03 | <1.08E-03 | <1.02E-03 | <1.10E-03 |
| Sr-90 (µCi/cc) | <5.51E-05 | <5.04E-05 | <5.23E-05 | <5.22E-05 | <5.47E-05 | <5.97E-05 |
| Tc-99 (µCi/cc) | <2.79E-04 | <1.98E-04 | <2.25E-04 | <2.65E-04 | <2.89E-04 | <5.67E-04 |
| I-129 (µCi/cc) | <3.51E-07 | <1.55E-07 | <2.28E-07 | <1.81E-07 | <3.00E-07 | <1.82E-07 |
| Cs-137 (µCi/cc) | <2.55E-07 | <2.44E-07 | 3.75E-07 | <1.85E-07 | <3.51E-07 | <3.03E-07 |
| Pu-238 (µCi/cc) | <6.30E-07 | <4.48E-07 | <7.57E-07 | <6.46E-07 | <7.71E-07 | <5.30E-07 |
| Pu-239 (µCi/cc) | <8.57E-07 | <5.01E-07 | <7.57E-07 | <6.46E-07 | <6.88E-07 | <4.38E-07 |
| Pu-241 (µCi/cc) | <1.12E-04 | <8.92E-05 | <1.10E-04 | <9.58E-05 | <1.06E-04 | <7.65E-05 |
| Am-241 (µCi/cc) | <6.22E-07 | <7.29E-07 | <6.01E-07 | <6.80E-07 | <1.34E-06 | <5.18E-07 |
| Cm-242 (µCi/cc) | <3.18E-07 | <4.62E-07 | <4.62E-07 | <3.97E-07 | <3.42E-07 | <3.49E-07 |
| Cm-243 (µCi/cc) | <5.18E-07 | <4.24E-07 | <5.32E-07 | <6.67E-07 | <3.90E-07 | <4.46E-07 |

*Table D-14*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant E | Plant E | Plant E | Plant E | Plant E | Plant E |
|---|---|---|---|---|---|---|
| **Sample number** | **413758014** | **413758015** | **413758016** | **413758017** | **413758018** | **413758019** |
| **Date** | **1/17/2017** | **1/18/2017** | **1/18/2017** | **1/18/2017** | **1/18/2017** | **1/19/2017** |
| H-3 (µCi/cc) | <2.30E-04 | <9.00E-05 | <1.99E-04 | <1.95E-04 | <1.93E-04 | <1.50E-04 |
| C-14 (µCi/cc) | <3.30E-05 | <1.46E-05 | <2.45E-05 | <1.90E-05 | <3.30E-05 | <2.51E-05 |
| Fe-55 (µCi/cc) | <2.71E-03 | <3.14E-03 | <2.51E-03 | <2.71E-03 | <2.62E-03 | <2.79E-03 |
| Co-60 (µCi/cc) | 8.90E-07 | <2.51E-07 | <3.52E-07 | <2.09E-07 | <3.36E-07 | <3.89E-07 |
| Ni-63 (µCi/cc) | <1.27E-03 | <1.15E-03 | <1.01E-03 | <1.09E-03 | <1.06E-03 | <1.23E-03 |
| Sr-90 (µCi/cc) | <6.13E-05 | <6.37E-05 | <5.54E-05 | <5.53E-05 | <5.97E-05 | <6.56E-05 |
| Tc-99 (µCi/cc) | <3.38E-04 | <3.75E-04 | <3.57E-04 | <4.01E-04 | <2.42E-04 | <1.71E-04 |
| I-129 (µCi/cc) | <2.64E-07 | <2.94E-07 | <1.88E-07 | <2.22E-07 | <2.61E-07 | <3.37E-07 |
| Cs-137 (µCi/cc) | <2.16E-07 | <2.06E-07 | <2.75E-07 | <2.61E-07 | <4.36E-07 | <2.79E-07 |
| Pu-238 (µCi/cc) | <6.02E-07 | <8.25E-07 | <3.74E-07 | <7.88E-07 | <1.19E-06 | <1.15E-06 |
| Pu-239 (µCi/cc) | <6.92E-07 | <4.00E-07 | <4.19E-07 | <4.85E-07 | <9.39E-07 | <7.36E-07 |
| Pu-241 (µCi/cc) | <1.02E-04 | <1.13E-04 | <8.29E-05 | <8.04E-05 | <1.33E-04 | <9.84E-05 |
| Am-241 (µCi/cc) | <2.81E-07 | <6.09E-07 | <1.08E-06 | <9.49E-07 | <1.01E-06 | <9.87E-07 |
| Cm-242 (µCi/cc) | <3.41E-07 | <4.15E-07 | <3.39E-07 | <2.81E-07 | <4.71E-07 | <3.10E-07 |
| Cm-243 (µCi/cc) | <5.52E-07 | <5.74E-07 | <4.98E-07 | <3.21E-07 | <6.53E-07 | <3/97E-07 |

*Table D-15*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant E | Plant Z | Plant Aa | Plant Aa | Plant Aa | Plant Aa |
|---|---|---|---|---|---|---|
| **Sample number** | **416063001** | **417526001** | **418401001** | **418401002** | **418401003** | **418401004** |
| **Date** | **2/10/2017** | **3/1/2017** | **3/14/2017** | **3/14/2017** | **3/14/2017** | **3/14/2017** |
| H-3 (µCi/cc) | <2.63E-04 | 1.95E-04 | 2.21E-06 | 1.54E-06 | 1.02E-06 | 2.52E-06 |
| C-14 (µCi/cc) | <1.94E-05 | <5.74E-06 | | | | |
| Fe-55 (µCi/cc) | <1.39E-03 | <4.27E-03 | | | | |
| Co-60 (µCi/cc) | 2.02E-07 | 4.39E-08 | | | | |
| Ni-63 (µCi/cc) | <6.30E-04 | <1.38E-03 | | | | |
| Sr-90 (µCi/cc) | <2.01E-05 | <4.64E-05 | | | | |
| Tc-99 (µCi/cc) | <3.04E-04 | <1.31E-04 | | | | |
| I-129 (µCi/cc) | <1.00E-07 | <1.23E-07 | | | | |
| Cs-137 (µCi/cc) | <9.65E-09 | 1.89E-07 | | | | |
| Pu-238 (µCi/cc) | <1.97E-06 | <7.86E-07 | | | | |
| Pu-239 (µCi/cc) | <1.11E-06 | <5.32E-07 | | | | |
| Pu-241 (µCi/cc) | <1.08E-04 | <1.23E-04 | | | | |
| Am-241 (µCi/cc) | <2.25E-08 | <2.23E-07 | | | | |
| Cm-242 (µCi/cc) | <4.81E-07 | <2.52E-07 | | | | |
| Cm-243 (µCi/cc) | <3.18E-07 | <2.21E-07 | | | | |

*Table D-16*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant Aa | Utility D | Plant F | Plant E | Utility D |
|---|---|---|---|---|---|
| **Sample number** | **418401005** | **421527003** | **422979001** | **429742001** | **450526005** |
| H-3 (µCi/cc) | 1.87E-06 | <4.43E-04 | <5.10E-04 | <3.51E-03 | <7.80E-04 |
| C-14 (µCi/cc) | | <9.06E-05 | <1.70E-04 | <1.35E-04 | <6.95E-05 |
| Fe-55 (µCi/cc) | | <2.16E-03 | <2.05E-03 | <2.00E-02 | <2.40E-03 |
| Co-60 (µCi/cc) | | <8.95E-08 | <1.02E-08 | 6.88E-06 | <3.51E-08 |
| Ni-63 (µCi/cc) | | <6.66E-04 | <6.22E-04 | <1.04E-02 | <9.72E-04 |
| Sr-90 (µCi/cc) | | <4.61E-05 | <4.31E-05 | <4.10E-05 | <1.73E-05 |
| Tc-99 (µCi/cc) | | <2.87E-04 | <4.55E-05 | <2.35E-04 | <2.09E-05 |
| I-129 (µCi/cc) | | <3.11E-07 | <2.55E-07 | <1.33E-07 | <1.70E-07 |
| Cs-137 (µCi/cc) | | 3.88E-07 | 3.63E-08 | <8.42E-08 | 3.99E-07 |
| Pu-238 (µCi/cc) | | <4.93E-07 | <6.22E-07 | <1.87E-06 | <1.61E-06 |
| Pu-239 (µCi/cc) | | <5.89E-07 | <1.28E-06 | <1.20E-06 | <1.61E-06 |
| Pu-241 (µCi/cc) | | <9.38E-05 | <1.90E-04 | <1.36E-04 | <1.69E-04 |
| Am-241 (µCi/cc) | | <3.36E-07 | <1.32E-06 | <6.59E-07 | <1.19E-07 |
| Cm-242 (µCi/cc) | | <2.24E-07 | <9.50E-07 | <4.97E-07 | <1.08E-06 |
| Cm-243 (µCi/cc) | | <3.68E-07 | <5.92E-07 | <7.87E-07 | <1.53E-06 |

The samples from Plant Aa included only tritium activity with no detection level reported for gamma emitters. Of the remaining 24 samples only sample 417526001 had detectable tritium. No other HTD radionuclides were detected in these used oil samples. Cobalt-60 and cesium-137 were reported at detectable levels in seven and six samples respectively. In general, HTD radionuclides are rarely present in oil samples and cobalt-60 and cesium-137 will be present at detectable levels when HTD radionuclides are present.

In an effort to improve detection levels, the new and used oil samples from plant X were reanalyzed. These results are summarized in Table D-17. The results from the initial analyses are included along with the results of the reanalysis. The tritium detection levels were improved significantly and for three of the samples the detection level increased for the carbon-14 analysis. These re-analyses resulted in detection of tritium and carbon-14 in five of the twelve samples. The detection level and error associated with the reported activity are included for the samples with detected levels of tritium and carbon-14. Carbon-14 was reported as 20.8 pCi/g for sample 46431006 and 8.88 pCi/g for sample 46431008. Both of these samples are for new oil. These results are above the expected level of carbon14 in new synthetic oil. The error was over thirty percent of the reported activity for 46431006 and over fifty percent for sample 46431008. Tritium was reported as detected in samples 46431005 and 46431009 at 5.79 and 5.78 pCi/g. These values are barely in excess of the reported detection levels of 5.44 and 5.32 pCi/g and the error is in excess of fifty percent. These reported tritium values are not significant. Carbon-14 was reported as 8.17 pCi/g for sample 46431009. This value is above the nominal detection level of 7.86 pCi/g but has an error of well in excess of fifty percent and is not considered significant.

*Table D-17*
*New and Used Oil Sample Analytical Data*

| Sample Number | Oil Description | Activity (pCi/g) (MDC and error are for result reported as detectable) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Initial analysis | | Reanalyzed | | MDC[11] | Error |
| | | H-3 | C-14 | H-3 | C-14 | | |
| 46431001 | totes 1-4 | <169 | <9.94 | <5.83 | <39.9 | | |
| 46431002 | totes 5-8 | <140 | <10.9 | <5.47 | <4.01 | | |
| 46431003 | TB oil (new) | <66.8 | <10.4 | <5.89 | <4.16 | | |
| 46431004 | DTE turbine (new) | <59.2 | <9.53 | <5.54 | <3.63 | | |
| 46431005 | DTE Heavy (new) | <50.4 | <11.3 | 5.79 | <3.58 | 5.44 | 3.34 |
| 46431006 | fyrquel (new) | <52.2 | <8.93 | <5.19 | 20.8 | 11.5 | 7.18 |
| 46431007 | fyrquel (used) | <62.7 | <9.86 | <4.7 | <10.1 | | |
| 46431008 | sullair (new) | <60.1 | <10.2 | <6.03 | 8.88 | 5.32 | 3.3 |
| 46431009 | sullair (used) | <57 | <10.4 | 5.78 | <36.1 | 5.68 | 3.48 |
| 46431010 | chiller (new) | <63.3 | <9.33 | <4.52 | <121 | | |
| 46431011 | chiller (used w freon) | <84.9 | <10.7 | <15.9 | 8.17 | 7.86 | 4.76 |
| 46431012 | recirc pump | <62.4 | <10.2 | <5.55 | <144 | | |

[11] MDC – Minimum detectable concentration

# Appendix E: Radiochemical Analysis Results for Used Oil Samples (SI Units)

Several plants and two analytical laboratories provided analytical results reported for used oil analysis. These results are summarized in Table E-1 through Table E-8 and Table E-10 through Table E-16. The information in Table E-1 through Table E-5 are focused on tritium and carbon-14. The data in Table E-6 through Table E-8 include data on additional HTD radionuclides. The information in Table E-9 is a summary of analytical details for a subgroup of samples. The sample data are grouped based on where the data was received from and what radionuclides were reported. Overall the data is limited with a total of 191 samples reported. These samples were all reported to be oil or oil and water mixtures however the system of origin was not identified nor was disposition reported as released from license control or disposed of as radwaste.

The data included in Table E-1 were received during the performance of the EPRI used oil survey and provided to DW James Consulting by EPRI. Results were limited to tritium and carbon-14 activity levels except for two samples from one utility which included cobalt-60 activity.

*Table E-1*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID / Utility ID | Sample Date | Sample Number | H-3 (Bq/L) | C-14 (if other specify) (Bq/L) |
|---|---|---|---|---|
| Utility D | 6/24/2017 | 62417-2 | <1.41E+02 | |
| Utility D | 6/24/2017 | 62417-3 | <1.49E+02 | |
| Utility D | 6/24/2017 | 62417-4 | 2.09E+03 | |
| Utility D | 7/5/2017 | 170629-1 | <8.33E+01 | |
| Utility D | 7/5/2017 | 170629-2 | <8.40E+01 | |
| Utility D | 7/5/2017 | 170629-3 | <8.95E+01 | |
| Utility D | 7/5/2017 | 170629-4 | <8.33E+01 | |
| Utility D | 7/5/2017 | 170629-5 | <9.29E+01 | |
| Utility D | 7/5/2017 | 170629-6 | <8.14E+01 | |
| Utility D | 7/5/2017 | 170629-7 | 1.44E+02 | |
| Utility D | 7/5/2017 | 170629-8 | 1.68E+02 | |
| Utility D | 7/5/2017 | 170629-9 | <9.07E+01 | |
| Utility D | 7/5/2017 | 170629-10 | 1.84E+02 | |
| Utility D | 7/13/2017 | 30283 | <8.62E+01 | |
| Utility D | 7/13/2017 | 30348 | <8.18E+01 | |
| Utility D | 7/13/2017 | 30472 | <1.05E+02 | |
| Utility D | 7/13/2017 | 30473 | <9.03E+01 | |
| Utility D | 7/13/2017 | 11233 | <8.36E+01 | |
| Utility D | 7/13/2017 | 30282 | <8.47E+01 | |
| Utility D | 7/13/2017 | 30281 | <8.21E+01 | |
| Utility D | 7/13/2017 | 30290 | <7.62E+01 | |
| Utility D | 7/13/2017 | 30344 | <8.44E+01 | |
| Utility D | 7/20/2017 | 30475 | <1.16E+02 | |

*Table E-1 (continued)*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID / Utility ID | Sample Date | Sample Number | H-3 (Bq/L) | C-14 (if other specify) (Bq/L) |
|---|---|---|---|---|
| Utility D | 7/20/2017 | 30270 | <1.42E+02 | |
| Utility D | 7/20/2017 | 30271 | <1.40E+02 | |
| Utility D | 7/20/2017 | 30272 | <1.35E+02 | |
| Utility D | 7/20/2017 | 30278 | <1.51E+02 | |
| Utility D | 7/20/2017 | 31223 | <1.35E+02 | |
| Utility D | 7/20/2017 | 31226 | <1.34E+02 | |
| Utility D | 7/20/2017 | 31227 | <1.30E+02 | |
| Utility D | 7/20/2017 | 12705 | <1.36E+02 | |
| Utility D | 7/20/2017 | 31127 | <1.48E+02 | |
| Utility D | 7/20/2017 | 30573 | <1.18E+02 | |
| Utility D | 7/20/2017 | 30570 | <1.18E+02 | |
| Utility D | 7/20/2017 | 30572 | <1.28E+02 | |
| Utility D | 7/20/2017 | 30353 | 2.36E+02 | |
| Utility D | 8/17/2017 | 30364 | <7.70E+01 | |
| Utility D | 8/17/2017 | 30496 | <8.92E+01 | |
| Utility D | 8/17/2017 | 30575 | <8.84E+01 | |
| Utility D | 8/17/2017 | 30363 | <7.96E+01 | |
| Utility D | 8/17/2017 | 31220 | <8.25E+01 | |
| Utility D | 8/17/2017 | 30591 | 8.07E+01 | |
| Utility D | 8/17/2017 | 30599 | 6.22E+01 | |
| Utility D | 8/17/2017 | 30588 | <8.07E+01 | |
| Utility D | 9/11/2017 | 30497 | <9.81E+01 | |
| Utility D | 9/11/2017 | 30379 | <8.36E+01 | |

*Table E-1 (continued)*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID / Utility ID | Sample Date | Sample Number | H-3 (Bq/L) | C-14 (if other specify) (Bq/L) |
|---|---|---|---|---|
| Utility D | 9/11/2017 | 30586 | <7.44E+01 | |
| Utility D | 9/11/2017 | 31196 | 9.10E+01 | |
| Utility D | 9/11/2017 | 31199 | <7.96E+01 | |
| Utility D | 9/11/2017 | 30585 | <8.21E+01 | |
| Utility D | 9/11/2017 | 31128 | 1.38E+02 | |
| Utility D | 9/11/2017 | 30587 | 1.18E+02 | |
| Utility D | 10/5/2017 | 30583 | <9.47E+01 | |
| Utility D | 10/6/2017 | 30582 | <1.11E+02 | |
| Utility D | 10/7/2017 | 30581 | <1.20E+02 | |
| Utility D | 10/8/2017 | 30584 | <1.15E+02 | |
| Utility D | 9/21/2017 | 30590 | <1.11E+02 | |
| Utility D | 9/22/2017 | 30365 | <1.11E+02 | |
| Utility D | 9/232017 | 30589 | <1.37E+02 | |
| Utility D | 9/24/2017 | 31209 | <1.03E+02 | |
| Utility D | 9/28/2017 | 30593 | <1.31E+02 | |
| Utility D | 9/28/2017 | 30598 | <1.27E+02 | |
| Utility D | 9/28/2017 | 30592 | <1.31E+02 | |
| Utility D | 9/28/2017 | 10605 | <1.23E+02 | |
| Utility D | 10/18/2017 | 31217 | <1.22E+02 | |
| Utility D | 10/18/2017 | 31218 | <1.25E+02 | |
| Utility D | 10/18/2017 | 30574 | <1.22E+02 | |
| Utility D | 10/18/2017 | 31219 | <1.18E+02 | |

*Table E-1 (continued)*
*Used Oil Analytical Results from EPRI Survey*

| Plant ID / Utility ID | Sample Date | Sample Number | H-3 (Bq/L) | C-14 (if other specify) (Bq/L) |
|---|---|---|---|---|
| Plant D | 9/20/2016 | 20-Sep-16-400080 | | 1.22E+01 (Co-60) |
| Plant D | 9/9/2014 | 9-Sep-14-00012 | | 1.48E+01 (Co-60) |
| Plant E | 2/10/2016 | 391399001 | <6.96E+04 | <7.44E+03 |
| Plant E | 1/30/2017 | 416063001 | <9.73E+03 | <7.18E+02 |
| Plant F | 4/25/2017 | 422979001 | <1.89E+04 | <6.29E+03 |
| Plant K | 1/6/2018 | 441020001 | <3.40E+01 | |
| Plant K | 1/6/2018 | 441020002 | <6.36E+01 | |
| Plant K | 1/6/2018 | 441020003 | <3.40E+01 | |
| Plant K | 1/6/2018 | 441020004 | <3.31E+01 | |
| Plant X | | 458073001 | <6.25E+03 | <3.68E+02 |
| Plant X | | 458073002 | <5.18E+03 | <4.03E+02 |
| Plant X | | 458073009 | <2.11E+03 | <3.85E+02 |
| Plant X | | 4580730011 | <3.14E+03 | <3.96E+02 |
| Plant X | | 4580730012 | <2.31E+03 | <3.77E+02 |
| Plant X | | 458073007 | <2.32E+03 | <3.65E+02 |

The data reported in Table E-1 are based on vendor analyses with the exception of the samples from Plant D which are onsite gamma spectroscopy results.

Vendor analytical data for several oil samples were included with 10 CFR § 61 data provided by Plant R to DW James Consulting, LLC. These data are summarized in Table E-2.

*Table E-2*
*Oil Sample Analytical Data*

| Sample number | Sample Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) | C-14 (Bq/L) |
|---|---|---|---|---|---|
| L14128-4 | 10/27/2000 | | | <1.48E+04 | <2.22E+04 |
| L17493-4 | 1/22/2002 | | | 7.03E+01 | <1.18E+01 |
| L20398-3 | 11/8/2002 | <2.78E+00 | 5.85E+00 | 6.59E+01 | <4.81E+01 |
| L23143-4 | 2/9/2004 | 5.81E-01 | <1.31E+00 | <2.24E+01 | <1.41E+01 |
| L25262-3 | 2/15/2005 | 2.35E+00 | <9.47E-01 | <5.44E+01 | <8.62E+00 |
| L27963-4 | 12/7/2005 | 4.18E+00 | <2.17E+00 | <4.29E+01 | <8.55E+00 |
| L32070-4 | 5/16/2007 | 4.92E+01 | 5.92E+00 | 1.88E+03 | <2.89E+01 |
| L35293-1 | 5/19/2008 | 2.16E+03 | 8.58E+01 | 6.81E+03 | <1.38E+01 |
| L38060-4 | 3/17/2009 | 1.14E+00 | <1.60E-01 | 2.43E+02 | <3.70E+01 |
| L39278-1 | 7/22/2009 | 1.96E+01 | <5.25E+00 | <5.14E+01 | <4.03E+01 |
| L41655-1 | 3/11/2010 | <1.04E+00 | <7.55E-01 | <4.77E+01 | <3.92E+01 |
| L43806-6 | 9/27/2010 | <3.18E+00 | <2.38E+00 | <8.77E+01 | <1.24E+02 |
| L48409-5 | 6/15/2011 | <4.33E+00 | <3.15E+00 | <4.22E+01 | <3.96E+01 |

Additional analytical data for used oil samples from three plants was provided to DW James Consulting, LLC by an analytical vendor. These data are summarized in Table E-3.

*Table E-3*
*Used Oil Analytical Data*

| Plant ID | Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) | C-14 (Bq/L) |
|---|---|---|---|---|---|---|
| Plant S | L52006-1 | 8/8/2012 | 2.96E+01 | <3.62E+00 | <1.28E+02 | <3.81E+01 |
| Plant S | L52006-2 | 8/8/2012 | <7.66E-01 | <1.36E+00 | <1.32E+02 | <8.07E+01 |
| Plant S | L52006-3 | 8/2/2012 | <9.21E+00 | <9.73E+00 | <1.11E+02 | <4.33E+01 |
| Plant S | L52006-4 | 8/2/2012 | <1.57E+01 | <1.35E+01 | <1.30E+02 | <3.47E+01 |
| Plant S | L52006-5 | 9/5/2012 | <2.35E+00 | <2.70E+00 | <1.28E+02 | <4.96E+01 |
| Plant M | L55985-1 | 8/30/2013 | <3.47E+00 | <3.77E+00 | <1.10E+02 | <2.90E+01 |
| Plant M | L55985-2 | 9/4/2013 | <2.33E+00 | <3.33E+00 | <1.09E+02 | <2.62E+01 |
| Plant R | L59979-1 | 8/8/2014 | 7.92E-01 | <2.01E-01 | <1.27E+02 | <2.52E+01 |
| Plant R | L67977-1 | 3/18/2016 | <4.44E+00 | <2.79E+00 | <1.46E+02 | <6.29E+01 |
| Plant R | L69419-1 | 8/19/2016 | 2.26E+00 | <1.28E+00 | <1.17E+02 | <2.18E+01 |
| Plant R | L74935-1 | 10/2/2017 | 8.55E-01 | <5.00E-01 | <2.38E+02 | <1.08E+02 |
| Plant R | L78300-1 | 7/9/2018 | 1.65E+01 | <1.49E-01 | <1.35E+02 | 2.65E+02 |
| Plant R | L79094-1 | 9/5/2018 | 1.47E+01 | <4.37E+00 | <8.70E+01 | <1.68E+02 |
| Plant R | L79095-1 | 9/7/2018 | <1.51E+01 | <1.52E+01 | <8.84E+01 | <7.77E+01 |

Review of this analytical data is performed with the intent of establishing that the analysis of oil for gamma emitters is sufficient to demonstrate whether oil will have detectable levels of tritium or carbon-14. The activity content is expected to be low because oil containing systems are typically sealed. In the case of vented systems that contain oil, there is little mixing with the ambient atmosphere. This leaves diffusion as the method for radioactive contamination of oil. There is no mechanism for tritium or carbon-14 to increase in concentration in oil. The diffusion of tritium and carbon-14 in oil is predicted to be slow due to the relatively low pressure and temperature of the oil system compared to the temperatures and pressures required to drive diffusion at a significant rate. The analytical results confirm these expected low activity levels in contaminated oil.

For data in Table E-1 pertaining to tritium and carbon-14 the analytical results do not identify whether gamma emitters were detected. The data for plant D are reported cobalt-60 activity levels and do not include analytical results for tritium or carbon-14. Only 10 samples of 68 total samples from utility D reported detectable levels of tritium. These samples were not analyzed for carbon-14 or gamma emitters. Information on the associated system and whether the oil had detectable levels of gamma emitting radionuclides was not provided. This makes this data of little use since there is also no process knowledge regarding the system from which the samples originated or if the used oil was segregated to minimize cross contamination. The lack of analytical data for gamma emitters limits the usefulness of the data in making conclusions about the suitability of gamma analyses as sufficient to predict the presence of tritium of carbon-14 in oil.

In Table E-2 and Table E-3 data from three plants are presented for a total of 27 samples. In Table E-5, 3 gamma emitters are detected for each sample that contained a detectable level of tritium. No samples contained detectable activity level for carbon-14. In Table E-2 gamma emitters were detected for six samples including the one sample with detectable levels of carbon-14. None of these samples had activity levels of tritium above the detection limit.

Additional data were received from a second analytical vendor and Plant X. The results are summarized in Table E-4. A total of 31 samples were submitted from seven plants.

*Table E-4*
*Used Oil Sample Analytical Data*

| Plant ID | Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) | C-14 (Bq/L) |
|---|---|---|---|---|---|---|
| Plant Y | 326128003 | 5/29/2013 | 3.05E+02 | 1.07E+01 | <8.84E+01 | <1.52E+03 |
| Plant E | 413758001 | 1/16/2017 | 2.23E+01 | <1.08E+01 | <6.99E+03 | <8.95E+02 |
| Plant E | 413758002 | 1/16/2017 | <9.55E+00 | 1.68E+01 | <5.81E+03 | <2.46E+02 |
| Plant E | 413758003 | 1/16/2017 | <2.27E+01 | <2.00E+01 | <7.92E+03 | <1.28E+03 |
| Plant E | 413758004 | 1/17/2017 | <8.55E+00 | <6.77E+00 | <7.10E+03 | <1.11E+03 |
| Plant E | 413758005 | 1/17/2017 | <1.37E+01 | <1.09E+01 | <5.81E+03 | <1.02E+03 |
| Plant E | 413758006 | 1/17/2017 | 2.47E+01 | <9.44E+00 | <8.18E+03 | <5.25E+02 |
| Plant E | 413758007 | 1/17/2017 | <5.18E+00 | <9.03E+00 | <7.14E+03 | <1.13E+03 |
| Plant E | 413758009 | 1/17/2017 | <1.15E+01 | 1.39E+01 | <5.99E+03 | <6.14E+02 |
| Plant E | 413758011 | 1/17/2017 | <8.36E+00 | <6.85E+00 | <8.03E+03 | <2.41E+02 |
| Plant E | 413758012 | 1/17/2017 | <1.49E+01 | <1.30E+01 | <5.07E+03 | <1.28E+03 |
| Plant E | 413758013 | 1/17/2017 | <9.03E+00 | <1.12E+01 | <6.18E+03 | <1.03E+03 |
| Plant E | 413758014 | 1/17/2017 | 3.29E+01 | <7.99E+00 | <8.51E+03 | <1.22E+03 |
| Plant E | 413758015 | 1/18/2017 | <9.29E+00 | <7.62E+00 | <3.33E+03 | <5.40E+02 |
| Plant E | 413758016 | 1/18/2017 | <1.30E+01 | <1.02E+01 | <7.36E+03 | <9.07E+02 |
| Plant E | 413758017 | 1/18/2017 | <7.73E+00 | <9.66E+00 | <7.22E+03 | <7.03E+02 |
| Plant E | 413758018 | 1/18/2017 | <1.24E+01 | <1.61E+01 | <7.14E+03 | <1.22E+03 |
| Plant E | 413758019 | 1/19/2017 | <1.44E+01 | <1.03E+01 | <5.55E+03 | <9.29E+02 |
| Plant E | 416063001 | 2/10/2017 | 7.47E+00 | <3.57E-01 | <9.73E+03 | <7.18E+02 |
| Plant Z | 417526001 | 3/1/2017 | 1.62E+00 | 6.99E+00 | 7.22E+03 | <2.12E+02 |
| Plant AA | 418401001 | 3/14/2017 | | | 8.18E+01 | |
| Plant AA | 418401002 | 3/14/2017 | | | 5.70E+01 | |
| Plant AA | 418401003 | 3/14/2017 | | | 3.77E+01 | |

*Table E-4 (continued)*
*Used Oil Sample Analytical Data*

| Plant ID | Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) | C-14 (Bq/L) |
|---|---|---|---|---|---|---|
| Plant AA | 418401004 | 3/14/2017 | | | 9.32E+01 | |
| Plant AA | 418401005 | 3/14/2017 | | | 6.92E+01 | |
| Utility D | 421527003 | 4/28/2017 | <3.31E+00 | 1.44E+01 | <1.64E+04 | <3.35E+03 |
| Plant F | 422979001 | 5/12/2017 | <3.77E-01 | 1.34E+00 | <1.89E+04 | <6.29E+03 |
| Plant E | 429742001 | 8/7/2017 | 2.55E+02 | <3.12E+00 | <1.30E+05 | <5.00E+03 |
| Utility D | 450526005 | 5/21/2018 | <1.30E+00 | 1.48E+01 | <2.89E+04 | <2.57E+03 |
| Plant X | 458073001 | | 3.07E+01 | | <6.25E+03 | <3.68E+02 |
| Plant X | 458073002 | | 1.21E+00 | | <5.18E+03 | <4.03E+02 |

The results from plant AA included only data on tritium with no information on plant system of origin or oil disposition. In the remaining 24 samples tritium was above the reported detection level in a single sample. Cobalt-60 and cesium-137 were detected in several samples and both were above the detection level in the sample with a detectable level of tritium.

Additional data was received from the analytical vendor that provided the data in Table E-2 and is summarized in Table E-5. This data was not linked to a specific nuclear plant. The samples that were included in Table E-1 are not repeated here.

*Table E-5*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) |
|---|---|---|---|---|
| L65879-1 | 11/21/2015 | <1.29E-01 | <1.32E-01 | |
| L71672-1 | 2/9/2017 | <1.12E-01 | <1.24E-01 | <1.47E+02 |
| L71672-2 | 2/9/2017 | <1.18E-01 | <1.13E-01 | <1.47E+02 |
| L72829-1 | 5/4/2017 | | | <1.52E+02 |
| L72829-2 | 5/4/2017 | | | <1.39E+02 |
| L72829-3 | 5/4/2017 | | | <1.49E+02 |

*Table E-5 (continued)*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) |
|---|---|---|---|---|
| L72829-4 | 5/4/2017 | | | <1.34E+02 |
| L72829-5 | 5/4/2017 | | | <1.27E+02 |
| L72829-6 | 5/4/2017 | | | <1.77E+02 |
| L72829-7 | 5/4/2017 | | | <1.59E+02 |
| L72829-8 | 5/11/2017 | | | <1.33E+02 |
| L72829-9 | 5/11/2017 | | | <1.78E+02 |
| L73110-1 | 5/25/2017 | | | 9.73E+02 |
| L73110-2 | 5/25/2017 | | | <1.23E+02 |
| L73110-3 | 5/25/2017 | | | 2.21E+02 |
| L73110-4 | 5/25/2017 | | | <1.35E+02 |
| L73110-5 | 5/25/2017 | | | 1.08E+03 |
| L76914-1 | 3/15/2018 | | | <1.64E+02 |
| L76914-2 | 2/15/2018 | | | <1.50E+02 |
| L76914-3 | 2/15/2018 | | | <1.61E+02 |
| L76914-4 | 2/15/2018 | | | <1.49E+02 |
| L76914-5 | 2/15/2018 | | | <1.76E+02 |
| L76914-6 | 3/15/2018 | | | <1.69E+02 |
| L76914-7 | 3/15/2018 | | | <1.76E+02 |
| L78805-1 | 7/18/2018 | | | <1.73E+02 |
| L78805-2 | 7/18/2018 | | | <1.75E+02 |

*Table E-5 (continued)*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) |
|---|---|---|---|---|
| L78805-3 | 7/18/2018 | | | <1.78E+02 |
| L78805-4 | 7/18/2018 | | | <1.74E+02 |
| L78805-5 | 8/10/2018 | | | <1.31E+02 |
| L78805-6 | 8/10/2018 | | | <1.38E+02 |
| L78805-7 | 8/10/2018 | | | <1.38E+02 |
| L78805-8 | 8/10/2018 | | | <1.36E+02 |
| L79334-1 | 9/18/2018 | | | <1.01E+02 |
| L79334-2 | 9/18/2018 | | | <9.99E+01 |
| L79334-3 | 9/18/2018 | | | <1.01E+02 |
| L79334-4 | 9/18/2018 | | | <9.99E+01 |
| L79334-5 | 9/18/2018 | | | <1.00E+02 |
| L79334-6 | 9/18/2018 | | | <9.88E+01 |
| L79334-7 | 9/18/2018 | | | <9.92E+01 |
| L79334-8 | 9/18/2018 | | | <9.88E+01 |
| L79334-9 | 9/18/2018 | | | <1.00E+02 |
| L79334-10 | 9/18/2018 | | | <9.84E+01 |
| L79334-11 | 9/18/2018 | | | <1.01E+02 |
| L79334-12 | 9/18/2018 | | | <1.01E+02 |
| L79334-13 | 9/18/2018 | | | <9.99E+01 |
| L79334-14 | 9/18/2018 | | | <9.84E+01 |

*Table E-5 (continued)*
*Used Oil Sample Analytical Results*

| Sample Number | Date | Co-60 (Bq/L) | Cs-137 (Bq/L) | H-3 (Bq/L) |
|---|---|---|---|---|
| L79334-15 | 9/18/2018 | | | <1.01E+02 |
| L79334-16 | 9/18/2018 | | | <9.84E+01 |
| L79334-17 | 9/18/2018 | | | <9.84E+01 |
| L79334-18 | 9/18/2018 | | | <1.01E+02 |
| L79334-19 | 9/18/2018 | | | <1.01E+02 |
| L79334-20 | 9/18/2018 | | | <9.84E+01 |

Several of the samples reported in this data set had been included in Table E-1 and are not repeated in Table E-5. Of the 52 samples summarized in Table E-5 three had results reported for gamma emitting radionuclides (one of these had no tritium reported). Of the remaining 49 samples, three had detectable levels of tritium. No gamma activity or detection levels were reported for these 49 samples. These results do confirm the tritium and gamma emitter detection levels discussed in section 2.

Data for hard to detect (HTD) radionuclide content in oil was obtained from Plant R personnel for the samples reported in Table E-2. These data are summarized in Table E-6 through Table E-8.

*Table E-6*
*Used Oil Sample HTD Radionuclide Activity*

| Sample Number | L14128-4 (Bq/L) | L17493-4 (Bq/L) | L20398-3 (Bq/L) | L23143-4 (Bq/L) | L25262-3 (Bq/L) |
|---|---|---|---|---|---|
| Date | 10/27/2000 | 1/22/2002 | 11/8/2002 | 2/9/2004 | 2/15/2005 |
| H-3 | <1.48E+04 | 7.03E+01 | 6.59E+01 | <2.24E+01 | <5.44E+01 |
| C-14 | <2.22E+04 | <1.18E+01 | <4.81E+01 | <1.41E+01 | <8.62E+00 |
| Fe-55 | <2.96E+03 | <1.41E+02 | <1.28E+02 | <1.48E+02 | <2.26E+02 |
| Co-60 | | | <2.78E+00 | 5.81E-01 | 2.35E+00 |
| Ni-63 | <7.40E+03 | <1.18E+01 | 1.64E+01 | <8.36E+00 | <1.14E+01 |
| Sr-90 | <3.33E+03 | <8.51E+00 | 6.51E+00 | <6.48E+00 | <3.81E+00 |
| Tc-99 | <1.11E+05 | <1.05E+01 | <3.92E+01 | <3.20E+01 | <3.50E+01 |
| I-129 | <1.48E+03 | | <1.37E+01 | <5.55E+00 | <4.77E+00 |
| Cs-137 | | | 5.85E+00 | <1.31E+00 | <9.47E-01 |
| Pu-238 | <3.70E+01 | <1.37E-01 | <1.12E-01 | <7.10E-02 | |
| Pu-239 | <3.70E+01 | <1.07E-01 | <1.12E-01 | <6.48E-02 | <8.10E-02 |
| Am-241 | <7.40E+01 | <1.18E-01 | <2.65E-01 | <2.32E-01 | 5.37E-02 |
| Pu-241 | <7.40E+03 | <1.59E+01 | <1.50E+01 | <9.07E+00 | <9.18E+00 |
| Cm-242 | <7.40E+01 | <9.62E-02 | <5.74E-02 | <8.36E-02 | 3.58E-02 |
| Cm-243 | <3.70E+01 | 3.22E-01 | <4.00E-01 | <1.32E-01 | 2.68E-02 |

*Table E-7*
*Used Oil Sample HTD Radionuclide Activity*

| Sample Number | L27963-4 (Bq/L) | L32070-4 (Bq/L) | L35293-1 (Bq/L) | L38060-4 (Bq/L) |
|---|---|---|---|---|
| **Date** | **12/7/2005** | **5/16/2007** | **5/19/2008** | **3/17/2009** |
| H-3 | <4.29E+01 | 1.88E+03 | 6.81E+03 | 2.43E+02 |
| C-14 | <8.55E+00 | <2.89E+01 | <1.38E+01 | <3.70E+01 |
| Fe-55 | <2.28E+02 | <2.55E+02 | <9.58E+01 | <1.37E+02 |
| Co-60 | | | 2.16E+03 | 1.14E+00 |
| Ni-63 | <1.06E+01 | <9.25E+00 | <8.18E+00 | <1.02E+01 |
| Sr-90 | <4.88E+00 | <5.48E+00 | <8.84E+00 | <8.70E+00 |
| Tc-99 | <2.31E+01 | <1.47E+02 | <6.51E+01 | <5.11E+01 |
| I-129 | <1.58E+01 | | <4.07E+00 | <1.26E+01 |
| Cs-137 | | | 8.58E+01 | <1.60E-01 |
| Pu-238 | <1.94E-01 | <1.44E-01 | <3.19E+00 | <7.29E-02 |
| Pu-239 | <1.12E-01 | <1.20E-01 | <8.10E-01 | <5.18E-02 |
| Am-241 | <9.47E-01 | <2.08E-01 | <1.31E+00 | <1.01E-01 |
| Pu-241 | <2.76E+01 | <9.51E+00 | <3.03E+02 | <2.86E+01 |
| Cm-242 | <6.22E-01 | <1.11E-01 | <9.92E-01 | 9.14E-02 |
| Cm-243 | <7.03E-01 | <1.03E-01 | <2.39E+00 | <5.00E-02 |

*Table E-8*
*Used Oil Sample HTD Radionuclide Activity*

| Sample Number | L39278-1 (Bq/L) | L41655-1 (Bq/L) | L43806-6 (Bq/L) | L48409-5 (Bq/L) |
|---|---|---|---|---|
| **Date** | **7/22/2009** | **3/11/2010** | **9/27/2010** | **6/15/2011** |
| H-3 | <5.14E+01 | <4.77E+01 | <8.77E+01 | <4.22E+01 |
| C-14 | <4.03E+01 | <3.92E+01 | <1.24E+02 | <3.96E+01 |
| Fe-55 | <3.29E+02 | <1.18E+02 | <9.62E+01 | <3.21E+02 |
| Co-60 | 1.96E+01 | <1.04E+00 | <3.18E+00 | <4.33E+00 |
| Ni-63 | <1.66E+01 | <8.73E+00 | <1.76E+01 | 1.88E+01 |
| Sr-90 | <1.89E+00 | <1.18E+01 | <5.88E+00 | <1.23E+01 |
| Tc-99 | <5.11E+01 | <5.74E+01 | <4.81E+01 | <4.85E+01 |
| I-129 | <3.59E+01 | <6.96E+00 | <1.25E+01 | <8.70E+00 |
| Cs-137 | <5.25E+00 | <7.55E-01 | <2.38E+00 | <3.15E+00 |
| Pu-238 | <8.07E-01 | <4.14E+00 | <2.89E-01 | |
| Pu-239 | <4.66E-01 | <1.52E+00 | <4.07E-01 | <1.35E-01 |
| Am-241 | <1.44E+00 | <2.34E+00 | <2.69E-01 | <4.70E-01 |
| Pu-241 | <2.33E+02 | <1.98E+02 | <5.14E+01 | <1.83E+01 |
| Cm-242 | 3.69E-01 | <1.18E+00 | <9.03E-02 | 3.00E-01 |
| Cm-243 | <1.01E+00 | <2.00E+00 | <1.04E-01 | <3.70E-01 |

These sample results demonstrate that the radioactivity level in oil is very low. Detected levels of radioactivity are very near the detection levels.

Details of the analytical results for several of the oil samples are presented in Table E-9 for the samples in Table E-6 through Table E-8. This table includes the reported LLD and error for several detected levels of radioactivity for oil samples. This analysis of analytical data is presented to emphasize the low levels of radioactivity that is detected and the high error levels associated with sample results in this activity range.

*Table E-9*
*Sample Result Analytical Details*

| Sample Number | Radionuclide | Reported Activity (Bq/L) | Error (Bq/L) | LLD (Bq/L) |
|---|---|---|---|---|
| L17493-4 | H-3 | 7.03E+01 | 2.22E+01 | NR |
| L17493-4 | Cm-243 | 3.22E-01 | 2.04E-01 | NR |
| L25262-3 | Am-241 | 5.37E-02 | 4.92E-02 | 4.29E-02 |
| L25262-3 | Cm-242 | 3.58E-02 | 3.59E-02 | 1.31E-02 |
| L25262-3 | Cm-243 | 2.68E-02 | 3.09E-02 | 1.31E-02 |
| L38060-4 | H-3 | 2.43E+02 | 2.43E+02 | 4.26E+01 |
| L38060-4 | Cm-242 | 9.14E-02 | 8.21E-02 | 2.68E-02 |
| L39278-1 | Cm-242 | 3.69E-01 | 5.22E-01 | 2.71E-01 |
| L48409-5 | Ni-63 | 1.88E+01 | 1.10E+01 | 1.62E+01 |
| L48409-5 | Cm-242 | 3.00E-01 | 2.38E-01 | 2.21E-01 |

Sample L48409-5 is unique in that for the remaining samples gamma emitters were detected with these HTD nuclides. The values reported were for nickel-63 and curium-242. These results are not considered to be valid positive analytical results. For sample L48409-5 the reported activity was 15 and 36 percent greater than the MDA for the nickel-63 and curium-242 respectively. The error was 58 and 80 percent of the reported values for nickel-63 and curium-242 respectively. These error values are in excess of typical analytical acceptance criteria. These results are not significantly different from the MDA for sample L48409-5.

For the remaining samples the other reported results are for TRU radionuclides and for tritium. The error for the radionuclide measurements are from 92 to 116 percent of the reported result and the MDA is exceeded by as little as 16 percent. For the reported tritium result in sample L38060-4 the error is 100 percent of the reported result.

Data for HTD radionuclide content in oil samples from several plants was obtained for samples reported in Table E-3 from an analytical vendor. These results are summarized in Table E-10 and Table E-11.

*Table E-10*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant S | Plant S | Plant S | Plant S | Plant S | Plant M |
|---|---|---|---|---|---|---|
| **Sample number** | **L52006-1** | **L52006-2** | **L52006-3** | **L52006-4** | **L52006-5** | **L55985-1** |
| **Date** | **8/8/2012** | **8/8/2012** | **8/2/2012** | **8/2/2012** | **9/5/2012** | **8/30/2013** |
| H-3 (Bq/L) | <1.28E+02 | <1.32E+02 | <1.11E+02 | <1.30E+02 | <1.28E+02 | <1.10E+02 |
| C-14 (Bq/L) | <3.81E+01 | <8.07E+01 | <4.33E+01 | <3.47E+01 | <4.96E+01 | <2.90E+01 |
| Fe-55 (Bq/L) | <3.23E+02 | <2.82E+02 | <2.63E+02 | <2.39E+02 | <2.16E+02 | <7.07E+02 |
| Co-60 (Bq/L) | 2.96E+01 | <7.66E-01 | <9.21E+00 | <1.57E+01 | <2.35E+00 | <3.47E+00 |
| Ni-63 (Bq/L) | <2.41E+01 | <2.40E+01 | <2.48E+01 | <2.40E+01 | <2.41E+01 | <1.47E+02 |
| Sr-90 (Bq/L) | <9.47E+00 | <1.14E+01 | <1.04E+01 | <9.66E+00 | <1.02E+01 | <1.03E+02 |
| Tc-99 (Bq/L) | <4.70E+00 | <4.70E+01 | <4.66E+01 | <6.77E+01 | <4.70E+00 | <5.96E+01 |
| I-129 (Bq/L) | <5.03E+00 | <9.51E+00 | <5.40E+00 | <3.85E+00 | <4.81E+00 | <4.00E+01 |
| Cs-137 (Bq/L) | <3.62E+00 | <1.36E+00 | <9.73E+00 | <1.35E+01 | <2.70E+00 | <3.77E+00 |
| Pu-238 (Bq/L) | <6.18E-01 | <5.66E-01 | <9.69E-01 | <9.81E-01 | <6.33E-01 | <1.42E+00 |
| Pu-239 (Bq/L) | <6.77E-01 | <7.99E-01 | <8.77E-01 | <9.40E-01 | <5.66E-01 | <1.08E+00 |
| Am-241 (Bq/L) | <1.07E+00 | <4.40E-01 | <1.96E+00 | <9.66E-01 | <1.27E+00 | <9.29E-01 |
| Pu-241 (Bq/L) | <8.21E+01 | <7.88E+01 | <8.58E+01 | <7.59E+01 | <9.03E+01 | <4.81E+01 |
| Cm-242 (Bq/L) | <7.10E-01 | <5.33E-01 | <1.23E+00 | <1.35E+00 | <5.44E-01 | <7.25E-01 |
| Cm-243 (Bq/L) | <1.03E+00 | <6.88E-01 | <2.23E+00 | <2.05E+00 | <8.03E-01 | <6.51E-01 |

*Table E-11*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant M | Plant R | Plant R | Plant R | Plant R | Plant R |
|---|---|---|---|---|---|---|
| **Sample Number** | **L55985-2** | **L59979-1** | **L67977-1** | **L69419-1** | **L74935-1** | **L78300-1** |
| **Date** | **9/4/2013** | **8/8/2014** | **3/18/2016** | **8/19/2016** | **10/2/2017** | **7/9/2018** |
| H-3 (Bq/L) | <1.09E+02 | <1.27E+02 | <1.46E+02 | <1.17E+02 | <2.38E+02 | <1.35E+02 |
| C-14 (Bq/L) | <2.62E+01 | <2.52E+01 | <6.29E+01 | <2.18E+01 | <1.08E+02 | 2.65E+02 |
| Fe-55 (Bq/L) | <7.96E+02 | <1.41E+02 | <1.31E+03 | <1.72E+03 | <7.14E+02 | <4.26E+03 |
| Co-60 (Bq/L) | <2.33E+00 | 7.92E-01 | <4.44E+00 | 2.26E+00 | 8.55E-01 | 1.65E+01 |
| Ni-63 (Bq/L) | <1.47E+02 | 3.20E+01 | <5.22E+01 | <1.85E+01 | <1.67E+02 | <2.16E+02 |
| Sr-90 (Bq/L) | <8.66E+01 | <6.62E+01 | <6.81E+01 | <8.03E-01 | <4.88E+01 | <1.04E+02 |
| Tc-99 (Bq/L) | <5.96E+01 | <5.92E+01 | <7.81E+01 | <5.85E+01 | <5.62E+01 | <5.85E+01 |
| I-129 (Bq/L) | <7.70E+01 | <6.29E+01 | <6.44E+00 | <1.19E+02 | <2.46E+02 | <2.14E+02 |
| Cs-137 (Bq/L) | <3.33E+00 | <2.01E-01 | <2.79E+00 | <1.28E+00 | <5.00E-01 | <1.49E-01 |
| Pu-238 (Bq/L) | <4.51E-01 | <8.81E+00 | <2.73E-01 | <1.66E+01 | <5.29E-01 | <4.00E+00 |
| Pu-239 (Bq/L) | <1.35E+00 | <4.40E+00 | <3.74E-01 | <1.25E+01 | <7.73E-01 | <2.08E+00 |
| Am-241 (Bq/L) | <1.07E+00 | <8.95E+00 | <7.44E-01 | <5.70E+00 | <3.47E-01 | <4.66E+00 |
| Pu-241 (Bq/L) | <5.33E+01 | <7.47E+01 | <3.77E+01 | <2.35E+03 | <5.11E+01 | <3.02E+02 |
| Cm-242 (Bq/L) | <6.81E-01 | <5.29E+00 | <4.88E-01 | <6.73E+00 | <2.28E-01 | <2.56E+00 |
| Cm-243 (Bq/L) | <6.11E-01 | <9.95E+00 | <5.99E-01 | <1.02E+01 | <5.66E-01 | <3.39E+00 |

For the sample data reported in Table E-10 and Table E-11 detectable activity concentrations were reported for very few radionuclides. Out of a total of 12 samples, cobalt-60 had a detectable level of activity in five samples, nickel-63 was detected in one sample and carbon-14 was detected in one sample. Cobalt-60 was detected for the samples in which carbon-14 and nickel-63 were detected. Tritium was not detected in any of the samples.

The data obtained from the second analytical vendor included all the HTD radionuclides for the 29 samples included in Table E-4. These data are included in Table E-12 through Table E-16.

*Table E-12*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant Y | Plant E | Plant E | Plant E | Plant E | Plant E |
|---|---|---|---|---|---|---|
| **Sample number** | **326128003** | **413758001** | **4.14E+08** | **4.14E+08** | **4.14E+08** | **4.14E+08** |
| **Date** | **5/29/2013** | **1/16/2017** | **1/16/2017** | **1/16/2017** | **1/17/2017** | **1/17/2017** |
| H-3 (Bq/L) | <8.84E+01 | <6.99E+03 | <5.81E+03 | <7.92E+03 | <7.10E+03 | <5.81E+03 |
| C-14 (Bq/L) | <1.52E+03 | <8.95E+02 | <2.46E+02 | <1.28E+03 | <1.11E+03 | <1.02E+03 |
| Fe-55 (Bq/L) | <2.52E+05 | <1.12E+05 | <1.07E+05 | <1.15E+05 | <1.12E+05 | <1.02E+05 |
| Co-60 (Bq/L) | 3.05E+02 | 2.23E+01 | <9.55E+00 | <2.27E+01 | <8.55E+00 | <1.37E+01 |
| Ni-63 (Bq/L) | <1.20E+05 | <3.92E+04 | <4.44E+04 | <4.63E+04 | <3.96E+04 | <4.18E+04 |
| Sr-90 (Bq/L) | <6.48E+03 | <1.97E+03 | <2.00E+03 | <2.09E+03 | <2.04E+03 | <2.02E+03 |
| Tc-99 (Bq/L) | <1.20E+04 | <1.17E+04 | <7.66E+03 | <1.19E+04 | <2.09E+04 | <1.37E+04 |
| I-129 (Bq/L) | <1.95E+01 | <1.25E+01 | <8.14E+00 | <1.07E+01 | <9.29E+00 | <9.66E+00 |
| Cs-137 (Bq/L) | 1.07E+01 | <1.08E+01 | 1.68E+01 | <2.00E+01 | <6.77E+00 | <1.09E+01 |
| Pu-238 (Bq/L) | <1.65E+01 | <5.81E+01 | <3.13E+01 | <1.82E+01 | <3.05E+01 | <2.24E+01 |
| Pu-239 (Bq/L) | <1.64E+01 | <3.96E+01 | <2.59E+01 | <2.20E+01 | <2.93E+01 | <2.07E+01 |
| Pu-241 (Bq/L) | <3.57E+03 | <4.03E+03 | <4.14E+03 | <3.26E+03 | <3.77E+03 | <3.67E+03 |
| Am-241 (Bq/L) | <1.22E+01 | <2.76E+01 | <1.23E+01 | <3.01E+01 | <2.24E+01 | <3.63E+01 |
| Cm-242 (Bq/L) | <8.55E+00 | <1.51E+01 | <1.49E+01 | <1.24E+01 | <1.40E+01 | <1.42E+01 |
| Cm-243 (Bq/L) | <1.21E+01 | <3.92E+01 | <1.71E+01 | <2.01E+01 | <2.07E+01 | <1.98E+01 |

*Table E-13*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant Y | Plant E | Plant E | Plant E | Plant E | Plant E |
|---|---|---|---|---|---|---|
| **Sample number** | **326128003** | **413758001** | **413758002** | **413758003** | **413758004** | **413758005** |
| **Date** | **5/29/2013** | **1/16/2017** | **1/16/2017** | **1/16/2017** | **1/17/2017** | **1/17/2017** |
| H-3 (Bq/L) | <8.18E+03 | <7.14E+03 | <5.99E+03 | <8.03E+03 | <5.07E+03 | <6.18E+03 |
| C-14 (Bq/L) | <5.25E+02 | <1.13E+03 | <6.14E+02 | <2.41E+02 | <1.28E+03 | <1.03E+03 |
| Fe-55 (Bq/L) | <1.07E+05 | <9.69E+04 | <9.36E+04 | <9.36E+04 | <9.29E+04 | <1.02E+05 |
| Co-60 (Bq/L) | 2.47E+01 | <5.18E+00 | <1.15E+01 | <8.36E+00 | <1.49E+01 | <9.03E+00 |
| Ni-63 (Bq/L) | <3.89E+04 | <4.00E+04 | <4.22E+04 | <4.00E+04 | <3.77E+04 | <4.07E+04 |
| Sr-90 (Bq/L) | <2.04E+03 | <1.86E+03 | <1.94E+03 | <1.93E+03 | <2.02E+03 | <2.21E+03 |
| Tc-99 (Bq/L) | <1.03E+04 | <7.33E+03 | <8.33E+03 | <9.81E+03 | <1.07E+04 | <2.10E+04 |
| I-129 (Bq/L) | <1.30E+01 | <5.74E+00 | <8.44E+00 | <6.70E+00 | <1.11E+01 | <6.73E+00 |
| Cs-137 (Bq/L) | <9.44E+00 | <9.03E+00 | 1.39E+01 | <6.85E+00 | <1.30E+01 | <1.12E+01 |
| Pu-238 (Bq/L) | <2.33E+01 | <1.66E+01 | <2.80E+01 | <2.39E+01 | <2.85E+01 | <1.96E+01 |
| Pu-239 (Bq/L) | <3.17E+01 | <1.85E+01 | <2.80E+01 | <2.39E+01 | <2.55E+01 | <1.62E+01 |
| Pu-241 (Bq/L) | <4.14E+03 | <3.30E+03 | <4.07E+03 | <3.54E+03 | <3.92E+03 | <2.83E+03 |
| Am-241 (Bq/L) | <2.30E+01 | <2.70E+01 | <2.22E+01 | <2.52E+01 | <4.96E+01 | <1.92E+01 |
| Cm-242 (Bq/L) | <1.18E+01 | <1.71E+01 | <1.71E+01 | <1.47E+01 | <1.27E+01 | <1.29E+01 |
| Cm-243 (Bq/L) | <1.92E+01 | <1.57E+01 | <1.97E+01 | <2.47E+01 | <1.44E+01 | <1.65E+01 |

*Table E-14*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant E | Plant E | Plant E | Plant E | Plant E | Plant E |
|---|---|---|---|---|---|---|
| **Sample number** | **413758014** | **413758015** | **413758016** | **413758017** | **413758018** | **413758019** |
| **Date** | **1/17/2017** | **1/18/2017** | **1/18/2017** | **1/18/2017** | **1/18/2017** | **1/19/2017** |
| H-3 (Bq/L) | <8.51E+03 | <3.33E+03 | <7.36E+03 | <7.22E+03 | <7.14E+03 | <5.55E+03 |
| C-14 (Bq/L) | <1.22E+03 | <5.40E+02 | <9.07E+02 | <7.03E+02 | <1.22E+03 | <9.29E+02 |
| Fe-55 (Bq/L) | <1.00E+05 | <1.16E+05 | <9.29E+04 | <1.00E+05 | <9.69E+04 | <1.03E+05 |
| Co-60 (Bq/L) | 3.29E+01 | <9.29E+00 | <1.30E+01 | <7.73E+00 | <1.24E+01 | <1.44E+01 |
| Ni-63 (Bq/L) | <4.70E+04 | <4.26E+04 | <3.74E+04 | <4.03E+04 | <3.92E+04 | <4.55E+04 |
| Sr-90 (Bq/L) | <2.27E+03 | <2.36E+03 | <2.05E+03 | <2.05E+03 | <2.21E+03 | <2.43E+03 |
| Tc-99 (Bq/L) | <1.25E+04 | <1.39E+04 | <1.32E+04 | <1.48E+04 | <8.95E+03 | <6.33E+03 |
| I-129 (Bq/L) | <9.77E+00 | <1.09E+01 | <6.96E+00 | <8.21E+00 | <9.66E+00 | <1.25E+01 |
| Cs-137 (Bq/L) | <7.99E+00 | <7.62E+00 | <1.02E+01 | <9.66E+00 | <1.61E+01 | <1.03E+01 |
| Pu-238 (Bq/L) | <2.23E+01 | <3.05E+01 | <1.38E+01 | <2.92E+01 | <4.40E+01 | <4.26E+01 |
| Pu-239 (Bq/L) | <2.56E+01 | <1.48E+01 | <1.55E+01 | <1.79E+01 | <3.47E+01 | <2.72E+01 |
| Pu-241 (Bq/L) | <3.77E+03 | <4.18E+03 | <3.07E+03 | <2.97E+03 | <4.92E+03 | <3.64E+03 |
| Am-241 (Bq/L) | <1.04E+01 | <2.25E+01 | <4.00E+01 | <3.51E+01 | <3.74E+01 | <3.65E+01 |
| Cm-242 (Bq/L) | <1.26E+01 | <1.54E+01 | <1.25E+01 | <1.04E+01 | <1.74E+01 | <1.15E+01 |
| Cm-243 (Bq/L) | <2.04E+01 | <2.12E+01 | <1.84E+01 | <1.19E+01 | <2.42E+01 | |

*Table E-15*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant E | Plant Z | Plant AA | Plant AA | Plant AA | Plant AA |
|---|---|---|---|---|---|---|
| **Sample number** | **416063001** | **417526001** | **418401001** | **418401002** | **418401003** | **418401004** |
| **Date** | **2/10/2017** | **3/1/2017** | **3/14/2017** | **3/14/2017** | **3/14/2017** | **3/14/2017** |
| H-3 (Bq/L) | <9.73E+03 | 7.22E+03 | 8.18E+01 | 5.70E+01 | 3.77E+01 | 9.32E+01 |
| C-14 (Bq/L) | <7.18E+02 | <2.12E+02 | | | | |
| Fe-55 (Bq/L) | <5.14E+04 | <1.58E+05 | | | | |
| Co-60 (Bq/L) | 7.47E+00 | 1.62E+00 | | | | |
| Ni-63 (Bq/L) | <2.33E+04 | <5.11E+04 | | | | |
| Sr-90 (Bq/L) | <7.44E+02 | <1.72E+03 | | | | |
| Tc-99 (Bq/L) | <1.12E+04 | <4.85E+03 | | | | |
| I-129 (Bq/L) | <3.70E+00 | <4.55E+00 | | | | |
| Cs-137 (Bq/L) | <3.57E-01 | 6.99E+00 | | | | |
| Pu-238 (Bq/L) | <7.29E+01 | <2.91E+01 | | | | |
| Pu-239 (Bq/L) | <4.11E+01 | <1.97E+01 | | | | |
| Pu-241 (Bq/L) | <4.00E+03 | <4.55E+03 | | | | |
| Am-241 (Bq/L) | <8.33E-01 | <8.25E+00 | | | | |
| Cm-242 (Bq/L) | <1.78E+01 | <9.32E+00 | | | | |
| Cm-243 (Bq/L) | <1.18E+01 | <8.18E+00 | | | | |

*Table E-16*
*Used Oil Sample HTD Radionuclide Activity*

| Plant | Plant AA | Utility D | Plant F | Plant E | Utility D |
|---|---|---|---|---|---|
| **Sample number** | **418401005** | **421527003** | **422979001** | **429742001** | **450526005** |
| H-3 (Bq/L) | 6.92E+01 | <1.64E+04 | <1.89E+04 | <1.30E+05 | <2.89E+04 |
| C-14 (Bq/L) | | <3.35E+03 | <6.29E+03 | <5.00E+03 | <2.57E+03 |
| Fe-55 (Bq/L) | | <7.99E+04 | <7.59E+04 | <7.40E+05 | <8.88E+04 |
| Co-60 (Bq/L) | | <3.31E+00 | <3.77E-01 | 2.55E+02 | <1.30E+00 |
| Ni-63 (Bq/L) | | <2.46E+04 | <2.30E+04 | <3.85E+05 | <3.60E+04 |
| Sr-90 (Bq/L) | | <1.71E+03 | <1.59E+03 | <1.52E+03 | <6.40E+02 |
| Tc-99 (Bq/L) | | <1.06E+04 | <1.68E+03 | <8.70E+03 | <7.73E+02 |
| I-129 (Bq/L) | | <1.15E+01 | <9.44E+00 | <4.92E+00 | <6.29E+00 |
| Cs-137 (Bq/L) | | 1.44E+01 | 1.34E+00 | <3.12E+00 | 1.48E+01 |
| Pu-238 (Bq/L) | | <1.82E+01 | <2.30E+01 | <6.92E+01 | <5.96E+01 |
| Pu-239 (Bq/L) | | <2.18E+01 | <4.74E+01 | <4.44E+01 | <5.96E+01 |
| Pu-241 (Bq/L) | | <3.47E+03 | <7.03E+03 | <5.03E+03 | <6.25E+03 |
| Am-241 (Bq/L) | | <1.24E+01 | <4.88E+01 | <2.44E+01 | <4.40E+00 |
| Cm-242 (Bq/L) | | <8.29E+00 | <3.52E+01 | <1.84E+01 | <4.00E+01 |
| Cm-243 (Bq/L) | | <1.36E+01 | <2.19E+01 | <2.91E+01 | <5.66E+01 |

The samples from Plant AA included only tritium activity with no detection level reported for gamma emitters. Of the remaining 24 samples only sample 417526001 had detectable tritium. No other HTD radionuclides were detected in these used oil samples. Cobalt-60 and cesium-137 were reported at detectable levels in seven and six samples respectively. In general, HTD radionuclides are rarely present in oil samples and cobalt-60 and cesium-137 will be present at detectable levels when HTD radionuclides are present.

In an effort to improve detection levels, the new and used oil samples from plant X were reanalyzed. These results are summarized in Table E-17. The results from the initial analyses are included along with the results of the reanalysis. The tritium detection levels were improved significantly and for three of the samples the detection level increased for the carbon-14 analysis. These re-analyses resulted in detection of tritium and carbon-14 in five of the twelve samples. The detection level and error associated with the reported activity are included for the samples with detected levels of tritium and carbon-14. Carbon-14 was reported as 20.8 pCi/g for sample 46431006 and 8.88 pCi/g for sample 46431008. Both of these samples are for new oil. These results are above the expected level of carbon-14 in new synthetic oil. The error was over thirty percent of the reported activity for 46431006 and over fifty percent for sample 46431008. Tritium was reported as detected in samples 46431005 and 46431009 at 5.79 and 5.78 pCi/g. These values are barely in excess of the reported detection levels of 5.44 and 5.32 pCi/g and the error is in excess of fifty percent. These reported tritium values are not significant. Carbon-14 was reported as 8.17 pCi/g for sample 46431009. This value is above the nominal detection level of 7.86 pCi/g but has an error of well in excess of fifty percent and is not considered significant.

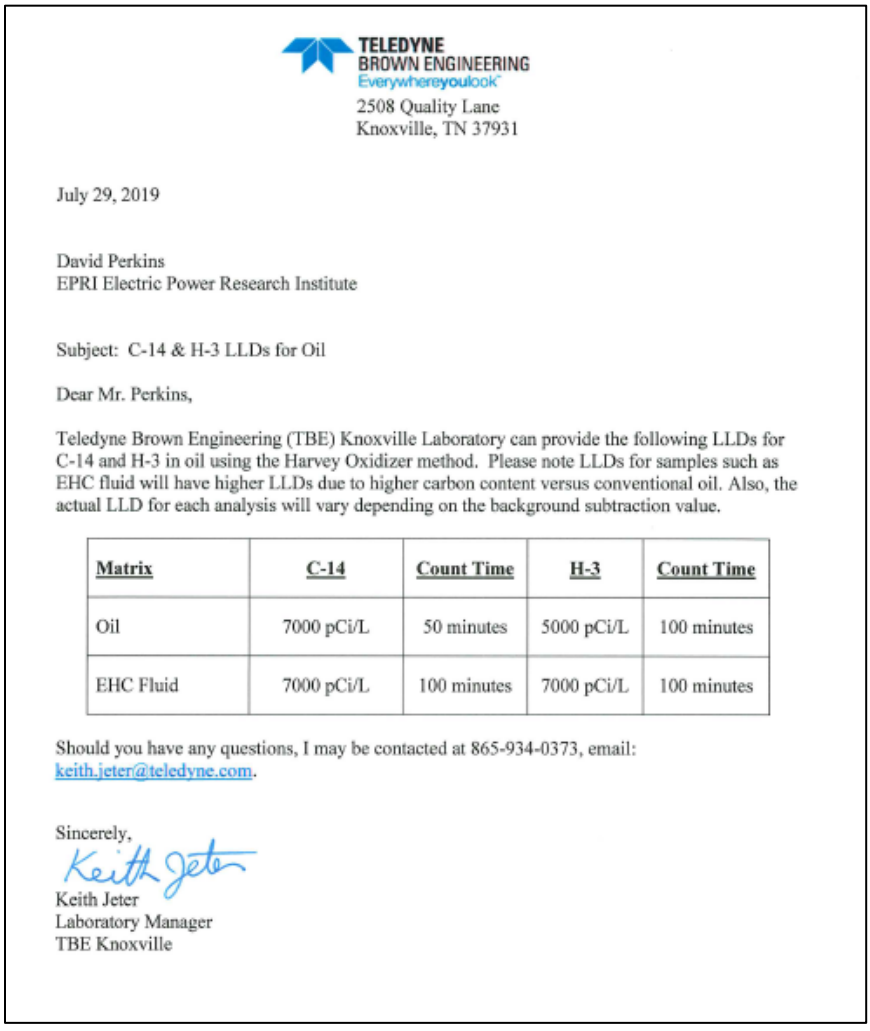
*Table E-17*
*New and Used Oil Sample Analytical Data*

| Sample Number | Oil Description | Activity (Bq/L) (MDC and error are for result reported as detectable) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Initial analysis | | Reanalyzed | | MDC[12] | Error |
| | | H-3 | C-14 | H-3 | C-14 | | |
| 46431001 | Totes 1-4 | 6.25E+03 | 3.68E+02 | 2.16E+02 | 1.48E+03 | | |
| 46431002 | Totes 5-8 | 5.18E+03 | 4.03E+02 | 2.02E+02 | 1.48E+02 | | |
| 46431003 | TB oil (new) | 2.47E+03 | 3.85E+02 | 2.18E+02 | 1.54E+02 | | |
| 46431004 | DTE turbine (new) | 2.19E+03 | 3.53E+02 | 2.05E+02 | 1.34E+02 | | |
| 46431005 | DTE Heavy (new) | 1.86E+03 | 4.18E+02 | 2.14E+02 | 1.32E+02 | 2.01E+02 | 1.24E+02 |
| 46431006 | Fyrquel (new) | 1.93E+03 | 3.30E+02 | 1.92E+02 | 7.70E+02 | 4.26E+02 | 2.66E+02 |
| 46431007 | Fyrquel (used) | 2.32E+03 | 3.65E+02 | 1.74E+02 | 3.74E+02 | | |
| 46431008 | Sullair (new) | 2.22E+03 | 3.77E+02 | 2.23E+02 | 3.29E+02 | 1.97E+02 | 1.22E+02 |
| 46431009 | Sullair (used) | 2.11E+03 | 3.85E+02 | 2.14E+02 | 1.34E+03 | 2.10E+02 | 1.29E+02 |
| 46431010 | Chiller (new) | 2.34E+03 | 3.45E+02 | 1.67E+02 | 4.48E+03 | | |
| 46431011 | Chiller (used with Freon) | 3.14E+03 | 3.96E+02 | 5.88E+02 | 3.02E+02 | 2.91E+02 | 1.76E+02 |
| 46431012 | Recirculation pump | 2.31E+03 | 3.77E+02 | 2.05E+02 | 5.33E+03 | | |

[12] MDC: Minimum Detectable Concentration

# Appendix F: Teledyne Brown Laboratory Reasonable Lower Limit of Detection

Teledyne Brown Engineering provided the EPRI project with the information as to the laboratory *state of art*. [21]



TELEDYNE
BROWN ENGINEERING
Everywhereyoulook™

2508 Quality Lane
Knoxville, TN 37931

July 29, 2019

David Perkins
EPRI Electric Power Research Institute

Subject: C-14 & H-3 LLDs for Oil

Dear Mr. Perkins,

Teledyne Brown Engineering (TBE) Knoxville Laboratory can provide the following LLDs for C-14 and H-3 in oil using the Harvey Oxidizer method. Please note LLDs for samples such as EHC fluid will have higher LLDs due to higher carbon content versus conventional oil. Also, the actual LLD for each analysis will vary depending on the background subtraction value.

| Matrix | C-14 | Count Time | H-3 | Count Time |
|---|---|---|---|---|
| Oil | 7000 pCi/L | 50 minutes | 5000 pCi/L | 100 minutes |
| EHC Fluid | 7000 pCi/L | 100 minutes | 7000 pCi/L | 100 minutes |

Should you have any questions, I may be contacted at 865-934-0373, email: keith.jeter@teledyne.com.

Sincerely,

Keith Jeter
Laboratory Manager
TBE Knoxville

# Appendix G: Gel Laboratory Reasonable Lower Limit of Detection

Gel laboratories provided the EPRI project with the information as to the laboratory *state of art*. [22]

GEL | Laboratories LLC

Summer 2019

*Carbon 14 and Tritium in Oil*

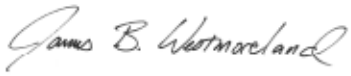
Page 1 of 1

This technical note is intended to provide information on the current methodologies and sensitivities for Carbon 14 and tritium analyses in the oil matrix at GEL. Oil samples can be difficult to analyze by liquid scintillation counting due to the variabilities in viscosity and coloration often encountered. If an oil is lightly colored and dissolves easily in scintillation fluid it is possible to do a direct measurement for these isotopes. The limitation of direct analysis is that any other beta emitters in the oil could interfere with the direct measurement. The more common analytical approach to overcome these interferences is to perform an initial dissolution of the oil either by wet oxidation or pyrolysis and then to distill and trap tritium and carbon 14 for analysis.

The table below shows typical detection limits for these isotopes in oils using GEL standard methods.

| *Isotope* | *MDA* | *Volume* | *Count Interval* |
|---|---|---|---|
| H-3 | 8,000 pCi/l | 0.5 ml | 120 minutes |
| C-14 | 5,000 pCi/l | 0.5 ml | 120 minutes |

We are available to discuss specifics as needed at the contact information below.



James Westmoreland

Director, Radiochemistry

GEL Laboratories LLC

843.556.8171 ext 4476

jbw@gel.com

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3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
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