NETL Life Cycle Inventory Data
Process Documentation File

Process Name: Nuclear Power, Generation II Reactor Operation

Reference Flow: 1 MWh of Electricity

Brief Description: Encompasses the energy, material, and water use and the emissions and discharges during the operation of a Generation II nuclear reactor.

Section I: Meta Data

Geographical Coverage: US **Region:** US

Year Data Best Represents: 1957-2009

Process Type: Energy Conversion (EC)

Process Scope: Gate-to-Gate Process (GG)

Allocation Applied: Yes

Completeness: Individual Relevant Flows Recorded

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:

PropOTC	*Proportion of the cooling systems which are once through cooling*
PropTowers	*Proportion of the cooling systems which are towers*

Tracked Input Flows:

UO2 (fuel assembly) [Intermediate products]	*Fuel assemblies which are loaded into the nuclear reactors for the creation of electricity*

Tracked Output Flows:

Electricity [Operation]	*1 MWh of electricity (the reference flow of this unit process)*

Section II: Process Description

Associated Documentation

This unit process is composed of this document and the data sheet (DS) *DS_Stage3_O_GenII_Nuclear_Reactor_2010.01.xls*, which provides additional details regarding calculations, data quality, and references as relevant.

Goal and Scope

This unit process accounts for the operating activities of the United States average Generation II nuclear power plant. The process is based on the reference flow of 1 MWh of electricity. The tracked input to the process is the uranium (UO_2) fuel assembly. Water is used for cooling and other process-related utilities; water is assumed to enter the boundaries of this unit process having no upstream resource consumption or environmental emissions. The outputs of this unit process are produced electricity, spent fuel, discarded water, air emissions, water emissions, and solid waste. The output electricity is transmitted to the grid for transportation in LC Stage #4.

Boundary and Description

Figure 1 provides an overview of the boundary of this unit process. Rectangular boxes represent relevant sub-processes, while trapezoidal boxes indicate upstream data that are outside of the boundary of this unit process. As shown, the upstream emissions from the creation of the uranium fuel assemblies are calculated in another unit process which should be added to this to provide an accurate inventory value. Water is assumed to enter the boundary of the unit process with no upstream resources or emissions. The methods for calculating these operating activities are described above.

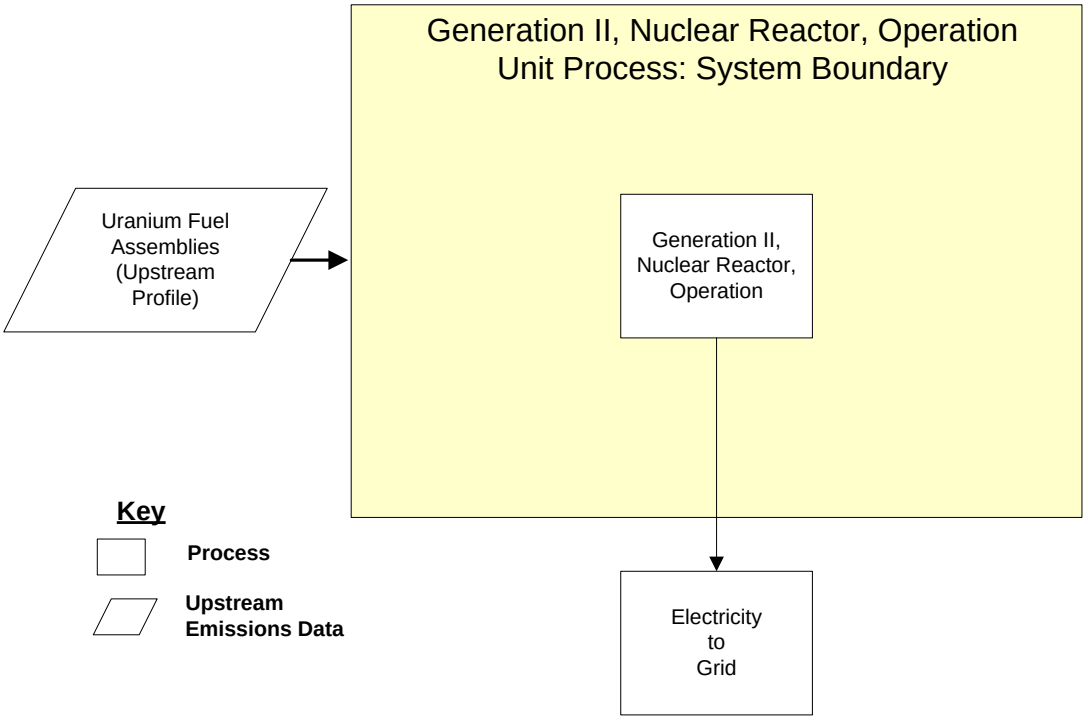

Figure 1: Unit Process Scope and Boundary

The model of Generation II nuclear power plant operation seeks to represent the industry average of existing nuclear reactors over a thirty year period from 1969 to 2009. Data for establishing this average comes partially from the Energy Information Administration's historical operating data on nuclear power plants. From this data, electricity output and proportion of installed Pressurized Water Reactors (PWR) to Boiling Water Reactors (BWR) was calculated. This ratio allows applying a weighted average to inputs and emissions inventoried separately for the two plant types. For example, fuel input data was reported by the Energy Technology Characterizations Handbook (DOE 1983) according to plant type. The fuel input from each of PWR and PWR plants was then weighted according to the relative power output of all plants of that type to the power output of the total existing fleet.

Water use and withdrawal data came from the Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437 Vol. 1). Because of high variability in water use between cooling water system types, this data was reported separately for once-through and closed-loop systems. Similarly to reactor type, the average water system type in the United was used to appropriately weight water withdrawal and discharge information to produce a national average. Data from Sandia National Laboratory provided the ratio of existing closed-loop to once-through cooling systems (35:60).

Air emissions data for the existing nuclear power plant fleet is taken from US EPA nuclear industry emission factors categorized under the North American Industry Classification System (NAICS) code 221113 (EPA 2005). A list of criteria air emissions

and hazardous air emissions inventoried by NAICS is available on the 'Average Operations' worksheet of the DS sheet. GHG Emissions produced during normal reactor operation are assumed to be negligible.

Water emissions were collected from the US EPA's *Enforcement & Compliance History Online* report. Reported emissions are separated by cooling type used at the proposed plant: closed-loop and once-through (ECHO 2009).

Radioactive emissions to air and water from several existing (Gen II) U.S. power plants was available from the Westinghouse AP 1000 (Gen III+ PWR) environmental report (Westinghouse 2009). These emissions were provided as comparative points for advanced reactor emissions reductions.

Table 1. Generation II Nuclear Power Plant Parameters

Parameter	Value	Source
Average Thermal Efficiency of Gen II (%) Reactors	31.6	WNA 2010
Average Annual Capacity Factor, 1969-2009(%)	70.7	EIA 2010
Average Annual Electric Output of a Single Reactor, 1969-2009 (MWh/ year)	4.93E+06	EIA 2010
Uranium Fuel Input per Electricity Output (kg/MWh)	4.33E-03	DOE 1983
Number of Operating Nuclear Reactors in 2009	104	EIA 2010
Number of Operating PWR Reactors in 2009	69	EIA 2010
Number of Operating BWR Reactors in 2009	35	EIA 2010

This unit process as 2 adjustable parameters. The adjustable parameters "PropOTC" and "PropTowers" attribute proportions to each type of cooling water. The sum of the two parameters should never exceed one nor should either of the values ever be negative. It is viable, however, to set one parameter for one and the other to zero to determine the effects of controling what type of cooling technology might be used in a given situation.

Table 2 provides a summary of modeled input and output flows for the Gen II nuclear reactor. Additional details regarding input and output flows, including calculation methods, are contained in the associated DS sheet.

Table 2: Unit Process Input and Output Flows

Flow Name*	Value	Units
Inputs		
Uranium Fuel Assemblies (UO2) [Intermediate product]	**4.33E-03**	**kg/MWh**
Water (surface water) [Water]	**103.67**	**kg/Mwh**
Outputs		
Electricity [Operation]	1.00E+00	MWh
Spent fuel (UO2)	4.34E-03	kg/MWh
Radionuclides [Radioactive emissions to air]	3.01E+06	Bq/MWh
Carbon dioxide [Inorganic emissions to air]	0.00E+00	kg/MWh
Methane [Organic emissions to air (group VOC)]	0.00E+00	kg/MWh
Nitrous oxide (laughing gas) [Inorganic emissions to air]	0.00E+00	kg/MWh
Nitrogen oxides [Inorganic emissions to air]	6.08E-04	kg/MWh
Sulphur dioxide [Inorganic emissions to air]	9.34E-05	kg/MWh
Carbon monoxide [Inorganic emissions to air]	1.17E-04	kg/MWh
NMVOC (unspecified) [Group NMVOC to air]	4.94E-05	kg/MWh
Dust (PM10) [Particles to air]	2.38E-04	kg/MWh
Dust (PM2.5) [Particles to air]	1.52E-04	kg/MWh
Lead (+II) [Heavy metals to air]	4.39E-09	kg/MWh
Mercury (+II) [Heavy metals to air]	6.55E-11	kg/MWh
Ammonia [Inorganic emissions to air]	8.00E-06	kg/MWh
Selenium [Heavy metals to air]	3.02E-10	kg/MWh
Chromium (unspecified) [Heavy metals to air]	6.05E-11	kg/MWh
Manganese (+II) [Heavy metals to air]	1.22E-10	kg/MWh
Nickel (+II) [Heavy metals to air]	6.46E-11	kg/MWh
Arsenic (+V) [Heavy metals to air]	2.71E-11	kg/MWh
Cadmium (+II) [Heavy metals to air]	6.05E-11	kg/MWh
Aluminum (+III) [Inorganic emissions to fresh water]	1.22E-03	kg/MWh
Chlorine (dissolved) [Inorganic emissions to fresh water]	1.19E-02	kg/MWh
Iron [Heavy metals to fresh water]	8.05E-02	kg/MWh
Nitrogen [Inorganic emissions to fresh water]	2.51E-03	kg/MWh
Arsenic (+V) [Heavy metals to fresh water]	4.92E-03	kg/MWh
Chromium (unspecified) [Heavy metals to fresh water]	3.47E-03	kg/MWh
Copper (+II) [Heavy metals to fresh water]	5.83E-03	kg/MWh
Mercury (+II) [Heavy metals to fresh water]	8.15E-09	kg/MWh
Zinc (+II) [Heavy metals to fresh water]	6.07E-02	kg/MWh

Biochemical oxygen demand [Organic emissions to fresh water]	1.29E+00	kg/MWh
Oxidants (unspecified) [Inorganic emissions to fresh water]	1.37E-02	kg/MWh
Oil (unspecified) [Hydrocarbons to fresh water]	7.99E-01	kg/MWh
Phosphorus [Inorganic emissions to fresh water]	1.10E-03	kg/MWh
Solids (suspended) [Particles to fresh water]	1.12E+00	kg/MWh
Water (river water) [Water]	1.01E+02	m3/MWh
Waste (solid) [Waste for disposal]	5.71E-05	kg/MWh
Mixed Waste (Hazardous or Radioactive)	2.70E-06	m3/MWh

* **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

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http://www.world-nuclear.org/info/inf08.html (Accessed July 18, 2010).

Section III: Document Control Information

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