5.7 URANIUM FUEL CYCLE AND TRANSPORTATION IMPACTS

This section describes the environmental impacts from the uranium fuel cycle (UFC) for operation of two or more small modular reactors (SMR) at the Clinch River Nuclear (CRN) Site. Subsection 5.7.1 describes the impacts of the UFC using Table S-3, “Table of Uranium Fuel Cycle Environmental Data,” in Title 10 of the Code of Federal Regulations (10 CFR) 51.51. The subsections below 5.7.1 assess individual resources impact by the UFC. Subsection 5.7.2 describes the transportation of radioactive materials to and from the CRN Site.

The subsections under 5.7.2.1, Transportation Assessment, address the conditions for use of Table S-4, “Environmental Impact of Transportation of Fuel and Waste To and From One Light-Water-Cooled Nuclear Power Reactor,” in 10 CFR 51.52 to characterize the impacts of radioactive materials transportation to and from the CRN Site. 10 CFR 51.52(a) provides a list of conditions that a planned reactor must meet to fully apply Table S-4 to assess the impacts from transportation of fuel and radioactive waste. However, the SMRs at the CRN Site do not meet the conditions for average fuel enrichment or average fuel burnup provided in 10 CFR 51.52(a)(2) and 10 CFR 51.52(a)(3), respectively. Therefore, detailed analyses of fuel transportation effects for normal conditions and for accidents are presented in Subsection 5.7.2.2 and Section 7.4, respectively.

5.7.1 Uranium Fuel Cycle Impacts

The environmental effects from the UFC to support operation of SMRs at the CRN Site using Table S-3 are described and assessed in this subsection. The UFC is defined as the total of those options and processes associated with the provision, utilization, and ultimate disposition of fuel for nuclear power reactors. The evaluation in this subsection addresses the following stages of the UFC:

- Uranium mining and milling
- Conversion to uranium hexafluoride
- Enrichment of uranium-235
- Fabrication of reactor fuel
- Reprocessing of irradiated fuel
- Transportation and management of radioactive wastes
- Disposal of the spent fuel

Natural uranium is extracted from the earth through either open-pit or underground mining or by an in-situ leaching (ISL) process. ISL involves injecting an acidic solution into the groundwater aquifer to partition uranium from a solid to aqueous phase and then pumping the uranium-rich solution to the surface for further processing. The ore or leaching solution is processed to produce uranium oxide (U_3O_8). The uranium oxide is then converted to uranium hexafluoride (UF_6) in preparation for the enrichment process.

The UF_6 is transported to a separate facility for uranium enrichment. Uranium enrichment involves increasing the percentage of the more fissile isotope uranium-235 (U-235) and decreasing the percentage of the isotope uranium-238 (U-238). The enrichment process exploits the slight differences in atomic weights of the two isotopes. A feature common to large-scale enrichment schemes is that they employ a number of identical stages which use a cascading process to produce successively higher concentrations of U-235. Each stage concentrates the product of the previous stage further before the product is sent to the next stage. Similarly, the tailings from each stage are returned to the previous stage for further processing.

At a fuel-fabrication facility, the enriched uranium is converted from UF_6 to uranium dioxide (UO_2). In Table 3.1-2, Item 18, the fuel for the SMRs at the CRN Site is assumed to be UO_2. The UO_2 is formed into pellets, inserted into hollow rods, and loaded into fuel assemblies. The fuel assemblies are placed in the reactor to produce power. After a significant amount of the U-235 contained within a fuel assembly has been depleted, the nuclear fission process becomes inefficient, and spent fuel assemblies are then replaced. Spent fuel assemblies are placed in an onsite, interim, wet storage to allow for short-lived fission product decay and to reduce the heat generation rate. Afterward, the fuel assemblies are transferred to dry storage casks and stored onsite while awaiting transportation to a spent fuel storage facility or a waste repository.

The Nuclear Non-proliferation Act of 1978 effectively banned any reprocessing or recycling of spent fuel from United States commercial nuclear power. The ban on reprocessing spent fuel was lifted in 1981, but the combination of economics, uranium ore stockpiles, and nuclear industry stagnation provided little incentive for the industry to pursue reprocessing. The Energy Policy Act of 2005 authorized the U.S. Department of Energy (DOE) to research and develop proliferation-resistant fuel recycling and transmutation technologies that minimize environmental or public health and safety effects. Therefore, federal policy does not prohibit reprocessing, but there are currently no mature projects pursuing commercial reprocessing or recycling of spent fuel in the United States.

Table S-3 of 10 CFR 51.51 provides estimates of the environmental effects of the UFC. The effects are calculated for a reference 1000-megawatt-electric (MWe) light water reactor (LWR) operating at an annual capacity factor of 80 percent for an effective electric output of 800 MWe. This LWR design is referred to as the reference plant throughout this section. Data are calculated and presented in tables for land use, water consumption, thermal effluents, radioactive releases, waste burial, and radiation doses. 10 CFR 51.51 requires that the data in Table S-3 be used as the basis for evaluation of a proposed project.

In developing the reference plant data, the U.S. Nuclear Regulatory Commission (NRC) staff considered two UFC options. The “no recycle” and “uranium-only recycle” options differ only in the resting place of spent fuel. The “no recycle” option assumes that all spent fuel would be stored at a federal waste repository. The “uranium-only recycle” option assumes that spent fuel would be reprocessed to recover unused uranium, which would be returned to the UFC. The reference plant values provided for reprocessing, waste management, and transportation are from the UFC option resulting in the larger environmental effect.

The reference plant values provided in Table S-3 were derived from industry averages for each type of facility or operation associated with the UFC. Recognizing that this approach results in a range of values for each estimate, the NRC staff defined the assumptions or factors to be applied so the calculated values are not underestimated. This approach was intended to ensure that the actual environmental effects are less than the quantities shown for the reference plant and envelop the widest range of operating conditions for LWRs.

The NRC regulation recommends evaluating UFC parameters, nuclear plant characteristics, and impacts to the environment based on a reference plant. To determine the annual fuel requirement, the NRC staff defined the “reference plant” as a 1000-MWe LWR. The characteristics of the reference plant include an 80 percent capacity factor, a 12-month fuel reloading cycle, and an average fuel burnup rate of 33,000 megawatt-days (MWd) per metric ton (MT) of uranium (MTU). The expected lifetime of a newly constructed nuclear plant is approximately 60 years (yr; the 40-yr initial licensing plus one 20-yr license renewal term). The sum of the initial fuel loading and all of the expected reloads for the lifetime of the reactor is divided by the 60-yr expected lifetime to obtain an average annual fuel requirement. This quantity of fuel was determined for both boiling water reactors (BWRs) and pressurized water reactors (PWR); the higher annual requirement, a BWR using 35 MTU, was chosen in Subsection 6.2.3, paragraph 3, of NUREG-1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants*, Rev. 0 as the basis for the reference plant.

In NUREG-1437, Rev. 0, the NRC staff provided a detailed analysis of the environmental effects of the UFC. NUREG-1437, Rev. 1, provides a less detailed analysis and often references NUREG-1437, Rev. 0 for additional details. Although NUREG-1437, Rev. 0 and Rev. 1, are specific to license renewal, the information is relevant because the SMRs described by the plant parameter envelope (PPE) in Table 3.1-2 use the same fuel cycle process and the same type of fuel as the reference plant. Section 6.2 of NUREG-1437, Rev. 0 discusses the sensitivity to changes in the UFC on the environmental effects in detail.

In the past, uranium market conditions led to the closing of most domestic uranium mines and mills, and substantially reduced the environmental effects in the United States from these activities. According to the U.S. Energy Information Administration (EIA), Uranium Marketing Annual Report for 2013, the majority of uranium [as uranium oxide equivalent (U_3O_8e)] purchased by the United States reactors has historically been imported. In 2013, 83 percent of uranium purchased by owners and operators of United States commercial nuclear power reactors was of foreign origin. (Reference 5.7-1)

Domestic production of uranium has been showing an upward trend since 2003 to meet increasing demand and projected demand from new plants involved in licensing and construction (Reference 5.7-2). However, purchases decreased slightly from 58 million pounds of U_3O_8e in 2012 to 57 million pounds U_3O_8e in 2013 (Reference 5.7-1). EIA conducted an additional analysis in 2014 examining the potential impacts of excess uranium offered into the market from inventories at the DOE's Portsmouth and Paducah gaseous diffusion plants. During the period from 2014 to 2033, the EIA reports that 129 million pounds the U_3O_8e would enter the market from the DOE stockpiles (Reference 5.7-3).

The slight decrease in U_3O_8e purchases in 2013 and DOE uranium coming on to the market suggest that the environmental effects of mining and milling could temporarily drop to levels below those given for the reference plant. However, the effects are still bounded by the reference numbers in NUREG-1437, Rev. 0 and Rev. 1. Therefore, for the purposes of this analysis, the reference plant estimates have not been reduced.

As provided in Table 3.1-2, Item 16.6, the maximum net power output of the SMRs at the CRN Site is 800 MWe. Table 3.1-2, Item 16.4, provides a station capacity factor of 98 percent resulting in an effective net power output 784 MWe. The ratio of the effective net power output value for the SMRs described by the PPE (784 MWe) to the net electrical output for the 1000 MWe reference plant (800 MWe) provides a scaling factor of 0.98 to convert reference plant values to project-specific values at the CRN Site (Table 5.7-1).

The environmental effects of the UFC from operating SMRs at the CRN Site were evaluated to assess qualitative effects to the environment. This assessment is based on the values calculated in Tables 5.7-1 and 5.7-2[1]; an analysis of the radiological effects from radiological emissions from the UFC including radon-222 (Rn-222) and technetium-99 (Tc-99) provided in Tables 5.7-3 and 5.7-4; and average doses to the United States population from UFC and non-UFC sources of radiation provided in Table 5.7-5.

5.7.1.1 Land Use

The total annual land requirement for the UFC supporting SMRs at the CRN Site is presented in Table 5.7-2. The table lists values for both permanently and temporarily committed land. Permanent land commitments are those that may not be released for use after plant shutdown and/or decommissioning. This limitation on land use is because decommissioning activities on the pertinent land may not remove sufficient radioactive material to meet the limits in 10 CFR 20, Subpart E, for release of land for unrestricted use. Temporary land commitments are for the life of the specific UFC plant (e.g., a mill, enrichment plant, or succeeding plants). Following completion of decommissioning, such land can be released for unrestricted use.

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[1] As scaled off the UFC impacts for the 1000-MWe reference plant in 10 CFR 51.51, Table S-3 using the ratio provided in Table 5.7-1.

As provided in Table S-3 for the reference plant, Table 5.7-2 equates the UFC disturbed land area and overburden requirements for the SMRs at the CRN Site to an equivalently-sized (in electrical power production) coal-fired power plant using strip-mined coal as a fuel and requiring the same area of disturbed land and overburden movement. The comparison shows that UFC land requirements for SMRs at the CRN Site producing 800 MWe are equivalent to the coal mining land use requirements (disturbed land) for a coal-fired plant producing only approximately 88 MWe. Therefore, an equivalent area of disturbed land for coal production yields about 89 percent less electrical output than an equivalent amount of land disturbed for electrical production with uranium fuel or, for an equivalent amount of energy produced with coal, the land use requirements would be nine times greater.

Due to the recent increase in natural gas production in the United States, the net electrical output associated with natural gas production was compared to the net electrical output from SMRs at the CRN Site based on an equivalent area of disturbed land. It is estimated that natural gas production in Marcellus shale disturbs about 8.8 acres (ac) per well pad (cleared lands for pad and infrastructure). (Reference 5.7-4) Each well pad contains on average two natural gas wells and each well typically produces 10 million cubic feet (ft^3) of natural gas per day (Reference 5.7-4). Using conversion factors of 1021 British thermal units (Btu) per cubic foot of natural gas and an assumed power plant heat rate of 8152 Btu per kilowatt-hour, the resulting net electrical output from natural gas production in the Macellus shale is about 11.8 MWe per ac (Reference 5.7-5). For comparison, if the 21.6 ac of disturbed land required to support the fuel needs for SMRs at the CRN Site (Table 5.7-2) were dedicated to natural gas production, the land would only produce enough fuel for a gas-fired plant producing approximately 255 MWe. Therefore, an equivalent area of disturbed land for natural gas fuel production yields 68 percent less net electrical output that an equivalent amount of land disturbed for electrical production with uranium fuel.

If the quality and opportunity costs of the land are equivalent, then it is reasonable to state that land requirements for nuclear power are SMALL compared to coal-fired power plants and natural gas production. Therefore, it is concluded that the effect on land use to support the UFC for SMRs at the CRN Site is considered to be SMALL.

5.7.1.2 Water Use

Power stations supply electrical energy to the enrichment stage of the UFC. The primary water requirement of the UFC is waste heat removal from these power stations. Table S-3 of 10 CFR 51.51 provides a total water discharge (usage) within the UFC for the reference plant as 11,377 x 10^6 gallons per year, less than 4 percent of the actual water used to cool the 1000 MWe reference plant. Applying the 0.98 scaling factor, the water use within the UFC to support SMRs at the CRN Site is estimated to be approximately 11,149 million gallons per year. Therefore, like the water average and maximum net water demands for the reactors themselves described in Subsection 5.2.2.1.1, the impact from the water used to manage power needs to support the SMRs at the CRN Site are also SMALL assuming similar water sources.

According to Table S-3, the annual thermal discharge of power plants used within the UFC to support the 1000-MWe reference plant is approximately 4063 billion Btu; this usage is less than 5 percent of the actual thermal discharge of the 1000 MWe reference plant. The expected thermal effluent value for SMRs at the CRN Site is approximately 3982 billion Btu as presented in Table 5.7-2. Similarly, because the thermal effluent value for the proposed plants is less than the thermal effluent value for the reference plant, the thermal discharge from the UFC for the SMRs at the CRN Site would also be SMALL.

From 10 CFR 51.51, Table S-3 states that the consumptive water use of the UFC in support of the 1000-MWe reference plant, i.e., water discharged to air from cooling towers, is 2 percent of the water consumption of the plant itself. Therefore, considering the scaling factor of 0.98, the water consumption from the UFC supporting the SMRs at the CRN Site would have a SMALL effect with respect to water use.

5.7.1.3 Fossil Fuel Effects

Electrical energy and process heat are consumed during various phases of the UFC. The electrical energy is often produced by combustion of fossil fuels (coal and/or natural gas) at conventional power plants. From 10 CFR 51.51, Table S-3, the electrical energy needs associated with the UFC associated with the reference plant are 323,000 MW-hours (MWh) and represents less than 5 percent of the annual electrical power production of the reference plant. For SMRs at the CRN Site, the UFC electrical energy needs would be approximately 316,540 MWh, which is equivalent to 115,640 MT of coal or 132 million ft^3 of natural gas (Table 5.7-2).

In NUREG-1437, Rev. 0, the NRC concludes that the effects of direct and indirect consumption of electric power for fuel cycle operations produced using fossil fuels are small and appropriate for the electric power being produced from uranium fuel by the reference plant. NUREG-1437, Rev. 1, does not provide any additional information that would alter this conclusion. Since the power output and UFC demands for the SMRs at the CRN Site are less than those for the reference plant, it is concluded that environmental effects from the combustion of fossil fuels associated with UFC operations is also considered to be SMALL.

The NRC estimates that the carbon footprint of the UFC to support the 1000-MWe reference plant for the 40-yr plant life is about 17,000,000 MT of carbon dioxide (Reference 5.7-6). Scaling the 10 CFR 51.51 reference plant's UFC carbon footprint to obtain a UFC carbon footprint for the SMRs at the CRN Site, the carbon footprint for 40 yr of UFC emissions would be approximately 16,660,000 MT. The average annual emission rate would then be approximately 416,000 MT. This rate compares to a total annual emissions of 5,500,000,000 MT in 2011 for the entire United States (Reference 5.7-7). Therefore, it is concluded that the carbon footprint associated with UFC operations is also considered to be SMALL.

5.7.1.4 Chemical Effluents

The quantities of gaseous, liquid, and solid effluents needed to support the UFC for the 10 CFR 51.51 reference plant and for the SMRs at the CRN Site are presented in Table 5.7-2.

Gaseous effluents include the entrainment of the pollutants provided in Table 5.7-2. The effluent quantities from the UFC for the reference plant are from 10 CFR 51.51, Table S-3. The 0.98 scaling factor is applied to estimate the effluent quantities for the UFC supporting the SMRs at the CRN Site provided in Table 5.7-2. According to 10 CFR 51.51, Table S-3, the gaseous effluents from the UFC supporting the reference plant are equivalent to the gaseous effluents from a 45 MWe coal power plant. Applying the 0.98 scaling factor to each of the gaseous effluents and summing them, the gaseous effluents from the UFC supporting the SMRs at the CRN Site are equivalent to the gaseous effluents from a 44 MWe coal power plant.

Because of the gaseous effluents from the UFC needed to support the SMRs at the CRN Site are equivalent to the effluents from a small 44 MWe coal-fired power plant or, for an equivalent amount of energy produced with coal, the chemical effluents would be about 2.3 times greater. Therefore, it is concluded that the effects to the degradation of air quality from the power generation needed to support the UFC is SMALL.

Liquid chemical effluents produced during the UFC are associated with the fuel enrichment, fuel fabrication, and fuel reprocessing steps. While fuel reprocessing is not currently performed commercially in the United States, the effluent amounts provided in 10 CFR 51.51, Table S-3, and Table 5.7-2 include potential reprocessing activities. In Table 5.7-2 the 0.98 scaling factor is used to estimate the quantities of liquid chemical effluents from the UFC needs of the SMRs at the CRN Site. Because the effluents at these quantities require only small amounts of dilution by the receiving bodies of water to achieve concentrations that are below established standards, the effects to the degradation of water quality from the power generation needed to support the UFC is SMALL. Additionally, any liquid discharges into the navigable waters of the United States from power plants associated with UFC operations are subject to requirements and limitations set in National Pollutant Discharge Elimination System permits issued by an appropriate federal, state, regional, local, or affected Native American tribal regulatory agency.

Tailings solutions and solids are generated during the milling process; however, these materials are not released in quantities that would have a significant effect on the environment. Amounts of tailings and solids for the reference plant and the SMRs at the CRN Site are provided in Table 5.7-2. The effect of all effluent waste streams (gaseous, liquid, and solid) associated with the UFC needs for the SMRs at the CRN Site are considered to be SMALL.

5.7.1.5 Radioactive Effluents

The estimates of radioactive effluent releases from the UFC to the environment from one year of operation for the 10 CFR 51.51 reference plant and the SMRs at the CRN Site are presented in Table 5.7-2. Radioactive effluents from the UFC include gaseous and liquid effluents. However,

Table 5.7-2 does not address Rn-222 and its progeny (herein after referred to as Rn-222) from the UFC activity or Tc-99 released from waste management or reprocessing activities.

The 100-yr involuntary environmental dose commitment to the United States population from the reference plant's impact on the UFC is provided in Table 5.7-3. From NUREG-1437, Rev 1, Table 4.12.1.1-1, "Population Doses from Uranium Fuel Cycle Facilities Normalized to One Reference Reactor Year," the portion of dose commitment from radioactive gaseous effluents is 400 person-rem per year and the portion of dose commitment from radioactive liquid effluents per year due to all UFC operations is 200 person-rem. Applying the ratio of effective electric output values from Table 5.7-1 and the 0.98 scaling factor for the SMRs at the CRN Site, the dose commitment from radioactive gaseous and liquid effluents provided in Table 5.7-3 would be approximately 392 person-rem and 196 person-rem, respectively. Thus, the total 100-yr environmental dose commitment to the United States population from radioactive gaseous and liquid releases resulting from these portions of the UFC provided in Table 5.7-3 is 588 person-rem per year for the SMRs at the CRN Site.

Currently, the radiological effects associated with Rn-222 and Tc-99 releases are not addressed in the reference plant data in 10 CFR 51.51. Most Rn-222 releases are from mining and milling operations and emissions from mill tailings, and most Tc-99 releases are from gaseous diffusion enrichment facilities. Although the gaseous diffusion plants in the United States have been shut down, the following assessment is based on the assumption that gaseous diffusion plants are in operation.

In Table 6.2 of NUREG-1437, Rev. 0, the NRC staff estimated the Rn-222 releases from mining plus milling and emanating from mill tailings required to support each year of operations of the 1000-MWe reference plant to total 5200 curies (Ci). The major risks from Rn-222 are bone and lung cancer, and there is a small risk from whole body exposure. The organ-specific dose weighting factors from 10 CFR Part 20 are applied to the bone and lung doses to estimate the 100-yr dose commitment from Rn-222 to the whole body, which is estimated to be 140 person-rem for the reference plant. Using the 0.98 scaling factor, the Rn-222 releases from the UFC associated with SMRs at the CRN Site are estimated to be 5096 Ci and the estimated population dose commitment from mining, milling, and tailings before stabilization for each year of operation of SMRs at the CRN Site is estimated to be 136 person-rem (Table 5.7-4).

In NUREG-1437, Rev. 0, the NRC staff also considered the potential health effects associated with the release of Tc-99 as part of UFC operations. It was found that the releases of Tc-99 are from chemical reprocessing of recycled UF_6 before it enters the isotope enrichment cascade. The annual Tc-99 releases (in Ci) from the reference plant (0.012 Ci) and scaled releases from the SMRs at the CRN Site (0.012 Ci) are presented in Table 5.7-4.

The major risks from Tc-99 are from exposure of the gastrointestinal tract and kidney; additionally, there is a small risk from whole-body exposure. Using the organ-specific dose weighting factors from 10 CFR 20, these individual organ risks were converted to a whole-body

100-yr dose commitment per year of operation. These values are presented in Table 5.7-4 for the reference plant (100 person-rem) and for the SMRs at the CRN Site (98 person-rem).

Many radiation protection experts assume that any amount of radiation may pose some risk of causing cancer or a severe hereditary effect and that the risk is higher for higher radiation exposures. Therefore, a linear, no-threshold dose response relationship is used to describe the relationship between radiation dose and detriments such as cancer induction. The Biological Effects of Ionizing Radiation (BEIR) VII report by the National Research Council, uses the linear, no-threshold dose response model as a basis for estimating the risks from low doses (Reference 5.7-8). This approach is accepted by the NRC as a conservative method for estimating health risks from radiation exposure, recognizing that the model may overestimate those risks. Based on this method, the risk to the public from radiation exposure using the nominal probability coefficient for total detriment can be estimated. This coefficient has the value of 570 fatal cancers, nonfatal cancers, and severe hereditary effects per 1,000,000 person-rem. From Table 5.7-3, the total whole body population doses (including Rn-222 and Tc-99) would be 840 person-rem/yr for the 1000-MWe reference plant and 822 person-rem/yr for the SMRs at the CRN Site. The estimated number of fatal cancers, nonfatal cancers, and severe hereditary effects would be less than one per year for both the 1000-MWe reference plant and the new plant.

In addition, at the request of the U.S. Congress, the National Cancer Institute conducted a study and published “Cancer in Populations Living near Nuclear Facilities: A Survey of Mortality Nationwide and Incidence in Two States” in 1991 (Reference 5.7-9). This report included an evaluation of health statistics around all nuclear power plants, as well as several other nuclear fuel-cycle facilities, in operation in the United States in 1981 and found “no evidence that an excess occurrence of cancer has resulted from living near nuclear facilities.” The contribution to the annual average dose received by an individual from the UFC-related radiation and other sources is presented in Table 5.7-5. (Reference 5.7-10)

Based on the information presented above, it is concluded that the environmental effect (population dose) from radioactive effluents from the UFC demands for the SMRs at the CRN Site is considered to be SMALL.

5.7.1.6 Radioactive Wastes

The quantities (in Ci) of radioactive waste material generated as part of the UFC (low-level waste [LLW], high-level waste [HLW], and transuranic [TRU] waste) are shown in 10 CFR 51.51(a), Table S-3, and Table 5.7-2. For LLW disposal, the NRC indicates in Table S-3 that no significant radioactive releases to the environment are expected.

Pursuant to 10 CFR 51.23(b) and 10 CFR 51.50(b)(2), this Environmental Report does not discuss the environmental impacts of spent nuclear fuel storage in a spent fuel pool or an interim spent fuel storage installation (ISFSI) for the period following the term of the reactor operating license, reactor combined license, or ISFSI license. Rather, the impact determination in NUREG-2157, *Generic Environmental Impact Statement for Contained Storage of Spent Nuclear Fuel,* regarding continued storage is deemed incorporated into the environmental impact statement.

5.7.1.7 Occupational Dose

As provided in Subsection 6.2.2.3 of NUREG-1437, Rev. 0, the annual occupational dose for the reference 1000 MWe reactor attributable to all phases of the fuel cycle is 600 person-rem. The fuel cycle for the SMRs would be similar to the fuel cycle for the reference plant. Individual occupational doses are maintained to meet the dose limits in 10 CFR Part 20, which is 5 rem/yr. Therefore, the environmental effects from this occupational dose is considered to be SMALL.

5.7.1.8 Transportation

As shown in Table 5.7-2, the annual transportation dose from exposure to workers and the general public for the 10 CFR 51.51 reference plant is approximately 2.5 person-rem. Applying the scaling ratio, the total annual occupational dose attributable to all phases of the UFC needs for the SMRs at the CRN Site is estimated to be approximately 2.4 person-rem. For comparative purposes, the estimated annual dose from natural background radiation to a person living within 50 miles (mi) of the CRN Site is 0.36 rem per person (Reference 5.7-11). Given the size of the total population (worker and general public) exposed during transportation, it is concluded that the dose from transportation is considered to be SMALL.

5.7.1.9 Summary

Using the federal evaluation process in NUREG-1437, Rev. 0 and Rev. 1, the evaluation subsection has examined the environmental effect of the UFC, including the dose from Rn-222 and Tc-99, as it relates to the operation of SMRs at the CRN Site. Based on this evaluation, it is concluded that the environmental effects of the contributions to the UFC from the operation of SMRs at the CRN Site is considered to be SMALL.

5.7.2 Transportation of Radioactive Materials

The public dose from the transportation of all radioactive waste (LLW, HLW, and TRU waste) is discussed in the preceding Subsection 5.7.1.8. The following information supports the assessment of spent nuclear fuel transportation:

- Reactor type and rated core thermal power (Section 3.2)
- Fuel assembly description (Subsection 3.8.1)
- Average irradiation level of irradiated fuel (Subsection 3.2.1)
- Capacity of onsite storage facilities and minimum fuel storage time (Subsection 3.8.2)
- Transportation distances (Section 7.4)

5.7.2.1 Transportation Assessment

As detailed in the following subsections, the SMRs at the CRN Site do not meet all of the conditions for the reactor and fuel provided in 10 CFR 51.52(a). Specifically, the SRM fuel enrichment can be greater than 4 percent by weight and SMR fuel burnup can be greater than 33,000 megawatt-days per metric ton. Therefore, the analyses of fuel transportation effects for normal conditions and for accidents are presented in Subsection 5.7.2.2 and Section 7.4, respectively.

Nonradiological effects from the transportation of fuel (new and spent) and other radiological wastes are traffic density, weight of the loaded truck or railcar, heat from the fuel cask, and transportation accidents. The NRC evaluated the environmental effects of transportation of fuel and waste for LWRs and found the impacts to be SMALL. The NRC analyses provided the basis for Table S-4 in 10 CFR 51.52, which summarizes the environmental effects of transportation of fuel and radioactive wastes to and from a reference plant (Table 5.7-6 and Table 5.7-7). Table S-4 addresses two categories of environmental consideration: (1) normal conditions of transport, and (2) accidents during transport.

Subparagraphs 10 CFR 51.52(a)(1) through (5) delineate specific conditions the reactor licensee must meet to use Table S-4 as part of its environmental report. For reactors not meeting all of the conditions in paragraph (a) of 10 CFR 51.52, paragraph (b) of 10 CFR 51.52 requires further analysis of the transportation effects.

The conditions in paragraph (a) of 10 CFR 51.52 establishing the applicability of Table S-4 are reactor core thermal power, fuel form, fuel enrichment, fuel encapsulation, average fuel irradiation, time after discharge of irradiated fuel before shipment, mode of transport for unirradiated fuel, mode of transport for irradiated fuel, radioactive waste form and packaging, and mode of transport for radioactive waste other than irradiated fuel. The following subsections describe the characteristics of the SMRs at the CRN Site relative to the conditions of 10 CFR 51.52 for use of Table S-4. If the conditions of Table S-4 are not met, detailed transportation accident analyses are required.

5.7.2.1.1 Reactor Core Thermal Power

Subparagraph 10 CFR 51.5(a)(1) requires that for comparison to the reference plant, the new reactor must have a core thermal power level not exceeding 3800 Megawatt thermal (MWt). In Table 3.1-2, Item 16.1, the SMRs on the CRN Site have a combined maximum thermal power level of 2420 MWt. Therefore the sum of the thermal power for all new SMRs at the CRN Site meets this condition.

The initial core loading of the reference plant is 100 MTU. In Table 3.1-2, Item 18.0.2, the surrogate SMR core contains 96 fuel assemblies. The mass of the uranium in the fuel assemblies is 0.304 MTU per fuel assembly, resulting in an initial core loading of about 30 percent of the 100 MTU assumed for the reference plant.

5.7.2.1.2 Fuel Form

Subparagraph 10 CFR 51.52(a)(2) requires that the reactor fuel be in the form of sintered uranium dioxide pellets. In Table 3.1-2, Item 18.0.1, fuel for the SMRs at the CRN site would be a sintered UO_2 fuel. Therefore, the requirement is met.

5.7.2.1.3 Fuel Enrichment

Subparagraph 10 CFR 51.52(a)(2) requires that the reactor fuel have a U-235 enrichment not exceeding 4 percent by weight. In Table 3.1-2, Item 18.1, the SMR fuel would have an enrichment of less than 5 percent which can exceed this condition. However, NUREG/CR-6703, *Environmental Effects of Extending Fuel Burnup Above 60 GWd/MTU,* supported the conclusion that the environmental impacts of enrichments up to 5 percent were bounded by the impacts reported in Table S-4.

5.7.2.1.4 Fuel Encapsulation

Subparagraph 10 CFR 51.52(a)(2) requires that the reactor fuel pellets be encapsulated in Zircaloy rods. In Table 3.1-2, Item 18.7, the SMR fuel would use Zircaloy cladding and, therefore, meets the requirement.

5.7.2.1.5 Average Fuel Irradiation

Subparagraph 10 CFR 51.52(a)(2) requires that the average fuel burnup not exceed 33,000 MW-days per MTU. In Table 3.1-2, Item 18.2, average burnup for the SMR fuel assembly would be less than or equal to 51,000 MW-days per MTU which exceeds the limits of Table S-4. However, NUREG/CR-6703 supports the conclusion that the environmental impacts of higher fuel burnup rates were bounded by the impacts reported in Table S-4.

5.7.2.1.6 Time After Discharge of Irradiated Fuel Before Shipment

Subparagraph 10 CFR 51.52(a)(3) requires that no irradiated fuel assembly be shipped until at least 90 days after it is discharged from the reactor. The analysis provided by the NRC and referenced in Table S-4 assumes 150 days of decay time before shipment of any irradiated fuel assemblies (Reference 5.7-12). NUREG/CR-6703 assumes a minimum of 5 yr between removal from the reactor and shipment. NUREG-1437, Rev. 1, indicates that the NRC specifies 5 yr as the minimum cooling period when it issues certificates of compliance for casks used for shipment of power reactor fuel. Therefore, five years is considered the minimum decay time expected before shipment of irradiated fuel assemblies. In Table 3.1-2, 18.0.4, SMRs at the CRN Site would have a minimum 6-yr storage capacity, which exceeds that needed to accommodate 5-yr cooling of irradiated fuel before removal from the spent fuel pool and either transferred to onsite dry storage or transport offsite. Therefore, the requirement is met.

5.7.2.1.7 Mode of Transport for Unirradiated Fuel

Subparagraph 10 CFR 51.52(a)(5) requires that unirradiated fuel be shipped to the reactor site by truck. Fuel is expected to be shipped to the CRN Site by truck from a fuel fabrication facility as far away as Washington State. Table S-4 includes a condition that truck shipment would not exceed 73,000 pounds. Fuel shipments to the CRN Site would comply with this and other state and federal requirements. Therefore, the criterion is met.

5.7.2.1.8 Mode of Transport for Irradiated Fuel

Subparagraph 10 CFR 51.52(a)(5) allows irradiated fuel to be shipped by truck, rail or barge. Irradiated fuel is expected to be shipped from the CRN Site by truck. Currently, the DOE is responsible for spent fuel transportation from reactor sites.

Subparagraph 10 CFR 51.52(a)(6) Table S-4 includes a condition that the heat generated from irradiated fuel per shipping cask in transit would not exceed 250,000 Btu per hour (Btu/hr). Using the guidance provided in ANSI/ANS 5.1-2014, *American National Standard for Decay Heat Power in Light Water Reactors*, a conservative estimate of the heat load in a shipping cask is approximately 233,000 Btu/hr. This estimate is based on the following assumptions and PPE values: the NRC approved General Atomics GA-4 or similar cask will be used for shipping spent fuel (NUREG-2125, *Spent Fuel Transportation Risk Assessment*); SMR fuel assemblies are one-third the length of standard PWR fuel assemblies; 12 SMR fuel assemblies will be shipped in a GA-4 shipping cask; the power density of each fuel assembly is approximately 9 MWt; fuel assemblies are burned through three fuel cycles and loaded into casks five years after the core offload of the third fuel cycle; fuel burnup is 51 GWd/MTU (Table 3.1-2, Item 18.2); and 0.304 MTU per assembly (Table 3.1-2, Item 18.0.2). Therefore, while no cask has been designed for shipment of irradiated SMR fuel, it is expected that the Table S-4 criterion be met for fuel shipments from the CRN Site.

5.7.2.1.9 Radioactive Waste Form and Packaging

Subparagraph 10 CFR 51.52(a)(4) requires that radioactive waste be shipped from the reactor in packages and in a solid form (with the exception of irradiated fuel). As described in Subsection 3.8.3, the LLW generated by the SMRs at the CRN Site would be prepared, packaged, and shipped according to the U.S. Department of Transportation regulations. Therefore, the requirement is met.

5.7.2.1.10 Mode of Transport for Radioactive Waste

Subparagraph 10 CFR 51.52(a)(5) requires that the mode of transportation of LLW be either by truck or rail. LLW is expected to be shipped from the CRN Site by truck in accordance with state and federal requirements, including limiting shipments to 73,000 pounds. Therefore, the requirement is met.

5.7.2.1.11 Number of Truck Shipments

The NRC references the “Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants,” also referred to as “WASH-1238,” for transportation impacts from the 10 CFR 51.52 (Table S-4) reference reactor. Table S-4 specifies the following conditions for traffic density: less than one truck shipment per day or less than three rail cars per month. The number of truck shipments of unirradiated fuel, irradiated fuel, and solid radioactive waste to and from the CRN Site was calculated using the same truck loading rates as used in WASH-1238 or based on information provided in Table 3.1-2. The WASH-1238 truck shipments per year (traffic density) are compared to the CRN Site shipments in Table 5.7-7.

TVA estimates that 492 shipments of unirradiated fuel would be required for operating SMRs described by the PPE over 40 yr. In WASH-1238, the NRC assumed 18 shipments of new fuel would be made for the initial reactor loading of the 10 CFR 51.52 Table S-4 reference reactor and an additional 6 shipments per year for 39 yr resulting in a total of 252 shipments (Reference 5.7-12). The annual number of shipments of new fuel to the reference plant and the SMRs at the CRN Site are provided in Table 5.7-6. While the maximum number of fuel shipments for initial loading is 40, because the SMR design has not been selected and the initial loading scheme is not known, the average annual number assumes the same number of fuel shipments over the 40-yr lifetime of the SMRs.

TVA estimates that there would be 46 annual shipments of irradiated fuel from the SMRs at the CRN Site. As provided in Table 5.7-7, the normalized number of annual shipments is 137. The number of annual shipments of irradiated fuel from the reference reactor is 60 (Reference 5.7-12).

The number of solid radioactive waste shipments from the CRN Site is based on a volume of 5000 ft^3 per year as provided in Table 3.1-2, Item 11.2.3. As shown in Table 5.7-7, the number of solid radioactive waste shipments from the CRN Site would be about 61 truck shipments per year normalized to 75 shipments per year.

As shown in Table 5.7-8, the sum of the number of yearly truck shipments of fuel and radioactive waste to and from the CRN Site is estimated to be 227 trucks per year, or less than one truck shipment per day. Table S-4 from 10 CFR 50.52 also states that the reference reactor would have less than one truck shipment per day. Therefore the traffic density from the CRN Site would be comparable to the traffic density from the reference reactor.

5.7.2.1.12 Summary

Although the SMRs at the CRN Site meet most of the conditions in 10 CFR 51.51 and 51.52, the conditions for fuel burnup and fuel enrichment are not met. Therefore, TVA provided additional transportation analyses. These analyses are presented in Subsection 5.7.2.2 and Section 7.4, respectively.

5.7.2.2 Incident-Free Transportation Impact Analysis

The environmental impacts of radioactive materials transportation were estimated using the most recent version of the RADTRAN 6.5 computer code (Reference 5.7-13). RADTRAN is a nationally accepted standard program and code for calculating the risks of transporting radioactive materials. RADTRAN was used in estimating the radiological doses and dose risks to populations and transportation workers resulting from incident-free transportation and to the general population from accident scenarios. For the analysis of incident-free transportation risks, the code used scenarios for persons who would share transportation routes with shipments, persons who live along the route of travel, and persons exposed at stops. Environment impacts of incident-free transportation of fuel are discussed in this subsection. Transportation accidents are discussed in Section 7.4.

5.7.2.2.1 Transportation of Unirradiated Fuel

Table S-4 of 10 CFR 51.52 includes conditions related to radiological doses to transport workers and members of the public along transport routes. These doses, based on calculations in WASH-1238 (Reference 5.7-12), are a function of the radiation dose rate emitted from the unirradiated fuel shipments, the number of exposed individuals and their locations relative to the shipment, the time of transit (including travel and stop times), and the number of shipments to which the individuals are exposed.

Calculation of worker and public doses associated with annual shipments of unirradiated fuel were performed using the WebTRAGIS 6.0 and RADTRAN computer codes (Reference 5.7-14). One of the key assumptions in WASH-1238 for the reference LWR unirradiated fuel shipments is that the radiation dose rate at 3 feet from the transport vehicle is 0.1 millirem/hour (hr). This assumption is reasonable for the new plant technologies because the fuel materials would be low-dose rate enriched uranium and would be packaged similarly to the fuel analyzed in WASH-1238 (inside a metal container that provides sufficient radiation shielding).

For unirradiated fuel shipments, highway routes are analyzed using the routing computer code WebTRAGIS. It is assumed that all unirradiated fuel shipments come from Richland, Washington. The highway route controlled quantity (HRCQ) route setting was used to generate highway routes generally used by commercial trucks. The distance from the CRN Site to Richland, Washington is 2451 mi. The population summary module of the WebTRAGIS computer code is used to determine the exposed populations within a half-mile band on either side of the route.

The per trip dose values are combined with the average annual number of shipments of unirradiated fuel to calculate annual doses to the public and workers for comparison to Table S-4 dose values. The number of shipments per year is obtained from Table 5.7-6. The incident-free dose rates (in person-rem per shipment) were calculated by RADTRAN and are provided in Table 5.7-9. The dose rates ranged from 4.59E-03 person-rem per year for the transportation crew exposed at stops and 7.85E-03 person-rem per year for crew along the route to 5.81E-03 person-rem per year for the public in other vehicles along the transportation route.

5.7.2.2.2 Transportation of Irradiated Fuel

The environmental impacts of transporting spent fuel from the CRN Site to a spent fuel disposal facility assume Yucca Mountain, Nevada as a possible location for a geologic repository. The impacts of the transportation of spent fuel to a possible repository in Nevada provides a reasonable determination of the transportation impacts to a monitored retrievable storage facility because of the distances involved and the representative exposure of members of the public in urban, suburban, and rural areas.

Incident-free transportation refers to transportation activities in which the shipments reach their destination without releasing any radioactive cargo to the environment. Impacts from these shipments are from the low levels of radiation that penetrate the heavily shielded spent fuel shipping cask. Radiation doses occur to the following:

- Persons residing along the transportation corridors between the CRN Site and the potential repository
- Persons in vehicles passing a spent fuel shipment
- Persons at vehicle stops for refueling, rest, and vehicle inspections
- Transportation crew workers

This analysis is based on shipment of spent fuel by legal-weight trucks in casks with characteristics similar to casks currently available (i.e., massive, heavily shielded, cylindrical metal pressure vessels). Each shipment is assumed to consist of a single shipping cask loaded on a modified trailer. These assumptions are consistent with assumptions made in evaluating environmental impacts of spent fuel transportation in Addendum 1 to NUREG-1437, Rev. 0. As discussed in NUREG-1437, Rev. 0, these assumptions are conservative because the alternative assumptions involve rail transportation or heavy-haul trucks that reduce the overall number of spent fuel shipments.

The transportation route selected for a shipment determines the total potentially exposed population and the expected frequency of transportation-related accidents. For truck transportation, the route characteristics most important to the risk assessment include the total shipping distance between each origin-destination pair of sites and the population density along the route.

For irradiated fuel, it is assumed that all irradiated fuel is sent to the potential Yucca Mountain repository. The distance from the CRN Site to the repository was determined to be 2292 mi by the WebTRAGIS (Reference) computer code for a highway route-controlled quantity. Routing and population data used in RADTRAN for truck shipments were obtained from the

WebTRAGIS computer code. The population data in the WebTRAGIS computer code is based on the 2010 United States census.

The population doses are calculated by multiplying the number of spent fuel shipments per year by the per-shipment doses. The numbers of shipments per year are obtained from Table 5.7-7. The incident-free dose rates (in person-rem per shipment) were calculated by RADTRAN and are provided in Table 5.7-9. The dose rates ranged from 5.55 person-rem per year for the transportation crew exposed at stops and 9.32 person-rem for the crew along the route to 3.66 person-rem per year for the public in other vehicles along the transportation route.

5.7.2.2.3 Transportation of Radioactive Waste

Incident-free transportation refers to transportation activities in which shipments reach their destination without releasing any radioactive cargo to the environment. Impacts from these shipments are from the low levels of radiation that penetrate the radioactive waste shipping containers. Radiation doses occur to the following:

- Persons residing along the transportation corridors between the CRN Site and the potential repository
- Persons in vehicles passing a radioactive waste shipment
- Persons at vehicle stops for refueling, rest, and vehicle inspections
- Transportation crew workers

This analysis is based on shipment of radwaste by legal-weight trucks in either sea-land containers or high-integrity containers similar to those currently available. Each shipment is assumed to consist of a single shipping container from the CRN Site to Andrews, Texas.

The transportation route selected for a shipment determines the total potentially exposed population and the expected frequency of transportation-related accidents. For truck transportation, the route characteristics most important to the risk assessment include the total shipping distance between each origin-destination pair of sites and the population density along the route.

For radioactive waste, WebTRAGIS selected a HRCQ route of Interstate highways through Tennessee, Arkansas, and Texas. The route is 1214 mi.

Routing and population data used in RADTRAN for truck shipments was obtained from the WebTRAGIS computer code. The population data in the TRAGIS computer code is based on the 2010 United States census. All radioactive waste shipments are transported by legal-weight trucks to the Texas site over commercial truck routes.

The population doses are calculated by multiplying the number of radioactive waste shipments per year by the per-shipment doses. The numbers of shipments per year are identified in Table

5.7-7. The incident-free dose rates (in person-rem per shipment) were calculated by RADTRAN and are provided in Table 5.7-9. The dose rates ranged from 1.61 person-rem per year for the transportation crew exposed at stops and 2.55 person-rem along the route to 1.92 person-rem per year for the public in other vehicles along the transportation route.

5.7.2.2.4 Comparison to 10 CFR 51.52 Table S-4

For an equal comparison to the reference reactor in 10 CFR 51.52 Table S-4, the number of shipments in Table 5.7-8 for the SMR must be normalized. For each technology, the number of shipments is normalized based on net electric generation relative to the 1100 MWe and 80 percent capacity factor reference reactor analyzed in WASH-1238 (NUREG-1555, *Standard Review Plans for Environmental Reviews for Nuclear Power Plants: Environmental Standard Review Plan*). Additionally, the unirradiated fuel shipments are adjusted to account for the initial core loading in the annual number of shipments for each reactor technology. The spent fuel shipments are scaled to reflect the capacity of 0.5 MTU/container used for the reference reactor. The number of radioactive waste shipments is based on 3800 ft^3 and 46 shipments per year from the reference reactor (from WASH-1238) or 82.6 ft^3 per shipment (2.34 cubic meters (m^3) per shipment). The resulting annual truck shipments normalized to the reference reactor are summarized in Table 5.7-8. Annual doses provided in Table 5.7-9 are based on the normalized number of shipments.

Table 5.7-9 provides a total crew dose of 19.1 person rem per reactor year. This compares against the Table S-4 value of 4 person-rem per reactor year. While the estimate is more than four times the Table S-4 value, it is still considered small given the increased number of normalized shipments, and the greater assumed transportation distances (WASH-1238 uses 1000 mi for unirradiated fuel shipments, 1000 mi for irradiated fuel shipments, and 500 mi for radioactive waste shipments (Reference 5.7-12)). The doses provided in Table 5.7-9 also assume the maximum dose rate for all shipment types, and the use of 30 minutes as the average time for a truck stop in the calculations.

Table 5.7-9 also provides a total public dose of 10.1 person rem per reactor year. Onlookers are members of the public exposed to a shipping container for a short duration during periods when the transportation vehicle is stopped. This compares against the Table S-4 value of 3 person-rem per reactor year. While the estimate is more than three times the Table S-4 value, it is still considered small given the increased number of normalized shipments, the greater assumed transportation distances, and the increased populations along the transportation routes. Table S-4 does not provide a cumulative dose for the population exposed along the transportation routes for direct comparison.

5.7.2.3 Summary

A detailed analysis of the environmental impacts for the transportation of unirradiated fuel, irradiated fuel, and radioactive waste transported to and from the CRN Site was performed in accordance with 10 CFR 51.52(b). An evaluation of the environmental impact due to transportation of unirradiated fuel, irradiated fuel, and radioactive waste at alternative indicates that the alternative sites are not obviously superior to the CRN Site.

The new plant would have sufficient fuel pool storage capacity to enable a minimum cooling period of five years and sufficient storage capacity to permit irradiated fuel to cool sufficiently to meet the requirements of shipping casks available at the time the fuel is shipped.

In the analysis it was assumed that all shipments of unirradiated fuel, irradiated fuel, and radioactive waste are by truck. The shipping weights would comply with federal, state, local, and tribal government restrictions as appropriate. The total number of shipments for the CRN Site are outlined in Table 5.7-8, is 227 per year (normalized) which meets the Table S-4 requirement of less than one per day.

The radiological effects of incident-free conditions of transport are summarized in Table 5.7-9. The radiological effects of accidents in transport are provided in Section 7.4. The values obtained from these analyses represent the impacts from incident-free transportation of radioactive materials to and from the CRN Site. The population doses to the transport crew and onlookers resulting from the new plant normalized to the reference reactor exceed Table S-4 values. However, these increases are reasonable given the different exposure parameters between WASH-1238 and the CRN Site RADTRAN model. Therefore, based on the analyses and above discussion, the environmental impacts of transportation of unirradiated fuel, irradiated fuel, and radioactive waste would be SMALL.

5.7.3 References

Reference 5.7-1. U.S. Department of Energy, 2013 Uranium Marketing Annual Report, Website: http://www.eia.gov/uranium/marketing/pdf/2013umar.pdf, 2013.

Reference 5.7-2. World Nuclear Association, Uranium Production Figures, 2003-2013, Website: http://www.world-nuclear.org/info/Facts-and-Figures/Uranium-production-figures/, December, 2014.

Reference 5.7-3. Meade, Thomas B. and Supko, Eileen M., Review of the Potential Impact of DOE Excess Uranium Inventory On the Commercial Markets, Website: http://www.energy.gov/sites/prod/files/2014/05/f15/ERI%20Market%20Analysis.pdf, April 25, 2014.

Reference 5.7-4. Johnson, Nels, "Pennsylvania Energy Impacts Assessment - Report 1: Marcellus Shale Natural Gas and Wind," The Nature Conservancy, November 15, 2010.

Reference 5.7-5. U.S. Energy Information Administration, FAQ: How much coal, natural gas, or petroleum is used to generate a kilowatt-hour of electricity?, Website: http://www.eia.gov/tools/faqs/faq.cfm?id=667&amp, 2013.

Reference 5.7-6. U.S. Nuclear Regulatory Commission, "Final Environmental Impact Statement for Combined Licenses for Virgil C. Summer Nuclear Station Units 2 and 3," NUREG-1939, Vol. 1, Washington, DC, April, 2011.

Reference 5.7-7. U.S. Energy Information Administration, International Energy Statistics: Total Carbon Dioxide Emissions from the Consumption of Energy, Website: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8#, 2013.

Reference 5.7-8. National Research Council, "BEIR VII: Health Risks from Exposure to Low Levels of Ionizing Radiation - Report in Brief," June, 2005.

Reference 5.7-9. National Cancer Institute, No Excess Mortality Risk Found in Counties with Nuclear Facilities - Fact Sheet, Website: http://www.cancer.gov/cancertopics/factsheet/Risk/nuclear-facilities, April 19, 2011.

Reference 5.7-10. U.S. Nuclear Regulatory Commission, Sources of Radiation, Website: http://www.nrc.gov/about-nrc/radiation/around-us/sources.html, June 28, 2013.

Reference 5.7-11. U.S. Nuclear Regulatory Commission, Personal Annual Radiation Dose Calculator, Website: http://www.nrc.gov/about-nrc/radiation/around-us/calculator.html, June 28, 2013.

Reference 5.7-12. U.S. Atomic Energy Commission, "Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants (WASH-1238)," December, 1972.

Reference 5.7-13. Sandia National Laboratories, "RADTRAN 6 Technical Manual," SAND2013-0780, January 2014.

Reference 5.7-14. UT-Battelle, LLC. Transportation Routing Analysis Geographic Information System (TRAGIS), Version 6.0. U.S. Department of Energy Contract No. DE-AC05-00OR22725. Website: https://webtragis.ornl.gov/tragis/app/map/view, 2017.

Table 5.7-1
Scaling Factor- Reference Plant and CRN SMRs

Parameter	10 CFR 51.51 Reference Plant (1000 MWe LWR)	CRN Site SMRs
Net Electric Output	1000 MWe	800 MWe
Capacity Factor	80 percent	98 percent
Effective Electric Output	1000 MWe x 80 percent = 800 MWe	800 MWe x 98 percent = 784 MWe
Ratio of Effective Electric Output Values	1	0.98[1]

[1] This scale factor is used to calculate the Standard Plants values in Tables 5.7-2 through 5.7-4.

Table 5.7-2 (Sheet 1 of 4)
Uranium Fuel Cycle Environmental Data

Environmental Considerations	**Annual Fuel Requirement Impacts 10 CFR 51.51 Reference plant**		**Annual Fuel Requirement Impacts CRN Site SMRs**	
	Reference plant Data	**Maximum effect per annual fuel requirement or RRY**	**Reference Reactor Data multiplied by scale factor = 0.98**	**Maximum effect per annual fuel requirement or RRY multiplied by scale factor**
Natural Resource Use				
Land (ac)				
Temporarily committed	100		98	
Undisturbed area	79		77.4	
Disturbed area	22	This is equivalent to a 110 MWe coal-fired power plant.	21.6	This is equivalent to an 88 MWe coal-fired power plant; 89% less energy per ac than the SMR option
Permanently committed	13		12.7	
Overburden moved, million MT	2.8	This is equivalent to a 95 MWe coal-fired power plant.	2.74	This is approximately equivalent to a 93 MWe coal-fired power plant; 88% less energy per ac than the SMR option
Water (millions of gal)				
Discharged to air	160	= 2 percent of model 1000 MWe LWR with cooling tower	157	< 2 percent of model 1000 MWe LWR with cooling tower
Discharged to water bodies	11,090		10,868	
Discharged to ground	127		124	
Total	11,377	< 4 percent of the water needs of the 1000 MWe LWR with once-through cooling.	11,149	< 4 percent of the water needs of the 1000 MWe LWR with once-through cooling.

Table 5.7-2 (Sheet 2 of 4)
Uranium Fuel Cycle Environmental Data

Environmental Considerations	Annual Fuel Requirement Impacts 10 CFR 51.51 Reference plant		Annual Fuel Requirement Impacts CRN Site SMRs	
	Reference plant Data	Maximum effect per annual fuel requirement or RRY	Reference Reactor Data multiplied by scale factor = 0.98	Maximum effect per annual fuel requirement or RRY multiplied by scale factor
Fossil fuel				
Electrical energy, MW hour (MWh)	323,000 MWh	< 5 percent of model 1000 MWe output	316,540 MWh	< 5 percent of model 1000 MWe output
Equivalent coal (MT)	118,000	This is equivalent to the consumption of a 45 MWe coal-fired power plant.	115,640	This is equivalent to the consumption of a 44 MWe coal-fired power plant.
Natural gas (standard cubic feet [scf])	135 million		132 million	
Chemical Effluents (MT)				
Gases, incl. entrainment				
SO_x	4400	These values are equivalent to the emissions from a 45 MWe coal-fired plant for a year.	4312	These values are equivalent to the emissions from a 44 MWe coal-fired plant for a year.
NO_x	1190		1166	
Hydrocarbons	14		13.7	
CO	29.6		29.0	
Particulates	1154		1131	
Other gases				
F	0.67		0.66	
HCl	0.014		0.014	
Liquids				
SO^-_4	9.9		9.7	
NO^-_3	25.8		25.3	

Table 5.7-2 (Sheet 3 of 4)
Uranium Fuel Cycle Environmental Data

Environmental Considerations	**Annual Fuel Requirement Impacts 10 CFR 51.51 Reference plant**		**Annual Fuel Requirement Impacts CRN Site SMRs**	
	Reference plant Data	**Maximum effect per annual fuel requirement or RRY**	**Reference Reactor Data multiplied by scale factor = 0.98**	**Maximum effect per annual fuel requirement or RRY multiplied by scale factor**
Fluoride	12.9		12.6	
Ca^{++}	5.4		5.3	
Cl^{-}	8.5		8.33	
Na^{+}	12.1		11.9	
NH_3	10.0		9.8	
Fe	0.4		0.4	
Tailings solutions	240,000		235,200	
Solids	91,000		89,180	
Radiological Effluents, Ci				
Gases, incl. entrainment				
Rn-222	-		-	
Ra-226	0.02		0.02	
Th-230	0.02		0.02	
U	0.034		0.033	
H-3 (thousands)	18.1		17.7	
C-14	24		23.52	
Kr-85 (thousands)	400		392	
Ru-106	0.14		0.13	
I-129	1.3		1.3	
I-131	0.83		0.81	

Table 5.7-2 (Sheet 4 of 4)
Uranium Fuel Cycle Environmental Data

Environmental Considerations	**Annual Fuel Requirement Impacts 10 CFR 51.51 Reference plant**		**Annual Fuel Requirement Impacts CRN Site SMRs**	
	Reference plant Data	**Maximum effect per annual fuel requirement or RRY**	**Reference Reactor Data multiplied by scale factor = 0.98**	**Maximum effect per annual fuel requirement or RRY multiplied by scale factor**
Tc-99	-		-	
Fission products and transuranics (TRU)	0.203		0.199	
Liquids				
Uranium and daughters	2.1		2.06	
Ra-226	0.0034		0.0033	
Th-230	0.0015		0.0015	
Th-234	0.01		0.0098	
Fission and Activation	5.9×10^6		5.8×10^6	
Solids (buried onsite)				
Other than high level waste (HLW) (shallow)	11,300		11,074	
TRU and HLW (deep)	11,000,000		10,780,000	
Other Environmental Considerations				
Thermal Effluents, (Billions of British thermal units [Btu])	4063 billion Btu	< 5 percent of the model 1000 MWe LWR	3982 billion Btu	< 5 percent of the model 1000 MWe LWR
Transportation				
Exposure of workers and the general public	2.5 person-rem		2.4 person-rem	
Occupational exposure	22.6 person-rem	From reprocessing and waste management	22.1 person-rem	From reprocessing and waste management

Table 5.7-3
Whole Body 100-Year Dose Commitment Estimate

Uranium Fuel Sources	10 CFR 51.51 Reference Plant (person-rem)	CRN Site SMRs (person-rem)
From radioactive gaseous effluents (all fuel operations excluding reactor releases and the dose commitment due to Rn-222 & Tc-99)	400	392
From radioactive liquid effluents (all fuel-cycle operations excluding reactor operation)	200	196
Subtotal	600	588
Total Rn-222 (see Table 5.7-4)	140	136
Total Tc-99 (see Table 5.7-4)	100	98
Total with Rn-222 and Tc-99	840	822

Table 5.7-4
Estimated 100-Year Environmental Dose Commitment from Mining and Milling for Each Year of Operation

	1000 MWe Reference plant NUREG-1437, Rev. 0, Subsection 6.2.2.1		Facility CRN Site SMRs	
	Annual Release (Ci)	100-year Committed Dose (person-rem)	Annual Release (Ci)	100-year Committed Dose (person-rem)
Radon-222				
Mining	4100	110	4018	108
Milling and tailings (other than stabilized)	1100	29	1078	28
Total for Rn-222	5200	140	5096	136
Technetium-99				
Chemical reprocess	0.007	100	0.007	98
Groundwater	0.005		0.005	
Total for Tc-99	0.012	100	0.012	98

Table 5.7-5
Radiation Exposure to the United States Population

Exposure Source	Average Dose Equivalent to United States Population (mrem/yr)
Natural:	
Radon/Thoron	229
Cosmic	31
Other	50
Occupational	0.62
Consumer Products	12
Medical:	
Medical Procedures	223
Nuclear medicine	74
Approximate Total	620

Source: (Reference 5.7-10)

Table 5.7-6
Number of Truck Shipments of Unirradiated Fuel

Reactor Type	Number of Fuel Shipments		
	Initial Load[1]	Annual Reload[2]	Total
Reference LWR	18[2]	6	252
SMRs at the CRN Site	40 (maximum)	12 (assumed even loading over 40 years)	492
Normalized	NA	15	600

1 Shipments of the initial core have been rounded up to the next highest whole number.
2 The initial core load for the reference PWR in WASH-1238 was 100 MTU with 18 truck shipments (Reference 5.7-12).

Notes:
NA = Not Applicable

Table 5.7-7
Number of Radioactive Waste Shipments

Reactor Type	Waste Generation Rate	Number of Shipments per reactor-yr	Normalized Shipments per reactor-yr
Irradiated Fuel			
Reference LWR	30 MTU per year	60	NA
SMRs at the CRN Site	56.1 MTU per year	46	137[1]
Solid Radioactive Waste			
Reference LWR	3800 cubic feet per year	46	NA
SMRs at the CRN Site	5000 cubic feet per year	61	75

[1] Normalized based on 0.5 MTU per shipping container and the net power using a conservative 90 percent capacity for the 800 MWe CRN Site SMRs.

Note:
NA = Not Applicable

Table 5.7-8
CRN Site SMR Comparisons to 10 CFR 51.52 Reference Conditions

Characteristic	Reference Reactor 10 CFR 51.52/WASH-1238[1]	CRN Site SMRs
Thermal Power Rating (MWt)	3800 MWt	2420 MWt
Fuel Form	Sintered uranium dioxide pellets	Sintered uranium dioxide pellets
U-235 Enrichment (%)	< 4	< 5
Fuel Rod Cladding	Zircaloy rods	Zircaloy rods
Average Fuel Irradiation (MWd per MTU)	≤ 33,000	≤ 51,000
Unirradiated Fuel		
Transport Mode	Truck	Truck
Irradiated Fuel		
Transport Mode	Truck, rail, or barge	Truck, rail, or barge
Decay time before shipment	> 5 years per contract with DOE	> 5 years per contract with DOE
Radioactive Waste		
Transport Mode	Truck or rail	Truck or rail
Waste Form	Solid	Solid
Packaged	Yes	Yes
Traffic Density (shipments)		
Unirradiated Fuel – Initial Loading	12	40
Unirradiated Fuel - Reload	15/year	12.3/year 15/year normalized
Irradiated Fuel	60/year	46/year 137/year - normalized
Radioactive Waste	46/year	61/year (75/year normalized)
Total	121/year	119.3/year (227 – normalized)
Trucks per day	< 1/day	< 1/day

[1] (Reference 5.7-12)

Table 5.7-9
Total Shipment Cumulative Dose Summary

Exposed Population	Source			
	Unirradiated Fuel	**Irradiated Fuel**	**Radioactive Waste**	**Total**
Crew Dose (person-rem per year)				
At Stops	4.59E-03	5.55E+00	1.61E+00	7.16E+00
Along Route	7.85E-03	9.32E+00	2.55E+00	1.19E+01
Total Crew Dose				**1.91E+01**
Public Dose (person-rem per year)				
At Stops				
Sharing Stops	2.15E-03	2.74E+00	7.50E-01	3.49E+00
Residents	1.95E-04	1.70E-01	1.02E-01	2.72E-01
Along Route				
Other Vehicles	5.81E-03	3.66E+00	1.92E+00	5.59E+00
Residents	8.84E-04	3.75E-01	3.28E-01	7.04E-01
Total Public Dose				**1.01E+01**