June 2025

Revision 25A

MAGNATRAN

(**M**odular **A**dvanced **G**eneration
Nuclear **A**ll-purpose **TRANsport**)

SAFETY ANALYSIS REPORT

RAI Responses

NON-PROPRIETARY VERSION

Docket No. 71-9356

NAC INTERNATIONAL
Kanadevia Group

Atlanta Corporate Headquarters: 2 Sun Court, Suite 220, Peachtree Corners, Georgia 30092 USA
Phone 770-447-1144, www.nacintl.com

Enclosure 1

Responses to NRC Request for Additional Information

for

NAC MAGNATRAN Transportation Package SAR
Revision 25A

NAC International

June 2025

NAC INTERNATIONAL

RESPONSES TO THE

UNITED STATES NUCLEAR REGULATORY COMMISSION

REQUEST FOR ADDITIONAL INFORMATION

June 2025

FOR REVIEW OF THE NAC MAGNATRAN Transportation Package SAR

(Docket No. 71-9356)

NAC International

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NAC INTERNATIONAL RESPONSE
TO
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STRUCTURAL AND MATERIALS ANALYSIS

RAI 1: Provide yield stress values for the M5 cladding alloy at 400 degrees Celsius (°C) to support the analysis in NAC calculation 71160-2140, revision 0, “Fuel Rod Evaluation for the MAGNATRAN 30-feet (ft) Side Drop Accident.” table 1.0-1 of the calculation lists the yield stress of pressurized-water reactor (PWR) M5 cladding at 400°C as 68.2 kilopound force per square inch (ksi) (470 megapascal [MPa]). Per section 4.0 of the calculation, the reference for this yield strength value is the ZrNb-1a entry of table 5 of Bourdiliau, B, et al., "Impact of Irradiation Damage Recovery During Transportation of the Subsequent Room Temperature Tensile Behavior of Irradiated Zirconium Alloys," JAI Vol. 7, No.9. Section 5.0 of the calculation states that this yield strength value does not consider any strain rate effects.

The staff notes that table 5 of the Bourdiliau publication lists values for Zr-1%Nb specimens whose tensile properties were determined at room temperature; whereas the ZrNb-1a entry associated with the 470 MPa (68.2 ksi) yield stress value had been subjected to over 3000 hours of 400°C temperature exposure prior to the determination of the published properties. The lower yield stress for this sample, compared to the yield strength of the as-irradiated material, is a result of the annealing of irradiation damage during the creep testing conducted at 400°C.

The applicant is requested to provide valid yield stress for M5 cladding at 400°C and revise calculation 71160-2140, as necessary to verify that the yield stress value for the M5 cladding is not exceeded for the 30-ft side drop accident analysis and make any necessary adjustments to the summary in safety analysis report section 2.11.4.

This information is required to satisfy the requirements of Title of the Code of Federal Regulations (10 CFR) Part 71.55(e) and 71.73(c)(1).

NAC INTERNATIONAL RESPONSE
TO
REQUEST FOR ADDITIONAL INFORMATION

NAC International Response to RAI 1:

[redacted]

NAC INTERNATIONAL RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

RAI 2: In sections 7.0 and 9.0 of NAC calculation 71160-2140, revision 0, explain why the results of the 30-foot drop analyses of PWR fuel rods with intact fuel grids at an acceleration of 48g are not presented.

The damaged PWR fuel rod analysis results are shown in sections 7.0 and 9.0 and may produce the bounding cladding stresses for both the damaged and undamaged fuel rods, due to their longer rod span. However, in section 6.4 of the calculation, it is stated that the damaged PWR fuel rods are analyzed for an acceleration of 33g while the intact PWR fuel rods are analyzed for an acceleration of 48g; therefore, it is not readily apparent which PWR rod configuration would produce the bounding cladding stresses.

This information is required to satisfy the requirements of 10 CFR Part 71.55(e) and 71.73(c)(1).

NAC International Response to RAI 2:

[redacted]

Enclosure 2

Supporting Calculations

for

NAC MAGNATRAN Transportation Package SAR
Revision 25A

NAC International

June 2025

Supporting Calculations

1. 71160-2126, REV 7
2. 71160-2140, REV 1

CACLULATIONS ARE PROPRIETARY AND WITHHELD
IN THEIR ENTIRETY PER 10 CFR 2.390

Enclosure 3

List of SAR Changes

for

NAC MAGNATRAN Transportation Package SAR
Revision 25A

NAC International

June 2025

List of Changes for the NAC MAGNATRAN Transportation Package SAR, Revision 25A

Chapter/Page/ Figure/Table	Description of Change
Chapter 1 – No Changes	
Chapter 2	
Page 2.11.1-2 thru 2.11.1-3	Revised text, where indicated.
Pages 2.11.4-1 thru 2.11.4-2	Revised text, where indicated.
Page 2.11.6-1	Revised text, where indicated.
Page 2.12.1-5	Revised text, where indicated.
Page 2.12.2-21	Editorial correction, where indicated.
Chapter 3 thru Chapter 8 – No Changes	

Enclosure 4

SAR Changed Pages

for

NAC MAGNATRAN Transportation Package SAR
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using brick elements to maintain the spacing between the fuel rods at the grid. The fuel tube is modeled using brick elements to restrict the lateral motion of the fuel assembly. Each of the fuel rods in the ANSYS model is simply supported at each end. Spring elements support the shell elements of the fuel rods at the locations of the grids and represent the fuel pellets. Static forces are applied between each grid to induce a maximum bow of 0.010 inch, which occurs between the lowest two grids. The purpose of the ANSYS model and solution is to provide the coordinates of the fuel clad for the LS-DYNA model. This is accomplished by obtaining a static solution with the ANSYS model, and then using the option to update the coordinates of the nodes based on the displacements from the solution. The LS-DYNA models are shown in Figure 2.11.1-2 and Figure 2.11.1-3 for Case 1 (intact grids) and Case 2 (one damaged grid), respectively. A section of bottom grid in the intact grid model was removed to create the damaged grid model as shown in the Figure 2.11.1-3. In the analysis of fuel rod assemblies, the thickness of the cladding given above is reduced by 120 microns (0.0047 inch).

An initial velocity of 527 in/sec is defined on all the nodes of fuel rod and fuel tube. The initial position of the fuel of the fuel assembly corresponds to the fuel assembly resting on the canister end. A deceleration curve, as shown in Figure 2.11.1-4, uses a maximum deceleration of 36 g's which bound the maximum axial acceleration in Table 2.6.7-37. The deceleration curve in Figure 2.11.1-4 is applied to the nodes of the elements representing the fuel tubes and fuel end fittings. The deceleration time history is defined to result in a final velocity of 0 in/sec at the end of the 30-foot drop.

The LS-DYNA model employs the same nodes and elements as the ANSYS models (with the incorporation of the 0.010 inch bow). Elastic material properties are used in the ANSYS model and bilinear material properties are employed in the LS-DYNA model. Material properties for

[redacted]

2.11.1.2 Analyses Results

The LS-DYNA analyses for the cases with no initial gap (Cases 1 and 2) were performed for the duration of 0.08 second to determine the maximum stresses in the fuel. Since the fuel is to remain elastic during the impact, the Von-Mises stress is computed for each element. Post-processing each analysis set identifies the maximum Von-Mises stress occurring at the shell surface during the 30-foot end drop.

The time history of the Von-Mises stress in the fuel clad for Case 1 (intact grid) is shown in Figure 2.11.1-5. The Von-Mises stress contour for the fuel corresponding to the time of the maximum Von-Mises stress is shown in Figure 2.11.1-6 (in conjunction with the location of the maximum Von-Mises stress).

The time history of the Von-Mises stress in the fuel clad for Case 2 (one damaged grid) is shown in Figure 2.11.1-7 and the Von-Mises stress contour for the fuel corresponding to the time of the maximum Von-Mises stress is shown in Figure 2.11.1-8 (with the identification of the element with the maximum stress).

The maximum internal pressure in the fuel clad is 2,000 psi. The axial stress in the fuel clad due to internal pressure is added algebraically to the Von-Mises stress obtained from LS-DYNA. The axial stress is calculated as:

$$\sigma = \frac{P \times r}{2 \times t} = \frac{2000 \times 0.18}{2 \times 0.0178} = 10{,}112 \quad \text{psi}$$

The maximum stresses for each case are summarized in the following table with the computed factor of safety. All factors of safety are greater than unity.

Case	Grid	Initial Bow (in)	Von-Mises Stress from Model (psi)	Initial Stress due to Pressure (psi)	Total Stress (psi)	Yield Strength (psi)	Factor of Safety
1	Intact	0.01	31,967	10,112	42,079	54,900	1.3
2	Damaged	0.01	29,214	10,112	39,326	54,900	1.4

2.11.4 Side Drop Evaluation

[redacted]

[redacted]

2.11.6 Fatigue Evaluation of Fuel Rods

The section presents a fatigue evaluation for the PWR and BWR high burnup fuel assemblies for normal condition of transport for the MAGNATRAN system.

The evaluation considers thirty-three PWR fuel assemblies (seven PWR fuel types) and twenty-seven BWR fuel assemblies (seven BWR fuel types) that comprise the MAGNATOR design basis fuel assembly inventory. For each fuel assembly type, one fuel rod is selected for analysis based on the cladding cross-sectional moment of inertia and loading from the fuel. Finite element models representing a single fuel rod for each of the PWR fuels are used (without missing grid and with missing grids) to determine the stress and strain in the fuel cladding during normal conditions of transport. Similar models are used for the BWR fuel without missing grids. The fuel rod is modeled with ANSYS three-dimensional BEAM4 elements to represent the fuel clad only, and the properties for the fuel clad take into account the reduction of the outer radius by 120 microns and 125 microns for the PWR and BWR fuel rods respectively. The density of the clad is adjusted to account for the mass of the fuel pellet. The effect of the flexural rigidity of the fuel pellet on the fuel rod cladding is included by factoring the cladding moment of inertia by 1.25 per Section 2.3.4 of NUREG-2224. The locations of the grids are modeled as simple supports in the lateral directions. The models for the missing grids case for PWR fuel rods have a maximum span of 60 inches.

Response spectrum analyses are performed for the fuel rods using response spectra of the transport cask platform from five test cases as documented in the ENSA/DOE rail cask test [SAND2018-13258R]. The response spectra include acceleration data in the axial and two lateral directions of the fuel rods up to 1,000 Hz frequency. Missing mass and Close Mode Grouping options are considered in the analyses.

The maximum stress and strain of the fuel rods from the spectrum analyses for the PWR fuel and BWR fuel are summarized in Table 2.11.6-1 and Table 2.11.6-2, respectively. The maximum strain is 0.056% for the PWR fuel and 0.043% for the BWR fuel, which are well below the 0.06% end point of the Lower-Bound Fatigue Curve as shown in Table 2-6 and Figure 2-12 of NUREG-2224, Dry Storage and Transportation of High Burnup Spent Nuclear Fuel. Therefore, fatigue is not a concern of the high burnup PWR and BWR fuel assemblies for transport conditions.

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69. Weaver, William Jr. and James M. Gere, "Matrix Analysis of Framed Structures," Second Edition, D. Van Nostrand Company, New York, 1980.
70. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendices, 2001 Edition with 2003 Addenda.
71. "Machinery's Handbook," 25th Edition, Industrial Press, New York, 1996.
72. ASME Boiler and Pressure Vessel Code, Section III, Division 1, Appendix F, Rules For Evaluation of Service Loadings With Level D Service Limits," American society of Mechanical Engineers, New York, New York, 2001 Edition with 2003 Addenda.
73. Blake, Alexander, Practical Stress Analysis in Engineering Design, 2nd Ed., Marcel Dekker, Inc., 1990.
74. Boyer, H.E., "Atlas of Stress-Strain Curves," ASM International, Metals Park, OH, 1987.
75. Field Manual of the Interchange Rules as Adopted by the Association of American Railroads, Rule 88, "Mechanical Requirements for Acceptance," Washington, DC, 1986.
76. ASME Boiler and Pressure Vessel Code, Code Cases – Nuclear Components, Code Case N-595-4, "Requirements for Spent Fuel Storage Canisters Section III, Division 1," Approved May 12, 2004.
77. ANSI N45.2.1-1973, "Cleaning of Fluid Systems and Associated Components During Construction Phase of Nuclear Power Plants," American National Standards Institute, Inc., Washington, DC.
78. NUREG-2224, "Dry Storage and Transportation of High Burnup Spent Nuclear Fuel, Final Report," U.S. Nuclear Regulatory Commission, Washington, DC, November 2020.
79. SAND2018-13258R, Data Analysis of ENSA/DOE Rail Cask Tests, Spent Fuel and Waste Disposition, US Department of Energy, Spent Fuel and Waste Science and Technology, November 19, 2018.
80. U.S. Department of Energy, PNNL-17700, "PNNL Stress/Strain Correlation for Zircaloy", Geelhood, K.J, et al., July 2008.
81. Not used.

2.12.2.3.16 Parametric Study for the effect of the Maximum Accelerations versus the Shallow Angle Drop for the NAC-STC Design

The study is performed using the STC-CY Side Drop Model. The shallow angle drops are associated with the slapdown effect. For casks with L/r (ratio of the cask length to the radius of gyration of the cask about the edge) greater than 2, the effect of the shallow angle drop is to increase the accelerations during the impact of the second impact limiter. The L/r ratio for the NC-STC-CY cask is 193/105.8 = 1.82. The L/r ratio for the MAGNATRAN cask is 214/115.5 = 1.85. The two ratios are very similar to that of the MAGNATRAN cask with less than 2% difference. Therefore, the parametric study using LSDYNA program performed for the NAC-STC cask as follows and is applicable to the MAGNATRAN cask.

This increase of the acceleration is due to a torque applied to the cask CG by the force generated in the initial crushing of the first limiter to impact the rigid plane. The L/r for the NAC-STC-CY cask is less than 2, which would minimize the slapdown effect. In the NAC-STC-CY cask design, the controlling design feature is the top impact limiter due to the presence of the pockets in the limiters for the trunnions. For this reason, the first impact limiter to contact the plane is the lower impact limiter followed by a rotation of the cask leading to the impact of the top impact limiter.

To perform dynamic simulation for the shallow angles impact study, the finite element model coordinates are rotated to match the shallow slapdown angle. The shallow angle, θ, represents the slope of the side of the cask with respect to the rigid plane as shown in Figure 2.12.2-12.

Where

30 ft = the vertical distance between the lowest positions of the cask assembly at the beginning of the drop accident and at the threshold of the impact. This is the definition of the drop distance defined by the NUREG 10CFR 71.73.

ΔH = the difference of the heights of the cask Center of Gravity from beginning of the drop accident to the threshold of the impact.

L = the projected axial distance from the corner of the impact limiter to the Center of Gravity of the cask body.

θ= the shallow angle between the line formed by the lowest sides of the impact limiters and surface of the unyielding surface.

Δh = the elevated differential height of the cask Center of Gravity with respect to the unyielding surface measured from the line formed by the lowest sides of the impact limiters = $L \times \sin\theta$