AREVA Report ANP-2661(NP), Revision 0,
Brunswick Nuclear Plant
New Fuel Storage Vault Criticality
Safety Analysis for ATRIUM™-10 Fuel,
dated September 2007

An AREVA and Siemens company

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Revision 0

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Nature of Changes

Item	Page	Description and Justification
1.	All	This is the initial release.

Contents

Tables

Figures

This document contains a total of 24 pages.

Nomenclature

k-eff	effective neutron multiplication factor
k_∞	infinite neutron multiplication factor

1.0 Introduction

This report presents the results of a criticality safety evaluation performed for the storage of AREVA NP Inc.* ATRIUM™-10† fuel assemblies in the new fuel storage vault of the Brunswick Nuclear Power Plant.

* AREVA NP Inc. is an AREVA and Siemens company.

† ATRIUM is a trademark of AREVA NP.

2.0 Summary

The ATRIUM-10 fuel design can be safely stored in the Brunswick new fuel storage vault as described in Section 4.2 of this report per the criticality safety limits defined in Table 2.1. The new fuel storage vault is a moderation controlled area subject to the proper administrative controls. The evaluation summarized in this report shows that under worst credible conditions and including uncertainties the highest k-eff of the new fuel vault with ATRIUM-10 fuel at 4.70 wt% U-235 and containing eight 2 wt% gadolinia rods is 0.928 at the 95% confidence level (CL). This meets the acceptance criterion of k-eff ≤0.95 for fully flooded conditions, (Reference 1). (Under dry conditions the k-eff is much less than the 0.90 limit specified in Reference 1). The conditions assumed for these cases are described in Sections 6.1 and 6.2.

This evaluation is conservative because:

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Table 6.1 shows that for the limiting condition (fully flooded), the storage of assemblies with fuel channels produces the largest k-eff. The maximum k-eff includes the worst condition relative to fuel channel, i.e., with channels. Hence, fuel assemblies may be stored with or without fuel channels.

Table 2.1 Criticality Safety Limits for Fuel Assemblies Stored in the Brunswick Nuclear Power Plant New Fuel Storage Vault

1. ATRIUM-10 Fuel Configuration

Parameter	Nominal ATRIUM-10 Values
Clad OD, in.	.3957
Clad ID, in.	.3480
Pellet Diameter, in.	.3413
Rod Pitch, in.	.510
Fuel Density, % Theoretical	96.26
Water Rods	Internal Channel

2. Fuel Design Limitations

Maximum Lattice Average Enrichment, wt% U-235	4.70
Minimum Number Gd* Rods	8
Minimum wt% Gd_2O_3 in each Gd Rod	2

3. New fuel storage rack design and dimensions are as defined in Reference 2.

4. Any protective wrapping material around the fuel assemblies must be open at the bottom to allow for water drainage.

* Gd means gadolinia-bearing (Gd_2O_3) fuel rods.

3.0 Criticality Safety Design Criteria

The criticality safety design criteria defined in Section 9.1.1.3 of Reference 1 was used for the new fuel storage vault evaluation. In general, the main criticality safety acceptance criteria applicable to this evaluation are as follows:

The k-eff of the array under dry conditions will be ≤0.90.

The k-eff of the array under flooded conditions will be ≤0.95.

In addition, the new fuel storage vault needs to be designated as a "moderation controlled area." This means keeping extraneous hydrogenous material out of the array through both administrative means, e.g., posting the area as indicated above, and engineered means, e.g., shielding any overhead water lines so that if there is a pipe burst water will not spray directly into the array.

4.0 Fuel and Storage Array Description

4.1 *Fuel Design*

The base fuel design assumed for the analysis is the ATRIUM-10, which is a 10x10 fuel assembly with an internal square water channel near the center of the assembly (taking the place of nine fuel rod locations). Table 4.1 summarizes the mechanical design parameters which define the assembly and Figure 4.1 depicts the assembly graphically. This analysis supports enriched ATRIUM-10 lattices with 4.70 wt% U-235 (maximum) and eight 2.0 wt% gadolinia rods. This is the highest reactivity design considered for the new fuel storage array.

4.2 *Fuel Storage Array*

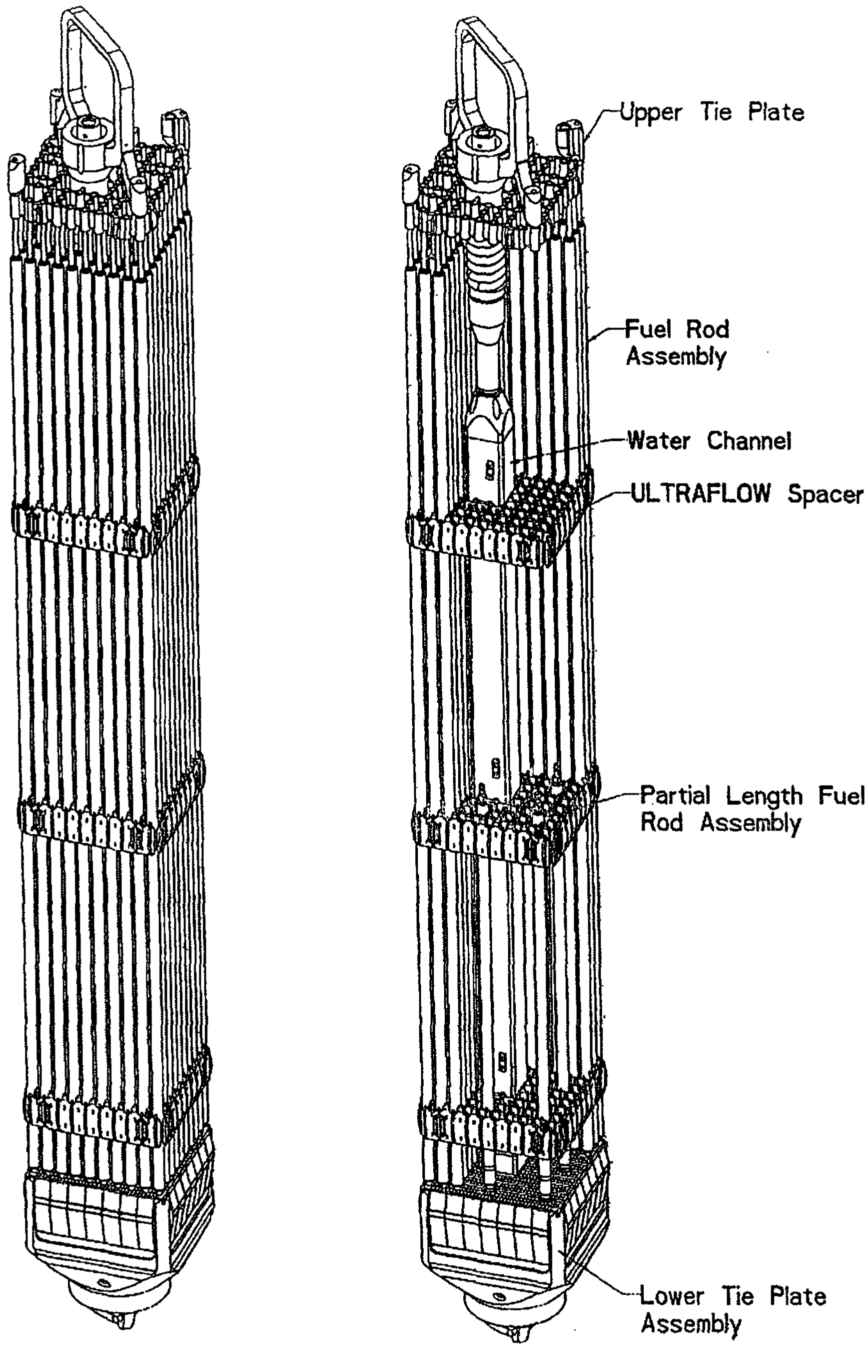
The new fuel storage vault dimensions defined in Reference 2 are represented in Figures 4.2 and 4.3. The new fuel vault consists of 21 fuel storage racks (Figure 4.2) arranged side by side to create an array of storage cells on 11.5" x 6.6" centers (Figure 4.3). There are 5" or 5.25" gaps between the racks and the surrounding 11" thick concrete walls. The floor is modeled as 12" of concrete with a 3.38" gap and the ceiling is modeled as 24" of concrete with a 17.6" gap.

The storage vault includes a floor drain that is plugged when fuel is stored in the vault to preclude the possibility of steam backing up through the drain system. The racks are designed to prevent accidental insertion of a fuel assembly in non-rack locations. The aluminum structural material in the racks has little impact on array reactivity and has been neglected in this analysis.

Table 4.1 ATRIUM-10 Fuel Assembly Parameters

Fuel Assembly	
Fuel Rod Array	10x10
Fuel Rod Pitch, in.	0.510
Number of Fuel Rods Per Assembly	91
Water Channel	1
Fuel Rods	
Fuel Material	UO_2
Fuel Enrichment, wt% U-235	4.70
Pellet Density, % of Theoretical non-liner fuel	96.26
Pellet Diameter, in.	0.3413
Pellet Void Volume, %	
Enriched UO_2	1.2
Cladding Material	Zircaloy-2
Cladding OD, in.	0.3957
Cladding ID, in.	0.3480
Internal Water Channel	
Outside Dimension, in.	1.378
Inside Dimension, in.	1.321
Channel Material	Zircaloy-2 or Zircaloy-4
Fuel Channel (100-mil standard)*	
Outside Dimension	5.478
Inside Dimension	5.278
Channel Material	Zircaloy-2 or Zircaloy-4

* The conclusions in this report are equally valid for fuel channels that may differ. Presence or absence of fuel channels has no significant impact on the results of this report. Hence, conclusions remain valid for other fuel channel types, e.g., AREVA Advanced fuel channels or similar design.



(Assembly length and number of spacers are reduced for pictorial clarity)

Figure 4.1 ATRIUM-10 Fuel Assembly

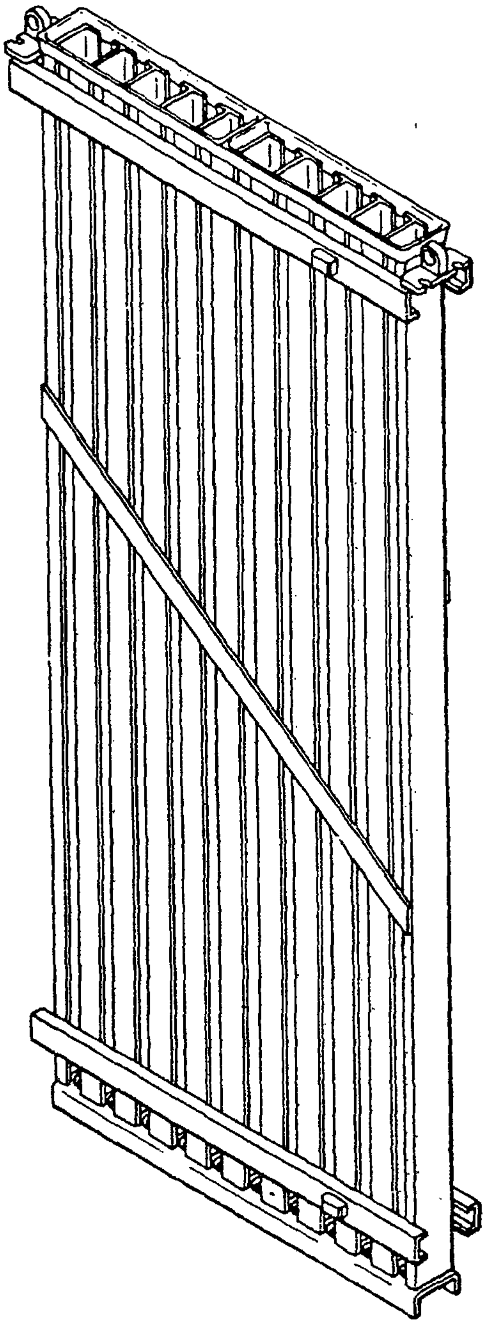


Figure 4.2 Brunswick New Fuel Storage Rack

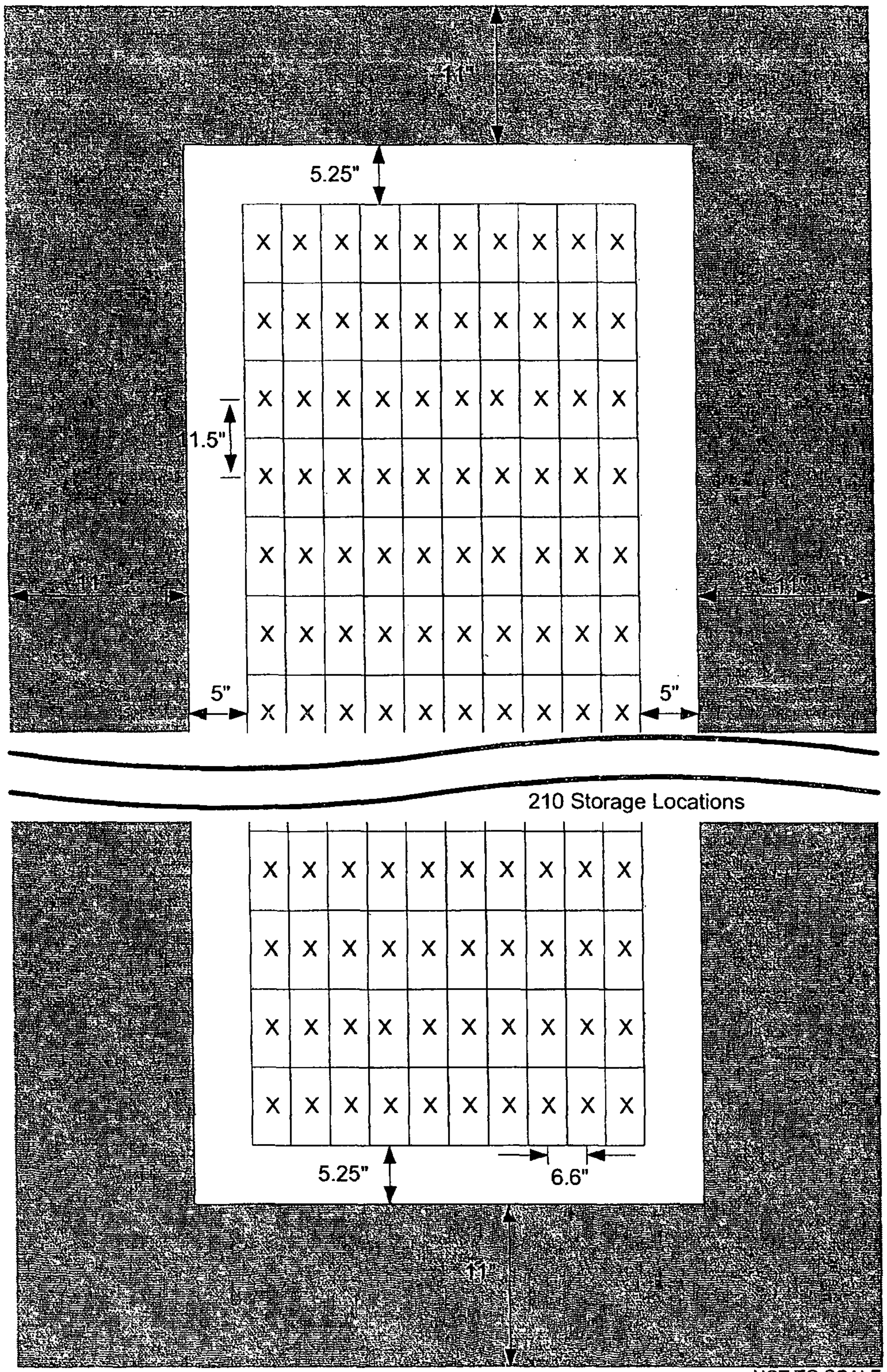


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Figure 4.3 Brunswick New Fuel Storage Vault KENO Model Dimensions

5.0 Calculation Methodology

The base case storage array k-eff calculations were performed with the KENO.Va Monte Carlo code, which is part of the SCALE 4.2 Modular Code System (Reference 3). Cross-section data input to KENO.Va were taken from the ENDF/B-IV, 27 energy group data library (Reference 3).

The CASMO-4 bundle depletion code (Reference 4) was used to calculate isotopic number densities for the fuel. CASMO-4 is a multigroup, two-dimensional transport theory code.

Both the KENO.Va and the CASMO-4 computer codes are widely used throughout the nuclear industry. They are used primarily for criticality safety and core physics calculations, respectively. AREVA has broad experience using both of these codes.

6.0 Storage Array Reactivity (k-eff)

The limiting conditions include the worst credible conditions addressed in Sections 6.3 and 6.4, and the ATRIUM-10 fuel assembly as defined in Section 4.1. The base k-eff is calculated with the KENO.Va code and the uncertainties due to manufacturing tolerances are primarily evaluated with CASMO-4.

6.1 *Geometry Model*

The storage vault is modeled in KENO.Va as defined in Section 4.2 and Figure 4.3. The center-to-center spacing of assemblies within the storage cells is 6.6" in the X direction (nominal spacing) and 11.5 inches in the Y direction (minimum spacing). Each cell is 150.0 inches in the Z direction. The array is reflected by concrete in all directions; 11 inches on the sides, 24 inches on the top of the array and 12 inches on the bottom.

6.2 *KENO.Va Results*

KENO.Va calculations were performed for dry and fully flooded conditions within the array. The base fuel assembly assumed for these calculations is defined in Section 4.1. Cases were run with and without a fuel channel. The results of the calculations are summarized in Table 6.1.

6.3 *Maximum Credible Accident Condition Results*

The design of the new fuel storage vault precludes the accidental insertion of a fuel assembly in any position not intended for fuel storage. In addition the new fuel storage vault is maintained as a moderation controlled area. This implies that the storage vault will be maintained at dry conditions and in an accident scenario it could be (partially or completely) flooded with water. The fully flooded condition bounds the partially flooded condition and has been directly modeled in this evaluation.

The case of a fuel assembly lying on the floor above the storage array is not considered significant because the 24 inches of concrete in the ceiling cap will effectively isolate the horizontal assembly from the assemblies in the storage array. [

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The orientation of the bundles within the racks is not restricted and since the ATRIUM-10 water channel and U235 enrichment distributions are not ¼ lattice symmetric, the effect of different assembly orientations must be considered. [

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6.4 *Maximum New Fuel Storage Vault k-eff*

The maximum k-eff for the new fuel storage racks includes: the highest KENO.Va calculated k-eff for the array at fully flooded conditions, the calculational bias, an adder for the limiting accident condition defined in Section 6.3, and uncertainties associated with the KENO.Va calculation and fuel manufacturing, i.e., fuel enrichment, gadolinia weight percents, uranium density, pellet diameter, cladding thickness, and storage cell pitch. The maximum k-eff is therefore defined as:

$$k_{max} = k_c + b_b + A + U\,(\sigma_c^2 + \sigma_b^2 + \sigma_t^2)^{1/2}$$

where:

k_c and σ_c equal the k_{eff} and standard deviation values from the worst case KENO.Va output

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The highest k-eff was obtained for the fully moderated condition with fuel channels. For this case (KENO.Va):

$k_c = 0.9012$

$\sigma_c = 0.0006$

The maximum k_{eff} then, using the above parameters is:

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= 0.928

This is below the acceptance criterion of 0.95 for the fully flooded condition.

By inspection of the results listed in Table 6.1, the k-eff of the storage vault is significantly less than the 0.90 acceptance criterion for the dry condition.

Table 6.1 New Fuel Storage Vault Reactivity Results

Fuel Assembly

Physical Description: See Section 4.1

Enrichment: 4.70 wt% U-235 in all rods

Gadolinia: 8 rods at 2.0 wt% Gd_2O_3 in each

Fuel Channel 100-mil

Storage Cell

Cell Center-to-Center Spacing: 6.6 ×11.5-inch centers

Array modeled explicitly with concrete walls, floor and ceiling. The storage rack was not modeled.

Moderator Temperature: 100°C

KENO.Va Results

	Without fuel channel		With fuel channels	
% of full density water	k-eff	σ	k-eff	σ
0	0.6484	-	0.6350	-
100	0.8976	-	0.9012	0.0006

7.0 Conclusions

This evaluation demonstrates that ATRIUM-10 fuel can be safely stored in the Brunswick Nuclear Plant new fuel storage vault given the assumptions defined in this report and assuming that the fuel to be stored meets the criticality safety limits and requirements defined in Table 2.1. Under dry storage array conditions, the k-eff of the new fuel storage vault will not exceed 0.90 at the 95% confidence level. Also under fully flooded conditions, the k-eff of the new fuel storage vault will not exceed 0.95 at the 95% confidence level.

8.0 References

1. *Updated FSAR Brunswick Steam Electric Plant, Units 1 and 2*, Revision 20, 2006.

2. ANP-2547(P) Revision 1, *Brunswick Unit 1 Cycle 17 Plant Parameters Document*, April 2007. (103-2547P-000)

3. *A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, SCALE 4.2, Oak Ridge National Laboratory, revised December 1993.

4. EMF-2158(P)(A) Revision 0, *Siemens Power Corporation Methodology for Boiling Water Reactors: Evaluation and Validation of CASMO-4/MICROBURN-B2*, Siemens Power Corporation, October 1999.

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