CANDU Three-Dimensional Neutron Transport Calculations with DRAGON

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Through the Industry Standard Toolset (IST) project, the Canadian nuclear industry has selected three reactor physics computer codes for use in safety analysis, licensing, and routine operations for CANDU® nuclear reactors. These computer codes are WIMS-IST (Reference 1), RFSP-IST (Reference 2), and DRAGON-IST (Reference 3); they are used for 2-D lattice-cell transport calculations, 3-D core analysis, and 3-D supercell transport calculations, respectively. The three IST reactor physics codes fit together to create a calculational system for the neutron distribution in CANDU reactors.

The DRAGON neutron transport code uses a 3-D multi-group formulation and solves the steady-state neutron transport equation. The code has been developed and maintained at École Polytechnique de Montréal, Canada. It uses collision probability methods to set up and solve the neutron transport equation in various spatial regions and in multiple neutron energy groups. DRAGON was designed for general geometry and can analyze CANDU clusters, light-water reactor (LWR) assemblies, and fast breeder reactor (FBR) hexagonal assemblies in two dimensions. The code can also perform 3-D supercell neutron transport calculations with the same group structures as those used in 2-D analysis. DRAGON has the capability to treat self-shielding of resonance cross sections and to perform burnup calculations. Several boundary condition choices are provided, including standard infinite-lattice reflective boundaries, void-free boundaries, albedos, and periodic conditions. Thus, DRAGON can serve as a cell code, which is very similar to WIMS-IST, APOLLO-2 (Reference 4), CASMO-3, and HELIOS (Reference 5).

The main reason that DRAGON is part of the suite of IST reactor physics codes is that DRAGON allows a good geometrical representation of the fuel bundles, reactivity devices, and fuel channels in three dimensions, and DRAGON's multigroup neutron transport method is theoretically rigorous and consistent with WIMS-IST cell calculations.

As an IST code, the demand for the application of the DRAGON code to CANDU 3-D neutron transport calculations is increasing. This paper summarizes some applications of DRAGON in CANDU reactor physics and fuel design.

1. Modelling of reactivity devices for current and future CANDU reactors

The study of CANDU core performance requires the pre-calculation of few-group homogenized

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cross sections for CANDU lattice cells, and of incremental cross sections for in-core reactivity devices such as adjuster rods and liquid zone controllers (LZC), which are located in the moderator, perpendicular to the horizontal fuel channels. The reactivity-device properties were generated with DRAGON by using a configuration of dimensions 2 lattice pitches x 1 lattice pitch x 1 bundle length, which is the normal supercell size given the device arrangement and symmetries in the reactor cores, for current and future CANDU reactors.

2. Modelling of CANDU liquid zone controllers in the upper reflector

The above-mentioned reactivity-device properties can be used directly in the RFSP-IST code for the representation of reactivity devices and of structural materials in the core. Although these in-core properties have frequently been used to represent the devices in the reflector, it is an approximation, because these properties are generated as incrementals to the fuel properties rather than to the reflector properties, and, when superimposed on reflector properties, they may result in unphysical local cross sections. Accordingly, the LZC in the upper reflector was modelled with the DRAGON code by using a more complicated configuration of dimensions 2 lattice pitches x 5.5 lattice pitches x 1 bundle length for the supercell (see Figure 1), and a new set of LZC properties was generated for use in the upper reflector.

3. Modelling of the fuel-bundle end region for current and future CANDU fuels

A CANDU-6 fuel channel contains 12 fuel bundles, each measuring about 50 cm in length. The region separating the fuel in two adjoining bundles in a channel is called the "end region"; typically, this is taken as the last 1 to 2 cm at each end of a bundle (see Figure 2). The thermal neutron flux is higher in the end region of the bundle than at the bundle axial mid-point, because of the gap between bundles and because the end region of the bundle is made up of very-low-neutron-absorption material, such as Zircaloy-4 and coolant. The end-region flux peaking leads to a higher fission rate, and hence, higher heat production and higher temperatures in the end region of the fuel bundle. For accurate evaluation of fuel performance, the 3-D spatial power distribution in the CANDU fuel bundle, including the end region, was calculated with DRAGON for current and future CANDU fuels.

4. Modelling of the fast fluence in the endplate of the CANDU fuel bundle

The fast fluence in the endplate of the CANDU fuel bundle is an important fuel design parameter that is used for secondary stress analysis. Calculation of fast fluence in the endplate is a complicated 3-D transport depletion problem. With a DRAGON 3-D supercell model, the time-dependent fast fluence in the endplate of a CANFLEX® natural uranium (NU) fuel bundle was calculated for the nominal-design power envelope condition.

The DRAGON code (version 3.03a, released as DRAGON981110) was used with its latest, 89-group ENDF/B-V library, to perform CANDU 3-D supercell transport calculations. The details of the DRAGON 3-D supercell model—e.g., the mesh spacing, boundary conditions, leakage treatment, self-shielding and transport calculations, and spatial homogenization editing—will be given in the full paper.

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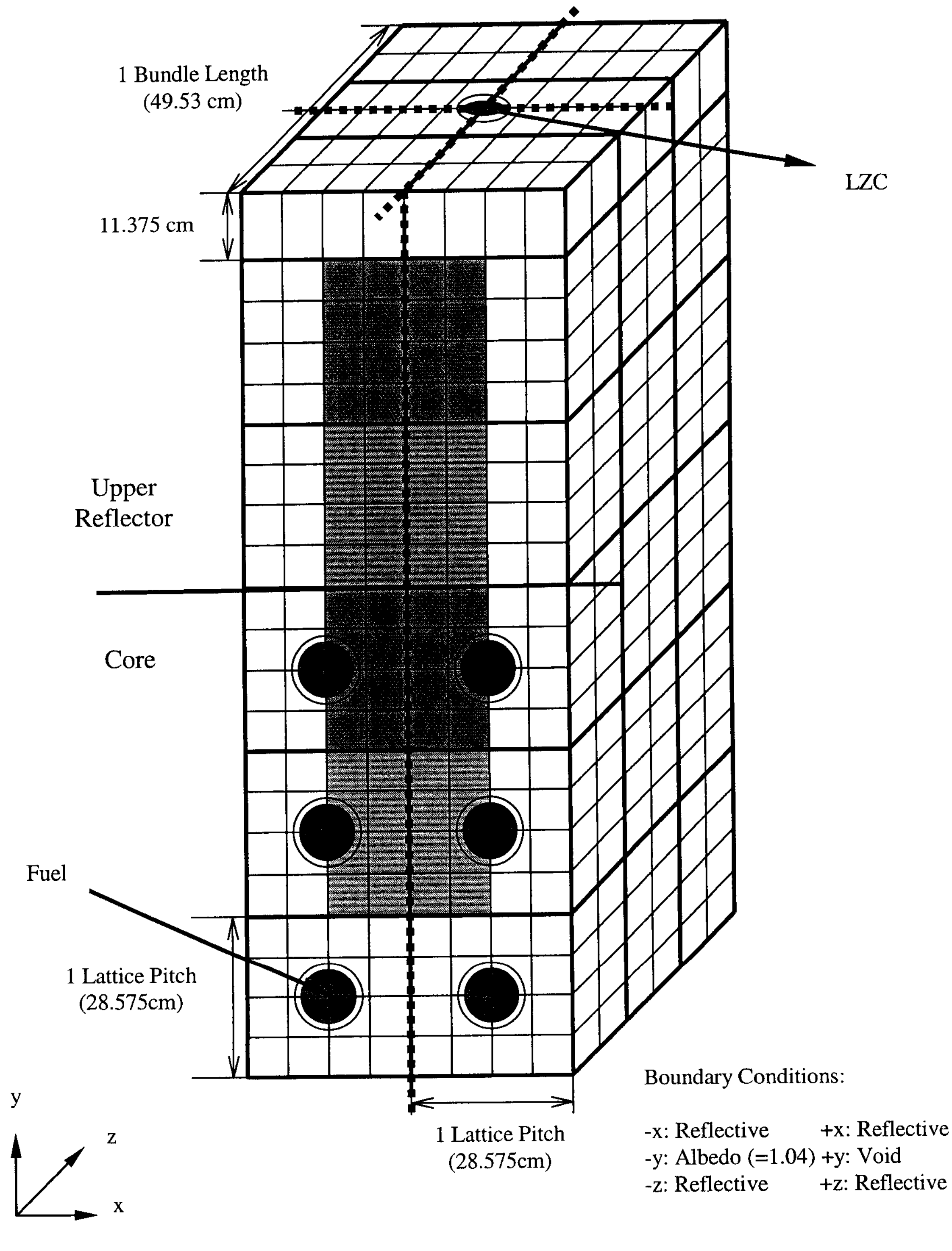

Figure 1. Supercell Modelling of LZC in the Upper Reflector with DRAGON

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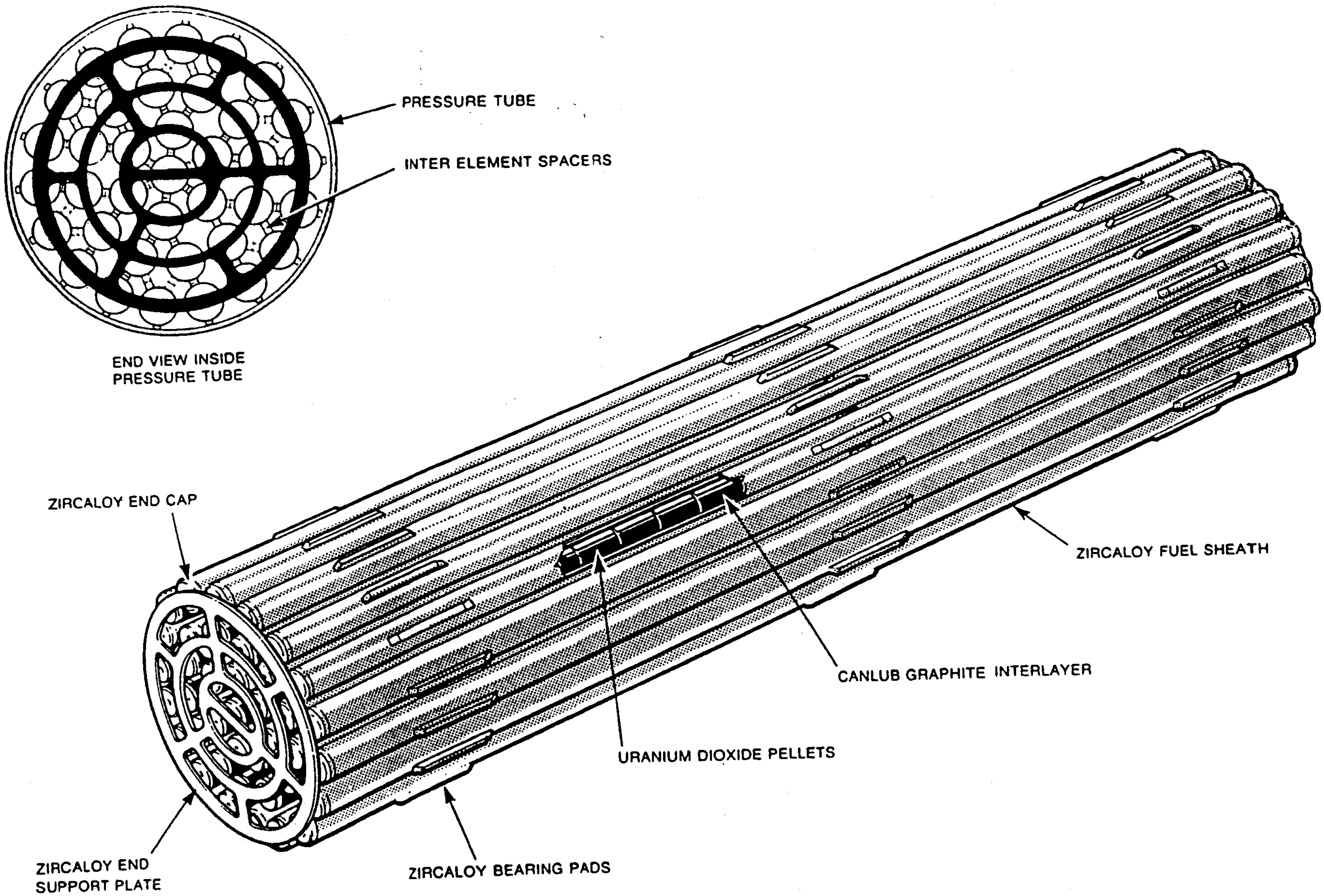

Figure 2. Schematic Representation of a CANDU Fuel Bundle