APPENDIX I
IMPACTS OF MIXED OXIDE FUEL USE IN DOMESTIC COMMERCIAL NUCLEAR POWER REACTORS

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This appendix to this *Final Surplus Plutonium Disposition Supplemental Environmental Impact Statement* (*SPD Supplemental EIS*) provides an assessment of the environmental impacts from the use of a partial mixed oxide (MOX) fuel core (i.e., up to 40 percent MOX fuel), rather than a 100-percent low-enriched uranium (LEU) core in commercial nuclear power reactors. Section I.1 addresses impacts of use of MOX fuel in two multiple-unit nuclear reactor facilities operated by the Tennessee Valley Authority (TVA) – namely, the Browns Ferry Nuclear Plant (Browns Ferry) near Athens, Alabama, and the Sequoyah Nuclear Plant (Sequoyah) near Soddy-Daisy, Tennessee. Section I.2 addresses impacts of use of MOX fuel within generic commercial nuclear reactors potentially located anywhere within the United States.

I.1 Impacts of Irradiating Mixed Oxide Fuel at Tennessee Valley Authority Reactor Sites

As discussed in Chapter 2, Section 2.3.3, of this *SPD Supplemental EIS*, use of MOX fuel within commercial nuclear reactors is evaluated for TVA's Browns Ferry and Sequoyah Nuclear Plants. Browns Ferry has three operating boiling water reactors (BWRs) and Sequoyah has two operating pressurized water reactors (PWRs) that could be used to irradiate MOX fuel assemblies. The U.S. Nuclear Regulatory Commission (NRC) licenses and regulates all commercial nuclear power plants that generate electricity in the United States, including the TVA reactors at Browns Ferry and Sequoyah. (For more information on NRC's power reactor regulatory program, see www.nrc.gov/reactors/operator-licensing.html.) **Table I–1** summarizes the operating power level for each of the Browns Ferry and Sequoyah reactors.

Tennessee Valley Authority's (TVA's) Commitment to Nuclear Safety

TVA's top priority for its nuclear plants is safety. TVA operates its nuclear plants with the latest safeguards and practices, with oversight by a number of internal and external agencies.

TVA's nuclear power activities are carried out with public health and safety, the protection of its employees, and the environment as paramount considerations. To support this objective, it is TVA's policy to maintain a strong nuclear safety culture that serves to make nuclear safety the overriding priority for each nuclear facility and for each individual associated with it. For the complete text of TVA's Commitment to Nuclear Safety, go to: www.tva.gov/foia/pdf/commitment_to_nuclear_safety.pdf.

Table I–1 Reactor Operating Power Level

Reactor	*Operator*	*Installed Power Level (megawatts electric)*
Browns Ferry Nuclear Plant 1	TVA	1,158 [a]
Browns Ferry Nuclear Plant 2	TVA	1,161 [a]
Browns Ferry Nuclear Plant 3	TVA	1,161 [a]
Sequoyah Nuclear Plant 1	TVA	1,216
Sequoyah Nuclear Plant 2	TVA	1,194

TVA = Tennessee Valley Authority.
[a] TVA plans to increase the generating capacity of each Browns Ferry unit to approximately 1,295 megawatts electric with an extended power uprate following approval from the NRC.
Source: TVA 2012.

In accordance with the alternatives presented in Chapter 2, Section 2.3, of this *SPD Supplemental EIS*, these reactors could use MOX fuel to partially fuel their reactor cores. Depending on the alternative chosen, between 34 metric tons (37.5 tons) and 45.1 metric tons (49.7 tons) of surplus plutonium could be fabricated into MOX fuel. The impact analyses presented in this section are based on publically available information and information provided by TVA. Data were also developed independently to support these analyses; this included projecting the population around the reactor sites out to 2020.[1] Analyses of potential radiation impacts from accident scenarios used this information. In addition, expected ratios of radionuclide activities in MOX fuel versus those in LEU fuel were calculated using the ORIGEN computer code and used to estimate the radiological consequences in the event of a number of reactor accidents (ORNL 2013).

Under the MOX fuel approach, both MOX and LEU fuel assemblies would be loaded into the reactors. When the MOX fuel completes its time in the reactor core, it would be withdrawn from the reactor in accordance with the plant's refueling procedures and placed in the plant's used fuel (also known as spent fuel) pool for cooling among other used fuel. The used fuel may be subsequently transferred to dry storage casks. No major changes are expected in the plant's used fuel storage plans to accommodate the used MOX fuel. Although the amount of fissile material would be higher in used MOX fuel rods than in LEU used fuel rods, the fuel assembly numbers and spacing in the used fuel pool and/or dry storage casks would be adjusted as necessary to maintain criticality and thermal safety margins.

Before MOX fuel could be used, the utility operating the reactor would be required to obtain a license amendment from NRC in accordance with Title 10 of the *Code of Federal Regulations* (CFR) Parts 50 or 52 (10 CFR Parts 50 or 52). NRC would determine whether to issue license amendments that would allow the reactor(s) to use MOX fuel. The NRC licensing process is described in Chapter 5, Section 5.3.3.

I.1.1 Construction Impacts

No new construction would likely be needed on undeveloped areas of the reactor sites to support the irradiation of MOX fuel (TVA 2012). Although the use of MOX fuel may require some changes to safety systems such as the number of control rods, the use of MOX fuel is expected to require only minor modifications at the reactor site itself. Minor changes may be needed to existing facilities for security upgrades and to provide adequate room to receive MOX fuel assemblies. As a result, there would be only minimal impacts on all resource areas.

I.1.2 Operational Impacts

This section describes and compares the impacts from the operation of the TVA reactors using a partial MOX fuel core versus a full LEU core. The No Action Alternative does not include the use of TVA reactors for this purpose but any of the other alternatives considered in this *SPD Supplemental EIS* could potentially result in MOX fuel becoming available for use in TVA reactors.

I.1.2.1 Air Quality

Continued operation of the reactors would result in small amounts of nonradiological air pollutants being released to the atmosphere, mainly due to the requirement to periodically test diesel generators and from the operation of auxiliary steam boilers. As shown in Chapter 3, Sections 3.3.1.1 and 3.3.2.1, of this *SPD Supplemental EIS,* all of the reactors operate within Federal, state, and local air quality regulations or guidelines. Release of air pollutants resulting from operation of the reactors is not expected to increase due to the use of MOX fuel (TVA 2012).

Estimated total emissions from shipping unirradiated MOX fuel to TVA reactors are presented in **Table I–2** conservatively assuming one Type B cask per shipment. Similar emissions would occur even if MOX fuel is not used in TVA reactors, because the MOX fuel would be replacing LEU fuel shipped to reactors under the No Action Alternative.

[1] *Populations for the area within a 50-mile (80-kilometer) radius around the proposed reactor sites were projected to 2020. By 2020, the MOX program should be firmly established and is expected to remain stable through the end of the program. Using 1990, 2000, and 2010 census data a linear trend was developed and the populations around the sites were projected to 2020.*

Table I–2 Criteria Pollutant Emissions from Shipping Unirradiated Mixed Oxide Fuel to the Browns Ferry and Sequoyah Nuclear Plants

	Total Emissions by Alternative (metric tons)				
Pollutant	*No Action* [a]	*Immobilization*	*MOX Fuel*	*H-Canyon/HB-Line*	*WIPP*
Carbon monoxide	N/A	6.7	9	8.2	6.7
Nitrogen dioxide	N/A	23	31	28	23
PM_{10}	N/A	0.66	0.89	0.81	0.66
$PM_{2.5}$	N/A	0.55	0.75	0.68	0.55
Sulfur dioxide	N/A	0.028	0.037	0.034	0.028
Volatile organic compounds	N/A	1.1	1.4	1.3	1.1

MOX = mixed oxide; N/A = not applicable; PM_n = particulate matter less than or equal to *n* microns in aerodynamic diameter; WIPP = Waste Isolation Pilot Plant.

[a] No MOX fuel would be shipped to the Sequoyah Nuclear Plant and the Browns Ferry Nuclear Plant under the No Action Alternative.

Note: To convert metric tons to tons, multiply by 1.1023.

Estimated carbon dioxide emissions from shipping unirradiated MOX fuel to TVA reactors would be less than 190 tons per year (170 metric tons per year).

I.1.2.2 Human Health Risk

This section describes the impacts from operation of the TVA reactors with the partial MOX fuel core on human health from normal reactor operations, facility accidents, and intentional destructive acts.

I.1.2.2.1 Human Health Risk from Normal Operations

Doses to workers – Under all alternatives, occupational doses to plant workers during periods of MOX fuel loading and irradiation are expected to be similar to those for LEU fuel (TVA 2012). Unirradiated MOX fuel could present a risk of higher radiation doses to reactor workers due to the presence of additional plutonium and other actinides compared to LEU fuel. However, worker doses would continue to meet Federal regulatory dose limits as required by NRC, and TVA would be required by NRC to take steps within its ALARA [as low as reasonably achievable] program to limit any increase in doses to workers that may occur from use of MOX fuel. The only time any increase in dose is likely to occur would be during acceptance inspections at the reactor when the fuel assemblies are first delivered to the plant and workers are required to inspect the fuel assemblies to ensure that they meet design specifications. After inspection, worker doses would be limited because the assemblies would be handled remotely as they are loaded into the reactor and subsequently removed from the reactor and transferred into the used fuel pool. For MOX fuel use at the Browns Ferry and Sequoyah Nuclear Plants, however, TVA personnel have indicated that any potential increases in worker dose would be prevented through the continued implementation of aggressive ALARA programs. If needed, additional shielding and remote handling equipment would be used to prevent an increase in worker dose (TVA 2012). Worker doses at the reactors would continue to meet Federal regulatory dose limits as required by NRC in 10 CFR Part 20, and steps would be taken at the reactor sites to limit any increase in dose to workers that could result from use of MOX fuel.

As discussed in Chapter 3, Sections 3.3.1.2 and 3.3.2.2, of this *SPD Supplemental EIS*, Browns Ferry workers received an average annual dose of 175 millirem from plant operations during the period from 2005 through 2009, while Sequoyah workers received an average annual dose of 110 millirem (TVA 2012). Over the same period, the average annual total worker dose at Browns Ferry was 532 person-rem, while the average annual total worker dose at Sequoyah was 142 person-rem (TVA 2012). Using a risk estimator of 600 cancer deaths per 1 million person-rem (DOE 2003), the risk of a latent cancer fatality (LCF) for the average worker would be 0.0001 and 0.00007 annually at Browns Ferry and Sequoyah, respectively. No LCFs are expected in the plant worker population at either reactor site from normal operations using either a partial MOX fuel core or a full LEU core.

Doses to members of the public – **Table I–3** shows the projected radiological doses that would be received by the offsite maximally exposed individual (MEI) and the general population. No change in radiation dose to the public is expected from normal operation of the reactors assuming a partial MOX fuel core versus a full LEU fuel core. This is consistent with findings in the *Surplus Plutonium Disposition Final Environmental Impact Statement (SPD EIS)* (DOE 1999).

Table I–3 Estimated Dose to the Public from Continued Operation of the Browns Ferry and Sequoyah Nuclear Plants in the Year 2020 (partial mixed oxide or low-enriched uranium core)

Impact	*Sequoyah Nuclear Plant* [a]	*Browns Ferry Nuclear Plant* [b]
Population within 50 miles (80 kilometers) for year 2020		
Dose (person-rem)	3	0.2
Percent of natural background [c]	0.00077	0.000058
Latent fatal cancers [d]	0 (0.002)	0 (0.0001)
Maximally exposed individual (millirem per year)		
Annual dose (millirem)	0.15	0.043
Percent of natural background [c]	0.047	0.013
Latent fatal cancer risk	9×10^{-8}	3×10^{-8}
Average exposed individual within 50 miles (80 kilometers)		
Annual dose (millirem)	0.0025	0.00018
Latent fatal cancer risk	2×10^{-9}	1×10^{-10}

[a] The population within 50 miles (80 kilometers) for the year 2020 is estimated to be approximately 1.2 million.
[b] The population within 50 miles (80 kilometers) for the year 2020 is estimated to be approximately 1.1 million.
[c] The natural background dose is 318 millirem per year (Chapter 3, Table 3–46).
[d] Estimated number of latent cancer fatalities in the entire offsite population out to a distance of 50 miles given exposure to the indicated dose. The number of latent cancer fatalities is calculated by multiplying the dose by the risk factor of 0.0006 LCFs per person-rem (DOE 2003). Because the risk factor is only calculated to one significant figure, the number of latent cancer fatalities is reported to one significant figure.

As discussed in Chapter 3, Section 3.3.1.2, of this *SPD Supplemental EIS*, the Browns Ferry MEI was calculated to receive an annual dose of 0.043 millirem from typical (representative) plant operations (TVA 2012). Using a risk estimator of 600 cancer deaths per 1 million person-rem (DOE 2003), the annual fatal cancer risk to the MEI from Browns Ferry operations using a partial MOX fuel core is estimated to be 3×10^{-8}, the same as would occur from using a full LEU core. That is, the estimated probability of this person developing a fatal cancer sometime in the future from 1 year of plant operations would be approximately 1 in 33 million. As also discussed in Section 3.3.1.2, the annual dose to the population residing within 50 miles (80 kilometers) of Browns Ferry was calculated to be 0.15 person-rem from typical recent plant operations. For the year 2020, the subject population is expected to be approximately 30 percent higher (see Appendix J); therefore, it was conservatively assumed that the population dose would also be 30 percent higher (0.20 person-rem) in 2020. Employing the same risk estimator as above, a calculated value of 0.00012 fatal cancers indicates that no fatal cancers are projected for the Browns Ferry general population from normal operations using a partial MOX fuel core or a full LEU fuel core.

As discussed in Chapter 3, Section 3.3.2.2, of this *SPD Supplemental EIS*, the Sequoyah MEI was calculated to receive an annual dose of 0.15 millirem from typical (representative) plant operations. Using a risk estimator of 600 cancer deaths per 1 million person-rem (DOE 2003), the annual fatal cancer risk to the MEI from Sequoyah operations using a partial MOX fuel core is estimated to be 9×10^{-8}, the same as would occur from using a full LEU core. That is, the estimated probability of this person developing a fatal cancer sometime in the future from 1 year of plant operations would be 1 in 11 million. As also discussed in Section 3.3.2.2, the annual dose to the population residing within 50 miles (80 kilometers) of Sequoyah was calculated to be 2.5 person-rem from typical recent plant operations. For the year 2020, the subject population is expected to be approximately 20 percent higher than in 2007 (see Appendix J); therefore, it was conservatively assumed that the population dose would also be

20 percent higher (3.0 person-rem) in 2020. Employing the same risk estimator as above, a calculated value of 0.002 fatal cancers indicates that no fatal cancers are projected for the Sequoyah general population from normal operations using a partial MOX fuel core or a full LEU fuel core.

For either reactor site, the average individual living within 50 miles (80 kilometers) of the reactor sites could expect to receive an annual dose of 0.00018 to 0.0025 millirem from normal operations regardless of whether the reactors were using MOX fuel or LEU fuel. This is a small dose compared with the average annual dose an individual would receive from natural background radiation near these sites (about 318 millirem as shown in Chapter 3, Table 3–46, of this *SPD Supplemental EIS*).

I.1.2.2.2 Reactor Accidents

Under all alternatives, the potential impacts of accidents at either TVA reactor would be similar. The focus of the analysis was an examination of the potential differences in the accidents' impacts if a partial MOX fuel core were used in commercial nuclear power plants. This question was addressed in the *SPD EIS* (DOE 1999) for use of MOX fuel in PWRs and is being reexamined and updated in this *SPD Supplemental EIS* for both PWRs and BWRs. This section summarizes the more detailed analyses of postulated reactor accidents presented in Appendix J.

The approach is straightforward. Sequoyah, which has PWRs, and Browns Ferry, which has BWRs, were used to represent typical commercial nuclear power reactors in the United States as well as being the specific reactors under consideration for use of MOX fuel.

Because Sequoyah and Browns Ferry are currently licensed by NRC to operate with LEU fuel, representative accidents were selected from current TVA licensing documents for comparison of the impacts if a partial MOX fuel core were substituted for the licensed full LEU fuel core. For this comparison, representative design-basis accidents and beyond-design-basis accidents were selected from TVA safety analyses. It should be noted that before MOX fuel could be used in these reactors or any commercial reactors in the United States, detailed safety analyses in support of licensing amendment requests would evaluate the probability of occurrence and consequences of all accident possibilities while using MOX fuel. These analyses would be reviewed and approved by the NRC prior to granting licensing amendments to use MOX fuel.

Depending on the accident being analyzed, the presence of MOX fuel would decrease or increase the consequences of the accident because it would result in different amounts of radiation being released due to the different isotopic distributions and quantities of radioactive isotopes being generated. Models currently accepted by NRC to estimate potential radiological impacts from reactor accidents were used to evaluate a selected suite of design-basis and beyond-design-basis accidents. Additional modeling would likely be required by NRC as part of the license amendment process should TVA decide to move forward with the proposal to use MOX fuel in its reactors. The methodology used is consistent with current U.S. Department of Energy (DOE) and industry practice (see Appendix J of this *SPD Supplemental EIS*).

TVA Reactor Design-basis Accidents. Design-basis accidents are not expected to take place, but are postulated because their consequences would include the potential release of radioactive material. They are the most drastic events that must be designed against and represent limiting design cases. The design-basis accidents evaluated in this *SPD Supplemental EIS* include a large-break loss-of-coolant accident and a used fuel-handling accident.

As shown in **Table I–4**, the design-basis accident with the greatest dose at the exclusion area boundary would be a loss-of-coolant accident. As also shown in Table I–4, the dose to a person at the exclusion area boundary for these accidents is well below the regulatory limit (25 rem) and would not be significantly different if the TVA reactor were partially fueled with MOX fuel.

Table I–4 Summary of Environmental Consequences from Design-Basis Accidents at the Browns Ferry and Sequoyah Nuclear Plants

Accident	Full LEU or Partial MOX Fuel Core	Impacts on the MEI at the Exclusion Area Boundary		Impacts on the Population within 50 Miles	
		Dose (rem) [a]	NRC Regulatory Limit (rem) [b]	Dose (person-rem) [a]	Average Individual Dose (rem) [c]
Browns Ferry Nuclear Plant					
Loss-of-coolant accident [d]	LEU	0.026	25	150	1.4×10^{-4}
	MOX	0.023	25	150	1.4×10^{-4}
Used-fuel-handling accident [e]	LEU	0.00014	25	0.085	7.8×10^{-8}
	MOX	0.00014	25	0.086	7.9×10^{-8}
Sequoyah Nuclear Plant					
Loss-of-coolant accident [f]	LEU	0.0023	25	0.75	6.2×10^{-7}
	MOX	0.0020	25	0.72	5.9×10^{-7}
Used-fuel-handling accident [f]	LEU	0.000036	25	0.018	1.5×10^{-8}
	MOX	0.000036	25	0.018	1.5×10^{-8}

LEU = low-enriched uranium; MEI = maximally exposed individual; MOX = mixed oxide; NRC = U.S. Nuclear Regulatory Commission; rem = roentgen equivalent man.

[a] The reactor accident doses were calculated over a 80-year period using the MACCS2 computer code. Eighty years was chosen to represent a typical person's lifetime.

[b] From 10 CFR 50.34 for design basis accidents.

[c] Average individual dose to the entire offsite projected population in 2020 (approximately 1,100,000 for Browns Ferry and 1,200,000 for Sequoyah) out to a distance of 50 miles for the indicated accident.

[d] Release would be through a 604-foot stack.

[e] Release was assumed to be through the top of the containment building at 173 feet.

[f] Release was assumed to be through the top of the containment building at 171 feet.

To convert feet to meters, multiply by 0.3048; miles to kilometers by 1.6093.

Source: Appendix J, Tables J–4 and J–5.

TVA Reactor Beyond-design-basis Accidents. Risk is determined by multiplying two factors, frequency and consequence. In the case of the beyond-design-basis reactor accidents evaluated in this *SPD Supplemental EIS*, no change is expected in the estimated frequency of the accident based on the presence of a partial MOX fuel core. The frequencies used in the analysis are the same as those used in each reactor's probabilistic risk assessment, which was prepared for NRC for the reactor's current LEU core. A recent analysis of severe accidents for reactors using partial MOX fuel cores determined them to have a similar accident progression as those for a full LEU fuel core for a number of accident scenarios including early and late containment failures (SNL 2010). These frequencies are event-based (e.g., frequency of an initiating event such as loss of offsite power) and depend on systems- and operational-response-related events (mitigation activities with probabilities to accomplish the required actions). They are not dependent on the type of the fuel in use in the reactor at the start of the accident.

Beyond-design-basis accident scenarios that would lead to containment bypass or failure were evaluated because these are the accidents that have the greatest potential consequences. The public health and environmental consequences would be significantly less for accident scenarios that do not lead to containment bypass or failure. A steam generator tube rupture, early containment failure, late containment failure, and an interfacing systems loss-of-coolant accident were chosen as the representative set of beyond-design-basis accidents (see Appendix J).

As shown in **Table I–5**, of the beyond-design-basis accidents evaluated for Sequoyah, the late containment failure accident represents the highest risk to the MEI, with an estimated frequency of approximately 1 chance in 330,000 of the accident occurring per year of operation. Of the beyond-design-basis accidents evaluated for Browns Ferry, the early containment failure accident represents the highest risk to the MEI, with an estimated frequency of approximately 1 chance in 9 million of the accident occurring per year of operation.

Table I–5 Summary of Environmental Consequences from Beyond-Design-Basis Accidents at the Browns Ferry and Sequoyah Nuclear Plants

			Impacts on the MEI at the Exclusion Area Boundary			*Impacts on the Population within 50 Miles*		
Accident	*Frequency (per year)*	*LEU or MOX Fuel Core*	*Dose (rem)* [a]	*Dose Risk (rem/year)* [b]	*Annual Risk of Fatal Cancer* [c]	*Dose (person-rem)* [a]	*Average Individual Dose Risk (rem/year)* [d]	*Risk of Fatal Cancer to Average Individual* [e]
Browns Ferry Nuclear Plant								
Early containment failure	1.1×10^{-7}	LEU	11,000 [f]	1.2×10^{-3}	1×10^{-7}	5.5×10^{6}	5.6×10^{-7}	3×10^{-10}
		MOX	11,000 [f]	1.2×10^{-3}	1×10^{-7}	5.4×10^{6}	5.5×10^{-7}	3×10^{-10}
Late containment failure	3.0×10^{-7}	LEU	190	5.7×10^{-5}	7×10^{-8}	420,000	1.2×10^{-7}	7×10^{-11}
		MOX	200	6.0×10^{-5}	7×10^{-8}	400,000	1.1×10^{-7}	7×10^{-11}
ISLOCA	4.6×10^{-8}	LEU	41	1.9×10^{-6}	2×10^{-9}	220,000	9.3×10^{-9}	6×10^{-12}
		MOX	38	1.7×10^{-6}	2×10^{-9}	210,000	8.9×10^{-9}	5×10^{-12}
Sequoyah Nuclear Plant								
Early containment failure	3.4×10^{-7}	LEU	27,000 [f]	0.0092	3×10^{-7}	2.3×10^{6}	6.5×10^{-7}	4×10^{-10}
		MOX	33,000 [f]	0.011	3×10^{-7}	2.4×10^{6}	6.7×10^{-7}	4×10^{-10}
Late containment failure	3.0×10^{-6}	LEU	790 [f]	0.0024	3×10^{-6}	1.5×10^{6}	3.7×10^{-6}	2×10^{-9}
		MOX	870 [f]	0.0026	3×10^{-6}	1.5×10^{6}	3.7×10^{-6}	2×10^{-9}
Steam generator tube rupture accident	1.4×10^{-6}	LEU	45,000 [f]	0.063	1×10^{-6}	4.0×10^{6}	4.6×10^{-6}	3×10^{-9}
		MOX	56,000 [f]	0.078	1×10^{-6}	4.2×10^{6}	4.9×10^{-6}	3×10^{-9}

ISLOCA = interfacing systems loss-of-coolant accident; LEU = low-enriched uranium; MEI = maximally exposed individual; MOX = mixed oxide; rem = roentgen equivalent man.

[a] The reactor accident doses were calculated over a 80-year period using the MACCS2 computer code. Eighty years was chosen to represent a typical person's lifetime.

[b] Annual dose risk to a hypothetical MEI at the exclusion area boundary (4,806 feet at Browns Ferry and 1,824 feet at Sequoyah) accounting for the probability of the accident occurring.

[c] Annual risk of a fatality or fatal latent cancer to a hypothetical MEI at the exclusion area boundary (4,806 feet at Browns Ferry and 1,824 feet at Sequoyah) accounting for the probability of the accident occurring.

[d] Average individual dose risk per year for the entire offsite projected population in 2020 (approximately 1,100,000 at Browns Ferry and 1,200,000 at Sequoyah) to a distance of 50 miles, given exposure to the indicated dose and accounting for the probability of the accident occurring.

[e] Annual risk of a cancer fatality to the average individual in the entire offsite projected population in 2020 to a distance of 50 miles accounting for the probability of the accident occurring.

[f] Doses of this magnitude would result in a prompt fatality. In these cases, the annual risk of a fatal cancer is equal to the estimated frequency of the accident.

Note: To convert feet to meters, multiply by 0.3048; miles to kilometers by 1.6093.

Source: Appendix J, Tables J–7 and J–8.

In terms of risks to the surrounding population, the evaluated beyond-design-basis accident at Sequoyah with the greatest risk would be a steam generator tube rupture accident. Taking into account the frequency of this accident, the average individual's probability of developing a fatal cancer would increase by about 1 chance in 330 million, regardless of whether the plant was operating with a partial MOX fuel core or a full LEU fuel core. The evaluated beyond-design-basis accident at Browns Ferry with the greatest risk would be an early containment failure accident. Taking into account the frequency of this accident, the average individual's probability of developing a fatal cancer would increase by about 1 chance in 3.3 billion, regardless of whether the plant was operating with a partial MOX fuel core or a full LEU fuel core. For comparison, using a risk factor of 0.0006 LCFs per rem, the dose from natural background radiation would increase the risk of a cancer by 1 chance in 5,200 for each year of exposure.

As discussed in Appendix J, Section J.3.4, and illustrated in **Tables I–6** and **I–7** of this *SPD Supplemental EIS*, accident risks projected for the MEI and the general population are comparable whether using a partial MOX fuel core or a full LEU core. Table I–6 presents a comparison of projected radiological impacts from a series of design-basis accidents that were analyzed in this *SPD Supplemental EIS*. The comparison is presented as the ratio of the accident impacts involving partial MOX fuel cores to those involving full LEU fuel cores. Impacts were estimated for a member of the general public at the exclusion area boundary at the time of the accident (i.e., the MEI) and the general population residing within 50 miles (80 kilometers) of the reactor. The numbers in parentheses are the calculated ratios (impacts for a partial MOX core divided by impacts for an LEU core). A ratio less than 1 indicates that the MOX fuel core could result in smaller impacts than the same accident with an LEU fuel core. A value of 1 indicates that the estimated impacts are the same for both fuel core types. A ratio larger than 1 indicates that the MOX fuel core could result in larger impacts than the same accident with an LEU fuel core. Outside the parentheses, the table shows a ratio of 1 for all accident scenarios. This is a rounded value because, when modeling and analytical uncertainties are considered, the precision of the results is no more than one significant figure.

Table I–6 Ratio of Design-Basis Accident Impacts for a Partial Mixed Oxide Fuel Core Compared to a Full Uranium Fuel Core Reactor (partial mixed oxide fuel core doses/full low-enriched uranium fuel core doses) [a, b]

Accident	*Browns Ferry Nuclear Plant*		*Sequoyah Nuclear Plant*	
	MEI at the Exclusion Area Boundary	*Population Within 50 Miles (80 kilometers)*	*MEI at the Exclusion Area Boundary*	*Population Within 50 Miles (80 kilometers)*
LOCA	1 (0.88)	1 (1.00)	1 (0.87)	1 (0.96)
Used-fuel-handling accident	1 (1.00)	1 (1.01)	1 (1.00)	1 (1.00)

LOCA = loss-of-coolant accident; MEI = maximally exposed individual.

[a] Reactor accidents involving the use of partial MOX fuel cores were assumed to involve reactor cores with approximately 40 percent MOX fuel and 60 percent LEU fuel.

[b] The values in parentheses reflect the ratio calculated by dividing the accident analysis results for a partial MOX fuel core by the results for a full LEU core. When modeling and analytical uncertainties are considered, the precision of the results is no more than one significant figure.

Source: Appendix J, Table J–9.

Table I–7 Ratio of Beyond-Design-Basis Accident Impacts for a Partial Mixed Oxide Fuel Core Compared to a Full Uranium Fuel Core Reactor (partial mixed oxide fuel core doses/full low-enriched uranium fuel core doses) [a, b]

Accident	*Browns Ferry Nuclear Plant*		*Sequoyah Nuclear Plant*	
	MEI at the Exclusion Area Boundary	*Population Within 50 Miles (80 kilometers)*	*MEI at the Exclusion Area Boundary*	*Population Within 50 Miles (80 kilometers)*
Early containment failure	1 (1.00)	1 (0.98)	1 (1.22)	1 (1.04)
Late containment failure	1 (1.05)	1 (0.95)	1 (1.10)	1 (1.00)
Steam generator tube rupture [c]	Not applicable	Not applicable	1 (1.24)	1 (1.05)
ISLOCA [d]	1 (0.93)	1 (0.95)	See SGTR	See SGTR

ISLOCA = interfacing systems loss-of-coolant accident; MEI = maximally exposed individual; SGTR = steam generator tube rupture.

[a] Reactor accidents involving the use of partial MOX fuel cores were assumed to involve reactor cores with approximately 40 percent MOX fuel and 60 percent LEU fuel.

[b] The values in parentheses reflect the ratio calculated by dividing the accident analysis results for a partial MOX fuel core by the results for a full LEU core. When modeling and analytical uncertainties are considered, the precision of the results is no more than one significant figure.

[c] Steam generator tube rupture is not applicable for boiling water reactors since they do not use steam generators.

[d] An ISLOCA was not analyzed in the *Watts Bar Nuclear Plant Severe Reactor Accident Analysis* (SAIC 2007), on which the analysis in this appendix is based, because the impacts were bounded by the SGTR accident.

Source: Appendix J, Table J–9.

Table I–7 presents a comparison of projected radiological impacts from a series of beyond-design-basis accidents that were analyzed in this *SPD Supplemental EIS.* As with the design-basis accidents, numbers in parentheses are the calculated ratios (impacts for a partial MOX core divided by impacts for an LEU core). Outside the parentheses, the table shows a ratio of 1 for all accident scenarios. This is a rounded value because, when modeling and analytical uncertainties are considered, the precision of the results is no more than one significant figure.

Based on this evaluation the potential risks of accidents involving the two types of cores are projected to be comparable for the MEI or the general population from these design-basis and beyond-design-basis accidents for both a PWR (Sequoyah) and a BWR (Browns Ferry). These results are similar to those in the *SPD EIS* (DOE 1999) for use of MOX fuel in PWRs.

I.1.2.2.3 Intentional Destructive Acts

Similar to the use of duplicate backup systems to ensure safety, TVA implements a layered approach to physical security at the reactor sites in accordance with NRC regulations and guidance. Nuclear power plants are inherently secure, robust structures built to withstand extreme natural phenomena such as hurricanes, tornadoes, and earthquakes. Additional security measures are in place including physical barriers; intrusion detection and surveillance systems; access controls; and coordination of threat information and response with Federal, state, and local agencies (NRC 2008).

Since September 11, 2001, NRC has strengthened requirements at nuclear power plants and enhanced coordination with Federal, state, and local organizations. Additional requirements (NRC 2005) address:

- Increased physical security programs to defend against a more challenging adversarial threat
- More restrictive site access controls for all personnel
- Enhanced communication and liaison with the intelligence community
- Improved capability for events involving explosions or fires
- Enhanced readiness of security organizations by strengthening training and qualifications programs for plant security forces
- Required vehicle checks at greater stand-off distances
- Enhanced force-on-force exercises to provide a more realistic test of plant capabilities to defend against an adversarial force
- Improved liaison with Federal, state, and local agencies responsible for protection of the national critical infrastructure through integrated response training

NRC has also performed comprehensive safety and security studies showing that a radiological release affecting public health and safety is unlikely from a terrorist attack, including one involving a large commercial aircraft. Factors supporting this conclusion included the hardened condition of power plants which are designed to withstand extreme events such as hurricanes, tornadoes, and earthquakes (e.g., thick concrete walls with heavy reinforcing steel); redundant safety systems operated by trained staff; multiple barriers protecting the reactor or serving to prevent or minimize offsite releases; and in-place mitigation strategies and measures. In addition, security measures at nuclear plants have been complemented by measures taken throughout the United States to improve security and reduce the risk of successful terrorist attacks, including measures designed to respond to and reduce the threats posed by hijacking large jet airplanes (e.g., reinforced cockpit doors, Federal Air Marshals) (NRC 2005, 2009).

An analysis of the consequences of the crash of a large aircraft at a nuclear power reactor site has been performed by the Electric Power Research Institute (EPRI) for the Nuclear Energy Institute. The analysis addressed the consequences of a large jet airline being purposefully crashed into sensitive nuclear facilities or containers including nuclear reactor containment buildings, used fuel storage pools, used fuel dry storage facilities, and used fuel transportation containers. Using conservative analyses, EPRI concluded that there would be no release of radionuclides from any of these facilities or containers because they are already designed to withstand potentially destructive events. The EPRI analysis used computer models in which a Boeing 767-400 was crashed into containment structures that were representative of reactor containment designs for U.S. nuclear power plants. The containment structures suffered some crushing and chipping at the maximum impact point but were not breached (EPRI 2002).

Notwithstanding the remote risk of a terrorist attack affecting operations at a nuclear power plant, in the very remote likelihood that a terrorist attack would successfully breach the physical and other safeguards at Browns Ferry or Sequoyah resulting in the release of radionuclides, the risks of such a release are reasonably captured by the consideration of the impacts of severe accidents discussed previously in this section.

I.1.2.3 Socioeconomics

Neither Browns Ferry nor Sequoyah would need to employ additional workers to support MOX fuel use (TVA 2012). This is consistent with information presented in the *SPD EIS*, which concluded that MOX fuel use would not result in increases in worker populations at reactor sites (DOE 1999). Therefore, as compared to the current use of full LEU fuel cores, use of a partial MOX fuel core in these reactors is expected to have no impact on socioeconomics in the communities surrounding the reactors.

I.1.2.4 Waste Management and Used Nuclear Fuel

Radioactive and Nonradioactive Waste Generation – Browns Ferry and Sequoyah are expected to continue to produce low-level radioactive waste, mixed low-level radioactive waste, hazardous waste, and nonhazardous waste as part of normal operations. As compared to the current use of full LEU fuel cores, use of MOX fuel is not expected to increase the annual volumes of these wastes (TVA 2012). This is consistent with information presented in the *SPD EIS* that stated that MOX fuel use is not expected to increase the amount or change the content of the waste being generated (DOE 1999).

Used Nuclear Fuel – As shown in **Table I–8**, it is likely that some additional used (irradiated) nuclear fuel would be generated from use of a partial MOX core in the TVA reactors compared to the current use of full LEU fuel cores. The amount of additional used nuclear fuel is estimated to range from approximately 8 to 10 percent of the total amount of used nuclear fuel that would be generated by the TVA reactors during the time period that MOX fuel would be used. Used MOX fuel would be managed in the same manner as LEU used fuel, by storing it in the reactor's used fuel pool or placing it in dry storage. The amount of additional used fuel is not expected to affect used fuel management at the reactor sites (TVA 2012).

Table I–8 Additional Used Nuclear Fuel Assemblies Generated by Mixed Oxide Fuel Irradiation

Reactor	*Number of Used Fuel Assemblies Generated With No MOX Fuel over a Typical Fuel Cycle*	*Number of Additional Used Fuel Assemblies With MOX Fuel*	*Percent Increase*
Sequoyah Nuclear Plant 1	81	8	9.9
Sequoyah Nuclear Plant 2	81	8	9.9
Browns Ferry Nuclear Plant 1	312 [a]	24 [a]	7.7
Browns Ferry Nuclear Plant 2	312 [a]	24 [a]	7.7
Browns Ferry Nuclear Plant 3	312 [a]	24 [a]	7.7

MOX = mixed oxide.

[a] The Browns Ferry Nuclear Plant is a BWR and the Sequoyah Nuclear Plant is a PWR. Fuel assemblies for boiling water reactors are smaller than those for pressurized water reactors; therefore, more assemblies are needed to power a boiling water reactor.

Source: TVA 2012.

I.1.2.5 Transportation

Transportation requirements would include shipments of MOX fuel from the Savannah River Site (SRS) to the reactor sites for irradiation, using the National Nuclear Security Administration's (NNSA's) Secure Transportation Assets. It is estimated (see Appendix E, Section E.7) that between approximately 2,100 and 2,900 shipments of unirradiated MOX fuel could be shipped from SRS to the reactor sites under the alternatives being considered in this *SPD Supplemental EIS*.[2] This range of shipments was determined assuming one Type B cask containing two unirradiated BWR or PWR MOX fuel assemblies per shipment to maximize the number of shipments for the analysis. Alternatively, DOE is considering the shipment of up to seven casks containing BWR fuel assemblies and up to five casks containing PWR fuel assemblies per shipment if escorted commercial trucks are used (under DOE/NNSA's Secure Transportation Asset Program), reducing the total number of shipments to approximately 330 to 440 shipments.

As analyzed in Appendix E of this *SPD Supplemental EIS* and shown in **Table I–9**, the estimated dose to the transportation crew from the incident-free transport of unirradiated MOX fuel to the TVA reactors is estimated to range from 15 person-rem (for 2,100 shipments containing one Type B cask per shipment for a combination of PWR and BWR shipments) to 20 person-rem (for 2,900 shipments containing one Type B cask per shipment for a combination of PWR and BWR shipments), depending on the alternative being analyzed. In terms of the number of LCFs related to the crew from this transportation, the crew risk would range from 0.009 to 0.01. If escorted commercial trucks carrying up to seven casks of BWR fuel or five casks of PWR fuel are used, the impacts to workers could increase about two times, with the risk of an LCF still less than 1 (about 0.02).

Table I–9 Transportation Impacts Associated with the Shipment of Unirradiated Mixed Oxide Fuel to the Browns Ferry and Sequoyah Nuclear Plants (assuming one Type B Cask per shipment)

Alternative	*Number of Shipments*	*Incident Free Dose person-(rem)*		*Number of Radiological LCFs* [a]		*Accident*	
		Crew	*Population*	*Crew*	*Population*	*Radiological LCF* [a]	*Traffic Fatality*
No Action [b]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Immobilization	2,100	15	24	0.009	0.01	0.0000004	0.03
MOX Fuel	2,900	20	32	0.01	0.02	0.0000005	0.04
H-Canyon/HB-Line	2,600	18	29	0.01	0.02	0.0000004	0.03
WIPP	2, 100	15	24	0.009	0.01	0.0000004	0.03

LCF = latent cancer fatality; MOX = mixed oxide; N/A = not applicable; rem = roentgen equivalent man; WIPP = Waste Isolation Pilot Plant.

[a] Estimated number of latent cancer fatalities in the affected population along the potential transportation routes given exposure to the indicated dose. The number of latent cancer fatalities is calculated by multiplying the dose by the risk factor of 0.0006 LCFs per person-rem (DOE 2003). Because the risk factor is only calculated to one significant figure, the number of latent cancer fatalities is reported to one significant figure.

[b] No MOX fuel would be shipped to the Sequoyah Nuclear Plant and the Browns Ferry Nuclear Plant under the No Action Alternative.

Note: To convert metric tons to tons, multiply by 1.1023.

The estimated dose to the public from the incident-free transportation of this material is estimated to range from 24 to 32 person-rem assuming shipments with one Type B cask per shipment. The number of LCFs expected to develop in the public from this transportation range from 0.01 to 0.02. Thus, no fatalities are expected as a result of incident-free transportation of unirradiated MOX fuel. If a larger number of casks are carried on each escorted commercial truck, as discussed above, the incident-free impacts to the population could decrease about 25 to 40 percent for PWR and BWR shipments, respectively. This reduction is due to an 85 percent decrease in the number of shipments. The risk of a

[2] *The shipments of MOX fuel to the reactors would largely be replacing shipments of LEU fuel that would have occurred for a full LEU core. Therefore, much of the transportation impacts would occur regardless of using a partial MOX fuel core. There is no discernible radiological impact difference for the transportation crew between LEU fuel and MOX fuel.*

traffic fatality ranges from 0.03 to 0.04 when single cask shipments are assumed; this risk would proportionally decrease with a decrease in the number of shipments if a larger number of casks were carried on each escorted commercial truck.

The estimated total risk in terms of the number of LCFs in the public from all projected accidents involving MOX fuel shipments is projected to range from 4×10^{-7} to 5×10^{-7}. These total accident risks were determined taking into account a spectrum of accident severities ranging from high-probability accidents of low severity (e.g., a fender bender) to hypothetical high-severity accidents having low probabilities of occurrence. The per-shipment radiological accident risk would not change if a larger number of casks were assumed per shipment as discussed above because it is assumed only one Type B cask would release its contents in the event of a severe accident regardless of the number of casks in a shipment.[3] However, the total radiological accident risk, taking into account the total number of shipments, would proportionally decrease with the decrease in the number of shipments. The risk of a traffic fatality ranges from 0.03 to 0.04; this risk would also proportionally decrease with a decrease in the number of shipments. In terms of a fatality from traffic accidents, it is estimated that the analyzed shipments would result in no fatalities under any of the alternatives being considered. The radiological and traffic fatality accident risks would decrease by about one order of magnitude if escorted commercial trucks were used due to the decrease in the number of shipments.

The maximum reasonably foreseeable offsite truck transportation accident having the highest consequence was also determined. This accident would involve truck transport of BWR MOX fuel to Browns Ferry (see Appendix E, Table E–13). These shipments would occur over about 23 years. Transportation accident probabilities were calculated for all route segments (i.e., rural, suburban, and urban), and maximum consequences were determined for those route segments having a likelihood of release frequency exceeding 1 in 10 million (1×10^{-7}) per year. The maximum reasonably foreseeable probability of a truck accident involving this material would be approximately 5×10^{-7} per year in a suburban area, or approximately 1 chance in 2 million each year. The consequences of the truck transport accident in terms of population dose would be about 4.1 person-rem. Such exposures would not likely result in an additional LCF among the exposed population. The likelihood of release frequency for a maximum reasonably foreseeable offsite truck accident involving PWR MOX fuel shipped to Sequoyah would be less than 1-in-10 million (1×10^{-7}) per year; transport of PWR MOX fuel was therefore not analyzed. For shipments potentially involving more than one Type B cask, the consequences would remain the same with the likelihood decreasing proportionally with the decrease in the number of shipments.

I.1.2.6 Environmental Justice

As demonstrated throughout the analyses in Section I.1.2.2.1, normal irradiation of MOX fuel in commercial nuclear reactors would pose no significant health risks to the public. The expected number of LCFs would not increase as a result of radiation released during normal operations because there would be essentially no increase in radiation doses received by the general population from the use of MOX fuel compared to the current use of full LEU fuel cores.

No LCFs are expected among the public assuming design-basis accidents (loss-of-cooling and used-fuel-handling accidents) at Browns Ferry or Sequoyah regardless of whether a full LEU fuel core or partial MOX fuel core were used (see Table I–4). Beyond-design-basis accidents, if they were to occur, are expected to result in major impacts on the surrounding communities and environment regardless of whether the reactors used a partial MOX core or a full LEU fuel core (Table I–5). However, because the probability of a beyond-design-basis accident actually happening is extremely unlikely, the risk to an

[3] Type B packages must meet the general packaging and performance standards for Type A packages and additionally must have the ability to survive serious accident damage tests (hypothetical accident conditions). After testing, there may be only a very limited loss of shielding capability and no loss of containment, as measured by leak-rate testing of the containment system of the package (DOT 2008). Specific requirements are summarized in Appendix E, Section E.3.1. Because of these stringent testing requirements, no more than one cask is assumed to fail in the accident analysis.

individual living within 50 miles (80 kilometers) of the reactors from these accidents is estimated to be low.

As shown in Section I.1.2.5 and Appendix E, no radiological or nonradiological fatalities are expected to result from incident-free transportation of MOX fuel to the reactor sites. Nor are radiological or nonradiological fatalities expected to result from transportation accidents.

The implementation of the MOX fuel irradiation program at either of the TVA reactor sites would not pose significant risks (when probability is considered) to the public, nor would implementation of this program pose significant risks to particular groups within the public. Therefore, because risks are low, there would be no disproportionately high and adverse effects on minority and low-income populations.

I.1.2.7 Other Resource Areas

This section of this appendix addresses resource areas having a lesser potential for environmental impacts than the resource areas addressed in Sections I.1.2.1 through I.1.2.6.

I.1.2.7.1 Land Resources

Additional land would not be required at the Browns Ferry or Sequoyah Nuclear Plants to support the use of MOX fuel. Nor would the use of MOX fuel at either reactor site affect the use of other onsite lands (e.g., buffer zones and undeveloped land areas) (TVA 2012). Prime farmland would not be affected and, because the use of MOX fuel would not result in an in-migration of workers, as discussed in Section I.1.2.3, Socioeconomics, no indirect impacts on offsite lands are expected.

I.1.2.7.2 Geology and Soils

No ground-disturbing activities related to the use of a partial MOX fuel core rather than a full LEU fuel core are expected at either of the reactor sites (TVA 2012). Therefore, there would be no impact on geology or soils from the use of MOX fuel compared to the current use of full LEU fuel cores.

I.1.2.7.3 Water Resources

There would be no change in water usage or discharge of pollutants, including thermal discharges, resulting from use of a partial MOX fuel core compared to the current use of full LEU fuel cores at Browns Ferry and Sequoyah. Each of the TVA reactor sites discharges wastewater in accordance with a National Pollutant Discharge Elimination System permit, or an analogous state-issued permit (TVA 2012). Therefore, there would be no additional impacts on water resources.

I.1.2.7.4 Noise

No increase in operational noise levels is expected from the operation of the Browns Ferry and Sequoyah due to use of a partial MOX fuel core rather than a full LEU fuel core (TVA 2012).

I.1.2.7.5 Ecological Resources

There would be no activities in undeveloped areas of the sites, and operational emissions of effluents from the reactors are not expected to change. Also, there would be no additional thermal releases to the environment as a result of using MOX fuel (TVA 2012). Therefore, as compared to the current use of full LEU fuel cores use of a partial MOX fuel core at Browns Ferry and Sequoyah is not expected to result in any impacts on ecological resources at the reactor sites.

I.1.2.7.6 Cultural Resources

No operational ground-disturbing activities are expected at Browns Ferry and Sequoyah related to the use of MOX fuel (TVA 2012). Therefore, the use of a either a partial MOX fuel core or a full LEU fuel core in these reactors is not expected to affect cultural and paleontological resources at the reactor sites. Similarly, no impacts on American Indian resources in the areas surrounding the reactor sites are expected.

I.1.2.7.7 Infrastructure

The existing site infrastructure would continue to serve Browns Ferry and Sequoyah. Each reactor site is equipped with a water supply, wastewater, and power distribution system that would adequately support the demands of the reactors should MOX fuel be used (TVA 2012). Therefore, additional infrastructure would not be required at the reactor sites to support operations using a partial MOX fuel core rather than a full LEU core.

I.2 Impacts of Irradiating Mixed Oxide Fuel at Generic Commercial Nuclear Power Reactor Sites

While Section I.1 includes an analysis of using MOX fuel in TVA's Browns Ferry and Sequoyah Nuclear Plants, and Chapter 4, Section 4.28, of the *SPD EIS* included an analysis of using MOX fuel in Duke Power's McGuire and Catawba Nuclear Plants and Virginia Power's (now Dominion Power's) North Anna nuclear reactors (DOE 1999), it is possible that the MOX fuel being produced at SRS could be used in any of the nation's nuclear power plants. Therefore, this section addresses the potential impacts of using MOX fuel in commercial nuclear reactors located anywhere in the United States. As discussed earlier in this Appendix, before MOX fuel could be used, the utilities operating the reactors would be required to obtain a license amendment from NRC in accordance with 10 CFR Parts 50 or 52. NRC would determine whether to issue license amendments that would allow the reactors to use MOX fuel.

As described in this *SPD Supplemental EIS* and the *SPD EIS* (DOE 1999), both MOX and LEU fuel assemblies would be loaded into the reactors. For the purposes of these analyses, it was assumed that the reactors would include a 40 percent MOX fuel core. As with LEU fuel assemblies, MOX assemblies would remain in the reactors for a set number of fuel cycles. When the MOX fuel completes its normal number of cycles, it would be withdrawn from the reactors in accordance with standard refueling procedures and placed in the reactors' used fuel storage pools for cooling among other used fuel. The used nuclear fuel may be subsequently transferred to dry storage casks. No changes are expected in the reactors' used fuel storage plans to accommodate the used MOX fuel. Although the amount of fissile material would be somewhat higher in used MOX fuel rods than in LEU used fuel rods, the fuel assembly number and spacing in the used fuel pools and/or dry storage casks could be adjusted as necessary to maintain the necessary criticality and thermal safety margins.

I.2.1 Construction Impacts

As discussed in Section I.1.1 and Chapter 4, Section 4.28, of the *SPD EIS* (DOE 1999), it is not expected that significant new construction would be required at commercial nuclear reactor sites to support the use of MOX fuel. The same is expected at any generic reactor considering the use of MOX fuel. As discussed earlier in this Appendix, the use of MOX fuel may require some changes to safety systems such as the number of control rods; however, the use of MOX fuel is expected to require only minor modifications at the reactor sites themselves, regardless of where they may be located in the United States. Therefore, minimal impacts on all resource areas are expected.

I.2.2 Operational Impacts

Based on the information presented in Section I.1.2 of this *SPD Supplemental EIS* and the *SPD EIS* (DOE 1999), from an operational standpoint the use of MOX fuel is not expected to require significant changes in the environmental impacts that may result from normal operations of a reactor.

I.2.2.1 Air Quality

Operation of a generic reactor within the United States would result in small amounts of nonradiological air pollutants being released to the atmosphere, because of activities such as periodic testing of diesel generators. Use of MOX fuel at a generic reactor, however, is not expected to result in an increase in these emissions.

Estimated total emissions from shipping unirradiated MOX fuel to a generic commercial nuclear reactor hypothetically located in the northwestern United States are presented in **Table I–10** assuming one Type B cask per shipment. (For purposes of this *SPD Supplemental EIS*, a generic transportation route was analyzed from SRS to the northwestern United States that is intended to envelop all of the transportation routes to currently operating commercial nuclear reactors in the country.) Similar emissions would occur even if MOX fuel is not used in generic reactors since the MOX fuel is replacing LEU fuel that would be shipped to the reactors.

Table I–10 Criteria Pollutant Emissions from Shipping Unirradiated MOX Fuel to a Generic Commercial Nuclear Reactor [a]

Pollutant	*Total Emissions by Alternative (metric tons)*				
	No Action	***Immobilization***	***MOX Fuel***	***H-Canyon/HB-Line***	***WIPP***
Carbon monoxide	69	69	91	83	69
Nitrogen dioxide	240	240	310	280	240
PM_{10}	6.8	6.8	9.0	8.2	6.8
$PM_{2.5}$	5.7	5.7	7.6	6.9	5.7
Sulfur dioxide	0.28	0.28	0.38	0.34	0.28
Volatile organic compounds	11	11	14	13	11

MOX = mixed oxide; PM_n = particulate matter less than or equal to *n* microns in aerodynamic diameter; WIPP = Waste Isolation Pilot Plant.

[a] For purpose of analysis, it was assumed that the generic commercial nuclear power reactor would be located at the Hanford Reservation, Washington, to maximize the distance traveled in order to envelope impacts related to shipping to other possible commercial nuclear power reactor sites. Only shipments of BWR fuel are analyzed because there would be a greater number of shipments to a BWR reactor than a PWR reactor, thus providing a conservative analysis of the distance traveled per alternative that would cover a smaller number of PWR shipments to a generic commercial nuclear power reactor for the same amount of unirradiated MOX fuel, should shipments be made to a PWR.

Note: To convert metric tons to tons, multiply by 1.1023.

Estimated carbon dioxide emissions from shipping unirradiated MOX fuel to generic reactors would be less than 1,900 tons per year (1,700 metric tons per year). (The greatest impacts would be associated with shipments to a BWR because more shipments would be required [4,500 shipments, if one Type B cask per shipment is assumed, see Section I.2.2.5]; emissions would be lower if the reactor were a PWR because there would be fewer shipments.)

I.2.2.2 Human Health Risk

I.2.2.2.1 Human Health Risk from Normal Operations

Doses to workers – Unirradiated MOX fuel could present a risk of higher radiation doses to reactor workers due to the presence of additional plutonium and other actinides compared to LEU fuel. However, worker doses would continue to meet Federal regulatory dose limits as required by NRC, and any reactor proposing to use MOX fuel would be required by NRC to take steps within its ALARA program to limit any increase in doses to workers that may occur from use of MOX fuel. The only time this difference is likely to cause an increased dose would be during acceptance inspections at the reactor, when the fuel assemblies are first delivered to the plant. Workers are required to inspect the fuel assemblies to ensure that they meet design specifications and they could receive a higher dose compared to LEU fuel assembly inspections. After the fuel rods are inspected, doses to workers would be limited because the assemblies would be handled remotely as they are loaded into the reactor and subsequently removed from the reactor and transferred to the used fuel pool.

Doses to members of the public – As addressed in Section I.1.2.2.1, no change in the radiation dose to the public is expected from normal operation of a TVA reactor operating with a partial MOX fuel core rather than a full LEU fuel core. Consistent with this assessment and Chapter 4, Section 4.28.2.4, of the

SPD EIS (DOE 1999), no change in the radiation dose to the public is expected from normal operation of generic commercial nuclear reactors using partial MOX fuel cores rather than full LEU cores.

I.2.2.2.2 Reactor Accidents and Intentional Destructive Acts

Reactor accidents – The reactor accident analyses included in Section I.1.2.2.2 of this appendix and Chapter 4, Section 4.28.2.5, of the *SPD EIS* (DOE 1999) indicate that, in the event of a postulated reactor accident, the doses to the public would be somewhat different for different reactors. The results of these accident analyses differ for each reactor based on a number of factors, including the size of the population surrounding the reactor, the distance from the reactor to the surrounding population, and site-specific meteorological conditions. The five sets of reactors analyzed in these documents include reactors located near large cities such as Charlotte, North Carolina, as well as reactors located in relatively less-populated areas. The reactors included both BWRs and PWRs.

Table I–11 presents a comparison of projected radiological impacts from a series of design-basis and beyond-design-basis accidents that were analyzed in this *SPD Supplemental EIS* and the *SPD EIS.* The comparison is presented as the ratio of the accident impacts involving partial MOX fuel cores to those using full LEU fuel cores. Impacts were estimated for a member of the general public at the exclusion area boundary at the time of the accident (i.e., the MEI) and the general population residing within 50 miles (80 kilometers) of the reactor. The numbers in parentheses are the calculated ratios (impacts for a partial MOX core divided by impacts for an LEU core); the range of numbers reflects the results for the five sets of reactors that were evaluated. A ratio less than 1 indicates that the MOX fuel core could result in smaller impacts than the same accident with an LEU fuel core. A value of 1 indicates that the estimated impacts are the same for both fuel core types. A ratio larger than 1 indicates that the MOX fuel core could result in larger impacts than the same accident with an LEU fuel core. Outside the parentheses, the table shows a ratio of 1 for all accident scenarios. This is a rounded value because, when modeling and analytical uncertainties are considered, the precision of the results is no more than one significant figure.

Table I–11 Ratio of Doses from Reactor Accidents for a Partial Mixed Oxide Fuel Core Compared to a Full Low-Enriched Uranium Fuel Core (partial mixed oxide fuel core dose/full low-enriched uranium fuel core dose) [a,b]

Accident	*MEI*	*Population*
Design-Basis Accidents		
Loss-of-coolant accident	1 (0.87 to 1.03)	1 (0.96 to 1.03)
Used-fuel-handling accident	1 (0.90 to 1.00)	1 (0.94 to 1.01)
Beyond-Design-Basis Accidents		
Steam generator tube rupture [c]	1 (1.06 to 1.24)	1 (1.04 to 1.09)
Early containment failure	1 (1.00 to 1.22)	1 (0.98 to 1.05)
Late containment failure	1 (1.01 to 1.10)	1 (0.95 to 1.09)
ISLOCA	1 (0.93 to 1.22)	1 (0.95 to 1.14)

ISLOCA = interfacing systems loss-of-coolant accident; MEI = maximally exposed individual.

[a] Reactor accidents involving the use of partial MOX fuel cores were assumed to involve reactor cores with approximately 40 percent MOX fuel and 60 percent LEU fuel.

[b] The values in parentheses reflect the range of results from analyses at 5 different reactors; they are the ratios calculated by dividing the accident analysis results for a partial MOX fuel core by the results for a full LEU core.

[c] Steam generator tube rupture is not applicable for boiling water reactors since they do not use steam generators.

Source: *SPD Supplemental EIS* Tables I–6 and I–7 and Table 4–217 of the *SPD EIS* (DOE 1999).

Intentional destructive acts **–** As addressed in Section I.1.2.2.3, operators of generic reactors using MOX fuel would implement a layered approach to physical security at the reactor site in accordance with NRC regulations and guidance. Nuclear power plants are inherently secure, robust structures built to withstand extreme natural phenomena such as hurricanes, tornadoes, and earthquakes. Additional security measures are in place, including physical barriers; intrusion detection and surveillance systems; access controls; and coordination of threat information and response with federal, state, and local agencies. Since September 11, 2001, physical security requirements at nuclear power plants have been strengthened, and security measures at nuclear plants have been complemented by measures taken throughout the United States to improve security and reduce the risk of successful terrorist attacks. NRC and others have performed comprehensive safety and security studies showing that a radiological release affecting public health and safety is unlikely from a terrorist attack, including one involving a large commercial aircraft.

I.2.2.3 Socioeconomics

Because it is expected that operators of a generic commercial nuclear would not need to employ additional workers to operate the reactor using a partial MOX fuel core rather than a full LEU core, use of a partial MOX fuel core rather than a full LEU core is expected to have no impact on socioeconomics in the communities surrounding the commercial nuclear reactor.

I.2.2.4 Waste Management and Used Nuclear Fuel

Radioactive and Nonradioactive Waste Generation – No change is expected in the type or amount of radioactive and nonradioactive waste generated at a generic commercial nuclear reactor using a partial MOX fuel core rather than a full LEU core.

Used Nuclear Fuel – Some additional used nuclear fuel would likely be generated from use of a partial MOX core in a commercial nuclear reactor. Based on the analyses in Section I.1.2.4 and Chapter 4, Section 4.28.2.8, of the *SPD EIS* (DOE 1999), the amount of additional used nuclear fuel generated during the period when MOX fuel would be used in a reactor is estimated to increase by approximately 2 to 16 percent compared to that for a reactor continuing to use only LEU fuel. It is expected that an increase of this magnitude would be managed within the reactor's normal planning for storage in its used fuel storage pool or dry storage casks.

I.2.2.5 Transportation

It is estimated (see Appendix E, Section E.7) that between approximately 3,400 and 4,500 shipments of unirradiated MOX fuel could occur from SRS to a generic BWR reactor under the various alternatives assuming one Type B cask per shipment. Transport of unirradiated BWR MOX fuel was analyzed to maximize the number of shipments; if the shipments were of PWR MOX fuel, the number of shipments would be lower as discussed in Section I.2.2.1. These shipments would likely replace similar shipments of unirradiated LEU fuel to the reactor sites, thereby reducing transportation risks associated with LEU fuel, while adding risks from the MOX fuel shipments. Although the risks associated with incident-free transport and accident conditions would be somewhat larger for shipment of unirradiated MOX fuel than for LEU fuel, the overall risks associated with MOX fuel shipments would be low, as shown in **Table I–12** and discussed below. Alternatively, up to seven casks containing BWR fuel assemblies could be transported in one shipment if escorted commercial trucks were used (under the Secure Transportation Asset Program), for a total of between approximately 490 to 640 shipments.

For purposes of this *SPD Supplemental EIS*, a generic transportation route was analyzed from SRS to the northwestern United States that is intended to envelop all of the currently operating commercial nuclear reactors in the country. The distance analyzed was approximately 4,400 kilometers (2,730 miles). The estimated dose to the transport crew from incident-free transport of unirradiated MOX fuel to a generic commercial nuclear reactor in the northwestern United States is estimated to range from 150 person-rem (for 3,400 shipments) to 190 person-rem (for 4,500 shipments), depending on the alternative being analyzed. The corresponding number of LCFs in the crew would range from 0.09 to 0.1. If a larger number of casks are carried on each escorted commercial truck as discussed in Section I.1.2.5, the impacts to workers could increase about 2 times, with the risk of an LCF still less than 1 (about 0.2).

Table I–12 Transportation Impacts Associated with the Shipment of Unirradiated Mixed Oxide Fuel to a Generic Commercial Nuclear Reactor (assuming one Type B Cask per shipment)

Alternative	*Number of Shipments*	*Incident Free Dose (person-rem)*		*Number of Radiological LCFs* [a]		*Accident Risk*	
		Crew	*Population*	*Crew*	*Population*	*Radiological LCF* [a]	*Traffic Fatality*
No Action	3,400	150	280	0.09	0.2	0.000002	0.3
Immobilization	3,400	150	280	0.09	0.2	0.000002	0.3
MOX Fuel	4,500	190	370	0.1	0.2	0.000002	0.4
H-Canyon/HB-Line	4,100	180	340	0.1	0.2	0.000002	0.4
WIPP	3,400	150	280	0.09	0.2	0.000002	0.3

LCF = latent cancer fatality; MOX = mixed oxide; WIPP = Waste Isolation Pilot Plant.

[a] Estimated number of latent cancer fatalities in the affected population along the potential transportation routes given exposure to the indicated dose. The number of latent cancer fatalities is calculated by multiplying the dose by a risk factor of 0.0006 LCFs per person-rem (DOE 2003). Because the risk factor is only calculated to one significant figure, the number of latent cancer fatalities is reported to one significant figure.

The estimated dose to the public from incident-free transport of this material is estimated to range from 280 person-rem to 370 person-rem assuming shipments with one Type B cask per shipment. The corresponding number of LCFs in the public would be about 0.2. If a larger number of casks were carried on each escorted commercial truck, as discussed in Section I.1.2.5, the incident-free impacts to the population could decrease about 40 percent. This reduction would be due to a decrease of up to 85 percent in the total number of shipments of unirradiated MOX fuel. Thus, no fatalities are expected from incident-free transport of unirradiated MOX fuel to a generic commercial nuclear reactor site regardless of the number of Type B casks per shipment.

The number of LCFs expected from transportation accidents is also projected to be small. The estimated total risk in terms of the number of LCFs in the public from all projected radiological accidents involving MOX fuel shipments is projected be about 0.000002. These total accident risks were determined taking into account a spectrum of accident severities ranging from high-probability accidents of low severity (e.g., a fender bender) to hypothetical high-severity accidents having low probabilities of occurrence. As discussed in Section I.1.2.5, the per-shipment radiological accident risk would not change because it is assumed only one Type B cask would release its contents in the event of a severe accident regardless of the number of casks in a shipment. The radiological and traffic fatality accident risks would decrease by about an order of magnitude if escorted commercial trucks were used due to the decrease in the number of shipments.

The maximum reasonably foreseeable offsite truck transportation accident having the highest consequence was also determined. This accident would involve truck transport of BWR MOX fuel to a generic commercial nuclear reactor located in the northwestern United States (see Appendix E, Table E–12). These shipments would occur over about 23 years. Transportation accident probabilities were calculated for all route segments (i.e., rural, suburban, and urban), and maximum consequences were determined for those route segments having a likelihood of release frequency exceeding 1-in-10 million per year. The maximum reasonably foreseeable probability of a truck accident involving this material would be 3.3×10^{-6} per year in a suburban area, or approximately 1 chance in 300,000 each year. The consequences of the truck transport accident in terms of population dose would be about 4.0 person-rem. If the accident were to occur, such an exposure would not likely result in an additional LCF among the exposed population. For shipments potentially involving more than one Type B cask, the consequences would remain the same with the likelihood decreasing proportionally with the decrease in number of shipments.

I.2.2.6 Environmental Justice

As discussed in Section I.2.2.2.1, normal irradiation of MOX fuel in a nuclear reactor is not expected to pose significant health risks to the public, because there would be essentially no increase in radiation doses received by the general population from the use of MOX fuel. In addition, as addressed in Section I.2.2.2.2, for all practical purposes, the results indicate that there is no difference in the potential impacts on the public from either a design-basis or beyond-design-basis accident between the use of a partial MOX fuel core or a full LEU fuel core. It may also be noted that the probability of a beyond-design-basis accident actually happening is extremely unlikely, so that the risk to any individual living within 50 miles (80 kilometers) of the reactor would be low. In addition, as addressed in Section I.2.2.5, no radiological or nonradiological fatalities are expected to result from incident-free transport of MOX fuel to a generic commercial nuclear reactor site, which for purposes of this *SPD Supplemental EIS* is conservatively assumed to be located within the northwestern United States. In terms of nonradiological fatalities resulting from possible traffic accidents, it is estimated that the analyzed shipments would result in no fatalities under any alternative.

Because the implementation of a MOX fuel irradiation program at a generic commercial nuclear reactor would not pose significant risks (when probability is considered) to the public, it is not expected that implementation of this program would pose significant risks to particular groups within the public. Therefore, because risks are low, there would be no disproportionately high and adverse effects on minority and low-income populations.

I.2.2.7 Other Resource Areas

This section of this appendix addresses resource areas having a lesser potential for environmental impacts than the resource areas addressed in Sections I.2.2.1 through I.2.2.6.

I.2.2.7.1 Land Resources

It is not expected that additional land would be needed at a generic commercial nuclear reactor site for operational use of a partial MOX fuel core rather than a full LEU fuel core; nor would other onsite lands such as buffer zones be affected. Operation of a generic commercial nuclear reactor using a partial MOX fuel core rather than a full LEU core would not change the designated land uses for the reactor and the areas within the vicinity of the reactor site; thus, it is not expected that prime farm land would be affected.

I.2.2.7.2 Geology and Soils

Operation of a generic commercial nuclear reactor using a partial MOX fuel core rather than a full LEU core would not require any excavation or any use of geological resources such as sand, gravel, stone, or cement.

I.2.2.7.3 Water Resources

No change is expected in water usage at a generic commercial nuclear reactor site or in the waterborne discharge of pollutants resulting from the use of a partial MOX fuel core rather than a full LEU fuel core.

I.2.2.7.4 Noise

No change is expected in the noise generated at a generic commercial nuclear reactor site from the use of a partial MOX fuel core rather than a full LEU fuel core.

I.2.2.7.5 Ecological Resources

Use of a partial MOX fuel core rather than a full LEU core at a generic commercial reactor site is not expected to result in any additional impacts on ecological resources at the reactor site because land use and emissions of effluents from the reactor are not expected to change.

I.2.2.7.6 Cultural Resources

Operation of a generic commercial nuclear reactor using a partial MOX fuel core rather than a full LEU core would not require any excavation or other activities at the reactor site that could disturb cultural resources.

I.2.2.7.7 Infrastructure

Use of a partial MOX fuel core rather than a full LEU core at a generic commercial nuclear reactor site is not expected to require additional use of utilities; thus, there would be no impact on the existing infrastructure at the reactor site.

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