NETL Life Cycle Inventory Data
Process Documentation File

Process Name:	Spent Fuel Reprocessing
Reference Flow:	1 kg of reprocessed nuclear fuel
Brief Description:	The energy and material requirements for operating a facility that reprocesses spent nuclear fuel.

Section I: Meta Data

Geographical Coverage:	United States	**Region:**	N/A
Year Data Best Represents:	2005		
Process Type:	Recovery Process (RP)		
Process Scope:	Gate-to-Gate Process (GG)		
Allocation Applied:	No		
Completeness:	All Relevant Flows Captured		

Flows Aggregated in Data Set:

☒ Process	☒ Energy Use	☐ Energy P&D	☐ Material P&D

Relevant Output Flows Included in Data Set:

Releases to Air:	☒ Greenhouse Gases	☒ Criteria Air Pollutants	☒ Other
Releases to Water:	☐ Inorganic Emissions	☐ Organic Emissions	☐ Other
Water Usage:	☐ Water Consumption	☐ Water Demand (throughput)	
Releases to Soil:	☐ Inorganic Releases	☐ Organic Releases	☐ Other

Adjustable Process Parameters:

none

Tracked Input Flows:

Spent nuclear fuel	*Spent nuclear fuel from a nuclear reactor*
Nitric acid	*An acid used for reprocessing of spent fuel*
Water (ground water)	*Ground water from nature*
Water (surface water)	*Surface water from nature*
Power [Electric power]	*Electricity used for process energy*
Natural gas	*Natural gas used for process energy*

Tracked Output Flows:

Reprocessed nuclear fuel

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_Spent_Fuel_Reprocessing _2011.01.xls*, which provides additional details regarding relevant calculations, data quality, and references.

Goal and Scope

This unit process provides a summary of relevant input and output flows associated with the operation of a spent fuel reprocessing facility. The facility uses the PUREX process to isolate uranium and plutonium from spent nuclear fuel. Energy inputs include natural gas and electricity. Nitric acid is used as a reagent for uranium and plutonium recovery. The calculations presented for this unit process are based on the reference flow of 1 kg of input reprocessed nuclear fuel, as described below and shown in **Figure 1**. This unit process is used within Life Cycle (LC) Stage #3 of NETL's model of nuclear power.

Boundary and Description

This unit process accounts for the energy and material requirements for operating a facility that reprocesses spent nuclear fuel. The reference flow of this unit process is one kilogram of reprocessed uranium fuel.

This unit process is representative of the plutonium and uranium recovery by extraction (PUREX) process for the reprocessing of spent uranium fuel. The feedstock input to the PUREX process is spent uranium fuel from U.S. Gen II reactors. The product output of the PUREX process is mixed oxide fuel (MOX), which is a composite of uranium and plutonium that can be used by Gen II light water reactors. Energy for the PUREX process is provided by electricity and natural gas. There are also ancillary inputs of nitric acid and water.

Based on NETL's 2010 LCA of nuclear power, the annual electricity output of an average Gen II nuclear power plant is 6.19 million MWh. In the same time frame, the average Gen II plant produces 2,870 kilogram of spent fuel. Dividing the spent fuel rate by the electricity rate translates to 0.00464 kilogram of spent fuel per MWh of electricity.

A solution of concentrated nitric acid is used as a reagent for extracting uranium oxide and plutonium from spent fuel. This acid treatment is followed by chemical separation and filtration processes that purify the uranium and plutonium (Boullix, 2006). It is necessary to feed the recovered uranium through the front end of the nuclear fuel cycle, including the conversion of uranium oxide to uranium hexafluoride (UF_6), followed by enrichment (by centrifuge) and fuel fabrication (World Nuclear Association, 2011).

On the basis of one MWh of electricity production and using a 70.7 percent capacity factor for the power plant (which is representative of the average historical capacity for Gen II power plants), the energy requirements are 0.024 MWh of thermal energy per MWh of electricity and 4.84E-06 MWh of electricity per MWh of electricity. On the basis of one kilogram of spent fuel, the energy requirements are 5.57 MWh thermal energy and 1.11 MWh of electricity. Finally, converting the thermal energy to a basis of natural gas consumption, 5.57 MWh of thermal energy is equivalent to 18,520 scf natural gas per kilogram of spent fuel (with natural gas having a heating value of 1,027 Btu/scf).

The amount of nitric acid required for the PUREX process was calculated from the reaction chemistry between nitric acid and uranium oxide. One molecule of uranium reacts with three molecules of HNO_3 to produce a mix of nitrates (Boullix, 2006). There is a similar reaction between nitric acid in plutonium, in which one molecule of plutonium reacts with four molecules of nitric acid; however, since uranium comprises 95 percent by mass of the spent fuel, the nitric acid requirements are driven mostly by the reaction stoichiometry for uranium nitrates. The molar mass of uranium oxide and nitric acid are 270 and 63 kg/kgmol, respectively. Thus, at a 1:3 molar ratio between uranium oxide and nitric acid, 0.70 kilogram of nitric acid are required for the reprocessing of 1 kilogram of uranium oxide.

Water is required for process cooling. Based on a draft environmental impact statement of nuclear fuel cycle alternatives (U.S. Department of Energy, 2008), spent fuel reprocessing increases the water demand for the nuclear fuel cycle by 24 billion L/yr for each gigawatt of nuclear power. A gigawatt-year of electricity is equivalent to 8,760,000 MWh, which translates to a water demand of 2,740 L/MWh. On the basis of spent fuel, 2,740 L/MWh is 631,000 L/kg of spent fuel. Ninety-nine percent of this water is returned to the source, and thus water consumption (the difference between withdrawal and discharge) is 6,310 L/kg of spent fuel.

No data are available for the operation of a nuclear fuel reprocessing facility; the U.S. currently does not have any facilities that reprocess spent nuclear fuel. The reprocessing of nuclear fuel uses acid reagents that isolate uranium, followed by a series of separation processes. This process is similar to uranium milling, and thus NETL's unit process for uranium milling is used as a surrogate for nuclear fuel reprocessing.

Figure 1 provides an overview of the boundary of this unit process. As shown, spent nuclear fuel that is produced by upstream processes of the nuclear fuel cycle enter the system. Natural gas and electricity are used to provide process energy; the environmental burdens for the production and delivery of natural gas and electricity are accounted for by upstream processes that are outside the scope of this unit process. Process water is sourced from a 50/50 split of ground and surface water, which are natural resources with no upstream environmental burdens. The air emissions from this unit process are due to the combustion of natural gas during the operation of the facility. The reference flow of this unit process is 1 kg of reprocessed fuel, which is the only tracked output of this unit process.

Figure 1: Unit Process Scope and Boundary

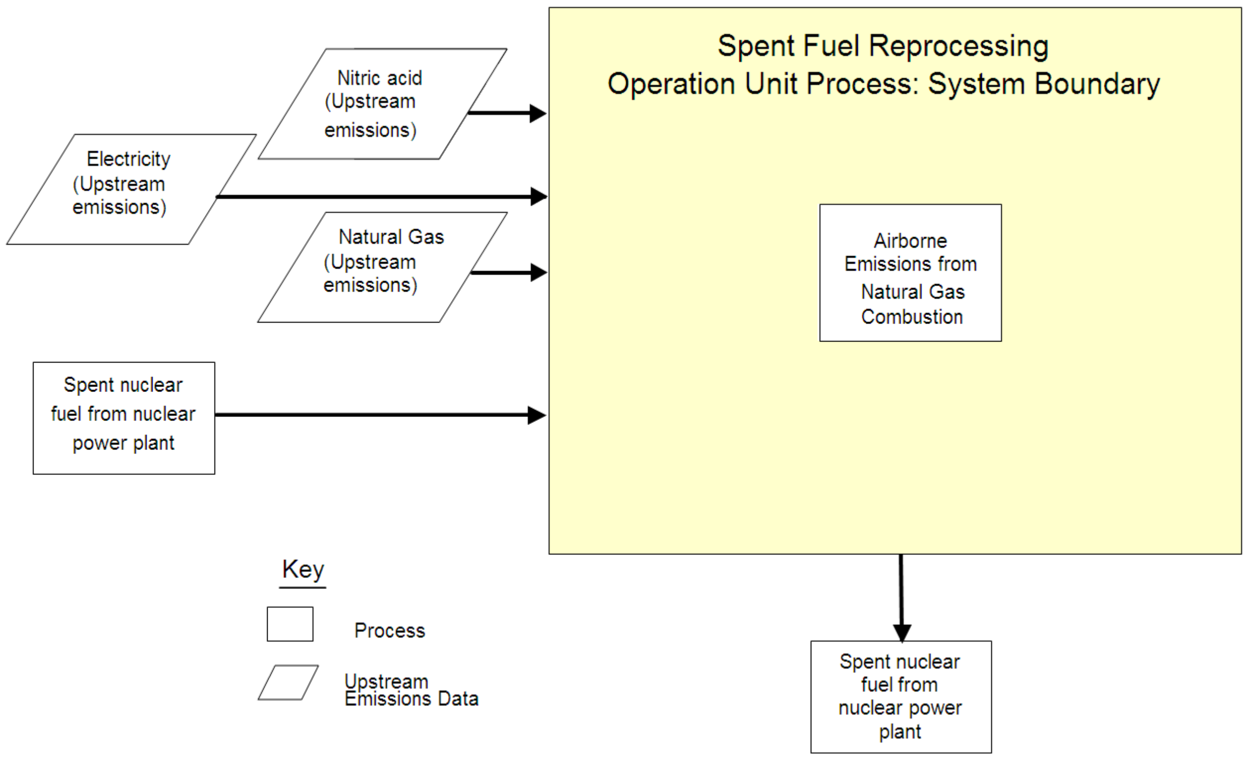

Table 1 summarizes airborne emissions factors and energy inputs and outputs that are applied within this unit process. **Table 2** provides a summary of modeled input and output flows. Additional detail regarding input and output flows, including calculation methods, is contained in the associated DS.

Table 1: Relevant Emission Factors

Flow Name	Value	Units
Carbon dioxide [Inorganic emissions to air]	2.86	kg/kg natural gas
Methane [Organic emissions to air (group VOC)]	5.48E-05	kg/kg natural gas
Nitrous oxide (laughing gas) [Inorganic emissions to air]	1.52E-05	kg/kg natural gas
Nitrogen oxides [Inorganic emissions to air]	1.19E-03	kg/kg natural gas
Sulphur dioxide [Inorganic emissions to air]	1.43E-05	kg/kg natural gas
Carbon monoxide [Inorganic emissions to air]	2.00E-03	kg/kg natural gas
NMVOC (unspecified) [Group NMVOC to air]	1.31E-04	kg/kg natural gas
Dust (PM10) [Particles to air]	1.81E-04	kg/kg natural gas

Table 2: Unit Process Input and Output Flows

Flow Name	Value	Units (Per Reference Flow)
Inputs		
Spent nuclear fuel	1.05	kg
Nitric acid	0.72	kg
Water (ground water) [Water]	436,364	kg
Water (surface water) [Water]	436,364	kg
Power [Electric power]	2.11E-03	MJ
Natural gas USA [Natural gas (resource)]	3.47E-03	kg
reprocessed nuclear fuel [Insert]	1	kg
Carbon dioxide [Inorganic emissions to air]	9.92E-03	kg
Methane [Organic emissions to air (group VOC)]	1.90E-07	kg
Nitrous oxide (laughing gas) [Inorganic emissions to air]	5.29E-08	kg
Nitrogen oxides [Inorganic emissions to air]	4.13E-06	kg
Sulphur dioxide [Inorganic emissions to air]	4.96E-08	kg
Carbon monoxide [Inorganic emissions to air]	6.95E-06	kg
NMVOC (unspecified) [Group NMVOC to air]	4.55E-07	kg
Dust (PM10) [Particles to air]	6.28E-07	kg
Lead (+II) [Heavy metals to air]	4.13E-11	kg
Water (wastewater) [Water]	864,000	kg
Solid waste to HLW disposition	0.76	kg

* **Bold face** clarifies that the value shown *does not* include upstream environmental flows. Upstream environmental flows were added during the modeling process using GaBi modeling software, as shown in Figure 1.

Embedded Unit Processes

None.

References

Boullix 2006 — Boullix, B (2006). *Spent fuel reprocessing: a fully mastered pathway.* CLEFS CEA 53. 2006.

EPA 1995 — EPA (1995). AP 42, Fifth Edition, Volume I, Chapter 1: External Combustion Sources. http://www.epa.gov/ttnchie1/ap42/ch01/final/c01s04.pdf (Accessed June 22, 2011)

Lenzen 2008 — Lenzen, Manfred (2008). *Life cycle energy and greenhouse gas emissions of nuclear energy.* Sydney, Australia: Energy Conversion and Management, 2008, Vol. 49, pp. 2178-2199.

U.S. DOE 2008 — U.S. Department of Energy, Office of Nuclear Energy (2008). *Draft Global Nuclear Energy Partnership Programmatic Environmental.* 2008. DOE/EIS-0396.

WNA 2011 — World Nuclear Association (2011). Processing of Used Nuclear Fuel. *World Nuclear Association.* [Online] [Cited: July 11, 2011.] http://www.world-nuclear.org/info/inf69.html.

Section III: Document Control Information

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