CA9110450

AECL-9824

ATOMIC ENERGY
OF CANADA LIMITED
Research Company

ENERGIE ATOMIQUE
DU CANADA LIMITEE
Société de Recherche

SAFETY-RELATED PARAMETERS FOR THE MAPLE RESEARCH REACTOR AND A COMPARISON WITH THE IAEA GENERIC 10-MW RESEARCH REACTOR

PARAMETRES DE SURETE DU REACTEUR DE RECHERCHE MAPLE ET COMPARAISON AVEC LE REACTEUR DE RECHERCHE GENERIQUE DE 10 MW DE L'AIEA

P. A. Carlson, A. G. Lee, H. J. Smith, R. J. Ellis

Whiteshell Nuclear Research
Establishment

Etablissement de recherches
nucléaires de Whiteshell

Pinawa, Manitoba R0E 1L0
July 1989 juillet

ATOMIC ENERGY OF CANADA LIMITED

SAFETY-RELATED PARAMETERS FOR THE MAPLE RESEARCH REACTOR AND A COMPARISON WITH THE IAEA GENERIC 10-MW RESEARCH REACTOR

by

P.A. Carlson, A.G. Lee, H.J. Smith and R.J. Ellis

Whiteshell Nuclear Research Establishment
Pinawa, Manitoba R0E 1L0
1989

AECL-9824

PARAMÈTRES DE SÛRETÉ DU RÉACTEUR DE RECHERCHE MAPLE ET COMPARAISON AVEC LE RÉACTEUR DE RECHERCHE GÉNÉRIQUE DE 10 MW DE L'AIEA

par

P.A. Carlson, A.G. Lee, H.J. Smith et R.J. Ellis

RÉSUMÉ

On résume certains des paramètres physiques principaux de sûreté du réacteur de recherche MAPLE et on compare celui-ci avec le réacteur générique de 10 MW de l'AIEA. Ceci donne un moyen d'évaluer les conditions de fonctionnement et besoins de chargement de combustible pour assurer l'exploitation sûre du réacteur de recherche MAPLE selon des normes admises.

Énergie atomique du Canada limitée
Établissement de recherches nucléaires de Whiteshell
Pinawa, Manitoba ROE 1LO
1989

AECL-9824

SAFETY-RELATED PARAMETERS FOR THE MAPLE RESEARCH REACTOR AND A COMPARISON WITH THE IAEA GENERIC 10-MW RESEARCH REACTOR

by

P.A. Carlson, A.G. Lee, H.J. Smith and R.J. Ellis

ABSTRACT

A summary is presented of some of the principal safety-related physics parameters for the MAPLE Research Reactor, and a comparison with the IAEA Generic 10-MW Reactor is given. This provides a means to assess the operating conditions and fuelling requirements for safe operation of the MAPLE Research Reactor under accepted standards.

Atomic Energy of Canada Limited
Whiteshell Nuclear Research Establishment
Pinawa, Manitoba ROE 1L0
1989

AECL-9824

CONTENTS

1. INTRODUCTION

Atomic Energy of Canada Limited (AECL) has developed a state-of-the-art multipurpose research reactor called MAPLE (Multipurpose Applied Physics Lattice Experimental). The MAPLE Research Reactor is similar in design to traditional Materials-Test-Reactor (MTR)-type pool reactors, where the reactor assemblies are also immersed in an open pool of water. The MAPLE Research Reactor has been designed as a pool-type rather than a tank-type reactor (e.g., NRU and NRX) because of the following advantages of that design: transparent radiation shielding, relatively easy core access, modest cost, and the safety advantage during an accident of a large unpressurized reservoir of water that acts as a heat sink. There are some differences in the designs of the MAPLE Research Reactor and typical MTR-type pool reactors. First, the MAPLE Research Reactor uses rod-type rather than the MTR plate-type fuel assemblies. The standard MAPLE low-enrichment uranium (LEU) fuel assembly contains 419 g ^{235}U, whereas the standard low-enrichment uranium-aluminum plate-type fuel assembly contains 390 g ^{235}U. Second, the MAPLE Research Reactor core is arranged on a hexagonal lattice with closely packed fuel sites rather than the rectangular lattice in MTR-type reactors. With a higher fissile content per fuel assembly, the MAPLE Research Reactor achieves a more compact core with the same total fissile loading as the MTR-type reactor. Third, the MAPLE Research Reactor has two separate shutdown systems rather than the single system used in the MTR-type reactors.

Many versions of the MTR-type pool reactor are in operation around the world, each slightly different from all the others. These differences, although often small, are significant. Consequently, the International Atomic Energy Agency (IAEA) has developed a 10-MW generic reactor model to generally describe the MTR-type pool reactors. This reactor model was developed to allow various laboratories to benchmark their physics codes and to establish a standard for MTR-type pool reactor performance. Matos and Freese [1] have analyzed the performance and safety characteristics of the IAEA Generic 10-MW Reactor.

A design criterion used to guide the development of the MAPLE Research Reactor was that important safety-related parameters should be at least similar in magnitude, or exceed, corresponding safety-related parameters of typical MTR-type reactors. The safety-related parameters evaluated from the physics calculations are

- control rod reactivity worth,
- shut-down margin,
- fuel temperature coefficient of reactivity,
- coolant temperature coefficient of reactivity,
- coolant void coefficient of reactivity, and
- reactivity balance.

This report compares the performance and safety characteristics of the MAPLE Research Reactor with the IAEA Generic 10-MW Reactor.

2. MAPLE RESEARCH REACTOR

The MAPLE Research Reactor has a reactor assembly immersed in an open pool of water. The reactor assembly consists of an inlet plenum, a core grid structure surrounded by a heavy-water tank (Figure 1) and a chimney. The core grid structure has 19 lattice sites arranged in a hexagonal array (Figure 2). Table 1 summarizes the key features of the MAPLE Research Reactor.

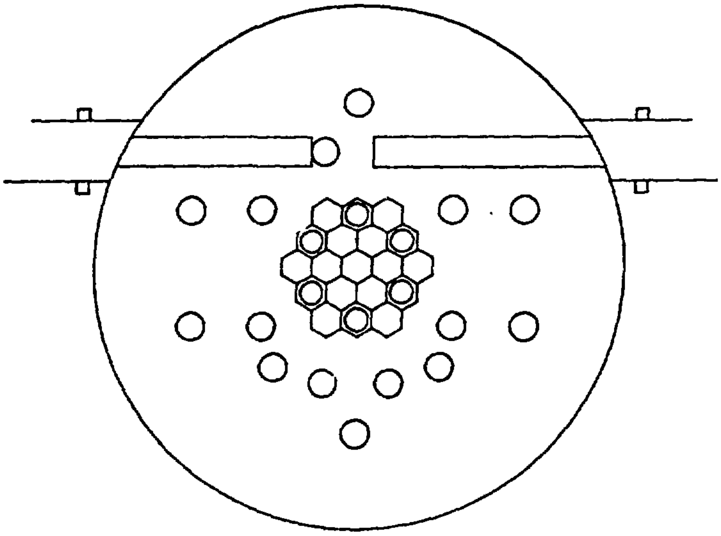

FIGURE 1: MAPLE Heavy-Water Tank

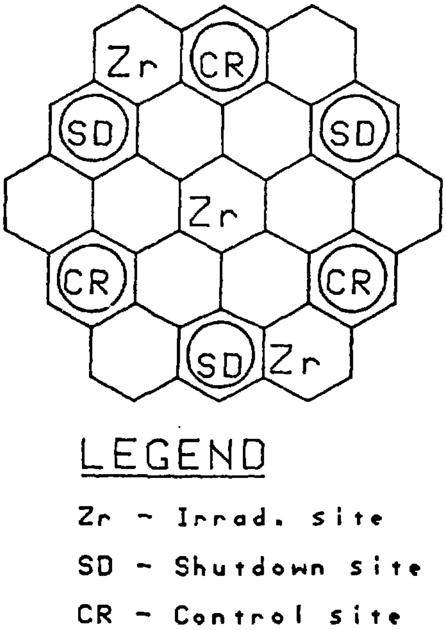

FIGURE 2: MAPLE Core Grid Structure

TABLE 1

MAPLE RESEARCH REACTOR KEY FEATURES

Reactor type	Pool-type
Steady-state power level	1-10 MW
Number of standard fuel elements	12
Number of control fuel elements	3
Number of shutoff fuel elements	3
Irradiation channels	up to 3-in.* core up to 15-in. reflector
Active core geometry	19 hexagonal sites
Grid plate	19 positions
Lattice pitch (mm)	80.1
Moderator, coolant	H_2O
Reflectors	D_2O
Coolant inlet temperature (°C)	35

The fuel is based upon the aluminum-clad, uranium-silicide-aluminum (U_3SiAl) dispersion fuel developed for use in the NRU and NRX reactors. The uranium is enriched to about 19.7 wt.% in ^{235}U. Table 2 gives the specifications for the standard and control fuel assemblies. The standard fuel assemblies consist of 36 fuel rods arranged in a hexagonal geometry around a central hanger rod. The fuel assemblies located in the absorber rod sites consist of 18 fuel rods arranged in a cylindrical geometry around a central hanger rod.

Neutron moderation and heat removal are achieved by light water flowing upwards through the core. Heavy water is used as a neutron reflector in the radial direction.

---

* 1 in. = 25.4 mm

TABLE 2

FUEL ELEMENT DESIGN DESCRIPTION FOR MAPLE RESEARCH REACTOR

Standard Assembly	
Shape	Hexagonal
Number of rods/assembly	36
Flow tube diameter (flat to flat) (mm)	
- inner	74.4
- outer	77.6
Mass of uranium (g)	2126.8
Mass of ^{235}U (g)	419.0
Initial linear fissile content (g ^{235}U/mm)	0.698
Rod pitch (mm)	12.0
Control Fuel Assembly	
Shape	Cylindrical
Number of rods/assembly	18
Flow tube diameter (mm)	
- inner	60.0
- outer	62.5
Mass of uranium (g)	1063.4
Mass of ^{235}U (g)	209.5
Initial linear fissile content (g ^{235}U/mm)	0.349
Rod pitch circle radii (mm)	
- inner	12.0
- outer	24.0

3. IAEA GENERIC 10-MW REACTOR

The key features of the IAEA Generic 10-MW Reactor are summarized in Table 3. Figure 3 shows the core arrangement. The core contains 23 MTR-type standard plate-type fuel elements, five control fuel elements and two irradiation elements. The core is reflected on two opposite faces with graphite and is surrounded by light water.

TABLE 3

IAEA GENERIC 10-MW REACTOR KEY FEATURES

Reactor type	Pool-type MTR
Steady-state power level	10 MW
Number of standard fuel elements	23
Number of control fuel elements	5
Irradiation channels	1 at core centre 1 at core edge
Active core geometry	5 x 6 positions
Grid plate	8 x 9 positions
Lattice pitch (mm^2)	77 x 81
Moderator, coolant	H_2O
Reflectors	C, H_2O
Coolant flow rate (m^3/h)	1000
Coolant inlet temperature (°C)	38

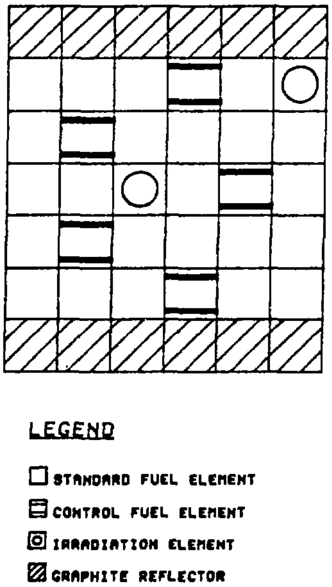

FIGURE 3: IAEA Generic 10-MW Reactor Core

Table 4 summarizes the fuel element specifications. The standard fuel elements have 23 plates, U_3Si_2-Al fuel and 390 g ^{235}U. The control fuel elements have 17 plates and 288 g ^{235}U. Each control fuel element has four aluminum spacer plates. The fork-type absorber blades are located between pairs of aluminum spacer plates.

TABLE 4

FUEL ELEMENT DESCRIPTIONS FOR IAEA GENERIC 10-MW REACTOR

Fuel type	U_3Si_2-Al
Uranium enrichment (wt.% ^{235}U)	19.75
Element dimensions (mm^3)	76 x 80 x 600
Plate thickness (mm)	1.27
Water channel thickness (mm)	2.19
Plates/standard element	23
Plates/control element	17 + 4 Al plates
Fuel meat dimensions (mm^3)	0.51 x 63 x 600
Clad material	Al
Clad thickness (mm)	0.380 inner 0.495 outer
Uranium density in fuel meat (g/cm^3)	4.45
^{235}U/standard fuel element (g)	390
^{235}U/control fuel element (g)	288

4. CODES USED IN MODELLING EACH CASE

A summary of the computer codes used in the reactor physics modelling of each of the two reactor systems is given in Table 5. The numerical results for the IAEA Generic 10-MW Reactor are taken directly from the comparisons given by Matos and Freese [1]. The results for the MAPLE Research Reactor are obtained by using the current AECL versions of WIMS [2] and 3DDT [3]. The cross-section data library used was an 89-group ENDFB/V in the case of the MAPLE Research Reactor, while the EPRI-CELL calculations for the IAEA Generic 10-MW Reactor were based on ENDFB/IV. A comparison of the two data sets with experiment has been recently completed [A. Okazaki, private communication], and except for a few nuclides, agreement is good.

TABLE 5

COMPARISON OF CODES USED

	IAEA Generic 10-MW Reactor	MAPLE Research Reactor
Detailed transport	EPRI-CELL (ENDFB/IV)	WIMS (ENDFB/V)
Core diffusion	DIF3D	3DDT
Fuel burnup and management	REBUS-3	FULMGR

5. COMPARISON OF CONTROL ROD WORTHS

The following tables contain a comparison of the safety-related parameters for the MAPLE Research Reactor with the equivalent values for the IAEA Generic 10-MW Reactor.

Table 6 compares the control rod worths for the two reactors at beginning of core (BOC) for equilibrium cores. In the case of the IAEA Generic 10-MW Reactor, the equilibrium core is the one obtained after a simulated transition [1] of 14 fuellings, with a gradual transition from HEU (93 w/o) to LEU (19.75 w/o). After this, a number of LEU refuellings are required to reach equilibrium. In the case of the MAPLE Research Reactor, the only fuel used is the LEU and the equilibrium is achieved by a gradual replacement of the zirconium block irradiation sites in the initial fresh core with fuel, until only one of these sites remains in the central position for the equilibrium core. The results show that the reactivity worths of the control systems of the two reactors are very similar. There is one important difference: all five of the reactivity shim rods on the IAEA Generic 10-MW Reactor are used for control, whereas only three out of the six reactivity shim rods in the MAPLE Research Reactor are used for control. The other three are used strictly as a fast shutdown system. It should be noted that the three control rods in the MAPLE Research Reactor, when fully inserted, have about the same worth as the five control rods in the IAEA Generic 10-MW Reactor. Also, the IAEA Generic 10-MW Reactor does not have a separate shutoff system.

TABLE 6

CONTROL ROD WORTHS IN LEU EQUILIBRIUM CORES AT BOC*

	IAEA 10-MW GENERIC REACTOR		MAPLE RESEARCH REACTOR	
Control Rod Configuration	k_{eff}	$\Delta\rho$ (mk)	k_{eff}	$\Delta\rho$ (mk)
All rods out	1.0767	0.	1.0764	0.
All rods in	0.9105	169.5	0.9097	170.2
All rods 50% out	1.0101	61.2	1.0309	41.0

* The IAEA Generic 10-MW Reactor uses all five shim rods for control, whereas the MAPLE Research Reactor uses three out of six shim rods for control.

6. REACTIVITY CONTROL REQUIREMENTS

Certain safety requirements need to be met for reactivity level control of a research reactor. The following are a summary of some of the typical requirements [D.J. Axford, private communication]:

1. Sufficient reactivity worth shall be provided in the reactivity control mechanisms so that the reactor can be shut down and maintained shutdown under all conditions.

2. Two independent reactivity reduction systems shall be incorporated in the design. One of these systems shall be fast acting, and one may be the normal reactivity control system.

3. A single failure in either reactivity reduction system shall not prevent the system from completing its safety function when required.

4. Reactor loading changes including fuelling shall follow specific procedures covering core assembly, disassembly and modifications. The reactor management should ensure that all reactor loading changes have been properly reviewed.

5. An up-to-date running record should be maintained of all reactor loading changes showing the current state of the reactor reactivity balance.

6. During normal operations, the reactor protective system should have a reactivity worth greater than the available excess reactivity of the reactor. It is common practice for many research reactors to have a safety margin of two on available excess reactivity.

7. The total rod worth less the most effective safety rod shall be greater than the maximum excess reactivity plus the reactivity worth of the worst single fuel-loading accident.

7. REACTIVITY BALANCE COMPARISON

In establishing reactivity balance tables and shutdown margins, the aforementioned reactivity control guidelines must be kept in mind when selecting any fuelling scheme for a research reactor. In the case of the MAPLE Research Reactor and the IAEA Generic 10-MW Reactor, the comparison is made between the LEU equilibrium cores in each case. The total excess reactivity in Table 7 is the reactivity worth of the beginning of core (BOC) k_{eff} in Table 6 with all rods out. This is broken down into components for ^{135}Xe poison load, fuel burnup, reactivity loading from experiments, control reserve and cold-to-hot swing. The shutdown margins are then displayed in Table 8. The first line in this table is the reactivity worth of all shutdown rods fully deployed minus the total excess reactivity from Table 7. In the second line one subtracts 1.5 times the total excess reactivity from the shutdown margin. The factor of 1.5 is a safety margin (Condition 6 of Section 6) some have suggested as minimal shutdown margin for all shutoff rods deployed. In the third line of Table 8, the figures represent the reactivity worth of all shutoff rods deployed except one minus the total excess reactivity. The one rod assumed excluded is the rod of greatest worth. This figure should be at least 10 mk for a safe shutdown margin in the event that one rod fails to deploy (Condition 7 of Section 6).

One fact to observe is that the MAPLE Research Reactor uses three out of six reactivity shim rods for shutdown and has separate control and shutoff systems. The IAEA Generic 10-MW Reactor uses the same system of five reactivity shim rods for both control and shutdown. In spite of using three instead of five, the shutdown margins using all rods for the MAPLE Research Reactor are equivalent to those for the IAEA Generic 10-MW Reactor. Even if one rod is lacking the margin is still above 10 mk for MAPLE and therefore acceptable. It is natural that losing one out of three will be more significant than failing one out of five, and this accounts for the difference from the IAEA 10-MW Generic Research Reactor.

TABLE 7

REACTIVITY BALANCE TABLES FOR THE LEU EQUILIBRIUM CORES AT BOC

Reactivity Component	IAEA $\Delta\rho$ (mk)	MAPLE $\Delta\rho$ (mk)
Burnup	16.5	13.0
Xe poison	31.7	26.5
Experiments	15.0	20.0
Control reserve	5.0	10.0
Cold-to-hot swing	3.0	1.5
Total excess reactivity	71.2	71.0
Excess reactivity x 1.5	106.8	106.5

TABLE 8

SHUTDOWN MARGINS IN LEU EQUILIBRIUM CORES AT BOC

Basis	IAEA $\Delta\rho$ (mk)	MAPLE $\Delta\rho$ (mk)
Total excess reactivity and all rods in	98.3	99.2
Excess reactivity x 1.5 and all rods in	62.7	63.7
Total excess reactivity and maximum worth rod out	28.9	18.1

8. COMPARISON OF KINETICS PARAMETERS

Table 9 shows a comparison of kinetics parameters along with reactivity coefficients for the IAEA Generic 10-MW Reactor and the MAPLE Research Reactor. The first parameter is the neutron generation time in microseconds. This is the ratio of neutrons present in the core to the generation rate of fission neutrons. It equals the prompt neutron lifetime divided by the neutron multiplication factor k. The values for the IAEA Generic 10-MW Reactor and the MAPLE Research Reactor are both in the 40 to 45 range. The next factor is the effective delayed neutron fraction. This is given in percent of total fission neutrons. Even for a uniform reactor core, the effective fraction differs from the actual fraction [4] because allowance is made in the former for the fact that the delayed neutrons have lower energies than the prompt fission neutrons. Thus the delayed neutrons usually have a greater importance in thermal reactors than do the prompt neutrons, and in some cases the difference may be as much as 20%. The value given in Table 9 for the IAEA Generic 10-MW Reactor is the effective delayed neutron fraction, while the value given for the MAPLE Research Reactor is the actual delayed neutron fraction. Initial estimates of the effective delayed neutron fraction for MAPLE give a value of 0.736%. Thus both reactor systems have reactivity margins to prompt critical of about 7.3 mk per dollar of reactivity.

TABLE 9

KINETICS PARAMETERS FOR LEU EQUILIBRIUM CORES

Parameter	IAEA	MAPLE
Generation time, Λ (μs)	42.4	45.0
Delayed neutron fraction, β_{eff} (%)	0.7311	0.687
Water temperature only (mk/°C)	-0.0737	-0.0426
Fuel temperature only (mk/°C)	-0.0247	-0.0103
Void coefficient (mk/% void) (0-10% void)	-2.7	-2.0

Following this, the reactivity coefficient figures are given. The MAPLE Research Reactor figures are for a fully fresh core, where extra zirconium blocks, each with three H_2O-filled holes, are included. This is intended to provide a worst case as adding extra driver fuel increases the undermoderation. Although not as large as the IAEA Generic 10-MW Reactor values, the MAPLE Research Reactor reactivity coefficients are still significantly negative for fuel temperature, coolant temperature and void.

9. CONCLUSIONS AND SUMMARY

1. The MAPLE Research Reactor control and shutoff systems have significant reactivity worth - one of the systems (3 out of 6) worth is the same as entire 5 rods in the IAEA Generic 10-MW Reactor. This allows similar reactivity balance conditions.

2. There are different control and shutoff systems for the MAPLE Research Reactor - each with the same worth because of symmetry but differently instrumented. Each of the separate systems in the MAPLE Research Reactor has a worth comparable to the one system in the IAEA Generic 10-MW Reactor.

3. Reactivity coefficients for the MAPLE Research Reactor are negative and similar to those for IAEA Generic 10-MW Reactor.

4. Kinetics parameters for the MAPLE Research Reactor are similar those for the IAEA Generic 10-MW Reactor.

REFERENCES

1. Matos, J.E. and Freese, K.E. 1986. Safety Analyses for HEU and LEU Equilibrium Cores and HEU-LEU Transition Core IAEA Generic 10 MW Reactor. In Applications in Nuclear Data and Reactor Physics, D.E. Cullen, R. Muranaka, and J. Schmidt, eds. World Scientific Publishing, Singapore, Appendix A-2, p. 796.

2. Askew, J.R. , Fayers, F.J. and Kemshell P.B. 1966. A General Description of the Lattice Code WIMS. J. Brit. Nucl. Energy Soc., 5(4), 564.

3. Vigil, J.C. 1970. 3DDT - A Three-Dimensional Multigroup Diffusion - Burnup Program", Los Alamos Scientific Laboratories Report, LA-4396.

4. Bell, G.J. and Glasstone, S. 1970. Nuclear Reactor Theory. Van Nostrand, New York, p. 472.

ISSN 0067-0367
To identify individual documents in the series
we have assigned an AECL—number to each.

Please refer to the AECL—number when
requesting additional copies of this document
from

Scientific Document Distribution Office
Atomic Energy of Canada Limited
Chalk River, Ontario, Canada
K0J 1J0

Price: A

ISSN 0067-0367
Pour identifier les rapports individuels
faisant partie de cette série, nous avons
affecté un numéro AECL—à chacun d'eux.

Veuillez indiquer le numéro AECL—lorsque
vous demandez d'autres exemplaires de ce rapport
au

Service de Distribution des Documents Officiels
Energie Atomique du Canada Limitée
Chalk River, Ontario, Canada
K0J 1J0

Prix: A