Joint Regulation of Radionuclides at Connecticut Yankee Haddam Neck Plant – Finding Common Ground and Lessons Learned

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ABSTRACT

During the site closure of nuclear facilities where both radionuclides and chemicals are present in environmental media, state and federal regulatory agencies other than the Nuclear Regulatory Commission often have a stake in the regulation of the site closure process. At the Connecticut Yankee Atomic Power Company (CYAPCO) Haddam Neck Plant in Haddam, Connecticut, the site closure process includes both radiological and chemical cleanup which is regulated by two separate divisions within the state and two federal agencies. Each of the regulatory agencies has unique closure criteria which pertain to radionuclides and, consequently, there is overlapping and in some cases disparate regulation of radionuclides. Considerable effort has been expended by CYAPCO to find common ground in meeting the site closure requirements for radionuclides required by each of the agencies. This paper discusses the approaches that have been used by CYAPCO to address radionuclide site closure requirements. Significant lessons learned from these approaches include the demonstration that public health cleanup criteria for most radionuclides of concern at nuclear power generation facilities are protective for chemical toxicity concerns and are protective for ecological receptors and, consequently, performing a baseline ecological risk assessment for radionuclides at power generation facilities is not generally necessary.

INTRODUCTION

The Connecticut Yankee Atomic Power Company (CYAPCO) operated the Haddam Neck Plant (HNP), a 600 megawatt nuclear reactor, from 1968 through 1996. The plant is located on the Connecticut River in Haddam, Connecticut in an area that is surrounded by open space, rural residential properties, and state parks. During operations, the plant held a Nuclear Regulatory Commission (NRC) license, and Resource Conservation and Recovery Act (RCRA) permits for the generation and storage of hazardous wastes. Operation of the plant produced fission byproducts, and standard operations required the use of chemicals such as fuel oils, lubricating oils, solvents, and paint containing lead and/or polychlorinated biphenyls (PCBs).

Decommissioning began in 1997. Once power generation ceased, CYAPCO began the Site closure process with a goal of achieving closure and vacating the property for unrestricted release by 2007. Because the HNP held both an NRC license and RCRA permits, and because the plant generated both radiological and chemical waste streams, site closure activities have been regulated by four separate federal and state agencies. These include:

- Nuclear Regulatory Commission (NRC)
- State of Connecticut Department of Environmental Protection – Bureau of Air Management, Radiological Division (CTDEP-RD)
- United States Environmental Protection Agency (EPA)
- Connecticut Department of Environmental Protection - Bureau of Waste Management (CTDEP–WB).

Common among all agencies is the requirement that, upon release of the Site from regulatory oversight, the residual levels of radionuclides not pose an unacceptable detriment to public health and the environment. However, each of these regulatory agencies has unique methods and metrics for demonstrating that an unacceptable detriment to public health and the environment does not exist. For example, all agencies require that site cleanup be protective for radiotoxicity to public health and the environment, and some also require that site cleanup be protective for

chemical toxicity. However, the basis for demonstrating protectiveness (radiation dose versus cancer risk and chemical toxicity risk), and the burden of proof for demonstrating protection of the environment, differ among these agencies.

This paper discusses the approaches used and lessons learned for addressing radionuclide site closure requirements at the HNP in each of four subject areas: 1) Approach used to meet the various agency requirements for protection of public health from radiotoxicity; 2) Approach used to meet agency requirements for protection of public health from chemical toxicity of radionuclides; 3) Approach used to meet agency requirements for protection of the environment from radiotoxicity; and 4) Approach used to meet agency requirements for protection of the environment from chemical toxicity of radionuclides.

OVERVIEW OF REGULATORY CLOSURE REQUIREMENTS

As indicated above, closure of HNP is regulated by two federal agencies and two divisions within the state agency, each of which have different methods and metrics for determining when radionuclides have been remediated to levels that are protective of public health and the environment. The regulatory closure requirements for each of these agencies are discussed below and summarized in Table I.

One of the key differentiators among the requirements of these four regulatory bodies is the distinction between cleanup criteria for radionuclides that are based on radiotoxicity and cleanup criteria for radionuclides that are based on chemical toxicity. Radiotoxicity refers to the adverse effects that may result from biological exposure to ionizing radiation. Within the application of the regulatory frameworks discussed in this paper, radiotoxicity is evaluated through an assessment of radiation dose or through an assessment of excess lifetime cancer risk. Chemical toxicity refers to the adverse effects that may result from biological exposure to and interaction with a chemical or element. Chemical toxicity is evaluated through an assessment of risk, or hazard, of effects other than cancer.

Nuclear Regulatory Commission

The NRC regulates the Decontamination and Decommissioning (D&D) of the HNP, which was initiated in 1997 immediately after cessation of power generation. The D&D process is stipulated in the License Termination Plan (LTP) which identifies the procedures that will be used to characterize and remediate radiological contamination to a level that is protective of public health and the environment. To terminate the NRC license for unrestricted use releases, the NRC requires that the Total Effective Dose Equivalent (TEDE) for combined exposure to radionuclides in environmental media must not exceed 25 millirem per year (mrem/yr) to the average member of the critical group and be As Low As Reasonably Achievable (ALARA) (CFR, Title 10, "Energy," Parts 20, 30, 40, 50, 51, 70, and 72, *Radiological Criteria for License Termination*). The measure of health detriment used by the NRC is, therefore, an annualized radiation dose that is compared to a radiation dose limit that is protective for radiotoxicity. The NRC regulations do not require separate assessment of chemical toxicity, nor do they require direct evaluation of radiotoxicity or chemical toxicity to environmental receptors.

Connecticut Department of Environmental Protection – Radiation Division

The State of Connecticut is not currently an NRC agreement state. Thus, it does not presently have published regulations governing the licensure, control, and use of radioactive materials at NRC-licensed facilities within the State[1]. However, in preparation for applying for agreement state status, the State has published draft regulations for decommissioning and radioactive materials license termination which are parallel to the NRC regulations, except that CTDEP-RD requires that the TEDE for combined exposure to radionuclides in environmental media must not exceed 19 mrem/yr to the average member of the critical group and be ALARA [1]. As with the NRC regulations, the CTDEP-RD regulations are based on protection of public health for radiotoxicity, and do not require separate assessment of chemical toxicity, nor do they require direct evaluation of radiotoxicity or chemical toxicity to environmental receptors. The requirements of the CTDEP-RD have been integrated through separate correspondence. These agreements state that CYAPCO will follow the LTP; however to satisfy the Connecticut

[1] NRC agreement states are authorized by the NRC to oversee and regulate the licensure, control, and use of certain categories of radioactive materials. Agreement states have state regulations that are comparable to those promulgated by the NRC.

Regulations, the DCGLs for the CTDEP will be based on 19 mrem/yr TEDE. The DCGLs for each radionuclide of concern are developed from ratios of the DCGLs used in the LTP.

U.S. Environmental Protection Agency – Resource Conservation and Recovery Act

The EPA regulates the RCRA closure of the Site, which is documented under the RCRA Corrective Action Program that was initiated at the HNP in 2002. RCRA closure requires that substances regulated under RCRA do not pose unacceptable excess lifetime cancer risks (ELCR) and non-cancer hazards to public health. The regulatory criteria for establishing acceptable exposure levels to contaminants at hazardous waste sites under EPA jurisdiction are contained in CFR Title 40, Part 300. The regulation states that acceptable exposure levels for known or suspected carcinogens are concentration levels that represent an ELCR to an individual of between one in ten-thousand (10^{-4}) and one in one-million (10^{-6}). The regulation further states that the 10^{-6} level represents the point of departure for determining if remediation may be required. Levels associated with risks below 10^{-6} do not require remedial action, levels associated with risks between 10^{-6} and 10^{-4} may require remedial action based on site-specific circumstances, and levels associated with risks greater than 10^{-4} typically require remedial action. The regulation also states that acceptable exposure levels for chemicals that produce health effects other than cancer, termed non-cancer risks (or "chemical toxicity"), are concentration levels that people (including sensitive individuals such as children) can be exposed to without adverse effects occurring. This criterion is numerically expressed as a hazard index (HI) that does not exceed a value of 1.

RCRA closure also requires that substances regulated under RCRA do not pose an unacceptable risk to ecological receptors of concern. CFR Title 40, Part 300 states that "Superfund remedies will …. be protective of environmental organisms and ecosystem." The regulation charges regulators with "identifying potential impacts on public health, welfare, and the environment" and defines baseline risk assessment as a process used for determining "whether the site poses a current or potential risk to human health and the environment". Because of the complexity of ecological systems (multiple species, and complex interactions within and among populations and communities), ecological risk characterization involves evaluating the overall likelihood of adverse ecological effects. Adverse ecological effects are defined in Guidelines for Ecological Risk Assessment (FedReg 63(03):26845-26924) as: "changes that are considered undesirable because they alter valued structural or functional characteristics of ecosystems or their components." The regulatory criteria for establishing acceptable exposure levels to contaminants at hazardous waste sites under EPA jurisdiction (CFR Title 40, Part 300) do not identify any general acceptable exposure levels for ecological receptors, although it is implied that "acceptable exposure levels" for chemicals are concentration levels that ecological receptors can be exposed to without adverse effects occurring. A point of departure for making this determination is a HI of 1.

Notably, RCRA excludes regulation of radionuclides, but not chemical elements. Hence, RCRA closure does not require characterization of the radiotoxicity associated with potential exposures to radionuclides, but does require characterization of the chemical toxicity associated with potential exposures to radionuclides as chemical elements. However, under the EPA-NRC Memorandum of Understanding (MOU) signed in 2002, if the soils and groundwater criteria listed in the MOU are not met at the time of license termination, the NRC must consult with EPA. At this time, EPA could potentially exert regulatory authority under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) (i.e., exert regulatory authority to control radiotoxicity) and require additional remediation [2].

Therefore, RCRA closure regulations require that chemical toxicity not pose an unacceptable risk to human health and the environment; radiotoxicity only becomes a component of RCRA closure regulations if conditions at the Site trigger involvement via the required consultation with EPA per the EPA-NRC MOU at the time of license termination. As defined in 40 CFR Section 300.430(a)(2), risks to human health and the environment are characterized in a baseline risk assessment. The baseline risk assessment at HNP is part of the RCRA Facility Investigation (RFI).

Connecticut Department of Environmental Protection – Waste Bureau

Under the State of Connecticut's Property Transfer Act, any establishment (i.e. industrial real estate property) in the state must comply with the requirements of the Remediation Standard Regulations (RSRs) contained in the State of Connecticut Regulation of the Department of Environmental Protection Sections 22a-133k-1 through 22a-133k-3, which are administered by the CTDEP-WB, prior to property transfer. The RSRs require that substances regulated

under RCRA do not pose unacceptable ELCR and chemical toxicity hazards to public health. Compliance with the RSRs may be achieved by demonstrating that the ELCR for potential exposures to regulated substances does not exceed one in one-hundred thousand (10^{-5}) and that the HI does not exceed a value of 1, or by demonstrating that levels of regulated substances in environmental media do not exceed numerical standards corresponding to these risk thresholds that are published by CTDEP-WB.

Similar to the EPA RCRA requirements, the RSRs also require that substances regulated under the RSRs do not pose an unacceptable risk to ecological values of concern. The method for evaluating risks to the environment and risk management criteria mirror the EPA regulations used in the RCRA closure.

However, unlike the RCRA regulations, the RSRs specifically include radiological materials as regulated alternate polluting substances. Therefore, site closure under the RSRs requires that both radiotoxicity and chemical toxicity not pose unacceptable risks to human health and the environment. The closure requirements of the CTDEP-WB have been integrated into the RFI for the HNP.

Table I. Summary of Requirements for Protection of Public Health and the Environment in Support of Regulatory Closure of Haddam Neck Plant

NRC	CTDEP – RD	EPA - RCRA	CTDEP - WB
Public Health - Radiotoxicity			
- Radiation dose, Total Effective Dose Equivalent (TEDE; peak annual dose) - Not to exceed 25 mrem/yr, combined for all media	- Radiation dose, Total Effective Dose Equivalent (TEDE; peak annual dose) - Not to exceed 19 mrem/yr, combined for all media	- Not required unless invoked by conditions in NRC-EPA Memorandum of Understanding	- Excess Lifetime Cancer Risk (ELCR) - Not to exceed ELCR of 1 in 100,000, combined for all media
Public Health – Chemical Toxicity			
- Not required	- Not required	- Non-cancer risk, Hazard Index (HI) - Not to exceed a HI of 1 for each target health effect, combined for all media	- Non-cancer risk, Hazard Index (HI) - Not to exceed a HI of 1 for each target health effect, combined for all media or - Not to exceed numerical standards based on HI of 1
Environment – Radiotoxicity			
- Not required	- Not required	- Not required	- Radiation dose - Not to exceed literature dose-based benchmarks
Environment – Chemical Toxicity			
- Not required	- Not required	- Hazard Index (HI) - Not to exceed a HI of 1 that is in excess of risks for background conditions, combined for all media	- Hazard Index (HI) - Not to exceed a HI of 1 that is in excess of risks for background conditions, combined for all media

HARMONIZING REGULATORY REQUIREMENTS TO ACHIEVE CLOSURE

The methods that have been used by CYAPCO to integrate the closure requirements of the NRC, EPA, CTDEP-RD, and CTDEP-WB are discussed in the following subsections.

Addressing Agency Requirements for Protection of Public Health from Radiotoxicity

As discussed previously, both the NRC and the CTDEP-RD regulate radiological materials in Connecticut, requiring that the TEDE for combined exposure to environmental media not exceed a radiation dose limit of 25 mrem/yr (NRC) and 19 mrem/yr (CTDEP-RD). To address the dose-based criterion for protection of public health from radiotoxicity, CYAPCO developed numerical dose-based values (Derived Concentration Guideline Levels [DCGLs]) for each of the 20 site-related radionuclides at the HNP [3]. DCGLs for each radionuclide were derived for the TEDE of 25 mrem/yr and 19 mrem/yr, for both soil and groundwater (Table II). DCGLs for soil are to be applied to soil, sediment, and concrete foundations that will remain at the Site. DCGLs for groundwater are to be applied to groundwater beneath the Site and surface water bodies at the Site. The DCGLs for the HNP were developed to be protective for a resident farmer who, after decommissioning, is assumed to live at the Site and obtain all or a portion of his/her dietary requirements from produce and livestock raised on the Site property. In addition, because the groundwater beneath the Site is considered by the State of Connecticut to be water that requires protection as a potable aquifer (Connecticut Class GA groundwater), groundwater DCGLs were derived to be protective for the same receptor population (resident farmer) who is assumed to obtain all potable and livestock/irrigation water from the aquifer beneath the Site. Because multiple radionuclides are known to be present in multiple media, the actual cleanup values were calculated to ensure that the TEDE for all media combined does not exceed 19 mrem/yr (Eq. 1):

$$\text{Dose}_{\text{total}} = \text{Dose}_{\text{groundwater}} + \text{Dose}_{\text{soil}} \leq 19 \text{ mrem/yr (TEDE)} \qquad \text{(Eq. 1)}$$

The CTDEP-WB RSRs require that radiotoxicity be evaluated and, if needed, addressed as a component of the remediation for the Site. The most sensitive long-term health effect associated with exposure to ionizing radiation is cancer. Radiation dose limits such as the NRC 25 mrem/yr TEDE are protective for cancer that may be induced by exposure to ionizing radiation. However, the CTDEP-WB evaluates carcinogenic risk through a calculation of ELCR rather than radiation dose, and regulates carcinogenic risk through comparison of Site ELCR to an ELCR limit of 10^{-5}. As with the NRC/CTDEP-RD regulations where a TEDE greater than the applicable dose-limit would trigger remediation, a ELCR greater than 10^{-5} would trigger remediation under the CTDEP-WB RSRs, However, the CTDEP-WB has determined that a TEDE of 19 mrem/yr is equal to a ELCR of 10^{-5}. Therefore, compliance with the 19 mrem/yr TEDE limit established by the CTDEP-RD also satisfies compliance with the CTDEP-WB RSR requirements for radiotoxicity.

The NRC and EPA have entered into a MOU regarding EPA involvement in NRC-licensed sites that are in the process of, or have completed, D&D in support of license termination [2]. Significantly, the MOU states that EPA will defer to NRC authority and decision-making on all sites undergoing decommissioning except at sites presenting certain circumstances. Circumstances under which NRC must involve EPA are as follows:

1. Radioactive groundwater contamination in excess of the EPA's Maximum Contaminant Levels (MCLs);
2. License termination based on restricted release (10 CFR 20.1403) or alternate criteria (10 CFR 20.1404); or
3. Planned or actual residual (post-decontamination) radionuclide levels in soil exceed the "trigger" levels presented in Table 1 of the MOU.

For facilities affected by the MOU, the NRC is expected to consult with EPA if the conditions at the time of license termination exceed the criteria outlined in the MOU. After the license is terminated by the NRC, the MOU states that EPA reserves the right to take CERCLA actions at such sites if EPA disagrees with NRC and deems that additional cleanups are required to be protective of human health and the environment.

Although the consultation is not required until license termination, NRC and EPA did hold discussions for facilities where the approved DCGLs would exceed the criteria published in the MOU. In March, 2004 CYAPCO received notification from EPA that the proposed cleanup values (DCGLs) specified in the HNP LTP for five radionuclides in soil and fourteen radionuclides in groundwater exceeded trigger levels presented in the MOU and/or exceeded EPA

MCLs. Consultation between NRC and EPA with participation by CYAPCO resulted in the following path forward:

- CYAPCO would ensure that post-remediation levels of radionuclides in soil do not exceed the EPA trigger levels presented in the MOU; and
- CYAPCO would use the lesser of EPA MCLs and the 19 mrem/yr DCGLs as the cleanup values for radionuclides in groundwater.

Table II presents the MCLs for groundwater. As indicated in Table II, MCLs for most radionuclides are more restrictive than the dose-based DCGLs. By meeting the 19mrem/yr TEDE and the MCLs, all regulatory agencies are satisfied that the closure criteria will be protective of public health from radiotoxicity.

Table II. Haddam Neck Plant Public Health Cleanup Values Protective for Radiotoxicity

Radionuclide	Soil DCGL @ 25 mrem/yr [a] (pCi/g)	Soil DCGL @ 19 mrem/yr (pCi/g)	Groundwater DCGL @ 25 mrem/yr [a] (pCi/l)	Groundwater DCGL @ 19 mrem/yr (pCi/l)	Groundwater MCL [b] (pCi/L)
H-3	412	313	652000	495520	20000
C-14	5.66	4.30	9010	6848	2000
Mn-54	17.4	13.2	24200	18392	300
Fe-55	27400	20824	65400	49704	2000
Co-60	3.81	2.90	1140	866	100
Ni-63	723	549	31500	23940	50
Sr-90	1.55	1.18	251	191	8
Nb-94	7.12	5.41	6750	5130	109
Tc-99	12.6	9.58	26400	20064	900
Ag-108m	7.14	5.43	4240	3222	44
Cs-134	4.67	3.55	342	260	80
Cs-137	7.91	6.01	431	328	200
Eu-152	10.1	7.68	7330	5571	200
Eu-154	9.29	7.06	5050	3838	60
Eu-155	392	298	32500	24700	600
Pu-238	29.6	22.5	15.1	11.5	15
Pu-239	26.7	20.3	13.6	10.3	15
Pu-241	870	661	460	350	300
Am-241	25.8	19.6	13.2	10.0	15
Cm-243	29.0	22.0	19.4	14.7	15

[a] Connecticut Yankee Atomic Power Company, Haddam Neck Plant, License Termination Plan (Through Revision 1A, October 2002)
[b] Federal Register. National Primary Drinking Water Regulations; Radionuclides; Final Rule. December 7, 2000 (Volume 65, Number 236)

Addressing Agency Requirements for Protection of Public Health from Chemical Toxicity of Radionuclides

The NRC and the CTDEP-RD are satisfied that the site-specific DCGLs (and MCLs for groundwater) are protective of public health, for all pathways. However, the EPA RCRA regulations and the CTDEP-WB RSRs require that the chemical toxicity to humans associated with radionuclides must be characterized and, if needed, addressed as a component of the Site remediation.

For radionuclides, adverse health effects other than cancer would be associated with direct exposure to, and biological interaction with, the radionuclide as an element. Therefore, health effects other than cancer (i.e., non-carcinogenic effects) related to exposures to radionuclides as elements (i.e., chemical toxicity) would be evaluated using elemental mass measurements in an exposure medium, typically in units of elemental mass per unit mass of environmental medium (e.g., milligram element per kilogram soil). The amount of radiation emitted by a given radionuclide is described by the specific activity of the radionuclide, typically in units of activity per unit mass of elemental radionuclide (e.g., picocurie per gram element). Radionuclides with high specific activities, such as Co-60 (1.13E+15 pCi/g) will have a lower elemental mass for each unit activity in an environmental medium (1 pCi/g

Co-60 in soil = 8.84E-10 mg/kg in soil), whereas radionuclides with low specific activities, such as U-238 (3.35E+05 pCi/g), will have a higher elemental mass for each unit activity in an environmental medium (1 pCi/g U-238 in soil = 2.98 mg/kg in soil).

In recognition of the relationship between specific activity and elemental mass, and specific activity and radiotoxicity, EPA published guidance stipulating that, with the exception of uranium, potential human health risks associated with exposure to radionuclides may be characterized solely based on the radiotoxicity, rather than on potential chemical toxicity [4]. The rationale for EPA's position on this is provided in EPA's guidance, which states "*…Uranium, in soluble form, is a kidney toxin at mass concentrations slightly above background levels, and is the only radionuclide for which the chemical toxicity has been identified to be comparable to or greater than the radiotoxicity, and for which a reference dose (RfD) has been established to evaluate chemical toxicity. For radioisotopes of uranium, both effects (radiogenic cancer risk and chemical toxicity) should be considered.*" Since uranium is not among the radioactive elements of concern in environmental media at HNP, characterization of chemical toxicity risks was not required to satisfy EPA RCRA closure requirements. However, CTDEP-WB requested that CYAPCO provide additional documentation to substantiate EPA's guidance indicating that uranium is the only radioactive element that could pose potential chemical toxicity concerns that are comparable to radiotoxicity concerns. To address the concerns of CTDEP-WB, CYAPCO provided documentation demonstrating that the mass concentrations of radionuclides that correspond to the 19 mrem/yr TEDE DCGLs would not be associated with a chemical toxicity concern. The evaluation for soil is shown in Table III.

As shown in Table III, the specific activities of the radionuclides at HNP are high and, therefore, the elemental masses that are associated with radionuclide activity concentrations are very low. Specifically, the activities that correspond to the 19 mrem/yr TEDE DCGLs for each radionuclide correspond to elemental mass concentrations that are generally several orders of magnitude lower than 1 microgram per kilogram (ug/kg). The DCGLs represent the maximum permissible activity for each radionuclide that is protective for carcinogenic health effects (since each DCGL is based on a 19 mrem/yr TEDE, and the TEDE for combined exposure from all radionuclides in all media must not exceed 19 mrem/yr, the actual residual levels that are listed in Table III will be lower than the DCGLs presented).

The mass concentrations calculated in Table III were also compared to available risk-based screening values that are protective for chemical toxicity at a HI of 1. Since all isotopes of a given radionuclide have the same chemical characteristics as the base element (for example, Ni-63 and Co-60 behave chemically the same as nickel (stable) and cobalt (stable), respectively), the risk-based values for elements could be used to evaluate the potential chemical toxicity of radionuclides. For this same reason, it was appropriate to add the masses of all isotopes of the same element (e.g., Cs-134 and Cs-137) together, and then compare the total mass to the risk-based value. As shown in Table III, the available screening values are several orders of magnitude greater than the elemental mass concentrations that are associated with the 19 mrem/yr TEDE DCGLs. This demonstrated that radiotoxicity is the limiting health effect endpoint.

In its documentation to CTDEP-WB, CYAPCO noted that although the chemical toxicity of some of the elements for which radioisotopes are included in the HNP list of radionuclides (e.g., Cs, Pu) has not been investigated by the EPA, it is highly unlikely that these elements would pose chemical toxicity concerns at the elemental mass concentrations that are associated with the DCGLs. For example, in order for the radionuclide with the highest mass concentration associated with the DCGL (Tc-99, with a mass concentration of 0.00056 mg/kg corresponding to the DCGL of 9.58 pCi/g) to pose a potential chemical toxicity concern, the reference dose (RfD) would need to be as low as 7.3E-09 mg/kg/day. An RfD value of that magnitude is several orders of magnitude lower than any RfD value published in EPA's Integrated Risk Information System (IRIS) data base of approximately 500 chemicals. It is highly unlikely that an element posing such a high order of chemical toxicity would not have been previously identified by EPA and characterized for chemical toxicity.

This documentation was sufficient to address CTDEP-WB concerns regarding the chemical toxicity of radionuclides to public health, and CTDEP-WB did not require any further consideration of chemical toxicity of radionuclides to public health to comply with RSR closure requirements.

Table III. Calculation of Radionuclide Mass at Soil DCGL and Comparison to Public Health Cleanup Values Protective for Chemical Toxicity

Radionuclide	Soil DCGL @ 19 mrem/yr [a] (pCi/g)	Specific Activity [b] (pCi/mg)	Mass-Equivalent of Activity @ DCGL (mg/kg)	Risk-Based Concentration for Soil Based on Chemical Toxicity of Element (mg/kg)	
H-3	313	9.649E+12	0.000000032	--	
C-14	4.30	4.460E+09	0.00000096	--	
Mn-54	13.2	7.731E+12	0.0000000017	1,600	EPA Region III Residential Soil RBC [c]
Fe-55	20824	2.408E+12	0.0000086	23,000	EPA Region III Residential Soil RBC [c]
Co-60	2.90	1.130E+12	0.0000000026	1,600	EPA Region III Residential Soil RBC [c]
Ni-63	549	5.920E+10	0.0000093	1,400	RSR Residential DEC [d]
Sr-90	1.18	1.365E+11	0.0000000086	47,000	EPA Region III Residential Soil RBC [c]
Nb-94	5.41	1.872E+08	0.000029	--	
Tc-99	9.58	1.709E+07	0.00056	--	
Ag-108m	5.43	2.604E+10	0.00000021	340	RSR Residential DEC [d]
Cs-134	3.55	5.580E+11	0.0000000064		
Cs-137	6.01	8.704E+10	0.000000069		
Total Cs			0.000000075	--	
Eu-152	7.68	1.736E+11	0.000000044		
Eu-154	7.06	2.699E+11	0.000000026		
Eu-155	298	4.794E+11	0.00000062		
Total Eu			0.00000069	--	
Pu-238	22.5	1.714E+10	0.0000013		
Pu-239	20.3	6.217E+07	0.00033		
Pu-241	661	1.030E+11	0.0000064		
Total Pu			0.00033	--	
Am-241	19.6	3.433E+09	0.0000057	--	
Cm-243	22.0	5.050E+10	0.00000044	--	

[a] Connecticut Yankee Atomic Power Company, Haddam Neck Plant, License Termination Plan (Through Revision 1A, October 2002)
[b] "Handbook of Health Physics and Radiological Health, Third Ed." Lippincott Williams & Wilkins, Baltimore, MD. 1998. Editors: Shleien, B., Slaback, L., and Birky, B.
[c] "Risk Based Concentration Table" USEPA Region III. October, 2004.
[d] State of Connecticut Regulation of the Department of Environmental Protection. 22a-133k-1 through 22a-133k-3. 1996.

Addressing Agency Requirements for Protection of the Environment from Radiotoxicity

The NRC and CTDEP-RD acknowledge that radiation dose-based criteria for the protection of human health are also protective for the environment (i.e., radiotoxicity to human health is limiting). EPA RCRA does not require characterization of radiotoxicity to ecological receptors, and the NRC-EPA MOU only applies to protection of public health. However, to meet the Site closure requirements of the CTDEP-WB, characterization of the radiotoxicity associated with potential ecological receptor exposures to the radionuclides at HNP was required.

To characterize potential ecological risks associated with exposure to ionizing radiation at the HNP, CYAPCO used the Department of Energy (DOE) evaluation methodology specified in "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" [5]. This guidance document specifies that 1 rad per day exposure level is protective of aquatic receptors and terrestrial plants, and 0.1 rad per day exposure level is protective for terrestrial and semi-aquatic wildlife. Over the operating life of the HNP, CYAPCO has been required to demonstrate that all radionuclides detected at the HNP's operational level were well below these criteria (operating requirements for the HNP under 40 CFR 190 and 10 CFR 20 require monthly and annual documentation that radioactivity releases from all pathways are below 25 mrem/yr for the general public and that occupational levels are below 5000 mrem/yr).

However, to satisfy the CTDEP-WB, a comparison was also completed between the approved DCGLs and MCLs to ecological screening values for soil, sediment, and surface water, published in the DOE guidance document that are protective for radiotoxic effects. The evaluation for sediment is provided in Table IV; similar evaluations were completed for surface water and soil. As indicated in Table IV, the values that are protective of human health from radiotoxic effects are protective for radiotoxicity to environmental receptors. Since the final site conditions at license termination must comply with the cleanup values that are protective for public health, this evaluation should be sufficient to address CTDEP-WB concerns regarding radiotoxicity to ecological receptors. Acceptance from CTDEP-WB is pending.

Table IV. Comparison of Ecological Screening Values Protective for Radiotoxicity to Public Health Cleanup Values Protective for Radiotoxicity

Radionuclide	Ecological Sediment Screening Values (pCi/g)					Soil DCGL @ 19 mrem/yr [d] (pCi/g)
	Ecological Screening Value [a]	Ecological Benchmark [b]			Lowest Value	
	Aquatic	Small fish	Large fish	Lowest		
H-3	400,000				400,000	313
C-14					82,636 [c]	4.30
Mn-54					254,040 [c]	13.2
Fe-55					400,040,000 [c]	20824
Co-60	1,000	21,000	22,400	21,000	1,000	2.90
Ni-63					10,555,800 [c]	549
Sr-90	600	557000*		557000*	60	1.18
Nb-94					103,952 [c]	5.41
Tc-99	40,000				40,000	9.58
Ag-108m					104,244 [c]	5.43
Cs-134		33,900	36,500	33,900	33,900	3.55
Cs-137	3,000	93200*	105000*	93200*	3,000	6.01
Eu-152					147,460 [c]	7.68
Eu-154	3,000	42,600	47,400	42,600	3,000	7.06
Eu-155	30,000	872,000	946,000	872,000	30,000	298
Pu-238		95,900,000	480,000,000	95,900,000	95,900,000	22.5
Pu-239	6,000				6,000	20.3
Pu-241					12,702,000 [c]	661
Am-241	5,000	1,670,000	2,440,000	1,670,000	5,000	19.6
Cm-243					21,170 [c]	22.0

[a] "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" Module 1, Principals and Applications. Table 6.2. DOE. (DOE-STD-1153-2002).

[b] "Radiological Benchmarks for Screening Contaminants of Potential Concern for Effects on Aquatic Biota at Oak Ridge National Laboratory, Oak Ridge, Tennessee. Bechtel Jacobs Company, LLC, 1998.

[c] These values are not published in source document and are therefore derived as the concentration in sediment that would be associated with the 1 Rad/d dose limit for aquatic animals proposed by the DOE (DOE-STD-1153-2002). The values are calculated by scaling the 19 mrem/yr DCGL to a value that corresponds to a 1 Rad/d limit, as follows: Eco Screening Value (pCi/g) =(DCGL (pCi/g) x 1 Rad/d) / [(19 mrem/yr) x (1 yr/365 d) x (1 Rem/1000 mrem) x (1 Rad/(1 Rem/Q))] Where Q is the radiation weighting factor, assigned a value of 20 (high energy protons, alpha particles, fission fragments, heavy nuclei) for Cm-243 and a value of 1 for other (non-alpha-producing) radionuclides.

[d] Connecticut Yankee Atomic Power Company, Haddam Neck Plant, License Termination Plan (Through Revision 1A, October 2002)

* Benchmark includes dose rate from short-lived progeny

Addressing Agency Requirements for Protection of the Environment from Chemical Toxicity of Radionuclides

The NRC and the CTDEP-RD do not require evaluation of the chemical toxicity of radionuclides to environmental receptors. Although the EPA requires evaluation of chemical toxicity of radionuclides under RCRA regulations, with respect to evaluating risks to the environment, EPA applies the EPA guidance document indicating that

uranium is the only radioactive element for which characterization of chemical toxicity is required. Therefore, the CTDEP-WB was the only regulatory entity that required that the chemical toxicity of radionuclides at HNP be evaluated for environmental receptors.

To characterize chemical toxicity hazards of radionuclides to environmental receptors, CYAPCO used an approach that was analogous to the approach that was used to address this concern relative to public health (discussed previously). Specifically, for each environmental medium of potential concern for ecological receptors (soil, sediment, and surface water), the mass concentrations of radionuclides associated with the public health protection criteria for those media (i.e., DCGLs and/or MCLs) were calculated and compared to available ecological risk-based screening values that are protective for chemical toxicity of the base element at a HI of 1. Table V presents this evaluation for soil.

As indicated in Table V, the comparisons between mass concentrations and screening values were expressed as hazard quotients (Eq. 2), and summed to yield cumulative hazard index values.

Hazard Quotient (HQ) = Exposure Concentration (pCi/g) / Screening Level (pCi/g) (Eq. 2)

To provide additional perspective to this evaluation, the maximum reported radionuclide activities in Site media were included in these evaluations. The available screening values were shown to be several orders of magnitude greater than the elemental mass concentrations that are associated with the 19 mrem/yr TEDE DCGLs and maximum Site concentrations. The hazard index values ranged from 0.00000006 (sediment, based on maximum detected Site activities) to 0.003 (soil, based on mass concentrations associated with the DCGLs). These calculations demonstrated that chemical toxicity to ecological receptors is not a concern for the radionuclides detected at the HNP.

This documentation should be sufficient to address CTDEP-WB concerns regarding the chemical toxicity of radionuclides to ecological receptors, and CTDEP-WB should not require any further consideration of chemical toxicity of radionuclides to the environment to comply with RSR closure requirements. Approval from CTDEP-WB is pending.

Table V. Calculation of Radionuclide Mass at Soil DCGL and Maximum Site Activity in Soil and Comparison to Ecological Screening Values Protective for Chemical Toxicity

Radionuclide	Soil DCGL @ 19 mrem/yr [a] (pCi/g)	Maximum Activity at Site (pCi/g)	Specific Activity [b] (pCi/mg)	Mass-Equivalent of Activity @ DCGL (mg/kg)	Mass-Equivalent of Activity @ Maximum Site Activity [SITE] (mg/kg)	Ecological Screening Value for Soil Based on Chemical Toxicity of Element (EV) (mg/kg)		DCGL Hazard Quotient (DCGL/EV)	Site Hazard Quotient (SITE/EV)
H-3	313	46	9.649E+12	0.000000032	0.0000000048	--			
C-14	4.3	0.84	4.460E+09	0.00000096	0.00000019	--			
Mn-54	13	0.11	7.731E+12	0.0000000017	0.000000000014	100	ORNL Soil Invert./Region IV Soil Benchmark [c]	0.000000000017	0.00000000000014
Fe-55	20824	102	2.408E+12	0.0000086	0.000000043	200	ORNL Soil Invert./Region IV Soil Benchmark [c]	0.000000043	0.00000000021
Co-60	2.9	47	1.130E+12	0.0000000026	0.000000041	190	Eco SSL Benchmark [d]	0.000000000013	0.00000000022
Ni-63	549	46	5.920E+10	0.0000093	0.00000078	90	ORNL Soil Invert./Region IV Soil Benchmark [c]	0.00000010	0.0000000086
Sr-90	1.2	5.2	1.365E+11	0.0000000086	0.000000038	--			
Nb-94	5.4	0.15	1.872E+08	0.000029	0.00000078	--			
Tc-99	9.6	1.4	1.709E+07	0.00056	0.000083	0.2	Region IV Soil Benchmark [c]	0.0028	0.00041
Ag-108m	5.4	0.16	2.604E+10	0.00000021	0.0000000060	50	ORNL Soil Invert. Benchmark [c]	0.0000000042	0.00000000012
Cs-134	3.5	0.19	5.580E+11	0.0000000064	0.00000000035				
Cs-137	6.0	834	8.704E+10	0.000000069	0.0000096				
Total Cs				0.000000075	0.0000096	--			
Eu-152	7.7	0.38	1.736E+11	0.000000044	0.0000000022				
Eu-154	7.1	0.45	2.699E+11	0.000000026	0.0000000017				
Eu-155	298	0.40	4.794E+11	0.00000062	0.00000000083				
Total Eu				0.00000069	0.0000000047	--			
Pu-238	22	0.29	1.714E+10	0.0000013	0.000000017				
Pu-239	20	0.072	6.217E+07	0.00033	0.0000012				
Pu-241	661	32	1.030E+11	0.0000064	0.00000031				
Total Pu				0.00033	0.0000015	--			
Am-241	20	2.5	3.433E+09	0.0000057	0.00000073	--			
Cm-243	22	0.23	5.050E+10	0.00000044	0.0000000045	--			
							Hazard Index	0.003	0.0004

[a] Connecticut Yankee Atomic Power Company, Haddam Neck Plant, License Termination Plan (Through Revision 1A, October 2002)

[b] "Handbook of Health Physics and Radiological Health, Third Ed." Lippincott Williams & Wilkins, Baltimore, MD. 1998. Editors: Shleien, B., Slaback, L., and Birky, B.

[c] Region IV Recommended Ecological Screening Values for Soil. From: Friday, G.P., November, 1998. Ecological Screening Values for Surface Water, Sediment and Soil. Westinghouse Savannah River Company, Savannah River Technology Center, SC (WSRC-TR-98-00110), Aiken, SC 29808.

[d] Peer Review Workshop Report on Ecological Soil Screening Level (Eco-SSL) Guidance Document; United States Environmental Protection Agency; Prepared by Versar Inc., Springfield, VA, Contract No. 68-C-99-238; 31 August 2000.

CONCLUSIONS AND LESSONS LEARNED

To satisfy each of the regulatory agencies that hold a stake in the decommissioning and closure of the HNP, the most conservative (lowest) of the applicable cleanup values must be used to characterize and remediate the Site to reach closure and property transfer. Significant conclusions from the effort expended by CYAPCO to meet the closure requirements of the NRC, EPA, CTDEP-RD, and CTDEP-WB include:

- Use of the radionuclide cleanup values derived to be protective for the CTDEP-RD 19 mrem/yr TEDE are protective for the NRC 25 mrem/yr TEDE and for radiotoxic effects to ecological receptors.

- MCLs for groundwater are generally lower than the approved site specific DCGLs. Although EPA does not regulate radionuclides under the RCRA, use of MCLs for groundwater will ensure that the NRC-EPA MOU is not triggered for additional involvement by EPA for groundwater.

- Elemental mass concentrations associated with both the 19 mrem/yr TEDE human health-based radionuclide cleanup values and the maximum detected radionuclide activities at the HNP are extremely low, ranging from less than one part-per-trillion to one-half a part-per-billion. These values are well below published human health and ecological risk based values that are protective for chemical toxicity, demonstrating that existing and post-remediation conditions at HNP will not pose chemical toxicity risks of concern to public health or the environment.

Consequently, radionuclide cleanup goals that are protective for the lesser of 19 mrem/yr TEDE and MCLs satisfy all applicable closure requirements for radionuclides at HNP, including:

- NRC 25 mrem/yr TEDE dose-based criterion to support decommissioning;

- CTDEP-RD 19 mrem/yr TEDE dose-based criterion to support decommissioning;

- EPA-NRC MOU trigger criteria that invoke EPA direct involvement in decommissioning; and

- CTDEP-WB criteria for protection of public health and the environment from radiotoxicity and chemical toxicity.

Furthermore, the evaluations performed by CYAPCO demonstrate that public health cleanup criteria for most radionuclides of concern at nuclear power generation facilities are protective for chemical toxicity concerns and are protective for the environment (ecological receptors). Consequently, it is not generally necessary to perform a baseline ecological risk assessment for radionuclides at nuclear power generation facilities.

REFERENCES

[1] State of Connecticut Department of Environmental Protection (CTDEP), 2002. Letter from Mr. Edward J. Wilds, Jr., PhD, Director Connecticut Department of Environmental Protection, to Mr. Joseph F. Bourass, Facility #00137, Connecticut Yankee Atomic Power Company. November 20, 2002.

[2] "Memorandum of Understanding Between the Environmental Protection Agency and the Nuclear Regulatory Commission: Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites" OSWER 9295.8-06, signed by EPA on September 30 and NRC on October 9, 2002.

[3] Connecticut Yankee Atomic Power Company, Haddam Neck Plant, License Termination Plan (Through Revision 1A, October 2002)

[4] "Radiation Risk Assessment at CERCLA Sites: Q&A" (OSWER 9200.4-31P; EPA 540/R/99/006; December, 1999.

[5] "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" Module 1, Principals and Applications. Table 6.2. DOE. (DOE-STD-1153-2002).