5.7 Uranium Fuel Cycle Impacts

This section discusses the environmental impacts from the uranium fuel cycle for STP 3 & 4. The uranium fuel cycle is defined as the total of those operations and processes associated with provision, utilization, and ultimate disposal of fuel for nuclear power reactors.

The regulations in 10 CFR 51.51(a) state that:

> "Every environmental report prepared for the construction permit stage of a light-water-cooled nuclear power reactor, and submitted on or after September 4, 1979, shall take Table S-3, Table of Uranium Fuel Cycle Environmental Data, as the basis for evaluating the contribution of the environmental effects of uranium mining and milling, the production of uranium hexafluoride, isotopic enrichment, fuel fabrication, reprocessing of irradiated fuel, transportation of radioactive materials and management of low level wastes and high level wastes related to uranium fuel cycle activities to the environmental costs of licensing the nuclear power reactor. Table S-3 shall be included in the environmental report and may be supplemented by a discussion of the environmental significance of the data set forth in the table as weighed in the analysis for the proposed facility."

Table S-3 is used to assess environmental impacts. Its values are normalized for a reference 1000-MWe LWR at 80% capacity factor. The 10 CFR 51.51(a) Table S-3 values are reproduced in Table 5.7-1. STPNOC has analyzed a 1350-MWe ABWR unit operating at 95% capacity factor for STP 3 & 4. STP has considered the approximately 60% increase in power level for the ABWR in the evaluation of the estimated environmental impacts for the ABWR relative to the reference reactor in Table 5.7-1. Details of this evaluation are discussed in the following paragraphs of this section, however it is important to recognize that the higher power level ~~ABWR~~ Advanced Boiling Water Reactor (ABWR) impact on the uranium fuel cycle is in the same order of magnitude as for the Normalized Model LWR Annual Fuel Requirement table (WASH 1248) or Reference Reactor Year (NUREG-0116) and, therefore, the values for the maximum effect per annum fuel total reactor year of Model 1000 MWe LWR of NUREG-1555.

Specific categories of natural resource use are included in Table S-3 (and duplicated in Table 5.7-1). These categories relate to land use, water and fossil fuel consumption, chemical and thermal effluents, radiological releases, disposal of transuranic, high-level and low-level wastes, and radiation doses from transportation and occupational exposure. In developing Table S-3, the NRC considered two fuel cycle options that differed in the treatment of spent fuel removed from a reactor. "No recycle" treats all spent fuel as waste to be stored at a federal waste repository, "uranium-only recycle" involves reprocessing spent fuel to recover unused uranium and return it to the system. Neither cycle involves the recovery of plutonium. The contributions in Table S-3 resulting from reprocessing, waste management, and transportation of wastes are maximized for both of the two fuel cycles (uranium-only and no recycle); that is, the identified environmental impacts are based on the cycle that results in the greater impact.

The Nuclear Nonproliferation Act of 1978, Pub. L. No. 95-242 (22 USC 3201 et seq.), has significantly affected the disposition of spent nuclear fuel by deferring indefinitely the commercial reprocessing and recycling of spent fuel produced in the U.S. commercial nuclear power program. While the ban on the reprocessing of spent fuel was lifted during the Reagan administration, economic circumstances changed, reserves of uranium ore increased, and the stagnation of the nuclear power industry provided little incentive for the industry to resume reprocessing. During the 109th Congress, the Energy Policy Act of 2005, Pub. L. No. 109-58 (119 Stat. 594 [2005]), was enacted. It authorized the DOE to conduct an advanced fuel recycling technology research and development program to evaluate proliferation-resistant fuel recycling and transmutation technologies that minimize environmental or public health and safety impacts. Consequently, while federal policy does not prohibit reprocessing, additional DOE efforts would be required before commercial reprocessing and recycling of spent fuel produced in the U.S. commercial nuclear power plants could commence.

The following assessment of the environmental impacts of the fuel cycle for an ABWR at the STP site is based on the values in Table S-3 and NRC's analysis of the radiological impacts from radon-222 and technetium-99 in NUREG-1437 (Reference 5.7-1) which STPNOC has reviewed and updated for this analysis. NUREG-1437 and Addendum 1 to the GEIS (Reference 5.7-2) provide a detailed analysis of the environmental impacts from the uranium fuel cycle. Although NUREG-1437 is specific to impacts related to license renewal, the information is relevant to this review because the ABWR design considered here is also a LWR and uses the same type of fuel.

The fuel cycle impacts in Table S-3 are based on a reference 1000 MWe LWR operating at an annual capacity factor of 80% for an electrical output of 800 MWe. STPNOC will operate two ABWR units at the site. The standard configuration (a single unit) will be used to evaluate uranium fuel cycle impacts relative to the reference reactor. In the following evaluation of the environmental impacts of the fuel cycle for the ABWR, STPNOC assumed a 1350 MWe reactor with a capacity factor of 95% for an electrical output of approximately 1280 MWe. The ABWR output is approximately 60% greater than the output used to estimate impact values in Table S-3 (reproduced in Table 5.7-1) for the reference reactor. As stated earlier in this section, data used for evaluation of the uranium fuel cycle environmental impact has been scaled from the reference reactor impacts to reflect the output of one ABWR.

NRC calculated the values in Table S-3 from industry averages for the performance of each type of facility or operation associated with the fuel cycle. NRC chose assumptions so that the calculated values will not be underestimated. This approach was intended to ensure that the actual values will be less than the quantities shown in Table S-3 for all LWR nuclear power plants within the widest range of operating conditions. Changes in the fuel cycle and reactor operations have occurred since Table S-3 was promulgated. For example, the estimated quantity of fuel required for a year's operation of a nuclear power plant can now reasonably be calculated assuming a 60-year lifetime (40 years of initial operation plus a 20-year license renewal term). This was done in NUREG-1437 for both BWRs and PWRs, and the highest annual requirement (35 metric tonnes [MT] of uranium made into fuel for a BWR) was used in

NUREG-1437 as the basis for the reference reactor year. A number of fuel management improvements have been adopted by nuclear power plants to achieve higher performance and to reduce fuel and enrichment requirements, reducing annual fuel requirements. Therefore, Table S-3 remains a conservative estimate of the environmental impacts of the fuel cycle fueling nuclear power reactors operating today.

Another change is the elimination of the U.S. restrictions on the importation of foreign uranium. The economic conditions of the uranium market now and in the foreseeable future favor full use of foreign uranium at the expense of the domestic uranium industry. These market conditions have forced the closing of most U.S. uranium mines and mills, substantially reducing the environmental impacts in the United States from these activities. However, the Table S-3 estimates have not been adjusted accordingly so as to ensure that these impacts, which will have been experienced in the past and may be fully experienced in the future, are considered. Factoring in changes to the fuel cycle suggests that the environmental impacts of mining and milling could drop to levels below those in Table S-3. Section 6.2.3 of NUREG-1437 discusses the sensitivity of these changes in the fuel cycle on the environmental impacts.

5.7.1 Land Use

The total annual land requirements for the fuel cycle supporting an ABWR will be about 181 acres. Approximately 21 acres will be permanently committed land, and 160 acres will be temporarily committed. A "temporary" land commitment is a commitment for the life of the specific fuel cycle plant (e.g., a mill, enrichment plant, or succeeding plants). Following decommissioning, the land could be released for unrestricted use. "Permanent" commitments represent land that may not be released for use after decommissioning because decommissioning does not result in the removal of sufficient radioactive material to meet the limits of 10 CFR 20, Subpart E for release of an area for unrestricted use.

In comparison, a coal-fired plant with the same MWe output as the ABWR using strip-mined coal requires the disturbance of about 320 acres per year for fuel alone. The impacts on land use from the uranium fuel cycle will be SMALL and will not warrant mitigation.

5.7.2 Water Use

Principal water use for the fuel cycle supporting STP 3 & 4 will be that required to remove waste heat from the power stations supplying electricity to the enrichment process. Scaling from Table S-3, of the total annual water use of 1.82×10^{10} gallons for the ABWR fuel cycle, about 1.78×10^{10} gallons will be required for the removal of waste heat. Evaporative losses from fuel cycle process cooling will be about 2.57×10^{8} gallons per year and mine drainage will account for 2.04×10^{8} gallons per year. Impacts on water use from the uranium fuel cycle will be SMALL and will not warrant mitigation.

5.7.3 Fossil Fuel Impacts

Electric energy and process heat are required during various phases of the fuel cycle process. The electric energy is usually produced by the combustion of fossil fuel at conventional power plants. Electric energy associated with the fuel cycle represents about 5% of the annual electric power production of the reference reactor. Process heat is primarily generated by the combustion of natural gas. This gas consumption, if used to generate electricity, represents less than 0.4% of the electrical output of the reference reactor. The direct and indirect consumption of electric energy for fuel cycle operations would be small relative to the power production of the proposed units.

5.7.4 Chemical Effluents

The quantities of liquid, gaseous, and particulate discharges associated with the fuel cycle processes are given in Table S-3 (Table 5.7-1) for the reference 1000-MWe LWR. The quantities of effluents for an ABWR will be approximately 60% greater than those in Table S-3 (Table 5.7-1). The principal effluents are SO_x, NO_x, and particulates. Based on the U.S. Environmental Protection Agency's National Air Pollutant Emissions Estimates (Reference 5.7-3), these ABWR emissions constitute less than 0.052% of all SO_2 emissions in 2005, and less than 0.012% of all NO_x emissions in 2005.

Liquid chemical effluents produced in the fuel cycle processes are related to fuel enrichment and fabrication and may be released to receiving waters. All liquid discharges into navigable waters of the United States from facilities associated with fuel cycle operations are subject to requirements and limitations set by an appropriate federal, state, regional, local, or tribal regulatory agency. Tailing solutions and solids are generated during the milling process and are not released in quantities sufficient to have a significant impact on the environment. Impacts from chemical effluents from the uranium fuel cycle will be SMALL and will not warrant mitigation.

5.7.5 Radioactive Effluents

Radioactive gaseous effluents estimated to be released to the environment from waste management activities and certain other phases of the fuel cycle are set forth in Table S-3 (Table 5.7-1). Using Table S-3 data, Subsection 6.2.2.1 of NUREG-1437 estimates the 100-year environmental dose commitment to the U.S. population from the fuel cycle (excluding reactor releases and dose commitments due to radon-222 and technetium-99) to be about 400 person-rem per reference reactor year. The estimated dose commitment to the U.S. population will be approximately 640 person-rem per year of operation for the ABWR.

Subsection 6.2.2.1 of NUREG-1437 estimates the additional whole body dose commitment to the U.S. population from radioactive liquid wastes effluents due to all fuel cycle operations (other than reactor operation) to be approximately 200 person-rem per reference reactor year. The estimated dose commitment to the U.S. population will be approximately 320 person-rem per year of operation for the ABWR. Thus, the estimated 100-year environmental dose commitment to the U.S. population from radioactive gaseous and liquid releases from fuel cycle operations is approximately 960 person-rem to the whole body per reactor-year for the ABWR.

The radiological impacts of radon-222 and technetium-99 releases are not included in Table S-3. Principal radon releases occur during mining and milling operations and as emissions from mill tailings. Principal technetium-99 releases occur as releases from the gaseous diffusion enrichment process. NRC provided an evaluation of these technetium-99 and radon-222 releases in NUREG-1437. STPNOC has reviewed the evaluation, considers it reasonable, and has provided it as part of this application for STP 3 & 4.

Section 6.2 of NUREG-1437 estimates radon-222 releases from mining and milling operations, and from mill tailings for a year of operation of the reference 1000-MWe LWR. The estimated releases of radon-222 for one ABWR are 8300 curies (Ci) per year. Of this total, approximately 78% will be from mining, 15% from milling, and 7% from inactive tails before stabilization. Radon releases from stabilized tailings were estimated to be 1.6 Ci per year for the ABWR; that is 60% greater than the NUREG-1437 estimate for the reference reactor year. The major risks from radon-222 are from exposure to the bone and lung, although there is a small risk from exposure to the whole body. The organ-specific dose weighting factors from 10 CFR 20 were applied to the bone and lung doses to estimate the 100-year dose commitment from radon-222 to the whole body. The 100-year estimated dose commitment from mining, milling, and tailings before stabilization for the ABWR will be approximately 1500 person-rem to the whole body. From stabilized tailing piles, the same estimated 100-year environmental dose commitment will be approximately 28 person-rem to the whole body.

NUREG-1437 considered the potential health effects associated with the releases of technetium-99 for the reference reactor. The estimated technetium-99 releases for the ABWR will be 0.011 Ci from chemical processing of recycled uranium hexafluoride before it enters the isotope enrichment cascade and 0.0080 Ci into groundwater from a high-level waste repository. The major risks from technetium-99 are from exposure of the gastrointestinal tract and kidneys, and a small risk from whole-body exposure. Applying the organ-specific dose weighting factors from 10 CFR 20 to the gastrointestinal tract and kidney doses, the total-body 100-year dose commitment from technetium-99 is estimated to be 160 person-rem for the ABWR.

Although radiation can cause cancer at high doses and high dose rates, no data unequivocally establish a relationship between cancer and low doses or low dose rates below approximately 10,000 person-rem. However, to be conservative, radiation protection experts assume that any amount of radiation may pose some risk of cancer, or a severe hereditary effect, and that higher radiation exposures create higher risks. Therefore, a linear, no-threshold dose response relationship is used to describe the relationship between radiation dose and detrimental effects. Simply stated, any increase in dose, no matter how small, results in an incremental increase in health risk. A recent report by the National Academy of Sciences (Reference 5.7-4) supports the linear, no-threshold dose response model.

Based on this model, risk to the public from radiation exposure can be estimated using the nominal probability coefficient (730 fatal cancers, nonfatal cancers, or severe hereditary effects per 1×10^6 person-rem) from the International Commission on Radiation Protection (ICRP) Publication 60 (Reference 5.7-5). This coefficient, multiplied by the sum of the estimated whole-body population doses estimated above for the ABWR, approximately 2600 person-rem per year, estimates that the U.S.

population could incur a total of approximately 1.9 fatal cancers, nonfatal cancers, or severe hereditary effects from the annual fuel cycle for the ABWR. This risk is small compared to the number of fatal cancers, nonfatal cancers, and severe hereditary effects that will be estimated to occur in the U.S. population annually from exposure to natural sources of radiation using the same risk estimation methods.

Based on these analyses, STPNOC concludes that the environmental impacts of radioactive effluents from the fuel cycle will be SMALL and will not warrant mitigation.

5.7.6 Radioactive Waste

The quantities of radioactive waste (low-level, high-level, and transuranic wastes) associated with fuel cycle processes are presented in Table S-3 (Table 5.7-1). For low-level waste disposal, NRC notes in 10 CFR 51.51(b) that there will be no significant radioactive releases to the environment. For high-level and transuranic wastes, NRC notes that these wastes are to be disposed at a repository, such as the candidate repository at Yucca Mountain, Nevada. No release to the environment is expected to be associated with such disposal because all of the gaseous and volatile radionuclides contained in the spent fuel are assumed to be released to the atmosphere before disposal of the waste.

There is some uncertainty associated with the high-level waste and spent fuel disposal component of the fuel cycle. The regulatory limits for offsite releases of radionuclides for the current candidate repository site have not been finalized. However, NRC has assumed that limits would be developed along the line of the 1995 National Academy of Sciences report, "Technical Bases for Yucca Mountain Standards" (Reference 5.7-6), and that in accordance with the Commission's Waste Confidence Decision (10 CFR 51.23), a repository can and likely will be developed at some site that will comply with such limits, with peak doses to virtually all individuals of 100 person-rem per year or less (Reference 5.7-1). It is reasonable to conclude that the offsite radiological impacts of spent fuel and high-level waste disposal would not be sufficiently great to preclude construction of new units at the STP site.

For the reasons stated above, STPNOC concludes that the environmental impacts of radioactive waste disposal will be SMALL and will not warrant mitigation.

5.7.7 Occupational Dose

The estimated occupational dose attributable to all phases of the fuel cycle is approximately 960 person-rem per year for the ABWR. This is based on a 600 person-rem-per-year occupational dose estimate attributable to all phases of the fuel cycle for the reference reactor (Reference 5.7-1). The dose to any individual worker would be maintained within the dose limit of 10 CFR 20, which is five rem per year. The environmental impacts from this occupational dose would be SMALL.

5.7.8 Transportation

The transportation dose to workers and the public totals about 2.5 person-rem per year for the reference reactor as presented in Table S-3 (Table 5.7-1). This corresponds to a dose of 4.0 person-rem per year for the ABWR. Estimated dose to workers is below established safe limit. For comparative purposes, the estimated collective dose from natural background radiation to the population within 50 miles of the STP site is 75,000 person-rem per year. On the basis of this comparison, STPNOC concludes that environmental impacts of transportation from the fuel cycle will be SMALL and will not warrant mitigation.

5.7.9 Summary

STPNOC evaluated the environmental impacts of the uranium fuel cycle as given in Table S-3 and considered the effects of radon-222 and technetium-99 releases based on the information presented in NUREG-1437. For determination of “small radiological impact” compliance with dose and release levels were utilized. Arguments based on comparison with natural background radiation were used only where dose and release levels cannot be established without great uncertainty, e.g., for large populations. NUREG-1437, Vol. 1, Section 6.2.4 Conclusions, in the paragraph states that “The aggregate nonradiological impact of the uranium fuel cycle resulting from the renewal of an operating license on any plant is small”. Based on this evaluation, STPNOC concludes that the impacts associated with the uranium fuel cycle would be SMALL, and mitigation would not be warranted.

5.7.10 References

5.7-1 “Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Section 6.2, ‘Impacts of the Uranium Fuel Cycle,’” NUREG-1437, Volume 1, May 1996.

5.7-2 “Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Section 6.3, ‘Transportation’, and Table 9.1, 'Summary of findings on NEPA issues for license renewal of nuclear power plants,'“ NUREG-1437, Volume 1, Addendum 1, August 1999.

5.7-3 “National Air Pollutant Emissions Estimates (fires and dust excluded) for Major Pollutants,” EPA 2006. Available at http://earth1.epa.gov/airtrends/pdfs/table3.pdf, accessed January 29, 2007.

5.7-4 “Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII – Phase 2,” Committee to Assess Health Risks From Exposure to Low Levels of Ionizing Radiation, Board on Radiation Effects Research, Division of Earth and Life Studies, National Research Council, National Academy Press, Washington D.C, 2006, NAS 2006. Available at http://www.nap.edu/books/030909156X/html.

5.7-5 “1990 Recommendations of the International Commission of Radiological Protection, ICRP Publication 60, Annals of the ICRP 21(1-3),” ICRP 1991, Pergammon Press, New York, New York, 1991.

5.7-6 "Technical Bases for Yucca Mountain Standards," Committee on Technical Bases for Yucca Mountain Standards, Board on Radioactive Waste Management, Commission on Geosciences, Environment, and Resources, National Research Council, National Academy Press, Washington D.C., 1995, NAS 1995. Available at http://books.nap.edu/books/0309052890/html/R1.html#pagetop.

Table 5.7-1 Uranium Fuel Cycle Environmental Data [1]

Environmental Considerations	Reference Reactor	ABWR
Natural Resource Use		
Land (acres)		
Temporarily committed [2]	100	160
Undisturbed area	79	127
Disturbed area	22	35
Permanently committed	13	21
Overburden moved (millions of MT)	2.8	4.5
Water (millions of gallons)		
Discharged to air	160	257
Discharged to water bodies	11,090	17,800
Discharged to ground	127	204
Total	11,377	18,200
Fossil Fuel		
Electrical energy (thousands of MW-hour)	323	520
Equivalent coal (thousands of MT)	118	190
Natural gas (millions of scf)	135	220
Gases (including entrainment) [3]		
SO_x	4400	7050
NO_x [4]	1190	1910
hydrocarbons	14	22
CO	29.6	47
particulates	1154	1850
Other gases		
F	0.67	1.1
HCl	0.014	0.022

Table 5.7-1 Uranium Fuel Cycle Environmental Data [1] (Continued)

Environmental Considerations	Reference Reactor	ABWR
Liquid		
SO_4^-	9.9	16
NO_3^-	25.8	41
fluoride	12.9	21
Ca^{++}	5.4	8.7
Cl^-	8.5	14
Na^+	12.1	19
NH_3	10	16
Fe	0.4	0.64
Tailings solutions (thousands of MT)	240	380
Solids	91,000	146,000
Effluents – Radiological (curies)		
Gases (including entrainment)		
^{222}Rn	[5]	[5]
^{226}Ra	0.02	0.032
^{230}Th	0.02	0.032
U	0.034	0.055
^{3}H (thousands)	18.1	29
^{14}C	24	38
^{85}Kr (thousands)	400	640
^{106}Ru	0.14	0.22
^{129}I	1.3	2.1
^{131}I	0.83	1.3
^{99}Tc	[5]	[5]
Fission products and TRU	0.203	0.33

Table 5.7-1 Uranium Fuel Cycle Environmental Data [1] (Continued)

Environmental Considerations	Reference Reactor	ABWR
Liquids		
U and daughters	2.1	3.4
^{226}Ra	0.0034	0.0055
^{230}Th	0.0015	0.0024
Effluents – Radiological (curies) (cont.)		
^{234}Th	0.01	0.016
fission and activation	5.90×10^{-6}	9.5×10^{-6}
Solids buried		
not HLW (shallow)	11,300	18,100
TRU and HLW (deep)	1.10×10^{7}	1.76×10^{7}
Effluents – Thermal (billions of Btu)	4063	6500
Transportation (person rem)		
exposure of workers and the general public	2.5	4.0
Occupational exposure – reprocessing and waste management	22.6	36

MT metric tonnes
TRU transuranic
HLW high-level waste

Notes:

[1] In some cases where no entry appears in Table S-3, it is clear from the background documents that the matter was addressed and that, in effect, the table should be read as if a specific zero entry had been made. However, there are other areas that are not addressed at all in the table. Table S-3 does not include health effects from the effluents described in the table, or estimates of releases of radon-222 from the uranium fuel cycle or estimates of technetium-99 released from waste management or reprocessing activities. Radiological impacts of these two radionuclides are addressed in NUREG-1437, “Generic Environmental Impact Statement for License Renewal of Nuclear Plants,” (Reference 1) and it was concluded that the health effects from these two radionuclides posed a small significance. Data supporting Table S-3 are given in the “Environmental Survey of the Uranium Fuel Cycle,” WASH-1248 (April 1974); the “Environmental Survey of Reprocessing and Waste Management Portion of the LWR Fuel Cycle,” NUREG-0116 (Supplement 1 to WASH-1248); the “Public Comments and Task Force Responses Regarding the Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle,” NUREG-0216 (Supp. 2 to WASH-1248); and in the record of final rule making pertaining to “Uranium Fuel Cycle Impacts from Spent Fuel Reprocessing and Radioactive Waste Management, Docket RM-50-3.” The contributions from reprocessing, waste management, and transportation of wastes are maximized for either of the two fuel cycles (uranium only and fuel recycle). The contribution from transportation excluded transportation of cold fuel to a reactor and of irradiated fuel and radioactive wastes from a reactor that are considered in Table S-4 of § 51.20(g). The contributions from the other steps of the fuel cycle are given in columns A-E of Table S-3A of WASH-1248.

[2] The contributions to temporarily committed land from reprocessing are not prorated over 30 years, since the complete temporary impact accrues regardless of whether the plant services one reactor for one year or 57 reactors for 30 years.

[3] Estimated effluents based on combustion of coal for equivalent power generation.

[4] 1.2% from natural gas use and process.

[5] Radiological impacts of radon-222 and technetium-99 are addressed in NUREG-1437, “Generic Environmental Impact Statement for License Renewal of Nuclear Plants,” (Reference 1). The GEIS concluded that the health effects from these two radionuclides pose a small risk.