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技 術 報 告 書

# 100% RIH 파단사고시 중수로용 개량핵연료의 충격해석모델 개발 및 해석



2003. 11

韓 國 原 子 力 研 究 所

# 제 출 문

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본 보고서를 이상유동 핵연료관 건전성 기술개발과제의 "100% RIH 파단사고시 중수로용 개량핵연료의 충격해석모델 개발 및 해석" 기술 보고서로 제출합니다.

2003. 11

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부록. 100% RIH 파단사고시 중수로용 개량핵연료의 충격해석 입력 자료

# 1. INTRODUCTION

There are 380 fuel channels in a CANDU-6 reactor, and twelve fuel bundles are loaded into each fuel channel. Heavy water coolant passes through the fuel bundle string to remove heat generated from the fuel. Due to the flow, a significant amount of the header-to-header pressure drop occurs in the fuel bundle string.

The hydraulic drag exerted by coolant flow past fuel bundles in a fuel channel forces the entire fuel string against the down-stream shield plug during normal reactor operations. If a break should occur in the upstream feeder, then the channel flow would rapidly reverse, forcing the string of bundles to accelerate and impact on the upstream shield plug. Should such an accident occur, the potential exists for bundle and channel damage, depending primarily on the velocity of the bundles at impact.

Energy considerations of moving fuel bundles impacting a stationary shield plug show that damage could occur to the fuel bundles, or the channel components, or both. Any significant damage to either the fuel or the fuel channel could result in coolant flow blockage, and thus pose additional safety related concerns beyond those addressed for the initial loss-of-coolant accident. Thus, the fuel bundles and the channel components are required to withstand these impact forces during a break accident of inlet piping.

A finite-element (FE) model for simulating the collision was developed using the structural analysis computer code ABAQUS [1]. The FE model was validated against the impact test results that were obtained during the normal refueling impact test performed at KAERI in 1996. The FE model was found to be in reasonable agreement with experiment results. With use of the FE model, the dynamic behavior of the fuel bundle string impacted on the shield plug was investigated and its effects on the fuel bundles and pressure tube were evaluated. The overall integrity of the fuel bundles as well as the possibility of bundle sticking or coolant flow blockage in the pressure tube was assessed.

# 2. MODEL DESCRIPTION

The FE model of a fuel bundle is presented with shell, beam and truss elements. The endplates are discretized into a series of four-noded 3-D shell elements, fuel sheathes into beam elements, and spacers into truss elements. Pressure tube and bearing pads are not modeled, and they are built into the analysis model by establishing appropriate boundary conditions. The interaction between them can be predicted by investigating the behavior of fuel elements at bearing pad locations. Figure 1 illustrates the FE model of a bundle and a shield plug. A specific description of the FE model for each component is presented in Table 1. Regarding material properties, tensile properties at 266°C are used for the analysis, which is the reactor inlet header temperature (See Table 2).

The FE model of the fuel bundle string is made by its actual alignment in the reactor fuel channel. A fuel bundle string is modeled as a row of twelve fuel bundles (Figure 2). The endplates of adjacent bundles are assumed to be in complete contact each other and their concavities are ignored. The twelve bundles are modeled to have an angle of 28 degrees clockwise, when viewed from the inlet, relative to the adjacent downstream bundle. The angle of 28 degrees is the bundle alignment angle in which the most probable pressure drop can be achieved in the pressure drop test with the CANFLEX fuel bundle string [2]. In such a manner, the actual random alignment of the twelve bundles in the fuel channel is simulated. The shield plug is modeled with three-dimensional solid elements. An FE model of the shield plug is shown in Figure 1. The shield plug is fixed by restraining all degrees of freedom of the nodes on the other side of the contact with the fuel string.

During normal reactor operations, the hydraulic drag exerted by coolant flow past fuel bundles in a fuel channel forces the entire fuel string against the down-stream shield plug. If a break should occur in the upstream feeder, then the channel flow would rapidly reverse, forcing the string of bundles to accelerate and impact on the upstream shield plug. The severity of the impact increases with the velocity of the bundle string. In this analysis, the velocity of the bundle string at impact was assumed to be 4.0 m/sec. This is a maximum velocity that is based on a 100% Reactor Inlet Header (R.I.H.) break during channel normal operation [3].

Damping by the coolant is simulated by specifying a damping factor that defines a damping contribution proportional to the mass matrix for a finite element. The damping forces that are introduced are caused by the absolute velocities of the nodes in the model. The resulting effect can be likened to the model through a viscous “ether” so that any motion of any point in the model triggers damping forces.

## 3. VALIDATION OF THE FE ANALYSIS MODEL

The FE model was validated against the test results that were obtained during the normal refueling impact test performed at KAERI in 1996. During the normal refueling sequence, a new bundle is accelerated a short distance by the coolant flow as it passes through the upstream liner hole region and hits the stationary bundles that are already in the channel.

With the use of the bundle FE model described in section 3, the normal refueling impact test was simulated. The FE model of the fuel bundle string is made by its actual alignment in the test. The endplates of adjacent bundles are assumed to be in complete contact with each other and their concavities are ignored. A fuel bundle string is modeled as a row of eleven fuel bundles, ten stationary bundles and one moving bundle. The simulated outlet shield plug supports the ten stationary bundles. The one moving bundle impacts the ten stationary bundles by hitting the upstream bundle endplate-to-endplate. The velocity of the moving bundle at impact is 2.8 m/sec, which is the actual impact speed at the test.

In the 1996 normal refueling impact test, accelerations of test bundles were not measured. Therefore, for the verification of this FE model, permanent deformations of test bundle endplates predicted by this FE model were compared to the measurements.

Figure 3 shows endplate waviness of three test bundles. They are the moving bundle, the impacted bundle and the downstream bundle supported by the shield plug. Analysis results show quite good agreement with the measurements for the moving and the impacted bundles whereas the downstream bundle shows a fairly bigger value of prediction over the measurement. This might be attributed to the imperfect simulations of the boundary condition and the damping effect by the coolant.

Figure 4 shows axial displacements in the downstream endplate of the bundle that rests on the shield plug. Test results are measurements relative to the axial displacement at the location of fuel element #1. Negative values of the displacement mean that it was pushed into the bundle. Magnitude of waviness shows quite a big difference between the measurements and the predictions but analysis results trace the measurements very well.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Dynamic Behavior of the Fuel Bundle String

Figure 5 presents energy contents of the whole model as a function of time. The deformation of the fuel bundle string transfers energy from kinetic energy to internal energy. It is seen that the internal energy increases as the kinetic energy decreases. However, much of the kinetic energy dissipates due to the damping by the water. The internal energy is the sum of the recoverable elastic energy and the plastically dissipated energy, both of which are plotted in the figure. Elastic energy rises to a peak and then falls as the elastic deformation recovers, but the plastically dissipated energy continues to rise as the fuel bundle is deformed permanently.

Figure 6 shows axial acceleration at midpoints of outer ring elements in bundles #1, #2 and #3 as a function of time. It reaches a peak of 610 g at approximately 1 ms in bundle #1. The maximum acceleration at the point decreases as the bundle is placed upstream and so does the impact force.

Figure 7 shows the histories of Von-Mises stress at six points along the length of the fuel bundle string. The stress data are taken from a point of fuel element at similar radial and circumferential locations in the bundles of #1, #3, #5, #7, #9 and #11. The stress propagates through the bundle string. The stress at the point increases as the stress travels through the point. Once the stress wave has passed completely through the point, the stress at the point oscillates about zero. The time difference between the steep stress rise in each bundle shows that it takes about 0.5 ms to transfer the impact to the adjacent bundle. The stress intensity reduces as the bundle places upstream because crushing of the downstream bundles and the water absorbed part of the impact energy.

### 4.2 Interaction between Fuel Bundle and Pressure Tube

Figure 8 shows the history of radial deflection at the midpoint of an outer ring element that shows the largest deflection in bundle #1. Magnitudes of radial deflections show a peak of 11.7 mm at approximately 14.5 ms. The radial displacements become smaller as the bundle locates upstream and the maximum displacement in bundle #3 is approximately 1.5 mm. However, radial deflection of the fuel element is constrained by the pressure tube and adjacent fuel elements in the actual CANDU reactor. Diametral clearance between the pressure tube and the bearing pad of the outer ring element is about 1 mm and the gap between the fuel elements is less than 1 mm [4]. Therefore, the fuel elements of these bundles are predicted to collide with the pressure tube or the adjacent fuel elements. The impact between fuel elements or the impact on the pressure tube is not simulated in this model. Instead, magnitudes of maximum radial velocities at midpoints of the fuel elements are calculated.

Figure 9 shows the history of radial velocities at the midpoint of an outer ring element that shows the largest velocity in bundle #1. It reaches a peak of 1.1 m/s at approximately 18 ms. In reality, however, fuel elements impact the pressure tube at a far lower velocity due to the narrow gap between the pressure tube or the adjacent fuel elements. Considering the energy balance, much of the lateral kinetic energy would be transferred to the axial kinetic energy. Therefore, damage of the pressure tube is not expected due to the impact by the reverse flow during a 100% RIH brake accident.

To investigate the possibility of bundle sticking in the pressure tube, radial displacements of the upstream and the downstream endplate of bundle #1 are calculated. Its time history showed peaks at approximately 14 ms. Figure 10 shows radial displacements of the upstream and the downstream endplate of bundle #1 at 14 ms. Upstream endplate shows a decrease of radius because the inner ring and center fuel elements bulge out and the plane figure of the endplate reduces in diameter after the impact. However, in the downstream endplate, a minor increase in diameter is observed in a part, in spite of the decrease in its diameter as a whole. Radial displacement at the location of 130 degree shows radial outward deflection of 0.3 mm, but it is smaller than the diametral clearance between the pressure tube and the outer ring element. Therefore, it can be concluded that there is a weak possibility of bundle sticking in the pressure tube.

### 4.3 Fuel Integrity

Figure 11 shows the stress contour of the downstream end plate at 5 ms. High stress appears at the junctions of the intermediate ring and the webs. Because the diameter of the shield plug inner ring is slightly smaller than the diameter of endplate intermediate ring, the shield plug cannot provide complete support for the intermediate ring. Therefore, the shield plug tends to penetrate into the intermediate ring, and junctions of the intermediate ring and the webs show large deformations. Figure 12 shows the history of the Von-Mises stress at the high stress point on the downstream end plate of bundle #1 that impacts the shield plug due to the reverse flow. The stress reaches a maximum of 281 MPa at approximately 1 ms and maintains the intensity for the rest of the calculation time. The magnitude of 281 MPa corresponds to the ultimate tensile strength of the material and the equivalent plastic strain at those points exceeded 30%.

Figure 13 shows stress contour of the downstream endplate of bundle #2, which appears different from that of bundle #1. Highest stress occurs at the outer ring of the endplate because the outer ring supports a large portion of the impact load. Figure 14 shows the maximum Von-Mises stress of the downstream endplate of bundle #2 as a function of time. The stress reaches a peak of 281 MPa at approximately 14 ms and two more peaks follow afterwards. Therefore, it is not expected that the downstream endplate is wholly free from failure.

Maximum Von-Mises stress in the fuel element is as high as 320 MPa. However, the fuel element is predicted to maintain better integrity than the endplates considering its high yield strength.

## 5. CONCLUSION

(1) An impact analysis FE model was developed to simulate the impact of the fuel bundle string against the inlet shield plug during a 100% R.I.H brake accident in a CANDU-6 reactor with use of the structural analysis code ABAQUS. This model was verified against test results on endplates axial displacements and waviness obtained from a normal refueling impact test for CANFLEX and the 37-element fuel. The predictions were in reasonable agreement with the measurements.

(2) The deformation of the fuel bundle string transfers energy from kinetic energy to internal energy and much of the kinetic energy dissipates due to the damping by water. The impact

force in bundle #1 shows a steep rise just after the impact and decays as time passes. Axial acceleration at the midpoint of outer ring elements reaches a peak of 610 g at approximately 1 ms. The impact force of the individual bundle reduces as the bundle places upstream and so does the stress intensity.

(3) Interaction between the fuel bundle and pressure tube is investigated. Lateral impact to the pressure tube by the fuel element will be small and the pressure tube damage is not expected. The deformation shape of the endplates in bundle #1 assures that the sticking of the bundles or coolant flow blockage in the pressure tube will not occur.

(4) Stress contour of the endplates in bundles #1 and #2 showed high stress intensity that corresponds to the ultimate tensile strength of the material at some points. The equivalent plastic strain at those points exceeded 30%.

**Acknowledgement**

This work was financially supported by the Nuclear Energy R&D Program of the Ministry of Science and Technology, Korea.

**References**

[1] Hibbitt, Karlson & Sorensen, Inc., “ABAQUS/Standard User’s Manual”, Ver. 5.8, 1998

[2] S. K. Chang, J. S. Park, C. H. Chung, H. C. Suk, P. Alavi, I. E. Oldaker and W.W. Inch, “Test Report - CANFLEX Fuel Bundle Impact Test”, KAERI/TR-CX-301, 1997 April.

[3] Component Verification Specification – CANFLEX Fuel Bundle Impact Test during LOCA Condition, To be issued in 2001.

[4] Fuel Bundle Design Drawing, “Joint AECL-KAERI CANFLEX 43 Element Bundle (CANDU-6) Reference Drawing”, CANFLEX-37000-1-1-GA-E, Rev. 5, KAERI/AECL, 2000 October.

**Table 1. Description of FE model for each component**

| Component | ABAQUS element type | Element description | Remark |
|---|---|---|---|
| **Endplate** | **S4R** | **4-Node, 3D Shell 6 DOF** | **422 elements per plate** |
| **Fuel sheath** | **PIPE31** | **2-Node, 3D Pipe 6 DOF** | **6 elements per rod** |
| **Spacer pad** | **T3D2** | **2-Node, 3D Truss 3 DOF** | |

**Table 2. Material properties at 266 °C [a]**

| Component | Young's modulus | Yield strength | Ultimate tensile strength | Poisson's ratio |
|---|---|---|---|---|
| **Endplate** | **79,706 MPa** | **165 MPa** | **281 MPa** | **0.4** |
| **Cladding tube** | **83,882 Mpa** | **314 MPa** | **421 MPa** | **0.4** |
| **Spacer** | **83,882 MPa** | **-** | **-** | **0.4** |

[a] Engineering Manual, DE-13(5.3-1), "Zirconium Alloys – Mechanical Properties and Corrosion Resistance", Chalk River Nuclear Laboratories Engineering Manual, 1969

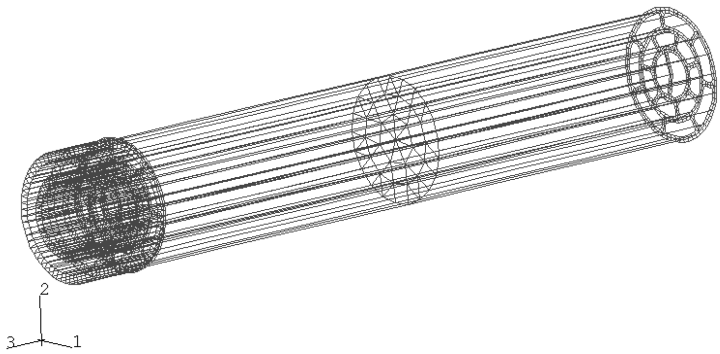


**Figure 1. FEM model for CANFLEX fuel bundle and shield plug**

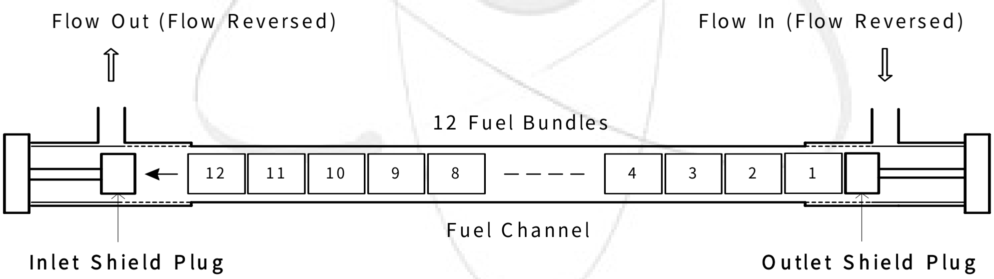


**Figure 2. Schematic diagram of fuel string impact to the inlet shield plug**

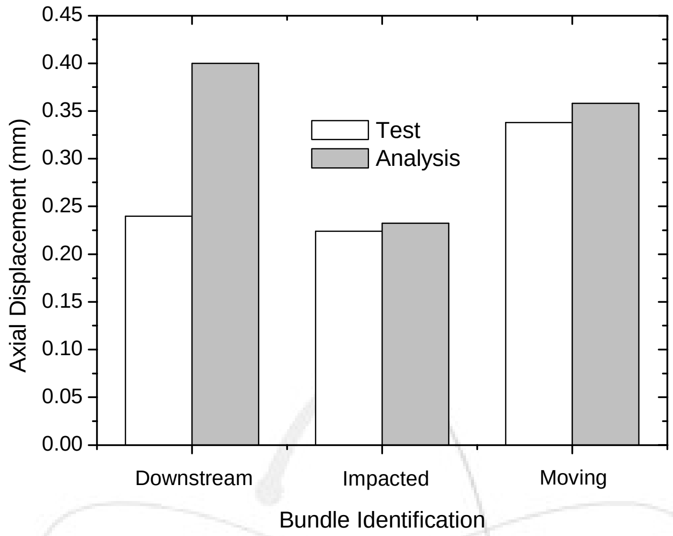


**Figure 3. Predicted vs. measured waviness in downstream endplates of three test bundles**

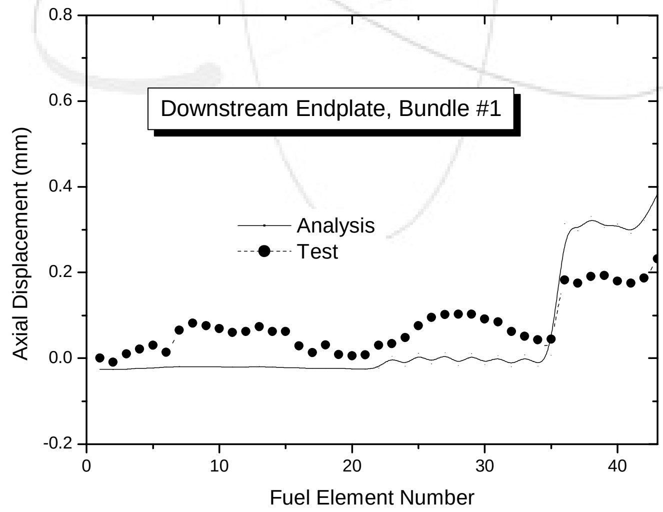


**Figure 4. Predicted vs. measured axial displacement in endplate supported by shield plug**

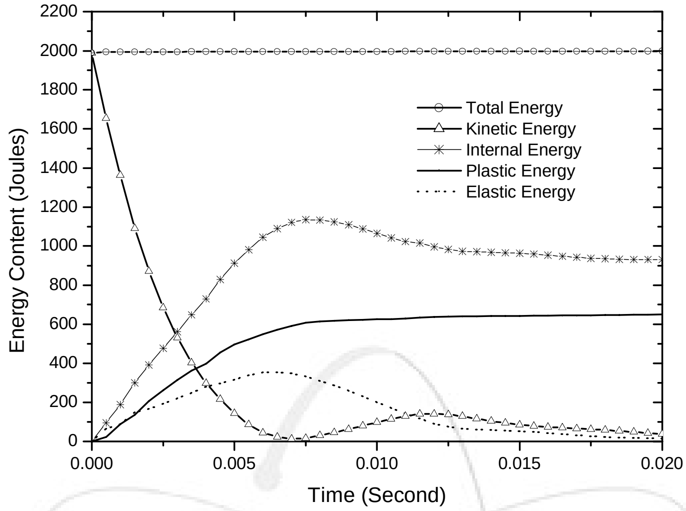


Figure 5. Energy terms as a function of time

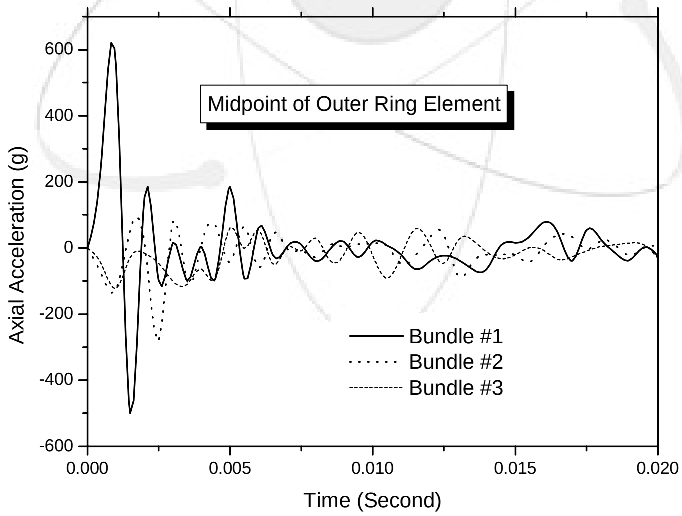


Figure 6. Axial acceleration history of bundle #1 ,#2 and #3

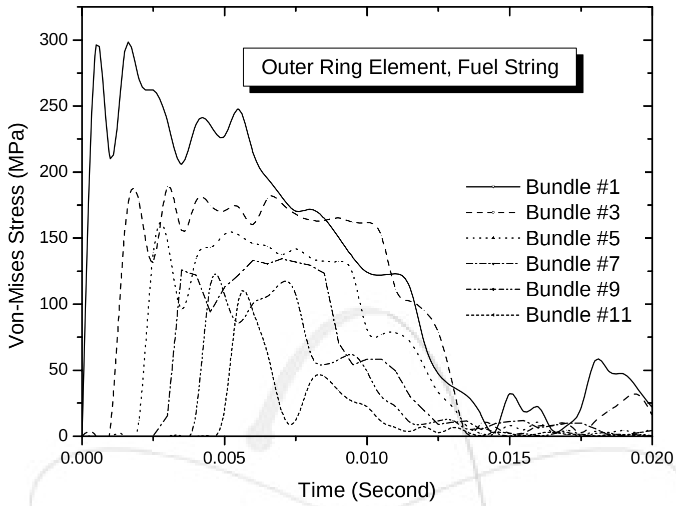


Figure 7. Time history of stress at six points along the fuel string

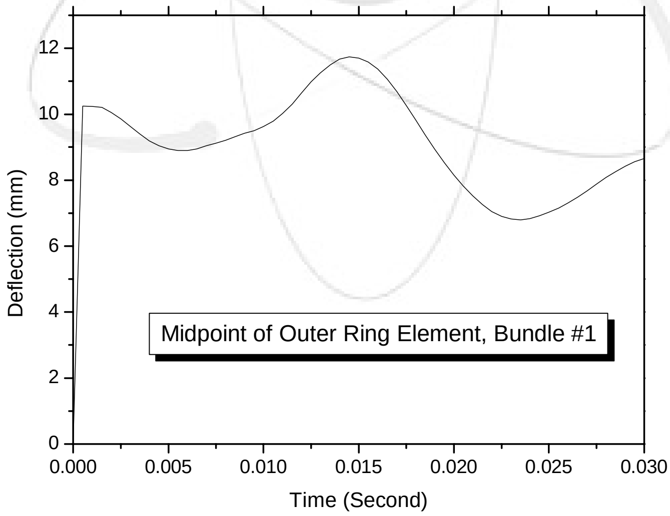


Figure 8. Radial deflection of bundle #1 outer ring element as a function of time

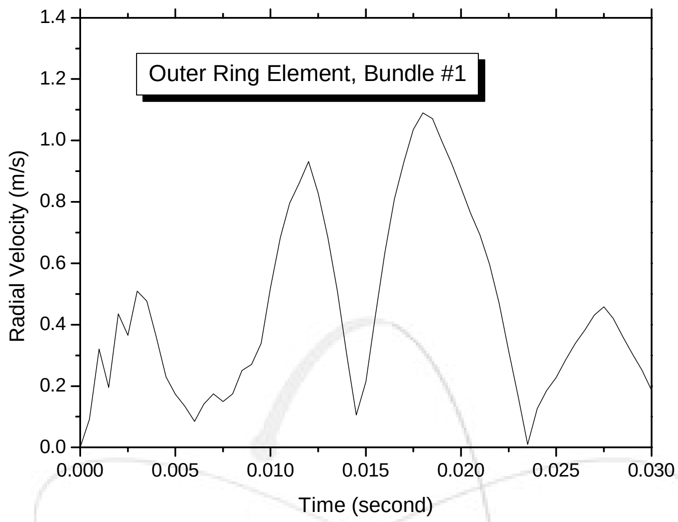


Figure 9. Radial velocity of bundle #1 outer ring element as a function of time

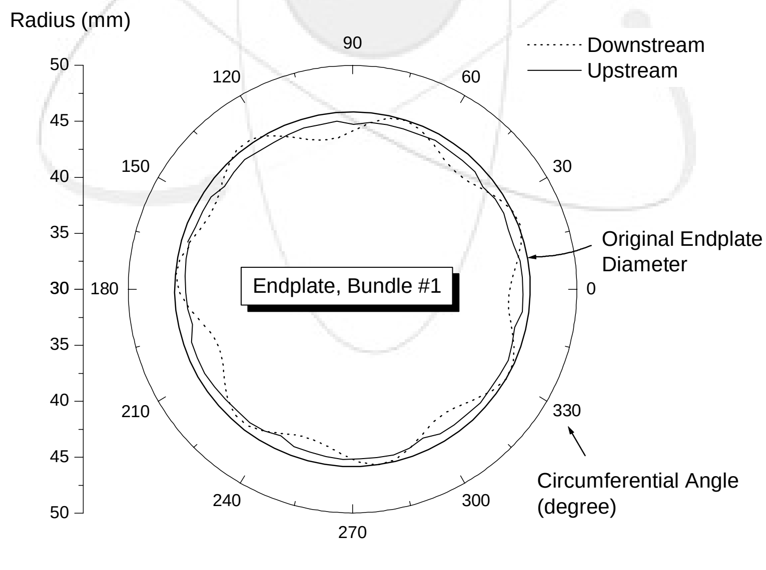


Figure 10. Radial displacement of endplates in bundle #1

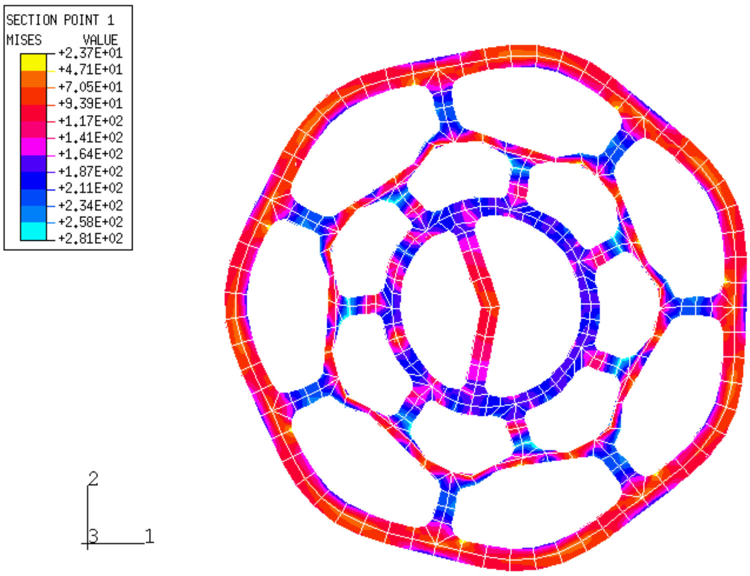


Figure 11. Stress contour of bundle #1 downstream endplate

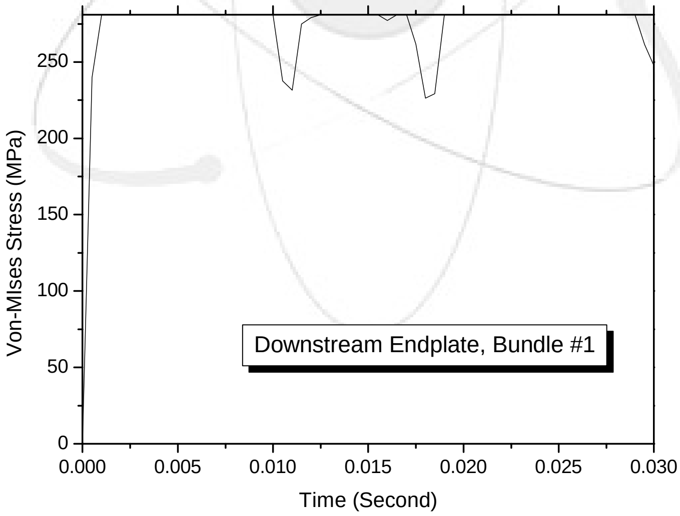


**Figure 12. Time history of Von-Mises stress at high stress area in bundle #1 downstream endplate**

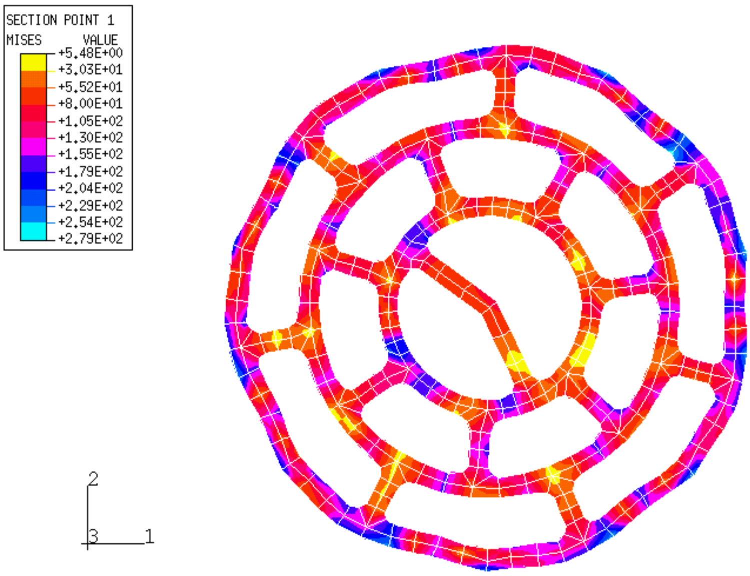


Figure 13. Stress contour of bundle #2 downstream endplate

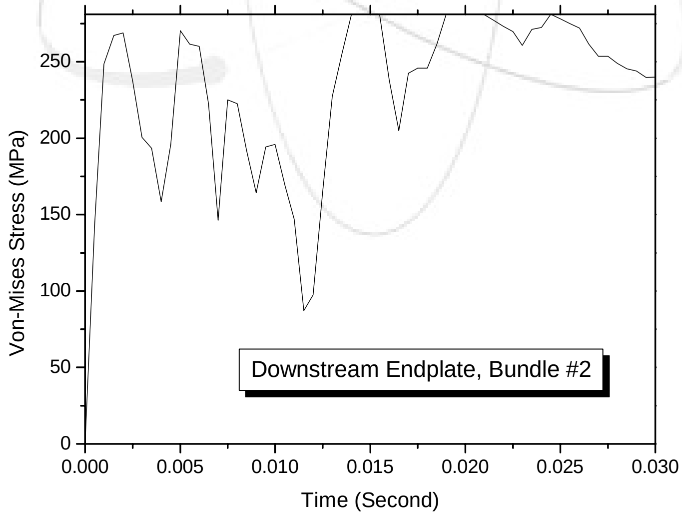


**Figure 14. Time history of Von-Mises stress at high stress area in bundle #2 downstream endplate**

# 부록 1 100% RIH 파단사고시 중수로용 핵연료의 충격해석 입력자료

```
** ABAQUS INPUT FILE UPGRADE: This input file was upgraded from
** version 5.8 or later to version 6.2 with 0 warning(s) and 0
** error(s).
**
* HEADING
CANFLEX BUNDLE 100% RIH BRAKE IMPACT ANALYSIS
UNITS :   N sec^2/mm (= g), mm, sec
Evenly distributed density
*PREPRINT,ECHO=YES,MODEL=NO,HISTORY=NO
**
**   Model Definition
**
** ENDPLATE
** OUTER RING
** OUTER NODES (N101 - N163)
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101, 45.84, 163.92857143, 0.0
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0., 0., 0., 0., 0., 1, -5.71428571
*NSET,NSET=NC1
N1, NC1
**
** MIDDLE NODES (N201 - N263)
** ELEMENTS LOCATE AT 3N+1 (N=0,1,2,3,,,20)
*NODE,NSET=N2,SYSTEM=C
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0., 0., 0., 0., 0., 1, -5.71428571
*NSET,NSET=NC2
N2, NC2
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** INNER NODES (N301 - N363)
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301, 41.84, 163.92857143, 0.0
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N3, NC3
**
** OUTER RIB
** OUTER ROOT, LEFT (N401, 403, 405,,, 413)
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N4, NC4
**
** OUTER ROOT, RIGHT (N402, 404, 406,,, 414)
*NODE,NSET=N5,SYSTEM=C
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0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC5
N5, NC5
**
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*NSET,NSET=NC6
N6, NC6
**
** OUT MIDDLE, RIGHT (N422, 424, 426,,, 434)
*NODE,NSET=N7,SYSTEM=C
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0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC7
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**
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**
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**INNER ROOT, RIGHT (N482, 484, 486,,,,494)
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0., 0., 0., 0., 0., 1, -8.57142857
*NSET,NSET=NC16
N16, NC16
**
**MIDDLE NODES (N601 - N642)
**ELEMENT LOCATE AT 3N+1 (N=0,1,2,3,,,13)
*NODE,NSET=N17,SYSTEM=C
601, 30.75, 159.64285715, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=41,SHIFT,NEW SET=NC17,OLD SET=N17
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET,NSET=NC17
N17, NC17
**
**INNER NODES (N701 - N742)
*NODE,NSET=N18,SYSTEM=C
701, 29, 159.64285715, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=41,SHIFT,NEW SET=NC18,OLD SET=N18
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET,NSET=NC18
N18, NC18
```

```
**
**OUTER RIB AGAIN - OVERWRITING
**OUTER RIB - IN MIDDLE, CENTER (N502, 508, 514,,, 538)
*NODE,NSET=N19,SYSTEM=C
502, 34.5, 152.5, 0.0
*NCOPY,CHANGE NUMBER=6,MULTIPLE=6,SHIFT,NEW SET=NC19,OLD SET=N19
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC19
N19, NC19
**
**INTERMEDIATE RIB
**OUTER ROOT, LEFT (N801, 803, 805,,, 813)
*NODE,NSET=N20,SYSTEM=C
801, 28.33, 132.00931428, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC20,OLD SET=N20
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC20
N20, NC20
**
**OUTER ROOT, RIGHT (N802, 804, 806,,, 814)
*NODE,NSET=N21,SYSTEM=C
802, 28.33, 121.56211428, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC21,OLD SET=N21
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC21
N21, NC21
**
**OUT MIDDLE, LEFT (N821, 823, 825,,, 833)
*NODE,NSET=N22,SYSTEM=C
821, 27.3, 130.38031428, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC22,OLD SET=N22
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
```

```
*NSET,NSET=NC22
N22, NC22
**
**OUT MIDDLE, RIGHT (N822, 824, 826,,, 834)
*NODE,NSET=N23,SYSTEM=C
822, 27.3, 123.19111428, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC23,OLD SET=N23
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC23
N23, NC23
**
**OUT MIDDLE, CENTER (N705, 711, 717,,, 741)
**OVERWRITE TO THE PREVIOUS DEFINED NODES
*NODE,NSET=N24,SYSTEM=C
705, 27.3, 126.78571428, 0.0
*NCOPY,CHANGE NUMBER=6,MULTIPLE=6,SHIFT,NEW SET=NC24,OLD SET=N24
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC24
N24, NC24
**
**CENTER MIDDLE, LEFT (N875, 878, 881,,, 893)
*NODE,NSET=N25,SYSTEM=C
875, 24.3225, 130.8190, 0.0
*NCOPY,CHANGE NUMBER=3,MULTIPLE=6,SHIFT,NEW SET=NC25,OLD SET=N25
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC25
N25, NC25
**
**CENTER MIDDLE, CENTER (N876, 879, 882,,, 894)
*NODE,NSET=N26,SYSTEM=C
876, 24.3225, 126.78571428, 0.0
*NCOPY,CHANGE NUMBER=3,MULTIPLE=6,SHIFT,NEW SET=NC26,OLD SET=N26
0., 0., 0.
```

```
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC26
N26, NC26
**
**CENTER MIDDLE, RIGHT (N877, 880, 883,,, 895)
*NODE,NSET=N27,SYSTEM=C
877, 24.3225, 122.7524, 0.0
*NCOPY,CHANGE NUMBER=3,MULTIPLE=6,SHIFT,NEW SET=NC27,OLD SET=N27
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC27
N27, NC27
**
**IN MIDDLE, LEFT (N841, 843, 845,,, 853)
*NODE,NSET=N28,SYSTEM=C
841, 21.345, 131.37937228, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC28,OLD SET=N28
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC28
N28, NC28
**
**IN MIDDLE, RIGHT (N842, 844, 846,,, 854)
*NODE,NSET=N29,SYSTEM=C
842, 21.345, 122.19205628, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC29,OLD SET=N29
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC29
N29, NC29
**
**INNER ROOT, LEFT (N861, 863, 865,,, 873)
*NODE,NSET=N30,SYSTEM=C
861, 19.7175, 133.76852448, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC30,OLD SET=N30
0., 0., 0.
```

```
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC30
N30, NC30
**
**INNER ROOT, RIGHT (N862, 864, 866,,, 874)
*NODE,NSET=N31,SYSTEM=C
862, 19.7175, 119.80290408, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=6,SHIFT,NEW SET=NC31,OLD SET=N31
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC31
N31, NC31
**
**INNER RING
**OUTER NODES (N901 - N942)
*NODE,NSET=N32,SYSTEM=C
901, 19.09, 146.7857, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=41,SHIFT,NEW SET=NC32,OLD SET=N32
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET,NSET=NC32
N32, NC32
**
** OUTER NODES (N904, 910,,, 940)
*NODE,NSET=N33,SYSTEM=C
904, 19.09, 115.7, 0.0
*NCOPY,CHANGE NUMBER=6,MULTIPLE=7,SHIFT,NEW SET=NC33,OLD SET=N33
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC33
N33, NC33
**
** MIDDLE NODES (N1001 - N1042)
** ELEMENTS LOCATE at 6N+1 (N=0,1,2,3,,,6)
*NODE,NSET=N34,SYSTEM=C
1001, 17.34, 146.7857, 0.0
```

```
*NCOPY,CHANGE NUMBER=1,MULTIPLE=41,SHIFT,NEW SET=NC34,OLD SET=N34
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET,NSET=NC34
N34, NC34
**
** INNER NODES (N1101 - N1142)
*NODE,NSET=N35,SYSTEM=C
1101, 15.59, 146.7857, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=41,SHIFT,NEW SET=NC35,OLD SET=N35
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET,NSET=NC35
N35, NC35
**
** INTERMEDIATE RIB AGAIN - OVERWRITING
** INTERMEDIATE RIB - IN MIDDLE, CENTER (N903, 909, 915,,, 939)
*NODE,NSET=N36,SYSTEM=C
903, 21.345, 126.78571428, 0.0
*NCOPY,CHANGE NUMBER=6,MULTIPLE=6,SHIFT,NEW SET=NC36,OLD SET=N36
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET,NSET=NC36
N36, NC36
**
** INNER RIB
** INNER RIB ROOTS (N1104, 1106, 1129, 1131)
** OVERWRITE
*NODE,NSET=N37,SYSTEM=C
1104, 14.92, 117.85314286, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=1,SHIFT,NEW SET=NC37,OLD SET=N37
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.292
*NSET,NSET=NC37
N37, NC37
**
```

```
*NODE,NSET=N38,SYSTEM=C
1129, 14.92, -91.854, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=1,SHIFT,NEW SET=NC38,OLD SET=N38
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.292
*NSET,NSET=NC38
N38, NC38
**
**N1201 - N1203
*NODE,NSET=N39,SYSTEM=C
1201, 10.4, 117.6987916, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=2,SHIFT,NEW SET=NC39,OLD SET=N39
0., 0., 0.
0., 0., 0., 0., 0., 1, -9.49164874
*NSET,NSET=NC39
N39, NC39
**
**N1204 - N1206
*NODE,NSET=N40,SYSTEM=C
1204, 10.4, -92.0083513, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=2,SHIFT,NEW SET=NC40,OLD SET=N40
0., 0., 0.
0., 0., 0., 0., 0., 1, -9.49164874
*NSET,NSET=NC40
N40, NC40
**
**N1207 - N1209
*NODE,NSET=N41,SYSTEM=C
1207, 5.2, 127.46424648, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=2,SHIFT,NEW SET=NC41,OLD SET=N41
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.25710362
*NSET,NSET=NC41
N41, NC41
**
**N1210 - N1212
```

```
*NODE,NSET=N42,SYSTEM=C
1210, 5.2, -82.2428964, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=2,SHIFT,NEW SET=NC42,OLD SET=N42
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.25710362
*NSET,NSET=NC42
N42, NC42
**
**N1213, N1215
*NODE,NSET=N43,SYSTEM=C
1213, 1.715, 183.354, 0.0
*NCOPY,CHANGE NUMBER=2,MULTIPLE=1,SHIFT,NEW SET=NC43,OLD SET=N43
0., 0., 0.
0., 0., 0., 0., 0., 1, -180
*NSET,NSET=NC43
N43, NC43
**
**N1214
*NODE,NSET=N44,SYSTEM=C
1214, 0., 0., 0.
**
** ADDITIONAL NODES FOR "ROUNDNESS" AT JUNCTION BETWEEN
** INNER RING AND INNER RIB (N1216 - N1221)
*NODE,NSET=N45,SYSTEM=C
1216, 13.59, 115.39964286, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=2,SHIFT,NEW SET=NC45,OLD SET=N45
0., 0., 0.
0., 0., 0., 0., 0., 1, -7.1925
*NSET,NSET=NC45
N45, NC45
**
*NODE,NSET=N46,SYSTEM=C
1219, 13.59, -94.3075, 0.0
*NCOPY,CHANGE NUMBER=1,MULTIPLE=2,SHIFT,NEW SET=NC46,OLD SET=N46
0., 0., 0.
0., 0., 0., 0., 0., 1, -7.1925
```

```
*NSET,NSET=NC46
N46, NC46
**
** Nset for Downstream Endplate of #1 Bundle
*NSET,NSET=NPLT1D
NC1,NC2,NC3,NC4,NC5,NC6,NC7,NC8,NC9,NC10,NC11,NC12,NC13,NC14,NC15,
NC16,NC17,NC18,NC19,NC20,NC21,NC22,NC23,NC24,NC25,NC26,NC27,NC28,
NC29,NC30,NC31,NC32,NC33,NC34,NC35,NC36,NC37,NC38,NC39,NC40,NC41,
NC42,NC43,N44,NC45,NC46
**
** AXIAL SEGMENTS
**
**N1301 TO N1448 : NODES BETWEEN 1ST AND 2ND AXIAL SEGMENTS
*NCOPY,CHANGE NUMBER=1100,SHIFT,NEW SET=N1C2,OLD SET=NC2
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=763,SHIFT,NEW SET=N1C17,OLD SET=NC17
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=405,SHIFT,NEW SET=N1C34,OLD SET=NC34
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=234,SHIFT,NEW SET=N1C44,OLD SET=N44
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NSET,NSET=NA1
N1C2, N1C17, N1C34, N1C44
**
**N1501 TO N1648 : NODES BETWEEN 2ND AND 3RD AXIAL SEGMENTS
*NCOPY,CHANGE NUMBER=200,SHIFT,NEW SET=NA2,OLD SET=NA1
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
**N1701 TO N1848 : NODES BETWEEN 3RD AND 4TH AXIAL SEGMENTS
*NCOPY,CHANGE NUMBER=200,SHIFT,NEW SET=NA3,OLD SET=NA2
0., 0., -82.55
```

```
0.,0.,0.,0.,0.,1.,0.
**
** N1901 TO N2048 : NODES BETWEEN 4TH AND 5TH AXIAL SEGMENTS
*NCOPY,CHANGE NUMBER=200,SHIFT,NEW SET=NA4,OLD SET=NA3
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
** N2101 TO N2248 : NODES BETWEEN 5TH AND 6TH AXIAL SEGMENTS
*NCOPY,CHANGE NUMBER=200,SHIFT,NEW SET=NA5,OLD SET=NA4
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
*NSET,NSET=NAA1
NA1, NA2, NA3, NA4, NA5
**
** UPSTREAM ENDPLATE - NPLT1U(N3101 - N4221)
** COPY OF NODES 101-163, 201-263, 301-363, 401-414, 421-434, 441-454, 551-557, 461-
474, 481-494
** COPY OF NODES 501-542, 601-642, 701-742, 801-814, 821-834, 841-854, 861-895
** COPY OF NODES 901-942, 1001-1042, 1101-1142, 1201-1221
*NCOPY,CHANGE NUMBER=3000,SHIFT,NEW SET=NPLT1U,OLD SET=NPLT1D
0., 0., -495.3
0.,0.,0.,0.,0.,1.,0.
**
** NODALIZATION FOR REMAINING 11 BUNDLES
**
** DOWNSTREAM ENDPLATES 11 SET MORE
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT2D,OLD SET=NPLT1D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-75
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT3D,OLD SET=NPLT2D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT4D,OLD SET=NPLT3D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
```

```
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT5D,OLD SET=NPLT4D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT6D,OLD SET=NPLT5D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT7D,OLD SET=NPLT6D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT8D,OLD SET=NPLT7D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT9D,OLD SET=NPLT8D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT10D,OLD SET=NPLT9D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,80.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT11D,OLD SET=NPLT10D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-80.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT12D,OLD SET=NPLT11D
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-80.
**
**
** SHEATH 11 SET MORE
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA2,OLD SET=NAA1
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-75.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA3,OLD SET=NAA2
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA4,OLD SET=NAA3
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
```

```
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA5,OLD SET=NAA4
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA6,OLD SET=NAA5
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA7,OLD SET=NAA6
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA8,OLD SET=NAA7
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA9,OLD SET=NAA8
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA10,OLD SET=NAA9
0., 0., -496.901
0.,0.,0.,0.,0.,1.,80.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA11,OLD SET=NAA10
0., 0., -496.901
0.,0.,0.,0.,0.,1.,80.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NAA12,OLD SET=NAA11
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-80.
**
** UPSTREAM ENDPLATES 11 set MORE
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT2U,OLD SET=NPLT1U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-75.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT3U,OLD SET=NPLT2U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT4U,OLD SET=NPLT3U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT5U,OLD SET=NPLT4U
```

```
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT6U,OLD SET=NPLT5U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT7U,OLD SET=NPLT6U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT8U,OLD SET=NPLT7U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT9U,OLD SET=NPLT8U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,0.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT10U,OLD SET=NPLT9U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,80.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT11U,OLD SET=NPLT10U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,80.
*NCOPY,CHANGE NUMBER=10000,SHIFT,NEW SET=NPLT12U,OLD SET=NPLT11U
0., 0., -496.901
0.,0.,0.,0.,0.,1.,-80.
*NSET,NSET=NPLATE
NPLT1D,NPLT2D,NPLT3D,NPLT4D,NPLT5D,NPLT6D,NPLT7D,NPLT8D,NPLT9D,NPLT10D,NPLT11D,N
PLT12D,
NPLT1U,NPLT2U,NPLT3U,NPLT4U,NPLT5U,NPLT6U,NPLT7U,NPLT8U,NPLT9U,NPLT10U,NPLT11U,N
PLT12U
*****************************************************************
** SIDE-STOP NODES (NA 5001-5363, NB 5401-5701, NC 5801-6163)
*NODE,NSET=NS1,SYSTEM=C
5001, 45.085, 163.92857143, 0.9
*NCOPY,CHANGE NUMBER=1,MULTIPLE=62,SHIFT,NEW SET=ND1,OLD SET=NS1
0., 0., 0.
0.,0.,0.,0.,0.,1.,5.71428571
*NSET,NSET=NS1
```

```
NS1, ND1
*NODE,NSET=NS2,SYSTEM=C
5101, 38.85, 163.92857143, 0.9
*NCOPY,CHANGE NUMBER=1,MULTIPLE=62,SHIFT,NEW SET=ND2,OLD SET=NS2
0., 0., 0.
0.,0.,0.,0.,0.,1.,5.71428571
*NSET,NSET=NS2
NS2, ND2
*NODE,NSET=NS3,SYSTEM=C
5201, 29.96, 163.92857143, 0.9
*NCOPY,CHANGE NUMBER=1,MULTIPLE=62,SHIFT,NEW SET=ND3,OLD SET=NS3
0., 0., 0.
0.,0.,0.,0.,0.,1.,5.71428571
*NSET,NSET=NS3
NS3, ND3
*NODE,NSET=NS4,SYSTEM=C
5301, 24.385, 163.92857143, 0.9
*NCOPY,CHANGE NUMBER=1,MULTIPLE=62,SHIFT,NEW SET=ND4,OLD SET=NS4
0., 0., 0.
0.,0.,0.,0.,0.,1.,5.71428571
*NSET,NSET=NS4
NS4, ND4
*NSET,NSET=NA
NS1, NS2, NS3, NS4
*NCOPY,CHANGE NUMBER=400,SHIFT,NEW SET=NB,OLD SET=NA
0.,0.,24.
0.,0.,0.,0.,0.,0.,0.
*NCOPY,CHANGE NUMBER=400,SHIFT,NEW SET=NC,OLD SET=NB
0.,0.,24.
0.,0.,0.,0.,0.,0.,0.
*NSET,NSET=NALL
NPLATE,NAA1,NAA2,NAA3,NAA4,NAA5,NAA6,NAA7,NAA8,NAA9,NAA10,NAA11,NAA12
**
**ELEMENTS
** SHIELD-PLUG (Side-stop) Elements (E16001 - E16252)
*ELEMENT,ELSET=E16001,TYPE=C3D8R
```

```
16001,5101,5001,5002,5102,5501,5401,5402,5502
*ELGEN,ELSET=ESTOP1
16001,62,1,1,2,400,63
*ELEMENT,ELSET=E16063,TYPE=C3D8R
16063,5163,5063,5001,5101,5563,5463,5401,5501
16126,5563,5463,5401,5501,5963,5863,5801,5901
*ELEMENT,ELSET=E16127,TYPE=C3D8R
16127,5301,5201,5202,5302,5701,5601,5602,5702
*ELGEN,ELSET=ESTOP2
16127,62,1,1,2,400,63
*ELEMENT,ELSET=E16189,TYPE=C3D8R
16189,5363,5263,5201,5301,5763,5663,5601,5701
16252,5763,5663,5601,5701,6163,6063,6001,6101
*ELSET,GENERATE,ELSET=ESTOP
16001,16252,1
*SOLID SECTION,MATERIAL=MSTOP,ELSET=ESTOP
*MATERIAL,NAME=MSTOP
*ELASTIC
200000, 0.3
*DENSITY
.000000079
**ELEMENT DEFINITION FOR CONTACT
*ELSET,GENERATE,ELSET=ESHLD1
16001, 16063, 1
*ELSET,GENERATE,ELSET=ESHLD2
16127, 16189, 1
**ENDPLATE
**OUTER RING - OUTER HALF (E9 - E71)
*ELEMENT,ELSET=EPT1D,TYPE=S4R
9, 101, 201, 202, 102
10, 102, 202, 203, 103
11, 103, 203, 204, 104
12, 104, 204, 205, 105
13, 105, 205, 206, 106
14, 106, 206, 207, 107
15, 107, 207, 208, 108
```

16, 108, 208, 209, 109
17, 109, 209, 210, 110
18, 110, 210, 211, 111
19, 111, 211, 212, 112
20, 112, 212, 213, 113
21, 113, 213, 214, 114
22, 114, 214, 215, 115
23, 115, 215, 216, 116
24, 116, 216, 217, 117
25, 117, 217, 218, 118
26, 118, 218, 219, 119
27, 119, 219, 220, 120
28, 120, 220, 221, 121
29, 121, 221, 222, 122
30, 122, 222, 223, 123
31, 123, 223, 224, 124
32, 124, 224, 225, 125
33, 125, 225, 226, 126
34, 126, 226, 227, 127
35, 127, 227, 228, 128
36, 128, 228, 229, 129
37, 129, 229, 230, 130
38, 130, 230, 231, 131
39, 131, 231, 232, 132
40, 132, 232, 233, 133
41, 133, 233, 234, 134
42, 134, 234, 235, 135
43, 135, 235, 236, 136
44, 136, 236, 237, 137
45, 137, 237, 238, 138
46, 138, 238, 239, 139
47, 139, 239, 240, 140
48, 140, 240, 241, 141
49, 141, 241, 242, 142
50, 142, 242, 243, 143
51, 143, 243, 244, 144

52, 144, 244, 245, 145
53, 145, 245, 246, 146
54, 146, 246, 247, 147
55, 147, 247, 248, 148
56, 148, 248, 249, 149
57, 149, 249, 250, 150
58, 150, 250, 251, 151
59, 151, 251, 252, 152
60, 152, 252, 253, 153
61, 153, 253, 254, 154
62, 154, 254, 255, 155
63, 155, 255, 256, 156
64, 156, 256, 257, 157
65, 157, 257, 258, 158
66, 158, 258, 259, 159
67, 159, 259, 260, 160
68, 160, 260, 261, 161
69, 161, 261, 262, 162
70, 162, 262, 263, 163
71, 163, 263, 201, 101
**OUTER RING - INNER HALF (E72 - E134)
72, 201, 301, 302, 202
73, 202, 302, 401, 203
74, 203, 402, 304, 204
75, 204, 304, 305, 205
76, 205, 305, 306, 206
77, 206, 306, 307, 207
78, 207, 307, 308, 208
79, 208, 308, 309, 209
80, 209, 309, 310, 210
81, 210, 310, 311, 211
82, 211, 311, 403, 212
83, 212, 404, 313, 213
84, 213, 313, 314, 214
85, 214, 314, 315, 215
86, 215, 315, 316, 216

87, 216, 316, 317, 217
88, 217, 317, 318, 218
89, 218, 318, 319, 219
90, 219, 319, 320, 220
91, 220, 320, 405, 221
92, 221, 406, 322, 222
93, 222, 322, 323, 223
94, 223, 323, 324, 224
95, 224, 324, 325, 225
96, 225, 325, 326, 226
97, 226, 326, 327, 227
98, 227, 327, 328, 228
99, 228, 328, 329, 229
100, 229, 329, 407, 230
101, 230, 408, 331, 231
102, 231, 331, 332, 232
103, 232, 332, 333, 233
104, 233, 333, 334, 234
105, 234, 334, 335, 235
106, 235, 335, 336, 236
107, 236, 336, 337, 237
108, 237, 337, 338, 238
109, 238, 338, 409, 239
110, 239, 410, 340, 240
111, 240, 340, 341, 241
112, 241, 341, 342, 242
113, 242, 342, 343, 243
114, 243, 343, 344, 244
115, 244, 344, 345, 245
116, 245, 345, 346, 246
117, 246, 346, 347, 247
118, 247, 347, 411, 248
119, 248, 412, 349, 249
120, 249, 349, 350, 250
121, 250, 350, 351, 251
122, 251, 351, 352, 252

123, 252, 352, 353, 253
124, 253, 353, 354, 254
125, 254, 354, 355, 255
126, 255, 355, 356, 256
127, 256, 356, 413, 257
128, 257, 414, 358, 258
129, 258, 358, 359, 259
130, 259, 359, 360, 260
131, 260, 360, 361, 261
132, 261, 361, 362, 262
133, 262, 362, 363, 263
134, 263, 363, 301, 201
** OUTER RIB (E135 - E190)
135, 401, 421, 303, 203
136, 203, 303, 422, 402
137, 421, 441, 551, 303
138, 303, 551, 442, 422
139, 441, 461, 502, 551
140, 551, 502, 462, 442
141, 461, 481, 602, 502
142, 502, 602, 482, 462
143, 403, 423, 312, 212
144, 212, 312, 424, 404
145, 423, 443, 552, 312
146, 312, 552, 444, 424
147, 443, 463, 508, 552
148, 552, 508, 464, 444
149, 483, 608, 508, 463
150, 508, 608, 484, 464
151, 425, 321, 221, 405
152, 321, 426, 406, 221
153, 445, 553, 321, 425
154, 553, 446, 426, 321
155, 465, 514, 553, 445
156, 514, 466, 446, 553
157, 485, 614, 514, 465

158, 614, 486, 466, 514
159, 428, 408, 230, 330
160, 330, 230, 407, 427
161, 448, 428, 330, 554
162, 554, 330, 427, 447
163, 468, 448, 554, 520
164, 520, 554, 447, 467
165, 488, 468, 520, 620
166, 620, 520, 467, 487
167, 339, 239, 409, 429
168, 410, 239, 339, 430
169, 555, 339, 429, 449
170, 450, 430, 339, 555
171, 526, 555, 449, 469
172, 470, 450, 555, 526
173, 626, 526, 469, 489
174, 490, 470, 526, 626
175, 412, 248, 348, 432
176, 248, 411, 431, 348
177, 432, 348, 556, 452
178, 348, 431, 451, 556
179, 452, 556, 532, 472
180, 556, 451, 471, 532
181, 472, 532, 632, 492
182, 532, 471, 491, 632
183, 413, 433, 357, 257
184, 257, 357, 434, 414
185, 433, 453, 557, 357
186, 357, 557, 454, 434
187, 453, 473, 538, 557
188, 557, 538, 474, 454
189, 473, 493, 638, 538
190, 538, 638, 494, 474
** INTERMEDIATE RING - OUTER HALF (E191-E232)
191, 501, 601, 602, 481
192, 482, 602, 603, 503

193, 503, 603, 604, 504
194, 504, 604, 605, 505
195, 505, 605, 606, 506
196, 506, 606, 607, 507
197, 507, 607, 608, 483
198, 484, 608, 609, 509
199, 509, 609, 610, 510
200, 510, 610, 611, 511
201, 511, 611, 612, 512
202, 512, 612, 613, 513
203, 513, 613, 614, 485
204, 486, 614, 615, 515
205, 515, 615, 616, 516
206, 516, 616, 617, 517
207, 517, 617, 618, 518
208, 518, 618, 619, 519
209, 519, 619, 620, 487
210, 488, 620, 621, 521
211, 521, 621, 622, 522
212, 522, 622, 623, 523
213, 523, 623, 624, 524
214, 524, 624, 625, 525
215, 525, 625, 626, 489
216, 490, 626, 627, 527
217, 527, 627, 628, 528
218, 528, 628, 629, 529
219, 529, 629, 630, 530
220, 530, 630, 631, 531
221, 531, 631, 632, 491
222, 492, 632, 633, 533
223, 533, 633, 634, 534
224, 534, 634, 635, 535
225, 535, 635, 636, 536
226, 536, 636, 637, 537
227, 537, 637, 638, 493
228, 494, 638, 639, 539

229, 539, 639, 640, 540
230, 540, 640, 641, 541
231, 541, 641, 642, 542
232, 542, 642, 601, 501
** INTERMADIATE RING - INNER HALF (E233-E274)
233, 601, 701, 702, 602
234, 602, 702, 703, 603
235, 603, 703, 704, 604
236, 604, 704, 801, 605
237, 605, 802, 706, 606
238, 606, 706, 707, 607
239, 607, 707, 708, 608
240, 608, 708, 709, 609
241, 609, 709, 710, 610
242, 610, 710, 803, 611
243, 611, 804, 712, 612
244, 612, 712, 713, 613
245, 613, 713, 714, 614
246, 614, 714, 715, 615
247, 615, 715, 716, 616
248, 616, 716, 805, 617
249, 617, 806, 718, 618
250, 618, 718, 719, 619
251, 619, 719, 720, 620
252, 620, 720, 721, 621
253, 621, 721, 722, 622
254, 622, 722, 807, 623
255, 623, 808, 724, 624
256, 624, 724, 725, 625
257, 625, 725, 726, 626
258, 626, 726, 727, 627
259, 627, 727, 728, 628
260, 628, 728, 809, 629
261, 629, 810, 730, 630
262, 630, 730, 731, 631
263, 631, 731, 732, 632

264, 632, 732, 733, 633
265, 633, 733, 734, 634
266, 634, 734, 811, 635
267, 635, 812, 736, 636
268, 636, 736, 737, 637
269, 637, 737, 738, 638
270, 638, 738, 739, 639
271, 639, 739, 740, 640
272, 640, 740, 813, 641
273, 641, 814, 742, 642
274, 642, 742, 701, 601
** INTERMEDIATE RIB (E275 - E330)
275, 801, 821, 705, 605
276, 605, 705, 822, 802
277, 821, 875, 876, 705
278, 705, 876, 877, 822
279, 875, 841, 903, 876
280, 876, 903, 842, 877
281, 861, 1003, 903, 841
282, 903, 1003, 862, 842
283, 823, 711, 611, 803
284, 711, 824, 804, 611
285, 878, 879, 711, 823
286, 879, 880, 824, 711
287, 843, 909, 879, 878
288, 909, 844, 880, 879
289, 863, 1009, 909, 843
290, 1009, 864, 844, 909
291, 825, 717, 617, 805
292, 717, 826, 806, 617
293, 881, 882, 717, 825
294, 882, 883, 826, 717
295, 845, 915, 882, 881
296, 915, 846, 883, 882
297, 865, 1015, 915, 845
298, 1015, 866, 846, 915

299, 723, 623, 807, 827
300, 828, 808, 623, 723
301, 885, 723, 827, 884
302, 886, 828, 723, 885
303, 921, 885, 884, 847
304, 848, 886, 885, 921
305, 1021, 921, 847, 867
306, 868, 848, 921, 1021
307, 629, 809, 829, 729
308, 810, 629, 729, 830
309, 729, 829, 887, 888
310, 830, 729, 888, 889
311, 888, 887, 849, 927
312, 889, 888, 927, 850
313, 927, 849, 869, 1027
314, 850, 927, 1027, 870
315, 635, 811, 831, 735
316, 812, 635, 735, 832
317, 735, 831, 890, 891
318, 832, 735, 891, 892
319, 891, 890, 851, 933
320, 892, 891, 933, 852
321, 933, 851, 871, 1033
322, 852, 933, 1033, 872
323, 813, 833, 741, 641
324, 641, 741, 834, 814
325, 833, 893, 894, 741
326, 741, 894, 895, 834
327, 893, 853, 939, 894
328, 894, 939, 854, 895
329, 853, 873, 1039, 939
330, 939, 1039, 874, 854
** INNER RING - OUTER HALF (E331-E372)
331, 901, 1001, 1002, 902
332, 902, 1002, 1003, 861
333, 862, 1003, 1004, 904

334, 904, 1004, 1005, 905
335, 905, 1005, 1006, 906
336, 906, 1006, 1007, 907
337, 907, 1007, 1008, 908
338, 908, 1008, 1009, 863
339, 1009, 1010, 910, 864
340, 910, 1010, 1011, 911
341, 911, 1011, 1012, 912
342, 912, 1012, 1013, 913
343, 913, 1013, 1014, 914
344, 914, 1014, 1015, 865
345, 866, 1015, 1016, 916
346, 916, 1016, 1017, 917
347, 917, 1017, 1018, 918
348, 918, 1018, 1019, 919
349, 919, 1019, 1020, 920
350, 920, 1020, 1021, 867
351, 868, 1021, 1022, 922
352, 922, 1022, 1023, 923
353, 923, 1023, 1024, 924
354, 924, 1024, 1025, 925
355, 925, 1025, 1026, 926
356, 926, 1026, 1027, 869
357, 870, 1027, 1028, 928
358, 928, 1028, 1029, 929
359, 929, 1029, 1030, 930
360, 930, 1030, 1031, 931
361, 931, 1031, 1032, 932
362, 932, 1032, 1033, 871
363, 872, 1033, 1034, 934
364, 934, 1034, 1035, 935
365, 935, 1035, 1036, 936
366, 936, 1036, 1037, 937
367, 937, 1037, 1038, 938
368, 938, 1038, 1039, 873
369, 874, 1039, 1040, 940

370, 940, 1040, 1041, 941
371, 941, 1041, 1042, 942
372, 942, 1042, 1001, 901
** INNER RING - INNER HALF(E373-E414)
373, 1001, 1101, 1102, 1002
374, 1002, 1102, 1103, 1003
375, 1003, 1103, 1104, 1004
376, 1004, 1104, 1105, 1005
377, 1005, 1105, 1106, 1006
378, 1006, 1106, 1107, 1007
379, 1007, 1107, 1108, 1008
380, 1008, 1108, 1109, 1009
381, 1009, 1109, 1110, 1010
382, 1010, 1110, 1111, 1011
383, 1011, 1111, 1112, 1012
384, 1012, 1112, 1113, 1013
385, 1013, 1113, 1114, 1014
386, 1014, 1114, 1115, 1015
387, 1015, 1115, 1116, 1016
388, 1016, 1116, 1117, 1017
389, 1017, 1117, 1118, 1018
390, 1018, 1118, 1119, 1019
391, 1019, 1119, 1120, 1020
392, 1020, 1120, 1121, 1021
393, 1021, 1121, 1122, 1022
394, 1022, 1122, 1123, 1023
395, 1023, 1123, 1124, 1024
396, 1024, 1124, 1125, 1025
397, 1025, 1125, 1126, 1026
398, 1026, 1126, 1127, 1027
399, 1027, 1127, 1128, 1028
400, 1028, 1128, 1129, 1029
401, 1029, 1129, 1130, 1030
402, 1030, 1130, 1131, 1031
403, 1031, 1131, 1132, 1032
404, 1032, 1132, 1133, 1033

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405, 1033, 1133, 1134, 1034
406, 1034, 1134, 1135, 1035
407, 1035, 1135, 1136, 1036
408, 1036, 1136, 1137, 1037
409, 1037, 1137, 1138, 1038
410, 1038, 1138, 1139, 1039
411, 1039, 1139, 1140, 1040
412, 1040, 1140, 1141, 1041
413, 1041, 1141, 1142, 1042
414, 1042, 1142, 1101, 1001
** INNER RIB (E415 - E430)
415, 1104, 1216, 1217, 1105
416, 1105, 1217, 1218, 1106
417, 1216, 1201, 1202, 1217
418, 1217, 1202, 1203, 1218
419, 1201, 1207, 1208, 1202
420, 1202, 1208, 1209, 1203
421, 1207, 1213, 1214, 1208
422, 1208, 1214, 1215, 1209
423, 1213, 1212, 1211, 1214
424, 1214, 1211, 1210, 1215
425, 1212, 1206, 1205, 1211
426, 1211, 1205, 1204, 1210
427, 1221, 1220, 1205, 1206
428, 1220, 1219, 1204, 1205
429, 1131, 1130, 1220, 1221
430, 1130, 1129, 1219, 1220
**GENERATION OF UPSTREAM ENDPLATE ELEMENTS (ELE.NO431-852/NODE NO3101-4221)
*ELEMENT,ELSET=EPLT1U,TYPE=S4R
*ELCOPY,OLD SET=EPT1D,NEW SET=EPLT1U,ELEMENT SHIFT=422,SHIFT NODES=3000
**
** SHEATH ELEMENTS
** 1ST SEGMENT (EL. 853 - 895)
*ELEMENT,ELSET=ETUBES1,TYPE=B31
853, 201, 1301
854, 204, 1304
```

855, 207, 1307
856, 210, 1310
857, 213, 1313
858, 216, 1316
859, 219, 1319
860, 222, 1322
861, 225, 1325
862, 228, 1328
863, 231, 1331
864, 234, 1334
865, 237, 1337
866, 240, 1340
867, 243, 1343
868, 246, 1346
869, 249, 1349
870, 252, 1352
871, 255, 1355
872, 258, 1358
873, 261, 1361
874, 601, 1364
875, 604, 1367
876, 607, 1370
877, 610, 1373
878, 613, 1376
879, 616, 1379
880, 619, 1382
881, 622, 1385
882, 625, 1388
883, 628, 1391
884, 631, 1394
885, 634, 1397
886, 637, 1400
887, 640, 1403
**
*ELEMENT,ELSET=ETUBEL1,TYPE=B31
888, 1001, 1406

889, 1007, 1412
890, 1013, 1418
891, 1019, 1424
892, 1025, 1430
893, 1031, 1436
894, 1037, 1442
895, 1214, 1448
**
** 2ND SEGMENT (EL 896-938)
*ELEMENT,ELSET=ETUBES2,TYPE=B31
896, 1301, 1501
897, 1304, 1504
898, 1307, 1507
899, 1310, 1510
900, 1313, 1513
901, 1316, 1516
902, 1319, 1519
903, 1322, 1522
904, 1325, 1525
905, 1328, 1528
906, 1331, 1531
907, 1334, 1534
908, 1337, 1537
909, 1340, 1540
910, 1343, 1543
911, 1346, 1546
912, 1349, 1549
913, 1352, 1552
914, 1355, 1555
915, 1358, 1558
916, 1361, 1561
917, 1364, 1564
918, 1367, 1567
919, 1370, 1570
920, 1373, 1573
921, 1376, 1576

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922, 1379, 1579
923, 1382, 1582
924, 1385, 1585
925, 1388, 1588
926, 1391, 1591
927, 1394, 1594
928, 1397, 1597
929, 1400, 1600
930, 1403, 1603
**Consequtive Copy of Segments
**3rd Segment (EL 939-973) by copying 2nd segment
*ELEMENT,ELSET=ETUBES3,TYPE=B31
*ELCOPY,OLD SET=ETUBES2,NEW SET=ETUBES3,ELEMENT SHIFT=43,SHIFT NODES=200
**4th Segment (EL 982-1017) by copying 3rd segment
*ELEMENT,ELSET=ETUBES4,TYPE=B31
*ELCOPY,OLD SET=ETUBES3,NEW SET=ETUBES4,ELEMENT SHIFT=43,SHIFT NODES=200
**5th Segment (EL 1025-1059) by copying 4th segment
*ELEMENT,ELSET=ETUBES5,TYPE=B31
*ELCOPY,OLD SET=ETUBES4,NEW SET=ETUBES5,ELEMENT SHIFT=43,SHIFT NODES=200
**
*ELEMENT,ELSET=ETUBEL2,TYPE=B31
931, 1406, 1606
932, 1412, 1612
933, 1418, 1618
934, 1424, 1624
935, 1430, 1630
936, 1436, 1636
937, 1442, 1642
938, 1448, 1648
**Consequtive Copy of Segments
**3rd Segment (EL 974-981) by copying 2nd segment
*ELEMENT,ELSET=ETUBEL3,TYPE=B31
*ELCOPY,OLD SET=ETUBEL2,NEW SET=ETUBEL3,ELEMENT SHIFT=43,SHIFT NODES=200
**4th Segment (EL 1018-1024) by copying 3rd segment
*ELEMENT,ELSET=ETUBEL4,TYPE=B31
*ELCOPY,OLD SET=ETUBEL3,NEW SET=ETUBEL4,ELEMENT SHIFT=43,SHIFT NODES=200
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**5th Segment (EL 1060-1067) by copying 4th segment
*ELEMENT,ELSET=ETUBEL5,TYPE=B31
*ELCOPY,OLD SET=ETUBEL4,NEW SET=ETUBEL5,ELEMENT SHIFT=43,SHIFT NODES=200
**
**6TH SEGMENT (EL 1068-1110)
*ELEMENT,ELSET=ETUBES6,TYPE=B31
1068, 2101, 3201
1069, 2104, 3204
1070, 2107, 3207
1071, 2110, 3210
1072, 2113, 3213
1073, 2116, 3216
1074, 2119, 3219
1075, 2122, 3222
1076, 2125, 3225
1077, 2128, 3228
1078, 2131, 3231
1079, 2134, 3234
1080, 2137, 3237
1081, 2140, 3240
1082, 2143, 3243
1083, 2146, 3246
1084, 2149, 3249
1085, 2152, 3252
1086, 2155, 3255
1087, 2158, 3258
1088, 2161, 3261
1089, 2164, 3601
1090, 2167, 3604
1091, 2170, 3607
1092, 2173, 3610
1093, 2176, 3613
1094, 2179, 3616
1095, 2182, 3619
1096, 2185, 3622
1097, 2188, 3625
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1098, 2191, 3628
1099, 2194, 3631
1100, 2197, 3634
1101, 2200, 3637
1102, 2203, 3640
*ELSET,ELSET=ES1
ETUBES1,ETUBES2,ETUBES3,ETUBES4,ETUBES5,ETUBES6,
**
*ELEMENT,ELSET=ETUBEL6,TYPE=B31
1103, 2206, 4001
1104, 2212, 4007
1105, 2218, 4013
1106, 2224, 4019
1107, 2230, 4025
1108, 2236, 4031
1109, 2242, 4037
1110, 2248, 4214
*ELSET,ELSET=EL1
ETUBEL1, ETUBEL2, ETUBEL3, ETUBEL4, ETUBEL5, ETUBEL6
**
**SPACER (EL 1111-1201)
*ELEMENT,ELSET=ESPAC1,TYPE=T3D2
1111, 1701, 1704
1112, 1704, 1707
1113, 1707, 1710
1114, 1710, 1713
1115, 1713, 1716
1116, 1716, 1719
1117, 1719, 1722
1118, 1722, 1725
1119, 1725, 1728
1120, 1728, 1731
1121, 1731, 1734
1122, 1734, 1737
1123, 1737, 1740
1124, 1740, 1743
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1125, 1743, 1746
1126, 1746, 1749
1127, 1749, 1752
1128, 1752, 1755
1129, 1755, 1758
1130, 1758, 1761
1131, 1761, 1701
1132, 1764, 1767
1133, 1767, 1770
1134, 1770, 1773
1135, 1773, 1776
1136, 1776, 1779
1137, 1779, 1782
1138, 1782, 1785
1139, 1785, 1788
1140, 1788, 1791
1141, 1791, 1794
1142, 1794, 1797
1143, 1797, 1800
1144, 1800, 1803
1145, 1803, 1764
1146, 1806, 1812
1147, 1812, 1818
1148, 1818, 1824
1149, 1824, 1830
1150, 1830, 1836
1151, 1836, 1842
1152, 1842, 1806
1153, 1701, 1764
1154, 1764, 1806
1155, 1806, 1848
1156, 1704, 1764
1157, 1704, 1767
1158, 1767, 1806
1159, 1707, 1767
1160, 1710, 1770

1161, 1770, 1812
1162, 1713, 1770
1163, 1713, 1773
1164, 1773, 1812
1165, 1716, 1773
1166, 1812, 1848
1167, 1719, 1776
1168, 1776, 1818
1169, 1818, 1848
1170, 1722, 1776
1171, 1722, 1779
1172, 1779, 1818
1173, 1725, 1779
1174, 1728, 1782
1175, 1782, 1824
1176, 1824, 1848
1177, 1731, 1782
1178, 1731, 1785
1179, 1785, 1824
1180, 1734, 1785
1181, 1737, 1788
1182, 1788, 1830
1183, 1830, 1848
1184, 1740, 1788
1185, 1740, 1791
1186, 1791, 1830
1187, 1743, 1791
1188, 1746, 1794
1189, 1794, 1836
1190, 1836, 1848
1191, 1749, 1794
1192, 1749, 1797
1193, 1797, 1836
1194, 1752, 1797
1195, 1755, 1800
1196, 1800, 1842

```
1197, 1842, 1848
1198, 1758, 1800
1199, 1758, 1803
1200, 1803, 1842
1201, 1761, 1803
**
**Generation of Elements for Bundles #2 - #12 (EL 1245-?????)
**Element Shift=1236 for #2, 844 for others, Shift Nodes:10000
**Bundle #2, Downstream Endplate, EL 1245-1666
*ELEMENT,ELSET=EPLT2D,TYPE=S4R
*ELCOPY,OLD SET=EPT1D,NEW SET=EPLT2D,ELEMENT SHIFT=1236,SHIFT NODES=10000
**Bundle #2, Upstream Endplate, EL 1667-2088
*ELEMENT,ELSET=EPLT2U,TYPE=S4R
*ELCOPY,OLD SET=EPLT1U,NEW SET=EPLT2U,ELEMENT SHIFT=1236,SHIFT NODES=10000
**Bundle #3, Downstream Endplate, EL 2089-2510
*ELEMENT,ELSET=EPLT3D,TYPE=S4R
*ELCOPY,OLD SET=EPLT2D,NEW SET=EPLT3D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #3, Upstream Endplate, EL 2511-2932
*ELEMENT,ELSET=EPLT3U,TYPE=S4R
*ELCOPY,OLD SET=EPLT2U,NEW SET=EPLT3U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #4, Downstream Endplate, EL 2933-3354
*ELEMENT,ELSET=EPLT4D,TYPE=S4R
*ELCOPY,OLD SET=EPLT3D,NEW SET=EPLT4D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #4, Upstream Endplate, EL 3355-3776
*ELEMENT,ELSET=EPLT4U,TYPE=S4R
*ELCOPY,OLD SET=EPLT3U,NEW SET=EPLT4U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #5, Downstream Endplate, EL 3777-4198
*ELEMENT,ELSET=EPLT5D,TYPE=S4R
*ELCOPY,OLD SET=EPLT4D,NEW SET=EPLT5D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #5, Upstream Endplate, EL 4199-4620
*ELEMENT,ELSET=EPLT5U,TYPE=S4R
*ELCOPY,OLD SET=EPLT4U,NEW SET=EPLT5U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #6, Downstream Endplate, EL 4621-5042
*ELEMENT,ELSET=EPLT6D,TYPE=S4R
*ELCOPY,OLD SET=EPLT5D,NEW SET=EPLT6D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #6, Upstream Endplate, EL 5043-5464
```

```
*ELEMENT,ELSET=EPLT6U,TYPE=S4R
*ELCOPY,OLD SET=EPLT5U,NEW SET=EPLT6U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #7, Downstream Endplate, EL 5465-5886
*ELEMENT,ELSET=EPLT7D,TYPE=S4R
*ELCOPY,OLD SET=EPLT6D,NEW SET=EPLT7D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #7, Upstream Endplate, EL 5887-6308
*ELEMENT,ELSET=EPLT7U,TYPE=S4R
*ELCOPY,OLD SET=EPLT6U,NEW SET=EPLT7U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #8, Downstream Endplate, EL 6309-6730
*ELEMENT,ELSET=EPLT8D,TYPE=S4R
*ELCOPY,OLD SET=EPLT7D,NEW SET=EPLT8D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #8, Upstream Endplate, EL 6731-7152
*ELEMENT,ELSET=EPLT8U,TYPE=S4R
*ELCOPY,OLD SET=EPLT7U,NEW SET=EPLT8U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #9, Downstream Endplate, EL 7153-7574
*ELEMENT,ELSET=EPLT9D,TYPE=S4R
*ELCOPY,OLD SET=EPLT8D,NEW SET=EPLT9D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #9, Upstream Endplate, EL 7575-7996
*ELEMENT,ELSET=EPLT9U,TYPE=S4R
*ELCOPY,OLD SET=EPLT8U,NEW SET=EPLT9U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #10, Downstream Endplate, EL 7997-8418
*ELEMENT,ELSET=EPLT10D,TYPE=S4R
*ELCOPY,OLD SET=EPLT9D,NEW SET=EPLT10D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #10, Upstream Endplate, EL 8419-8840
*ELEMENT,ELSET=EPLT10U,TYPE=S4R
*ELCOPY,OLD SET=EPLT9U,NEW SET=EPLT10U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #11, Downstream Endplate, EL 8841-9262
*ELEMENT,ELSET=EPLT11D,TYPE=S4R
*ELCOPY,OLD SET=EPLT10D,NEW SET=EPLT11D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #11, Upstream Endplate, EL 9263-9684
*ELEMENT,ELSET=EPLT11U,TYPE=S4R
*ELCOPY,OLD SET=EPLT10U,NEW SET=EPLT11U,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #12, Downstream Endplate, EL 9685-10106
*ELEMENT,ELSET=EPLT12D,TYPE=S4R
*ELCOPY,OLD SET=EPLT11D,NEW SET=EPLT12D,ELEMENT SHIFT=844,SHIFT NODES=10000
**Bundle #12, Upstream Endplate, EL 10107-10528
```

```
*ELEMENT,ELSET=EPLT12U,TYPE=S4R
*ELCOPY,OLD SET=EPLT11U,NEW SET=EPLT12U,ELEMENT SHIFT=844,SHIFT NODES=10000
*ELSET,ELSET=EPLATE
EPT1D,EPLT2D,EPLT3D,EPLT4D,EPLT5D,EPLT6D,EPLT7D,EPLT8D,EPLT9D,EPLT10D,EPLT11D,
EPLT12D,EPLT1U,EPLT2U,EPLT3U,EPLT4U,EPLT5U,EPLT6U,EPLT7U,EPLT8U,EPLT9U,EPLT10U,
EPLT11U,EPLT12U
*SHELL SECTION,MATERIAL=MPLATE,ELSET=EPLATE
1.60,
*MATERIAL,NAME=MPLATE
*ELASTIC
79706.0, 0.40
*PLASTIC
170., 0.0
286., 0.20
*DENSITY
.000000007
*DAMPING,ALPHA=130.
**.000000006653(original )
**
** Tube Elements for #2 - #12 Bundles (EL 11373-14210)
** SMALL DIA TUBE
*ELEMENT,ELSET=ES2,TYPE=B31
*ELCOPY,OLD SET=ES1,NEW SET=ES2,ELEMENT SHIFT=10520,SHIFT NODES=10000
*ELEMENT,ELSET=ES3,TYPE=B31
*ELCOPY,OLD SET=ES2,NEW SET=ES3,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES4,TYPE=B31
*ELCOPY,OLD SET=ES3,NEW SET=ES4,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES5,TYPE=B31
*ELCOPY,OLD SET=ES4,NEW SET=ES5,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES6,TYPE=B31
*ELCOPY,OLD SET=ES5,NEW SET=ES6,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES7,TYPE=B31
*ELCOPY,OLD SET=ES6,NEW SET=ES7,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES8,TYPE=B31
*ELCOPY,OLD SET=ES7,NEW SET=ES8,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES9,TYPE=B31
```

```
*ELCOPY,OLD SET=ES8,NEW SET=ES9,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES10,TYPE=B31
*ELCOPY,OLD SET=ES9,NEW SET=ES10,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES11,TYPE=B31
*ELCOPY,OLD SET=ES10,NEW SET=ES11,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=ES12,TYPE=B31
*ELCOPY,OLD SET=ES11,NEW SET=ES12,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELSET,ELSET=ES
ES1,ES2,ES3,ES4,ES5,ES6,ES7,ES8,ES9,ES10,ES11,ES12
*BEAM SECTION,MATERIAL=MSTUBE,SECTION=PIPE,ELSET=ES
5.75, 0.33
1., 0., 0.
*MATERIAL,NAME=MSTUBE
*ELASTIC
83882.0, 0.4
*PLASTIC
314., 0.0
421., 0.19
*DENSITY
.000000079
*DAMPING,ALPHA=130.
**
**
** LARGE DIA TUBE
*ELEMENT,ELSET=EL2,TYPE=B31
*ELCOPY,OLD SET=EL1,NEW SET=EL2,ELEMENT SHIFT=10520,SHIFT NODES=10000
*ELEMENT,ELSET=EL3,TYPE=B31
*ELCOPY,OLD SET=EL2,NEW SET=EL3,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL4,TYPE=B31
*ELCOPY,OLD SET=EL3,NEW SET=EL4,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL5,TYPE=B31
*ELCOPY,OLD SET=EL4,NEW SET=EL5,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL6,TYPE=B31
*ELCOPY,OLD SET=EL5,NEW SET=EL6,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL7,TYPE=B31
*ELCOPY,OLD SET=EL6,NEW SET=EL7,ELEMENT SHIFT=258,SHIFT NODES=10000
```

```
*ELEMENT,ELSET=EL8,TYPE=B31
*ELCOPY,OLD SET=EL7,NEW SET=EL8,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL9,TYPE=B31
*ELCOPY,OLD SET=EL8,NEW SET=EL9,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL10,TYPE=B31
*ELCOPY,OLD SET=EL9,NEW SET=EL10,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL11,TYPE=B31
*ELCOPY,OLD SET=EL10,NEW SET=EL11,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELEMENT,ELSET=EL12,TYPE=B31
*ELCOPY,OLD SET=EL11,NEW SET=EL12,ELEMENT SHIFT=258,SHIFT NODES=10000
*ELSET,ELSET=EL
EL1,EL2,EL3,EL4,EL5,EL6,EL7,EL8,EL9,EL10,EL11,EL12
*BEAM SECTION,MATERIAL=MLTUBE,SECTION=PIPE,ELSET=EL
6.75, 0.36
1., 0., 0.
*MATERIAL,NAME=MLTUBE
*ELASTIC
83882.0, 0.4
*PLASTIC
314., 0.0
421., 0.19
*DENSITY
.000000087
*DAMPING,ALPHA=130.
**
*ELSET,ELSET=ETUBE
ES, EL
** Spacer Elements for #2 - #11 Bundles (EL 14469-15378)
*ELEMENT,ELSET=ESPAC2,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC1,NEW SET=ESPAC2,ELEMENT SHIFT=13358,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC3,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC2,NEW SET=ESPAC3,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC4,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC3,NEW SET=ESPAC4,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC5,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC4,NEW SET=ESPAC5,ELEMENT SHIFT=91,SHIFT NODES=10000
```

```
*ELEMENT,ELSET=ESPAC6,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC5,NEW SET=ESPAC6,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC7,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC6,NEW SET=ESPAC7,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC8,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC7,NEW SET=ESPAC8,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC9,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC8,NEW SET=ESPAC9,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC10,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC9,NEW SET=ESPAC10,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC11,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC10,NEW SET=ESPAC11,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELEMENT,ELSET=ESPAC12,TYPE=T3D2
*ELCOPY,OLD SET=ESPAC11,NEW SET=ESPAC12,ELEMENT SHIFT=91,SHIFT NODES=10000
*ELSET,ELSET=ESPAC
ESPAC1,ESPAC2,ESPAC3,ESPAC4,ESPAC5,ESPAC6,ESPAC7,ESPAC8,
ESPAC9, ESPAC10,ESPAC11,ESPAC12
*SOLID SECTION,MATERIAL=MSPACER,ELSET=ESPAC
100,
*MATERIAL,NAME=MSPACER
*ELASTIC
83882., 0.4
*DENSITY
1E-15,
*DAMPING,ALPHA=130.
**
** APPLY BOUNDARY CONDITIONS
*NSET,NSET=NCNTR,GENERATE
1214,121214,10000
4214,124214,10000
*NSET,NSET=NSTOP,GENERATE
5801, 5863, 1
5901, 5963, 1
6001, 6063, 1
6101, 6163, 1
*BOUNDARY
```

```
NSTOP, 1, 3
NCNTR, 1, 2
*NSET,NSET=IMPACT
NALL
*INITIAL CONDITION,TYPE=VELOCITY
IMPACT, 3, 4.0E3
**
*NSET,NSET=UX
NPLT1D,NPLT1U,NAA1
*NSET,NSET=U3,GENERATE
201,263,1
601,642,1
1001,1042,1
1214,1214,1
3201,3263,1
3601,3642,1
4001,4042,1
4214,4214,1
*NSET,NSET=U33,GENERATE
201,261,3
601,640,3
1001,1037,6
1214,1214,1
3201,3261,3
3601,3640,3
4001,4037,6
4214,4214,1
**
****************** HISTORY DATA*****************
*SURFACE,NAME=PLATE1,TYPE=ELEMENT, MAX RATIO
EPT1D, SPOS
*SURFACE,NAME=SHLD1,TYPE=ELEMENT, MAX RATIO
ESHLD1, S1
*SURFACE,NAME=PLATE2,TYPE=ELEMENT, MAX RATIO
EPT1D, SPOS
*SURFACE,NAME=SHLD2,TYPE=ELEMENT, MAX RATIO
```

```
ESHLD2, S1
*SURFACE,NAME=SURF1U,TYPE=ELEMENT, MAX RATIO
EPLT1U, SNEG
*SURFACE,NAME=SURF2D,TYPE=ELEMENT, MAX RATIO
EPLT2D, SPOS
*SURFACE,NAME=SURF2U,TYPE=ELEMENT, MAX RATIO
EPLT2U, SNEG
*SURFACE,NAME=SURF3D,TYPE=ELEMENT, MAX RATIO
EPLT3D, SPOS
*SURFACE,NAME=SURF3U,TYPE=ELEMENT, MAX RATIO
EPLT3U, SNEG
*SURFACE,NAME=SURF4D,TYPE=ELEMENT, MAX RATIO
EPLT4D, SPOS
*SURFACE,NAME=SURF4U,TYPE=ELEMENT, MAX RATIO
EPLT4U, SNEG
*SURFACE,NAME=SURF5D,TYPE=ELEMENT, MAX RATIO
EPLT5D, SPOS
*SURFACE,NAME=SURF5U,TYPE=ELEMENT, MAX RATIO
EPLT5U, SNEG
*SURFACE,NAME=SURF6D,TYPE=ELEMENT, MAX RATIO
EPLT6D, SPOS
*SURFACE,NAME=SURF6U,TYPE=ELEMENT, MAX RATIO
EPLT6U, SNEG
*SURFACE,NAME=SURF7D,TYPE=ELEMENT, MAX RATIO
EPLT7D, SPOS
*SURFACE,NAME=SURF7U,TYPE=ELEMENT, MAX RATIO
EPLT7U, SNEG
*SURFACE,NAME=SURF8D,TYPE=ELEMENT, MAX RATIO
EPLT8D, SPOS
*SURFACE,NAME=SURF8U,TYPE=ELEMENT, MAX RATIO
EPLT8U, SNEG
*SURFACE,NAME=SURF9D,TYPE=ELEMENT, MAX RATIO
EPLT9D, SPOS
*SURFACE,NAME=SURF9U,TYPE=ELEMENT, MAX RATIO
EPLT9U, SNEG
*SURFACE,NAME=SURF10D,TYPE=ELEMENT, MAX RATIO
```

```
EPLT10D, SPOS
*SURFACE,NAME=SURF10U,TYPE=ELEMENT, MAX RATIO
EPLT10U, SNEG
*SURFACE,NAME=SURF11D,TYPE=ELEMENT, MAX RATIO
EPLT11D, SPOS
*SURFACE,NAME=SURF11U,TYPE=ELEMENT, MAX RATIO
EPLT11U, SNEG
*SURFACE,NAME=SURF12D,TYPE=ELEMENT, MAX RATIO
EPLT12D, SPOS
*NSET, NSET=NOUT1
NAA1,NAA2,NAA3,NAA4,NAA5,NAA6,NAA7,NAA8,NAA9,NAA10,NAA11,NAA12
*ELSET,ELSET=EALL
ETUBE,EPLATE
*STEP
CANFLEX IMPACT
*DYNAMIC,EXPLICIT
, 0.02
*diagnostics,deformation speed check=detail
** CONTACT DEFINITION FOR SIDE-STOP
*CONTACT PAIR,INTERACTION=NOFRIC1,small sliding
PLATE1, SHLD1
*SURFACE INTERACTION,NAME=NOFRIC1
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC2,small sliding
PLATE2, SHLD2
*SURFACE INTERACTION,NAME=NOFRIC2
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
** DEFINITION FOR CONTACTS BETWEEN ENDPLATES - DOWNSTREAM
*CONTACT PAIR,INTERACTION=NOFRIC3,small sliding
SURF2D, SURF1U
*SURFACE INTERACTION,NAME=NOFRIC3
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
```

```
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC4,small sliding
SURF2U, SURF3D
*SURFACE INTERACTION,NAME=NOFRIC4
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC5,small sliding
SURF3U, SURF4D
*SURFACE INTERACTION,NAME=NOFRIC5
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC6,small sliding
SURF4U, SURF5D
*SURFACE INTERACTION,NAME=NOFRIC6
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC7,small sliding
SURF5U, SURF6D
*SURFACE INTERACTION,NAME=NOFRIC7
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC8,small sliding
SURF6U, SURF7D
*SURFACE INTERACTION,NAME=NOFRIC8
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC9,small sliding
SURF7U, SURF8D
*SURFACE INTERACTION,NAME=NOFRIC9
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
```

```
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC10,small sliding
SURF8U, SURF9D
*SURFACE INTERACTION,NAME=NOFRIC10
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*CONTACT PAIR,INTERACTION=NOFRIC11,small sliding
SURF9U, SURF10D
*SURFACE INTERACTION,NAME=NOFRIC11
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
** DEFINITION FOR CONTACTS BETWEEN ENDPLATES
*CONTACT PAIR,INTERACTION=NOFRIC12,small sliding
SURF10U, SURF11D
*SURFACE INTERACTION,NAME=NOFRIC12
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
** DEFINITION FOR CONTACTS BETWEEN ENDPLATES
*CONTACT PAIR,INTERACTION=NOFRIC13,small sliding
SURF11U, SURF12D
*SURFACE INTERACTION,NAME=NOFRIC13
*SURFACE BEHAVIOR, PRESSURE-OVERCLOSURE=LINEAR
11.,
**
*RESTART,WRITE
*OUTPUT,FIELD, NUMBER INTERVAL=40
*CONTACT OUTPUT
CFORCE,CSTRESS
*NODE OUTPUT,VARIABLE=PRESELECT,NSET=NOUT1
*NODE OUTPUT,VARIABLE=PRESELECT,NSET=NPLATE
*ELEMENT OUTPUT,VARIABLE=PRESELECT,ELSET=EALL
*OUTPUT,HISTORY, VARIABLE=PRESELECT,FREQUENCY=40
*CONTACT OUTPUT
```

```
CFN,
*ENERGY OUTPUT
*END STEP
```

## 서 지 정 보 양 식

| 수행기관보고서번호 | 위탁기관보고서번호 | 표준보고서번호 | INIS 주제코드 |
|---|---|---|---|
| KAERI/TR-2594/2003 | | | |

| 제목/부제 | |
|---|---|

100% RIH 파단사고시 중수로용 개량핵연료의 충격해석모델 개발 및 해석

| 주저자 및 부서명 | 조문성 (미래형원자로연료개발부) |
|---|---|
| 연 구 자 및 부 서 명 | 석호천 (미래형원자로연료개발부) |

| 출 판 지 | 대전 | 발행기관 | 한국원자력연구소 | 발행년 | 2003. 11 |
|---|---|---|---|---|---|
| 페 이 지 | 70 | 도 표 | 있음( V ), 없음( ) | 크 기 | 19 x 26 Cm. |

| 참고사항 | | | |
|---|---|---|---|
| 비밀여부 | 공개(V ) | 보고서종류 | 기술보고서 |
| 연구위탁기관 | | 계약 번호 | |

초록 (15-20 줄 내외)

CANDU-6 원자로에서의 100% Reactor Inlet Header 파단사고시, 채널내 핵연료열이 Inlet Shield Plug 에 가하는 충격을 모사하기 위한 구조해석을 수행하였다. 충격으로 인해 핵연료나 핵연료채널에 손상이 발생할 경우 냉각수 흐름이 차단될 수 있고, 그럴 경우 냉각수 상실 사고 이상의 안전상의 문제를 야기시킨다. 상용 구조해석 소프트웨어인 ABAQUS 를 이용하여 100% Reactor Inlet Header 파단사고시 충격을 모사하기위한 유한요소해석모델을 개발하였다. FE 모델은 1996 년 한국원자력연구소에서 수행된 재장전 충격해석 결과를 이용하여 검증되었다. 본 모델을 이용하여 Shield Plug 에 부딪힌 핵연료 다발열의 동적 거동을 조사하였으며 아울러 핵연료 다발 및 압력관에 미치는 영향을 평가하였다. 다발의 sticking 혹은 냉각수 흐름의 차단 가능성 및 핵연료 다발의 건전성을 평가하였다.

주제명 키워드 (10 단어내외)

CANFLEX 핵연료, 충격강도해석, 중수 원자로, 100% RIH 파단, 유한요소해석, 압력관, 냉각수 상실

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Abstract (15-20 Lines)


A structural analysis was performed to simulate the impact of the fuel bundle string on the inlet shield plug during a 100% Reactor Inlet Header (R.I.H) brake accident in a CANDU-6 Reactor. Any significant damage to either the fuel or the fuel channel due to the collision could result in coolant flow blockage, and thus pose additional safety related concerns beyond those addressed for the initial loss-of-coolant accident. A finite-element (FE) model for simulating the collision was developed using the structural analysis computer code ABAQUS. The FE model was validated against the test results that have been obtained during the normal refueling impact test performed at KAERI in 1996. With use of the FE model, dynamic behavior of the fuel bundle string impacted on the shield plug was investigated and its effects on the fuel bundles and pressure tube were evaluated. The overall integrity of the fuel bundles as well as the possibility of bundle sticking or coolant flow blockage in the pressure tube was assessed.



Subject Keywords (About 10 words)

CANFLEX fuel, Impact strength analysis, CANDU-6 reactor, 100% RIH brake, Finite element analysis, Pressure tube, Loss of coolant