Source Ist 2.0: Fission Product Release Code

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ABSTRACT

Ontario Power Generation (OPG) in cooperation with nuclear industry partners has developed SOURCE IST 2.0, the Canadian Nuclear Industry Standard Toolset (IST) code to calculate the extent of release of fission products from the uranium dioxide fuel pellets in a fuel element during normal operation and transient (postulated accident) conditions [1]. This paper provides information regarding the capabilities of the code, validation results and code qualification. The code simulates the behaviour of the fission products in the fuel from the beginning of the normal operating conditions irradiation through to the end of the accident scenario. SOURCE IST 2.0 is to be used in CANDU® safety analysis for modelling fission-product release from fuel under accident conditions. Ontario Power Generation (OPG), as the host organization for the code, distributed SOURCE IST 2.0 to IST participants in 2004.

SOURCE IST 2.0 models radionuclide production and decay, as well as all of the primary phenomena affecting fission-product release from CANDU fuel under accident conditions [2]: diffusional release of fission products from the fuel grains, grain-boundary sweeping / grain growth, grain-boundary bubble coalescence / tunnel interlinkage, vapour transport / columnar grain growth, thermal fuel cracking, fuel-to-sheath gap transport, effect of the average uranium oxidation state on diffusion coefficient, effect of phase changes, fission-product vaporization and volatilization (including advective release of fission products), temperature transients, grain-boundary separation and fission-product leaching.

In each simulation, the quantities of 150 isotopes of more than 30 actinide and fission product elements are calculated as a function of time. At each time step, SOURCE IST 2.0 simulates the transfer of fission products between the following inventory partitions: the fuel grain-matrix, the fuel grain-boundary, the fuel surface, the fuel-sheath gap, and the inventory released to the coolant. The code can be applied to accident simulations for the range of conditions shown in Table 1.

The code is suitable for calculations with natural and low-enriched uranium oxide fuels. Calculations of fission product releases from the “fuel surface” in the transient are bounded by a minimum

temperature of 1000 K and a maximum temperature of 3000 K. Also, the average fuel stoichiometry is not calculated in SOURCE IST 2.0, but must be estimated by the code user. The same is true of the extent of Zircaloy-fuel interaction, and of leaching, liquefaction and vaporization of the uranium oxide.

Table 1: Range of Applicability of SOURCE IST 2.0

Parameters	Ranges of Application
Fuel Temperature Range:	273 K < T < 3812 K (from just below the freezing point of light water to the boiling point of urania)
Fuel Stoichiometry ($UO_{2\pm x}$) Range:	$1.8 \leq 2 \pm x \leq 2.667$ ($UO_{1.8}$ to U_3O_8)
Fuel Environment:	Air, steam, hydrogen and inert
Burnup Range:	0 < Burnup < 800 MW·h/kgU

Some of the models in SOURCE IST 2.0 assume bounding behaviour. It has been considered that an appropriate bound is to assume more complete release, or earlier release where the release mechanism is not modelled to the maximum level of detail required for accurate assessments. Therefore, over-estimation of the release (or early release) is expected in some cases.

Eighteen validation exercises have been done with recent code versions. The base cases of validation exercises have been repeated with the latest production code version. These validation exercises [3] encompass a wide variety of experimental conditions, mainly out-of-reactor tests, with temperatures from 1000 K to 2500 K, and gas flows that range from strongly reducing (Ar/H_2) to mildly oxidizing (H_2O/H_2) and oxidizing (air) conditions (Table 2). Several of the validation exercises involved calculations for tests done using slightly enriched or Light Water Reactor fuels, and there was considerable variation in fuel burnups and peak powers. In general, the calculated releases are either in agreement with experimentally observed releases within the experimental uncertainties, or exceed the experimental values.

Table 2: Conditions for Selected SOURCE IST 2.0 Validation Exercise Tests

Atmosphere	**Test**	**Maximum Temperature (K)**	**Fuel Burnup (MW·h/(kg U))**	**Fuel Sample Type**
Steam	UCE12 T01	1373	441	Fragment
Steam	HCE2 BM5	1787	465	Mini-element
Steam	HCE2 BM4	1803	567	Mini-element
Steam	HCE4 J03	1913	219	Mini-element
Steam	BTF-105B	2100	160	Element
Steam	HCE3 H03	2110	233	Mini-element
Steam	BTF-104	2173	152	Element
Steam	MCE2 T19	2303	457	Fragment
Steam	VERCORS 05	2570	964	Mini-element
Steam/Hydrogen	PHEBUS FPT1	2800	560	Bundle
Helium/Hydrogen	VERCORS 04	2570	964	Mini-element
Helium/Hydrogen	ORNL VI-5	2720	1008	Mini-element
Inert	UCE12 T09	1671	370	Mini-element
Inert	HCE1 M12	1872	457	Mini-element
Inert	MCE2 T03	2105	457	Fragment
Air	GBI3 DL5	1313	233	Fragment
Air	HCE3 H02	2160	233	Mini-element
Air	MCE T4	2268	338	Fragment

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