reprocessing. During the 109th Congress, the Energy Policy Act of 2005 was enacted. It authorized the U.S. Department of Energy (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 no-recycle option is presented schematically in Figure 6-1. Natural uranium is mined in either open-pit or underground mines or by an *in situ* leach solution mining process. *In situ* leach mining, presently the primary form of mining in the United States, involves injecting a lixiviant solution into the uranium ore body to dissolve uranium and then pumping the solution to the surface for further processing. The ore or *in situ* leach solution is transferred to mills where it is processed to produce "yellowcake" (U_3O_8). A conversion facility prepares the U_3O_8 by converting it to uranium hexafluoride (UF_6), which is then processed by an enrichment facility to increase the percentage of the more fissile isotope uranium-235 and decrease the percentage of the non-fissile isotope uranium-238. At a fuel fabrication facility, the enriched uranium, which is approximately five percent uranium-235, is then converted to uranium oxide (UO_2). The UO_2 is pelletized, sintered, and inserted into tubes to form fuel assemblies, which are destined to be placed in a reactor to produce power. When the content of the uranium-235 reaches a point where the nuclear reaction has become inefficient with respect to neutron economy, the fuel assemblies are withdrawn from the reactor as spent fuel. After being stored onsite for sufficient time to allow for short-lived fission product decay and to reduce the heat generation rate, the fuel assemblies would be transferred to a waste repository for internment. Disposal of spent fuel elements in a repository constitutes the final step in the no-recycle option.

The following assessment of the environmental impacts of the fuel cycle as related to the operation of the proposed project is based on the values given in Table S–3 (Table 6-1) and the NRC staff's analysis of the radiological impact from radon-222 and technetium-99. In NUREG-1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (GEIS) (NRC 1996, 1999),[(a)] the NRC staff provides a detailed analysis of the environmental impacts from the uranium fuel cycle. Although NUREG-1437 is specific to the impacts related to license renewal, the information is relevant to this review because the advanced LWR design considered here uses the same type of fuel; the NRC staff's analyses in Section 6.2.3 of NUREG-1437 are summarized and provided here.

The fuel cycle impacts in Table S–3 are based on a reference 1000-MW(e) LWR operating at an annual capacity factor of 80 percent for a net electric output of 800 MW(e). In the following

(a) NUREG-1437 was originally issued in 1996. Addendum 1 to NUREG-1437 was issued in 1999. Hereafter, all references to NUREG-1437 include NUREG-1437 and its Addendum 1.

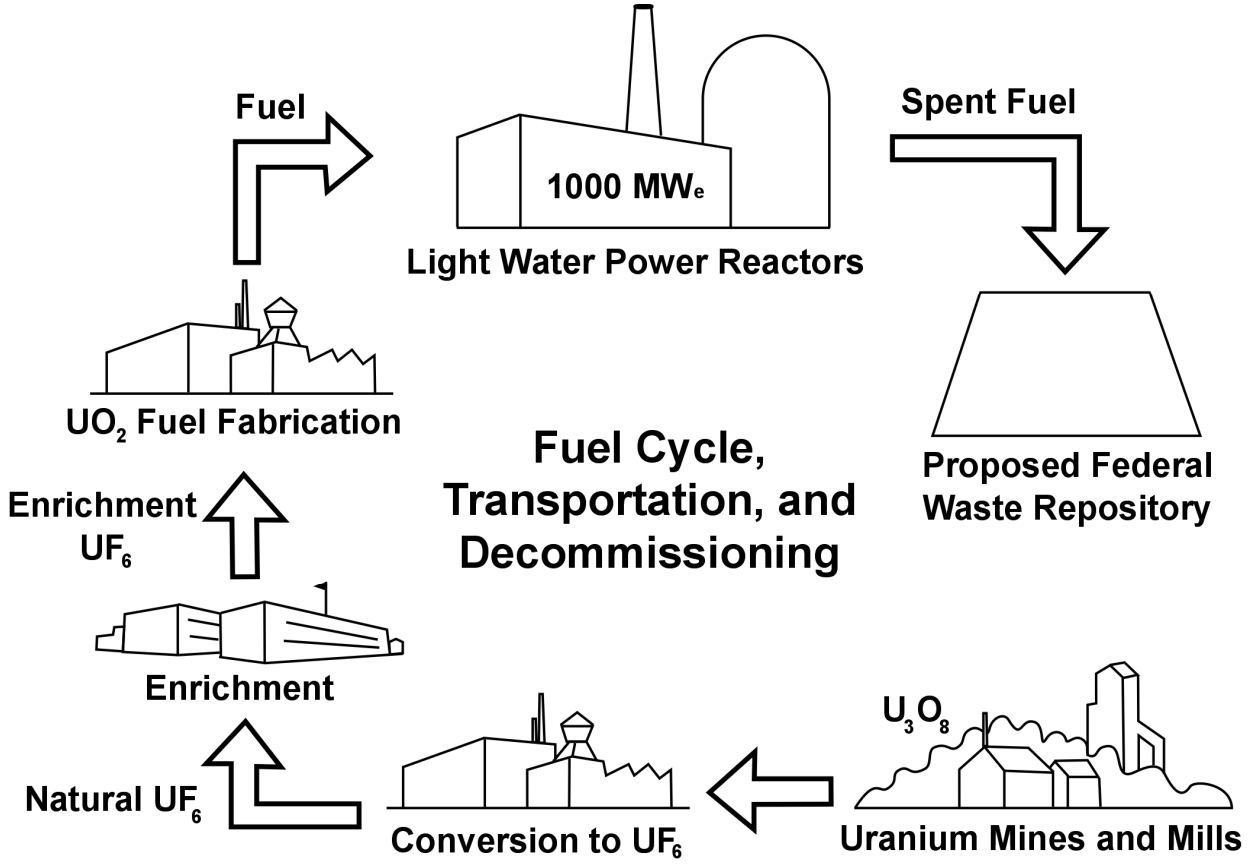

Figure 6-1. The Uranium Fuel Cycle: No-Recycle Option (derived from NRC 1999)

review and evaluation of the environmental impacts of the fuel cycle, the NRC staff considered the capacity factor of 95 percent with a total net electric output of 1280 MW(e) for each of the proposed Units 3 and 4 at the STP site for a total of 2560 MW(e) (STPNOC 2010a) this is about 3.2 times (i.e., 2560 MW(e) divided by 800 MW(e) yields 3.2) the impact values in Table S–3 (see Table 6-1). Throughout this chapter, this will be referred to as the 1000-MW(e) LWR-scaled model, 2560 MW(e) for the site.

Recent changes in the fuel cycle may have some bearing on environmental impacts; however, as discussed below, the staff is confident that the contemporary fuel cycle impacts are below those identified in Table S–3. This is especially true in light of the following recent fuel cycle trends in the United States:

- Increasing use of in-situ leach uranium mining, which does not produce mine tailings.
- Transitioning of U.S. uranium enrichment technology from gaseous diffusion to gas centrifuge. The latter centrifuge process uses only a small fraction of the electrical energy

per separation unit compared to gaseous diffusion. (U.S. gaseous diffusion plants relied on electricity derived mainly from the burning of coal.)

- Current LWRs use nuclear fuel more efficiently due to higher fuel burnup. Therefore, less uranium fuel per year of reactor operation is required than in the past to generate the same amount of electricity.
- Fewer spent fuel assemblies per reactor-year are discharged, hence the waste storage/repository impact is lessened.

The values in Table S–3 were calculated from industry averages for the performance of each type of facility or operation within the fuel cycle. Recognizing that this approach meant that there would be a range of reasonable values for each estimate, the NRC staff used an approach of choosing the assumptions or factors to be applied so that the calculated values would not be underestimated. This approach was intended to ensure that the actual environmental impacts would be less than the quantities shown in Table S–3 for all LWR nuclear power plants within the widest range of operating conditions. Many subtle fuel cycle parameters and interactions were recognized by the NRC staff as being less precise than the estimates and were not considered or were considered but had no effect on the Table S–3 calculations. For example, to determine the quantity of fuel required for a year's operation of a nuclear power plant in Table S–3, the NRC staff defined the model reactor as a 1000-MW(e) LWR reactor operating at 80-percent capacity with a 12-month fuel reloading cycle and an average fuel burn-up of 33,000 MWd/MTU. This is a "reactor reference year" or "reference reactor year" depending on the source (either Table S–3 or NUREG-1437), but it has the same meaning. The sum of the initial fuel loading plus all the reloads for the lifetime of the reactor can be divided by the now more likely 60-year lifetime (40-year initial license term and 20-year license renewal term) to obtain an average annual fuel requirement. This was done in NUREG-1437 for both boiling water reactors and pressurized water reactors; the higher annual requirement, 35 metric tons (MT) of uranium made into fuel for a boiling water reactor, was chosen in NUREG-1437 (NRC 1996, 1999) 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 separative work (enrichment) requirements. Since Table S–3 was promulgated, these improvements have reduced the annual fuel requirement.

Another change is the elimination of the U.S. restrictions on the importation of foreign uranium. Until recently, the economic conditions of the uranium market favored use of foreign uranium at the expense of the domestic uranium industry. These market conditions resulted in the closing of most U.S. uranium mines and mills, substantially reducing the environmental impacts in the United States from these activities. However, more recently the spot price of uranium has increased from $24 per pound in April 2005 to $135 per pound in July 2007 and has decreased to near $44 per pound as of April 2009 (UxC 2009). As a result, there is some renewed interest in uranium mining and milling in the United States and the NRC anticipates receiving multiple

license applications for uranium mining and milling in the next several years. The majority of these applications are expected to be for *in situ* leach solution mining that does not produce tailings. Factoring in changes to the fuel cycle suggests that the environmental impacts of mining and tail millings could drop to levels below those given in Table S–3; however, Table S–3 estimates have not been reduced for these analyses.

Section 6.2 of NUREG-1437 discusses the sensitivity to recent changes in the fuel cycle on the environmental impacts in greater detail.

6.1.1 Land Use

The total annual land requirement for the fuel cycle supporting the 1000-MW(e) LWR-scaled model would be about 366 ac. Of this land requirement, approximately 42 ac are permanently committed and 324 ac are 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 completion of decommissioning, such land can be released for unrestricted use. "Permanent" commitments represent land that may not be released for use after plant shutdown and decommissioning because decommissioning activities do not result in removal of sufficient radioactive material to meet the limits in 10 CFR Part 20, Subpart E, for release of that area for unrestricted use. Of the 324 ac of temporarily committed land, 254 are undisturbed, and 70 ac are disturbed. In comparison, a coal-fired power plant using the same MW(e) output as the LWR-scaled model and using strip-mined coal requires the disturbance of about 640 ac per year for fuel alone. The NRC staff concludes that the impacts on land use to support the 1000-MW(e) LWR-scaled model would be SMALL.

6.1.2 Water Use

The principal water use for the fuel cycle supporting the 1000-MW(e) LWR-scaled model would be that required to remove waste heat from the power stations supplying electrical energy to the enrichment step of this cycle. Scaling from Table S–3, of the total annual water use of 3.65×10^{10} gallons, about 3.56×10^{10} gallons are required for the removal of waste heat. Also scaling from Table S-3, other water uses involve the discharge to air (e.g., evaporation losses in process cooling) of about 5.13×10^{8} gallons per year and water discharged to the ground (e.g., mine drainage) of about 4.07×10^{8} gallons per year. The NRC staff concludes that the impacts on water use for these combinations of thermal loadings and water consumption would be SMALL.

6.1.3 Fossil Fuel Impacts

Electric energy and process heat are required during various phases of the fuel cycle process. 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 percent of the annual

electric power production of the reference 1000-MW(e) LWR. Process heat is primarily generated by the combustion of natural gas. This gas consumption, if used to generate electricity, would be less than 0.4 percent of the electrical output from the model plant.

The largest source of carbon dioxide (CO_2) emissions associated with nuclear power is from the fuel cycle, not the operation of the plant, as indicated above and in Table S–3. The CO_2 emissions from the fuel cycle are about 5 percent of the CO_2 emissions from an equivalent fossil fuel-fired plant.

The largest use of electricity in the fuel cycle comes from the enrichment process. It appears that gas centrifuge (GC) technology is likely to eventually replace gaseous diffusion (GD) technology for uranium enrichment in the United States. The same amount of enrichment from a GC facility uses less electricity and therefore results in lower amounts of air emissions such as carbon dioxide than a GD facility. Therefore, the NRC staff concludes that the values for electricity use and air emissions in Table S-3 continue to be appropriately bounding values. In Appendix I, the NRC staff estimates that the carbon footprint of the fuel cycle to support a reference 1000 MW(e) LWR for a 40-year plant life is on the order of 17,000,000 metric tons of CO_2 including a small contribution from other greenhouse gases. Scaling this footprint to the power level and capacity factor of STP Units 3 and 4, the review team estimates the carbon footprint for 40 years of fuel cycle emissions to be about 54,000,000 metric tons (an emission rate of about 1,400,000 metric tons annually, averaged over the period of operation) of CO_2, as compared to a total United States annual emissions rate of 6,000,000,000 metric tons (EPA 2010).

On this basis, the NRC staff concludes that the fossil fuel impacts, including greenhouse gas emissions, from the direct and indirect consumption of electric energy for fuel cycle operations would be SMALL.

6.1.4 Chemical Effluents

The quantities of gaseous and particulate chemical effluents produced in fuel-cycle processes are given in Table S–3 (Table 6-1) for the reference 1000-MW(e) LWR and, according to WASH-1248 (AEC 1974), result from the generation of electricity for fuel cycle operations. The principal effluents are sulfur oxides, nitrogen oxides, and particulates. Table S–3 states that the fuel cycle for the reference 1000-MW(e) LWR requires 323,000 MW-hr of electricity. The fuel cycle for the 1000-MW(e) LWR scaled model would therefore require 1,033,600 MW-hr of electricity, or 0.025 percent of the 4.1 billion MW-hr of electricity generated in the United States in 2008 (DOE 2009). Therefore, the gaseous and particulate chemical effluents would add about 0.025 percent to the national gaseous and particulate chemical effluents for electricity generation.