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ABAQUS를 이용한 중수로용 핵연료의 유한요소해석 모델 개발 및 강도 해석

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제 출 문

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부록 2 37봉 핵연료 유한요소해석 입력 자료

1. 서론

CANDU-6 원자로에는 380개의 핵연료 채널이 있으며, 각 핵연료 채널마다 12개의 핵연료집합체가 장전된다. 핵연료로부터 발생되는 열을 제거하기 위해 중수로 냉각재가 핵연료 집합체열을 통과한다. 이러한 냉각재 유동으로 인해 집합체열에는 상당한 크기의 압력강하가 발생한다.

CANDU-6 원자로의 경우, 핵연료는 원자로 가동 중에 8 다발씩을 한꺼번에 교체하는 것이 원칙이다. 핵연료 채널의 한쪽 끝에서 냉각재 흐름을 따라 8개의 새로운 핵연료 다발이 장전되고 같은 채널의 반대쪽 끝에서 8개의 조사후 핵연료 다발이 배출된다. 이를 위해 CANDU 원자로에서는 원자로 양편에서 원격 조정되는, 동일한 두 개의 핵연료 장전기를 사용한다. 이들 장치가 핵연료 재장전 중에 동일한 핵연료 채널의 단말고정기(end fitting)에 장착되어 하나는 새로운 다발을 장전하고, 다른 하나는 조사된 다발을 받아낸다. 두 개의 핵연료 분리장치가 각각의 핵연료 장전기 헤드에 설치된다. 핵연료 분리 장치는 센서와 두 개의 걸쇠(side-stop), 그리고 푸셔(pusher)로 구성된다. 센서는 핵연료 두 다발마다의 간격을 감지한다. 두 개의 핵연료 다발이 냉각재 흐름의 하류에 위치한 핵연료 장전기 속으로 거의 다 들어갈 즈음에, 걸쇠가 그 다음 다발과의 틈 사이에 삽입되도록 센서가 신호를 보낸다. 걸쇠는 집합체를 구성하는 연료봉 중 외곽에 위치한 8개 혹은 9개 연료봉의 봉단마개 경사면에 접촉된다. 걸쇠는 핵연료 집합체열을 지탱하게 되며, 따라서 채널내 냉각재 유동으로 인해 발생하는 수력적 견인력(hydraulic drag)에 의한 집합체의 축방향 움직임을 막아준다. 핵연료 푸셔는 장전기 속에 삽입된 한쌍의 다발을 밀어서 핵연료 장전기 안으로 밀어 넣는다. 상류측 핵연료 장전기는 핵연료 집합체열에 전혀 힘을 가하지 않으므로 걸쇠에 미치는 힘은 보통 견인력과 동일하다. 핵연료 재장전중 견인력의 크기는 냉각재 흐름내 다발 수에 따라 변화하고 따라서 첫 번째 다발이 배출되기 전 즉, 12개의 조사된 핵연료가 걸쇠에 의해 지탱될 때 최대 하중이 걸리게 된다. 정상 상태에서 걸쇠에 걸리는 최대하중은 7,300N으로 추정된다. 두 개의 걸쇠 중 하나가 오작동 하는 경우는 거의 일어나지 않는다. 만약 이러한 일이 발생하더라도 비상신호가 발생하여 필요시 작업자가 적절한 시정 조치를 취하도록 하게 된다. 이 경우에도 핵연료 외곽 4개 혹은 5개 연료봉에 의해 걸쇠에 걸리는 힘은 견인력에 의한 것뿐이며, 그 크기는 7,300N 이다.

CANDU-6 원자로에 사용될 수 있도록 개발된 핵연료는, 심각한 변형 혹은 성능의 저하 없이, 위에 서술된 모든 핵연료 취급 하중을 견딜 수 있어야 한다. 37봉 핵연료 집합체 및 CANFLEX 43봉 핵연료 집합체가 이러한 요구조건을 만족시킨다는 것을 입증하기 위해 쌍걸쇠 시험(double side-stop test) 혹은 외걸쇠 시험(single side-stop test)으로 일컬어지는 노외 시험들이 수행되었다[1]. 쌍걸쇠 시험의 경우 정상상태 최대하중의 1.6배에 달하는 하중조건에서 시험이 실시되었으며, 시험 결과 핵연료의 강도는 우수한 것으로 나타났다.

재장전중 발생하는 걸쇠의 반력을 핵연료가 충분히 견딜 수 있음은 시험을 통해 입증될 수 있다. 그러나 재장전 과정 중에 발생하는 다양한 현상들을 조사하기 위해 시험을 반복 수행하는 것은 매우 비용이 많이 드는 일이다. 게다가, 시험을 통해 관측될 수 없는 물리적 변수들 즉, 환봉들 간의 하중 전가, 양단접합판 립(rib) 효과, 집합체열에서 소성변형이 시작되는 견인력의 크기 등을 조사할 필요가 있다. 이런 점에서, 컴퓨터를 이용하여 노외 강도시험을 시뮬레이션하기 위한 기법을 개발코자 하였다.

컴퓨터 구조해석 소프트웨어인 ABAQUS[2]를 이용하여 핵연료 노외강도시험을 시뮬레이션하기 위한 정적 유한요소해석 모델을 개발하였다. 이 유한요소해석 모델에서는 견인력 을 받는 연료봉의 휨과 양단접합판의 응력 및 변위 분포를 고려하였다. 본 논문에서는, 전술한 물리적 변수들의 관점에서 강도시험 결과를 분석하기 위해, CANFLEX 43봉 핵연료 및 기존의 37봉 핵연료에 대해 수행된 강도시험 조건에 맞추어 유한요소해석 모델을 개발하였다.

2. 유한요소 모델

2.1 핵연료 집합체의 모델링

37봉 핵연료 다발은 7개의 부품으로 구성된다. 각 연료봉은 지르칼로이 피복관 내에, 일정한 길이로 맞춰진 이산화우라늄 소결체를 포함하고 있다. 피복관 내면에는 흑연이 얇게 도포되어 있어서 피복관과 소결체를 분리시키며 둘 간의 상호간섭을 감소시킨다. 피복관의 양단에 봉단 마개가 저항용접 방식으로 접합되어 연료봉 내부를 밀폐시킨다. 37개 봉단마개 끝에 양단 접합판이 용접되어 연료봉들을 집합체의 형태로 유지시킨다. 연료봉간 거리를 최소 간격으로 적절히 유지하기 위해 집합체 중앙면을 따라 봉간 인접 위치에 간격체를 접합시킨다. 집합체 외곽 연료봉의 양단 및 중간 지점에는 지지체가 접합되며, 따라서 집합체는 압력관과의 사이에 지지체 두께만큼의 간격을 갖게된다. 또 다른 부품 즉, 버튼은 CANFLEX 핵연료를 위해 고안된 것으로서 임계열유속을 증대시키기 위해 모든 연료봉에 접합된 것이다.

핵연료 집합체의 유한요소 모델은 쉘, 빔 및 트러스 요소로 구성된다. 즉, 양단접합판은 쉘, 피복관 및 걸쇠는 빔 그리고 간격체는 트러스 요소로 만들어졌다. 버튼은 해석결과에 영향을 미치지 않으므로 유한요소 모델에 포함시키지 않았다. 압력관과 지지체 역시 모델링되지 않았으나 2.3 절에서와 같이 적절한 경계조건을 대신 설정함으로써 동일한 효과를 갖도록 하였다. Figure 1과 2는 핵연료 집합체의 유한요소 모델을 보여주고 있다. 각 부품의 유한요소해석 모델에 대한 설명은 Table 1과 같다.

노외시험이 120°C에서 수행되었으므로, 재료의 물성치는 120°C 상태에서의 값을

이용하였다(Table 2 참조).

2.2 핵연료 집합체열의 유한요소 모델링

핵연료 집합체열의 유한요소 모델은 시험장치에서의 실제 배열을 근거로 만들어졌다. 인접한 집합체들의 양단접합판은 서로 완전한 접촉 상태를 유지한다고 가정하였으며 접합판의 요철은 무시하였다. 접합판 표면의 접선 방향 운동에 저항하는, 접합판사이의 전단력은 없는 것으로 가정하였으며 법선 방향 힘만 인접 접합판으로 전달된다.

핵연료 집합체열은 13개 핵연료가 일렬로 늘어서 있는 것으로 모델링된다. 이것은 재장전시 핵연료 채널에 들어있는 20개 다발 (조사후 다발 12개 및 새 다발 1개) 중 냉각재 흐름의 영향을 받는 13개 핵연료 다발을 시뮬레이션한 것이다 (Figure 3). CANFLEX 핵연료 집합체열의 해석에 있어서, 냉각재 하류의 3개 다발은, 시험장치에서의 배열과 동일하게, 다발간 비뚤어짐 없이 정렬(회전각=0°) 되어 인접 다발간 대응 봉들이 서로 맞닿아 있는 것으로 모델링 하였다. 나머지 10개 다발은 냉각재 입구측에서 봤을 때, 인접한 하류측 다발에 대해 시계방향으로 28°의 회전각을 가지도록 모델링하였다. 회전각 28°는 CANFLEX 핵연료 집합체열에 대한 압력강하 시험에서, 최빈 압력강하가 얻어지는 다발 상호간의 회전각이다[3]. 그러한 방식으로 시험장치에서 임의로 정렬된 상류측 10개 다발을 모델링하였다. 37봉 핵연료의 해석에 있어서는, 시험장치에서의 배열과 동일하게, 냉각재 하류측에서 두 번째 및 세 번째 다발이 첫 번째 다발에 대해 115°의 회전각을 가지도록 모델링하였다. 나머지 10개 다발은, 냉각재 입구측에서 봤을 때, 인접한 하류측 다발에 대해 시계방향으로 31°의 회전각을 가지도록 모델링하였다. 회전각 31°는 CANFLEX 핵연료 집합체열에 대한 압력강하 시험에서 최빈 압력강하가 얻어지는, 다발 상호간의 회전각이다[3].

2.3 경계 조건

최하류측 다발(13번 다발)은 걸쇠에 의해 지지된다. 하나의 걸쇠는 핵연료 외곽의 4개 봉과 접촉한다. 2 질점 빔요소를 이용하여 걸쇠와 1개 핵연료봉 간의 접촉을 모델링하였다. 따라서, 걸쇠와 8개 외곽 봉과의 접촉을 모델링 하기 위해 8개의 빔요소가 사용되었다. Figure 2에서 보듯이, 빔 요소의 한쪽은 모든 자유도가 구속되며, 다른 한쪽은 핵연료봉과 접촉된다. 따라서, 최하류 다발의 +z 방향 변위가 구속된다.

모든 핵연료 다발 양단접합판 중심 질점에서 횡변위(U_x, U_y) 및 회전이 구속되며, 따라서 공간상에서 이들 질점들이 고정되게 된다.

2.4 하중

견인력은 강도시험에서 가장 지배적인 변수인데, Table 3에서 견인력의 크기를 경계조건 및 핵연료 형태별로 보여주고 있다. 견인력은 핵연료 집합체열 및 모든 핵연료봉에 일정하게 분포, 작용하는 것으로 가정한다. 따라서, 13개 CANFLEX 핵연료 집합체에 가해지는 12,010N의 힘은 각 핵연료봉에 대해 0.04338N/mm의 힘으로 작용한다.

3. 노외검증시험에의 응용

3.1 노외 검증시험[3]

강도시험을 위한 장치는 15개의 핵연료 다발과 재장전기에 부착된 걸쇠 시뮬레이터로 구성된다. 걸쇠 시뮬레이터는 시험 장치의 출구 측 단말고정기에 제대로 끼워 맞춰 질 수 있도록 설계되었다. 세 개의 시험 다발과 12개의 충진 다발로 구성되는 집합체열이 핵연료 채널에 장전되었다. 채널 내 유량은 정해진 압력강하에 부합되도록 조절되어, 필요한 만큼의 수력하중이 걸쇠에 전달되도록 하였다. 압력강하의 크기는 핵연료 재장전중 냉각수 유동 영역내에 있는 최대 핵연료 다발수(13.1 다발)에 해당되는 것이다. 각각의 시험에 있어서 냉각수 온도와 입구 측 압력은 120° 및 11.2MPa로 설정되었으며, 하중은 약 15분간 가해졌다. 시험 완료 후, 시험 다발의 변형량을 알아내기 위해 정밀 측정을 실시하였다.

3.2 유한요소 모델의 검증

3.2.1 최하류 접합판상의 변위

Figure 4는 쌍걸쇠 지지조건에서 CANFLEX 핵연료 최하류 접합판의 축방향 변위를 보여주고 있다. 시험결과는 1번 연료봉의 축방향 변위를 기준으로 한 상대변위 값이다. (각 연료봉의 위치는 Figure2(a)와 같다.) 해석 결과는 측정치와 매우 잘 일치하고 있다. 음의 값을 보이는 부분은 걸쇠와 접촉하는 부분인데, 집합체 쪽으로 밀려들어갔음을 뜻한다. 해석 결과와 측정치간에 다소 차이를 보이는 것도 이 부분이다. 이 차이는, 해석모델에서 고려할 수 없었던, 시험다발 접합판의 굴곡에 기인한 것으로 판단된다.

Figure 5는 쌍걸쇠 지지 37봉 핵연료 최하류 접합판의 축방향 변위를 보여주고 있다. 이 경우에도, 시험결과는 1번 연료봉의 축방향 변위를 기준으로 한 상대변위 값이다. (각 연료봉의 위치는 Figure2(b)와 같다.) 이 그림에서도 Figure 4와 같은

결과가 발견된다: 해석 결과는 측정치와 잘 일치하나, 시험다발 접합판에 존재하는 굴곡으로 인해 걸쇠와 접촉한 부분에서 해석 결과와 측정치간에 다소 차이를 보인다.

Figure 6과 7은 외걸쇠 지지조건에서 CANFLEX 및 37봉 핵연료 최하류 접합판의 축방향 변위를 각각 보여주고 있다. 일반적으로, 해석결과와 측정치가 크기 및 형태 모두에서 잘 일치하고 있다.

3.2.2 연료봉의 변형

Figure 8(a)는 쌍걸쇠와 접촉하는 CANFLEX 다발, 12번 연료봉의 반경방향 변위를 나타낸다. 해석결과와 측정치 모두 연료봉의 가운데 지점 부근에서 최대값을 보이나, 측정치가 해석결과에 비해 거의 두 배에 이른다. 이와 같은 현상은 시험 전, 시험 다발에 존재하는 연료봉의 휨에 기인한 것이다. 연료봉의 휨은 얇은 봉에 지지체나 간격체등과 같은 부속물을 경납땜할 때 발생한다. 시험 전 12번 연료봉의 반경방향 변형의 크기는 0.1mm, 21개 외곽 연료봉의 평균치는 0.17mm 이었다. 시험 전에 존재하는 연료봉의 휨으로 인해 측정치가 해석결과보다 큰 값을 나타낸다. Figure 8(b)는 하류측 1/6 지점에서 21개 외곽 연료봉의 반경 방향 변형의 크기를 나타낸다. 측정치와 해석결과가 유사한 변화 형태를 보이고 있다.

3.3 핵연료 집합체열의 거동 분석

3.3.1 CANFLEX 핵연료 집합체열에 대한 쌍걸쇠 강도 시험

Figure 10은 쌍걸쇠 지지조건에서 CANFLEX 핵연료 집합체열의 각 환봉이 지탱하는 견인력의 크기를 나타낸다. 다발이 하류에 위치할수록 외환봉에 걸리는 견인력의 크기는 커지며, 최하류에 위치한 13번 다발에 있어서는 전체 하중의 93%가 외환봉에 걸린다. (Figure 11) 이것은 내부 연료봉은 지지되지 않기 때문이다. 외환봉의 하중 곡선의 기울기는 8번 다발부터 빠르게 증가한다.

Figure 11은 CANFLEX 핵연료 집합체열과 37봉 핵연료 집합체열의 하중 전가메커니즘을 상호 비교한 것이다. 상류측 다발의 외환봉에 의해 지탱되는 하중의 크기는 CANFLEX 핵연료보다 37봉 핵연료에서 더 크다. 이것은 접합판의 디자인이 다르기 때문이다. CANFLEX 핵연료의 접합판에 립(rib)이 더 많으므로, 내환의 지지력을 높여주고 따라서 외환에 하중이 집중되는 것을 완화시켜준다.

Figure 12는 쌍걸쇠 지지조건에서 13개 CANFLEX 핵연료 집합체열의 각 다발에 발생하는 최대응력을 나타낸다. 응력 곡선 기울기가 8번 다발에서 크게 변화하는 것을 알 수 있다. 이러한 경향은 Figure 10의 하중전가 곡선에서도 볼 수 있었던 바, 이것은 응력의 급격한 증가가 내·외환봉간 하중전가에 기인한 것임을 나타낸

다. 10번 다발에서 응력 증가가 멈춘 것은 소성 변형이 시작됐음을 의미한다. 12번 및 13번 다발에서 응력이 다소 증가한 것은 최하류 다발의 외곽 8개봉이 걸쇠에 의해 지지되는, 경계조건의 변화에 기인한다.

Figure 13은 쌍걸쇠에 접한 CANFLEX 접합판(13번 다발의 하류측 접합판)의 응력 분포를 보여준다. 최대 응력은 걸쇠와 맞닿는 부분에서 발생하며, 4개의 립에서 높은 응력이 발생한다. 이것은, 앞에서 언급하였듯이, 내환봉으로부터 외환봉으로 하중이 전가됨에 따른 결과이며, 내환봉에 가해진 하중이 이들 립에 의해 지탱되기 때문이다.

Figure 14는 쌍걸쇠 지지조건에서 CANFLEX 핵연료 집합체열을 구성하는 각 다발의 최대 축방향 변위를 나타낸다. 축방향 변위는, Figure 10의 하중전가와 Figure 12에서 논의된 재료의 소성 변형으로 인해 다발이 하류에 놓일수록 커진다.

3.3.2 CANFLEX 핵연료 집합체열에 대한 외걸쇠 강도 시험

Figure 15는 외걸쇠 지지조건에서 13개 CANFLEX 핵연료 집합체열의 각 다발에 발생하는 최대응력을 나타낸다. 집합체열을 따라 응력이 변화하는 모습은 그 경향에서 쌍걸쇠 지지 CANFLEX 핵연료 집합체열의 경우와 동일하다. 소성 변형은 8번 다발에서 발생하고 있다.

Figure 16은 외걸쇠에 접한 CANFLEX 접합판(13번 다발의 하류측 접합판)의 응력 분포를 보여준다. 쌍걸쇠 지지 CANFLEX 집합체열의 경우(Figure 13)와 정성적 공통점들을 발견할 수 있다. 즉, 최대응력이 걸쇠와 맞닿는 부분에서 발생하며, 내·외환봉간 하중전가로 인해 2개의 외곽 립에서 높은 응력이 발생한다.

Figure 17은 외걸쇠 지지조건에서 CANFLEX 집합체열을 구성하는 각 다발에서의 최대 축 방향 변위를 나타낸다. 대체적인 경향은 쌍걸쇠 지지 CANFLEX의 경우 (Figure 14)와 유사한 것으로 보인다. 그러나, Figure 14에서의 최대값은 2.5mm로서 총 하중이 훨씬 작은데도 불구하고 Figure 14의 2.2.mm에 비해 크다. 이것은 4개의 외환봉만이 걸쇠에 의해 지지되므로 더욱 집중된 반력을 받기 때문이다.

3.3.3 CANFLEX 43봉 핵연료와 기존의 37봉 핵연료간 집합체열 거동 비교

Figure 18은 쌍걸쇠 지지조건에서 CANFLEX 및 37봉 핵연료 집합체열의 각 다발에서 발생하는 최대 응력을 서로 비교한 것이다. 응력 변화의 대체적인 양상은 서로 비슷하다. 그러나 37봉 핵연료의 경우 탄성 영역에서 더 높은 응력값을 나타낸다. 그리고 CANFLEX의 경우 약 9,200N의 축방향 하중이 걸리는 10번 다발에서 소성변형이 시작되는 반면, 37봉 핵연료는 약 8,000N의 하중을 받는 9번 다발에서 상대적으로 일찍 소성변형을 일으킨다. CANFLEX에 비해 37봉 핵연료에서 더 높은 하중 전가가 발생한다는 사실을 보여준 Figure 11로부터 이러한 현상은 예측될

수 있었다. 접합판 립 형상의 상이함에 기인한 불균일한 하중 분포가 37봉 핵연료에서 상대적으로 높은 최대응력을 발생시킨 것이다. CANFLEX 핵연료가 소성변형을 일으키면서 두 곡선은 같이 움직인다.

Figure 19는 걸쇠에 접한 외환봉에서의 응력을 비교한 것이다. 37봉(13 mm)에 비해 CANFLEX 외환봉(11.5mm)의 직경이 작으므로 CANFLEX에서 더 큰 응력이 발생한다. 그러나 CANFLEX 핵연료봉에 발생하는 응력은 재료의 항복응력에 비해 매우 작은 값이다.

Figure 20은 외걸쇠 지지조건에서 CANFLEX 및 37봉 핵연료 집합체열의 각 다발에서 발생하는 최대 응력을 서로 비교한 것이다. 응력 변화의 대체적인 양상은 거의 비슷하다. 그러나 응력 곡선 기울기의 급작스러운 변화는, 쌍걸쇠 지지의 경우와 마찬가지로, 37봉 핵연료(5번 다발)에서 먼저 발생하였다. 그리고 CANFLEX의 경우, 약 5,000N의 축방향 하중이 걸리는 9번 다발에서 소성변형이 시작되는 반면, 37봉 핵연료는 약 4,600N의 하중을 받는 8번 다발에서 상대적으로 일찍 소성변형을 일으킨다.

Figure 21은 쌍걸쇠 지지조건에서 CANFLEX 및 37봉 핵연료 집합체열의 각 다발에 발생하는 축방향 변위를 서로 비교한 것이다. 두 개의 곡선은 거의 동일한 크기와 변화 형태를 나타내며 겹치고 있다. 그러나, Figure 18에서 보여진 2종 핵연료간 최대응력의 차이로 인해, 변위크기에 있어서도 미소하나마 차이가 발생함을 알 수 있다.

Figure 22는 외걸쇠 지지조건에서 CANFLEX 및 37봉 핵연료 집합체열의 각 다발에 발생하는 축방향 변위를 서로 비교한 것이다. 변화 형태는 거의 같으나, 크기에 있어서는 비교적 큰 차이를 보이고 있다. 그런데 이것은 Figure 20에서 보여지듯이, 37봉과 CANFLEX 집합체열간의 최대응력 차이가 외걸쇠 지지조건의 경우에 더 크다는 사실에 근거할 때 당연한 결과로 이해된다.

3.4 유량 증가에 따른 영향 계산

Figure 23은 극히 높은 유량조건에서, 쌍걸쇠에 접한 CANFLEX 핵연료 13번 다발의 접합판에 발생한 변위 및 최대응력을 계산한 것이다. 견인력은 유량의 크기에 비례한다. 즉, 40kg/s의 유량은 12,310N의 견인력에 해당되고, 60kg/s는 27,700N에 해당된다. 유량(즉, 견인력)이 증가함에 따라 응력과 변위도 증가한다. 견인력 28,600N에 해당하는 61kg/s의 유량에서 접합판의 최대인장응력에 도달하였다.

4. 결론

(1) 상용 구조해석 소프트웨어인 ABAQUS를 이용하여 노외 핵연료 정적 강도시험을 시뮬레이션하기 위한 유한요소 모델을 개발하였다. 핵연료 접합판의 변위와 연료봉의 휨에 대한 해석 결과를 CANFLEX 42봉 및 37봉 핵연료에 대한 강도시험결과와 비교함으로써 개발된 모델을 검증하였다. 해석 결과는 측정치와 매우 잘 일치하였다.

(2) 핵연료의 제작공정에서, 부속물을 피복관에 경납땜할 때 발생하는 연료봉의 휨이, 노외 시험으로 인한 연료봉의 반경방향 변형에 매우 큰 영향을 미친다는 사실을 알았다.

(3) 환봉간 하중전가 메커니즘이 접합판의 디자인에 따라 많은 영향을 받는다는 사실을 알았다. CANFLEX 접합판의 립이 37봉 핵연료보다 많으므로 CANFLEX 핵연료에 발생하는 최대응력 및 변위는 37봉 핵연료에 비해 작았다. 그리고, 37봉 핵연료에 비해 CANFLEX 핵연료에서는 더 높은 하중에서 접합판의 소성변형이 발생하였다. 그러나, 소성 변형이 발생하는 하중의 크기는 CANFLEX가 9,200N, 37봉 핵연료가 8,000N으로서 모두 CANDU-6 핵연료 채널내 최대 견인력인 7,300N보다 컸다. CANFLEX 접합판의 최대인장응력을 초과하는 응력은 61kg/s의 유량 혹은 28,600N의 견인력에서 발생하였는데, 이것은 CANFLEX 핵연료가 대단히 높은 유량조건에서도 기하학적 건전성을 유지할 수 있음을 보여주는 것이다.

5. 참고문헌

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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 ea. for CANFLEX 328 ea. for CANDU
Fuel sheath	PIPE31	2-Node, 3D Pipe 6 DOF	6 elements per rod
Spacer pad	T3D2	2-Node, 3D Truss 3 DOF	
Side-stop simulator	B31	2-Node, 3D Beam 6 DOF	4 elements consist one side-stop

Table 2 Material properties at 120 °C

Component	Young's modulus	Yield strength	Ultimate tensile strength	Poisson's ratio
Endplate	87,980 MPa	228 MPa	378 MPa	0.4
Cladding tube	89,015 Mpa	403 MPa	443 MPa	0.4
Spacer	89,015 MPa	-	-	0.3

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

Table 3 Axial hydraulic drag in strength tests

Boundary condition	Load in CANFLEX	Load in CANDU
Double side-stops	12,010 N	11,559 N
Single side-stop	7,300 N	7,468 N

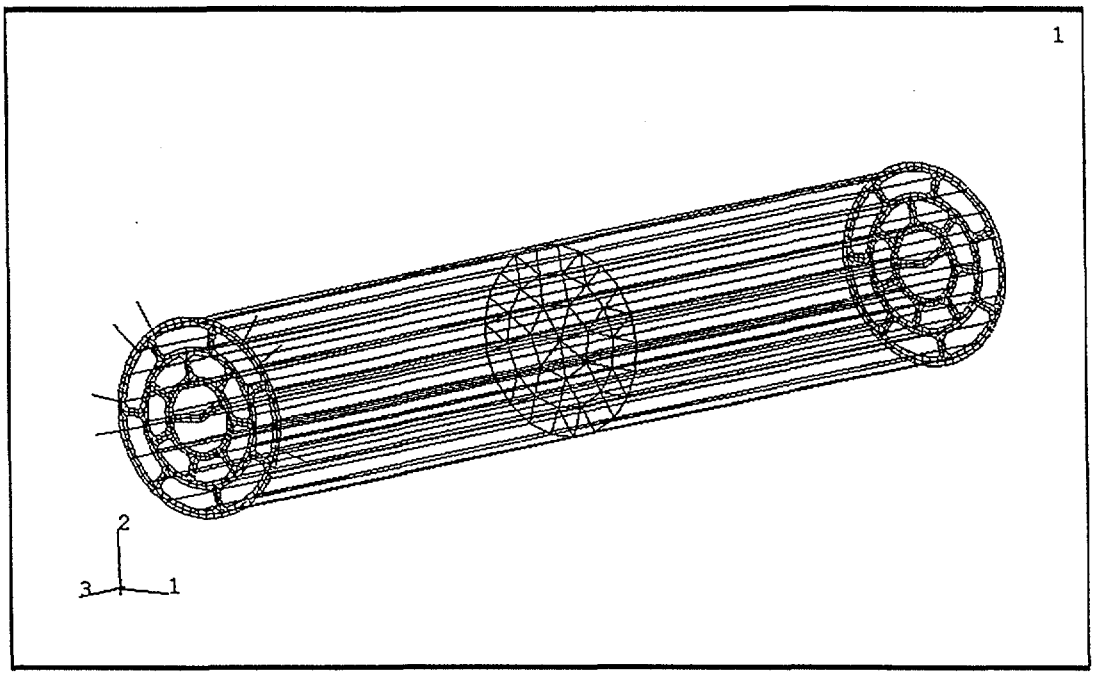
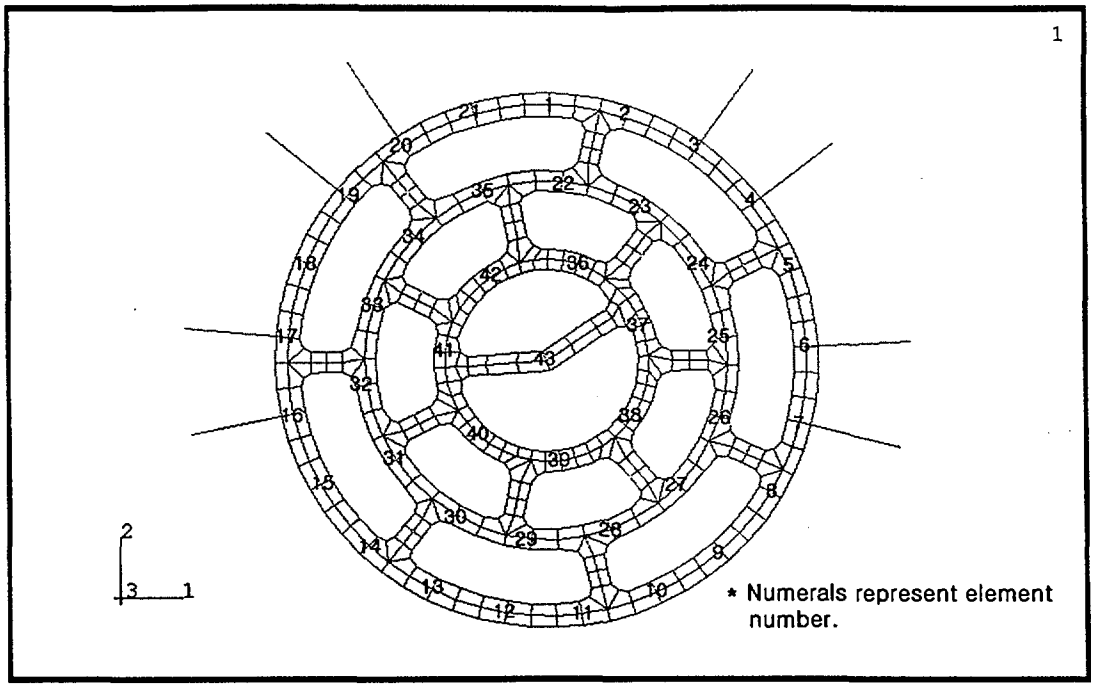
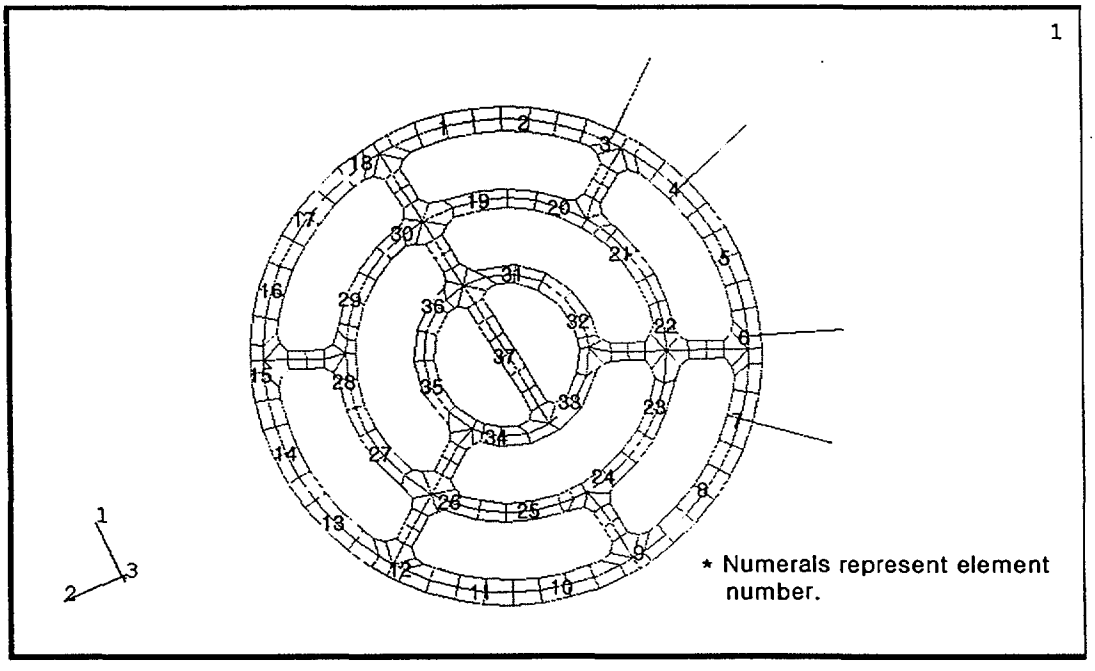


Figure 1 FEM Model for CANFLEX Fuel Bundle



2(a) CANFLEX endplate against double side-stops



2(b) 37-element fuel endplate against double side-stops

Figure 2 Illustration of FE model for endplate

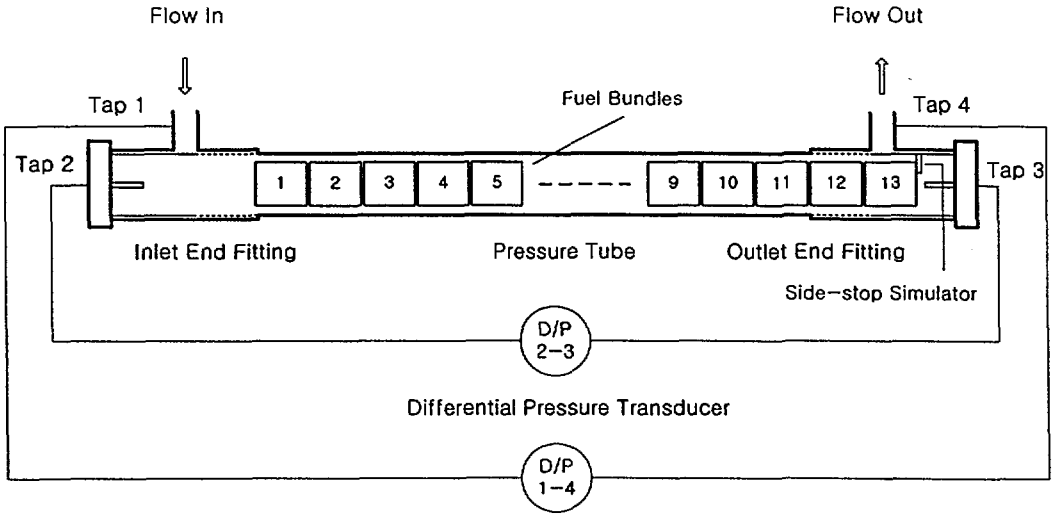


Figure 3 Schematic diagram of strength test set-up

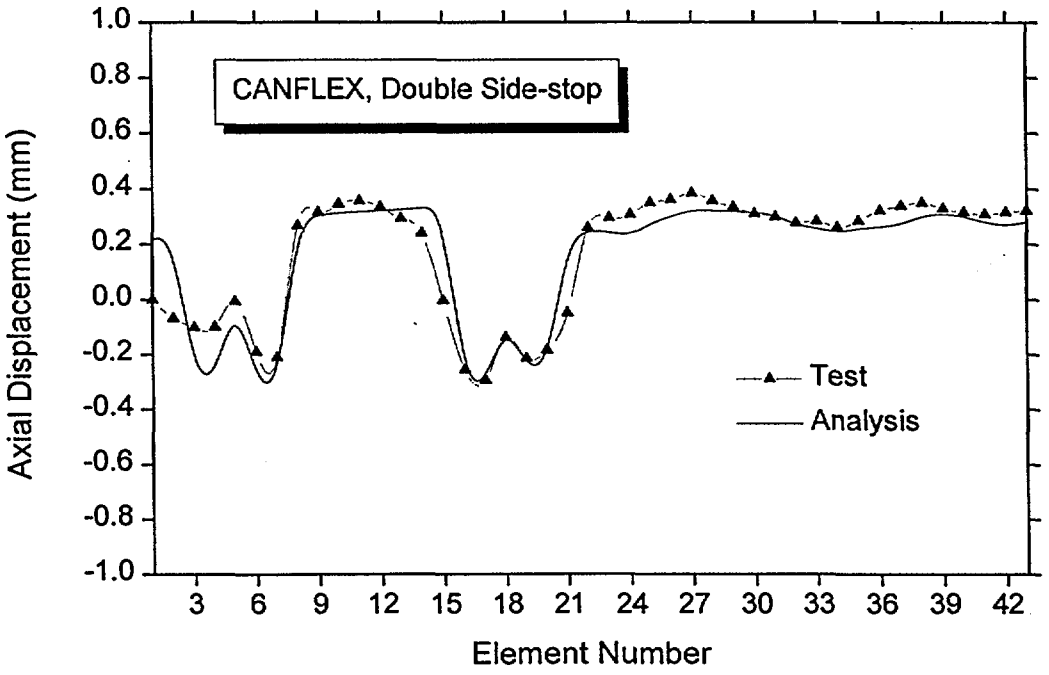


Figure 4 Predicted vs. measured axial displacement in CANFLEX endplate supported by double side-stops

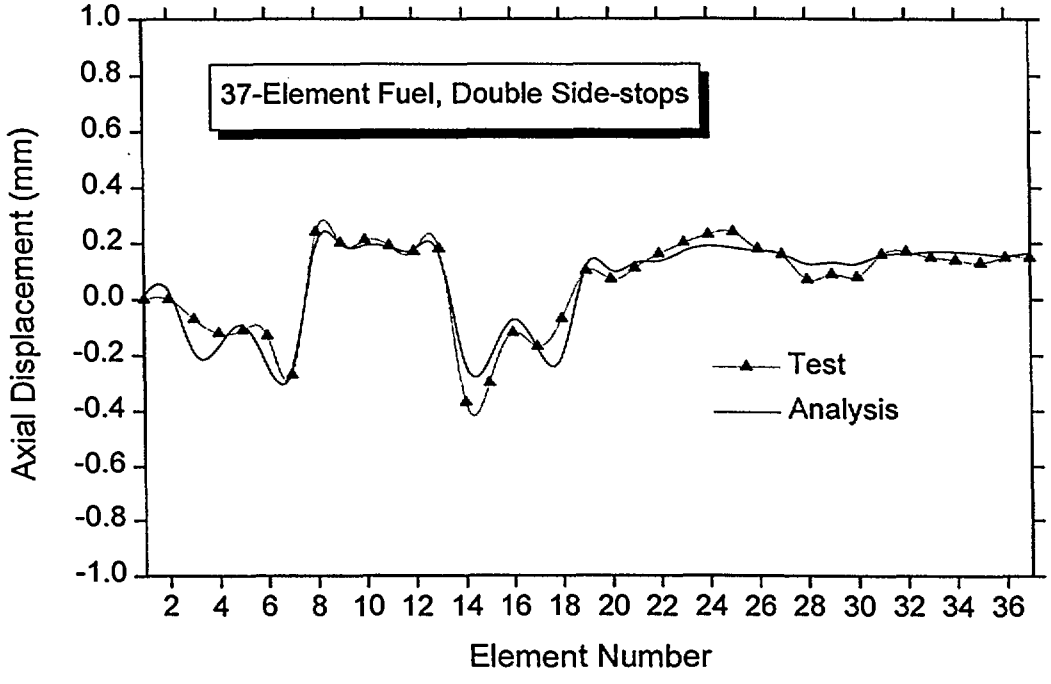


Figure 5 Predicted vs. measured axial displacement in the 37-element fuel endplate supported by double side-stops

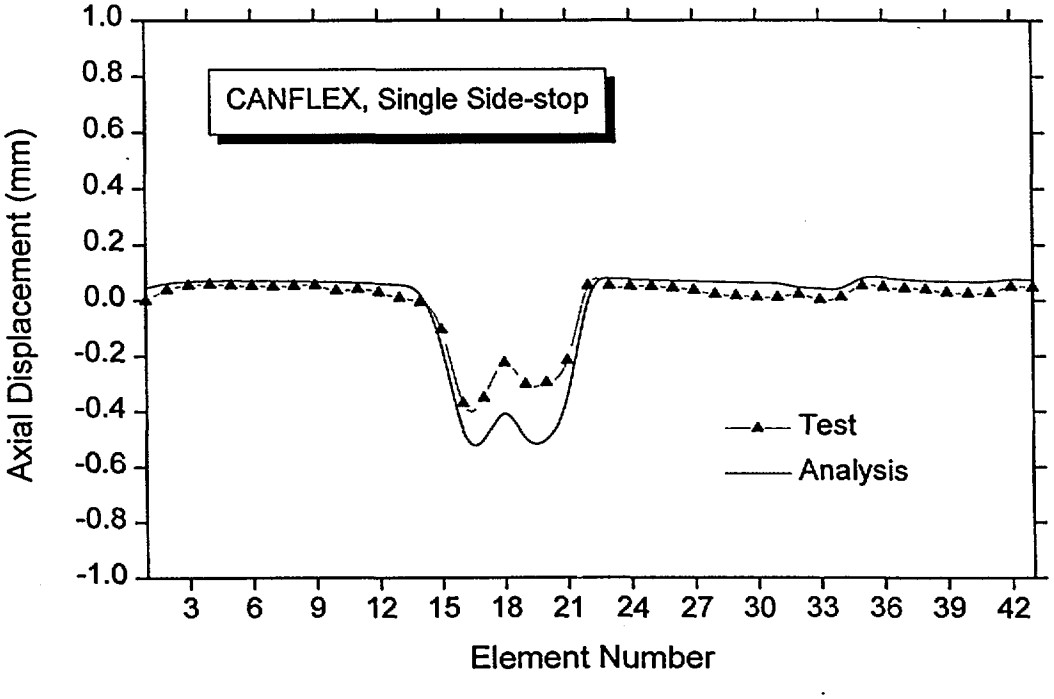


Figure 6 Predicted vs. measured axial displacement in CANFLEX endplate supported by single side-stop

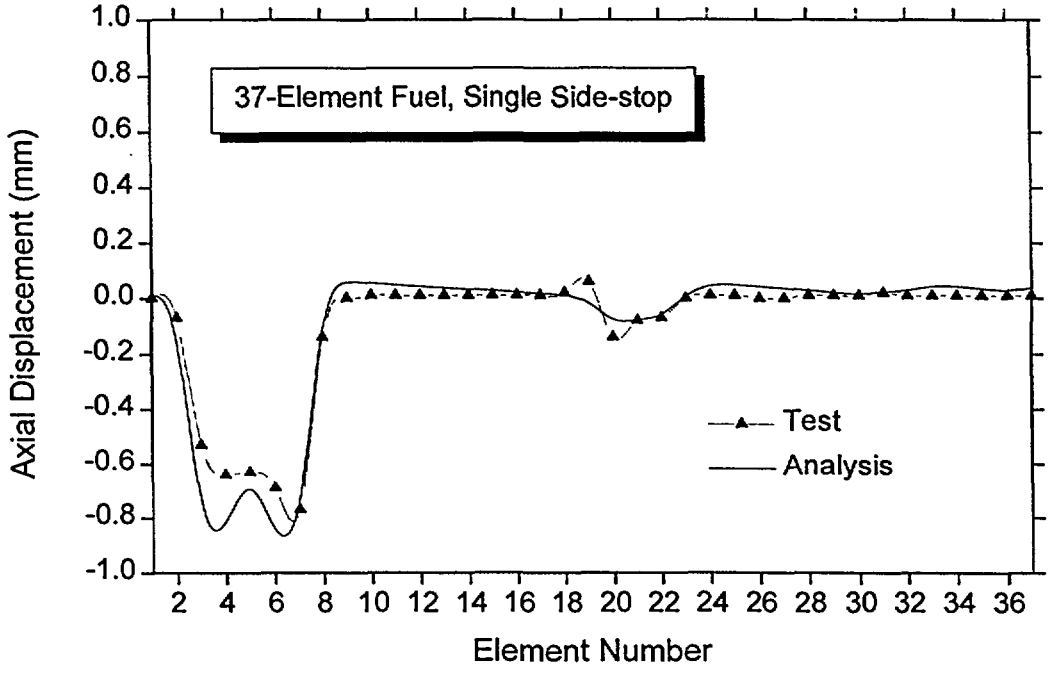
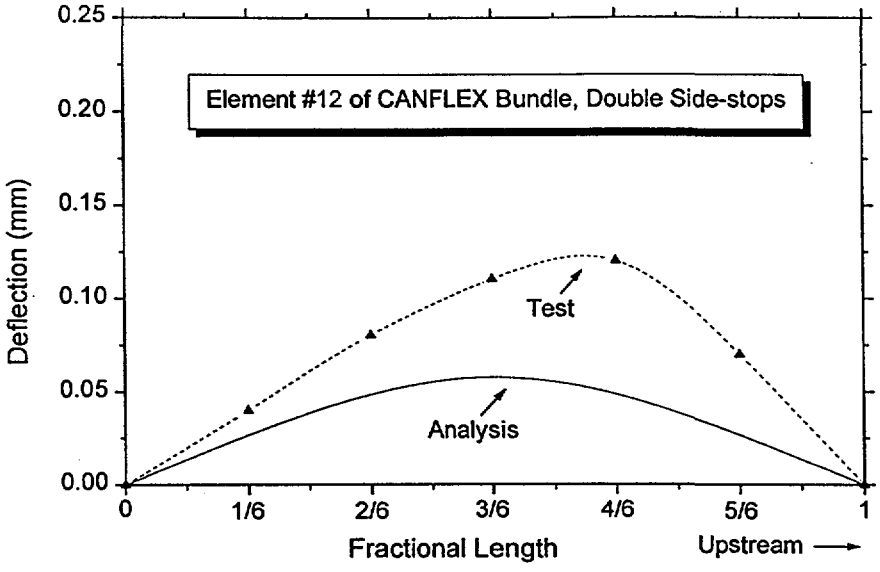
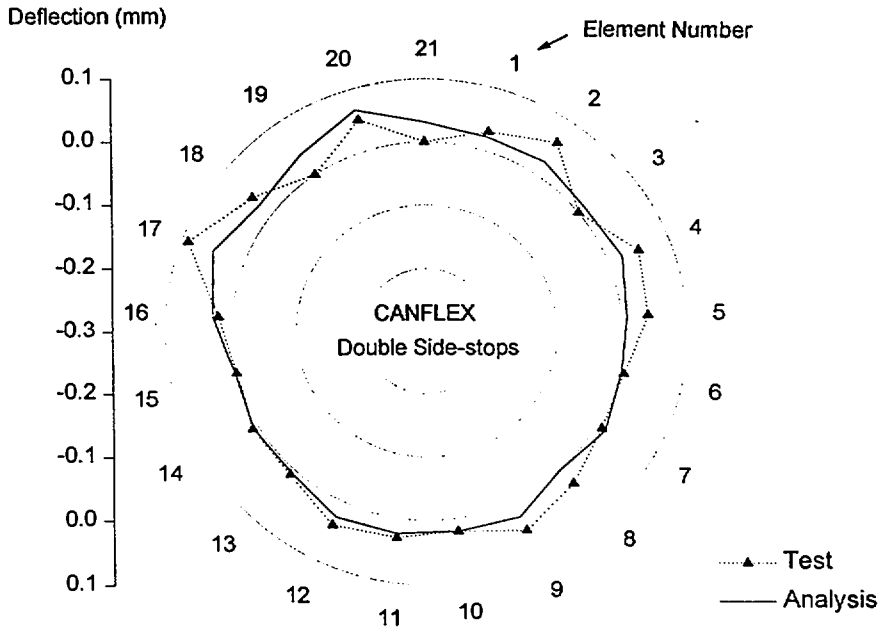


Figure 7 Predicted vs. measured axial displacement in the 37-element fuel endplate supported by single side-stop

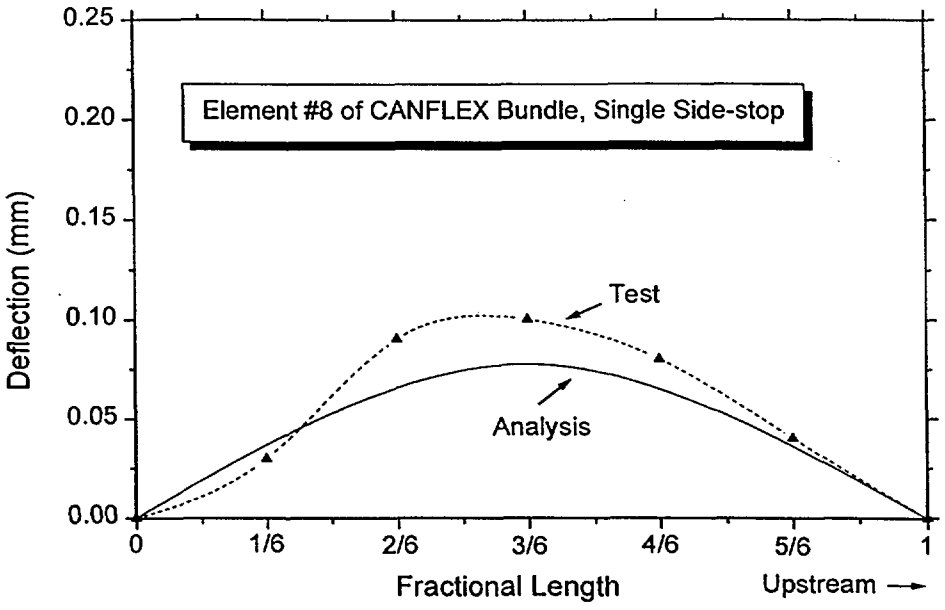


8(a) Radial deflection along fuel element #12

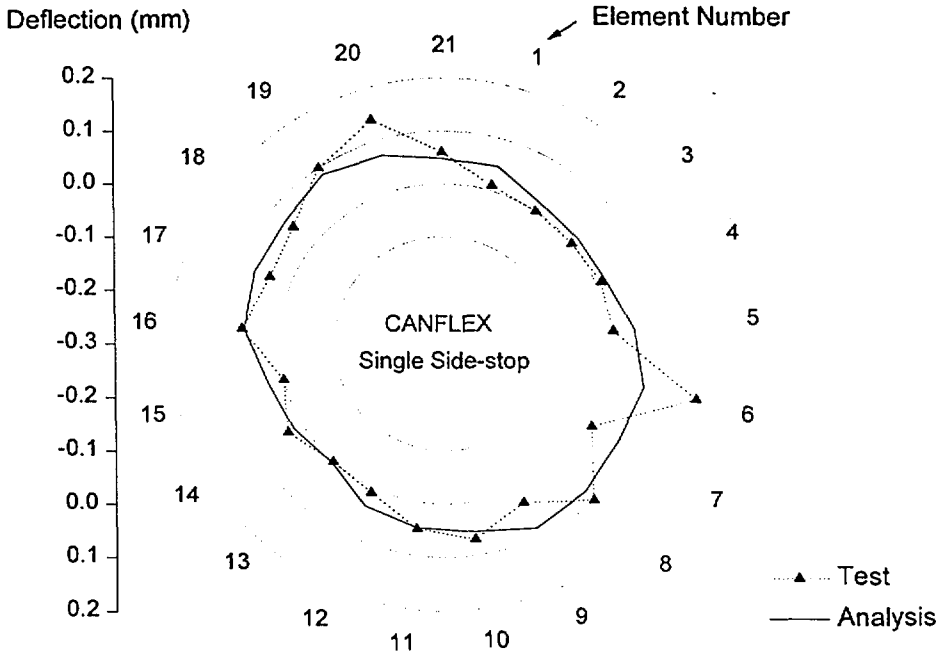


8(b) Radial deflection in 21 outer elements at 1/6 plane

Figure 8 Predicted vs. measured radial deflection in CANFLEX bundle #13 (Double side-stops)



9(a) Radial deflection along fuel element #8



9(b) Radial deflection in 21 outer elements at mid-plane

Figure 9 Predicted vs. measured radial deflection in CANFLEX bundle #13 (Single side-stop)

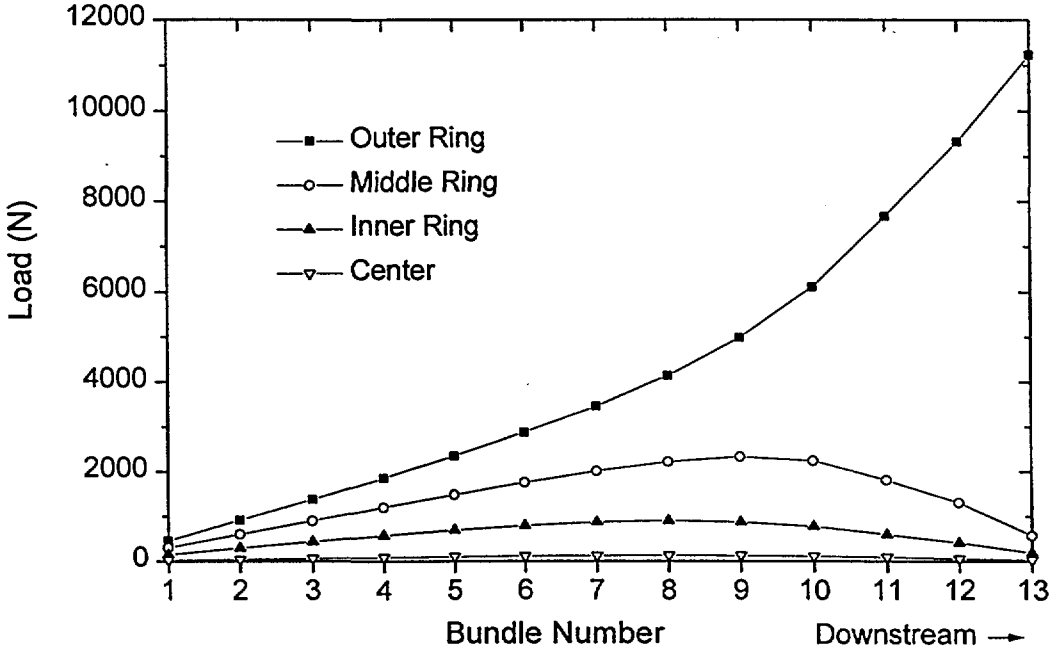


Figure 10 Drag load carried by outer, middle & inner ring elements in CANFLEX fuel bundle string

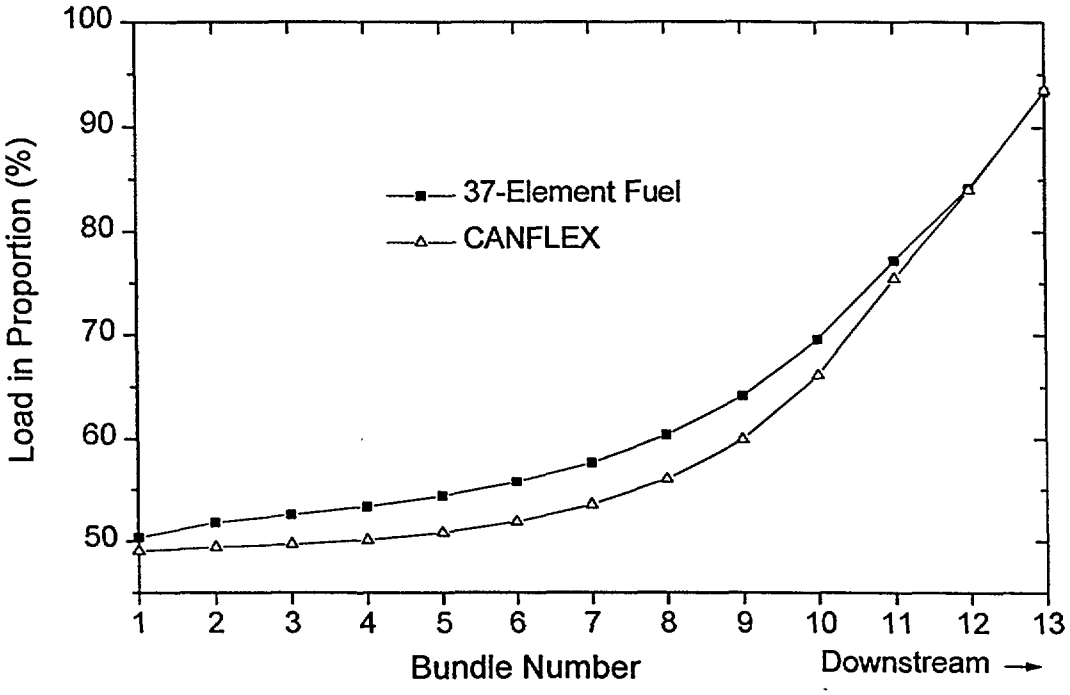


Figure 11 Comparison of the load carried by outer ring elements of CANFLEX and the 37-element fuel

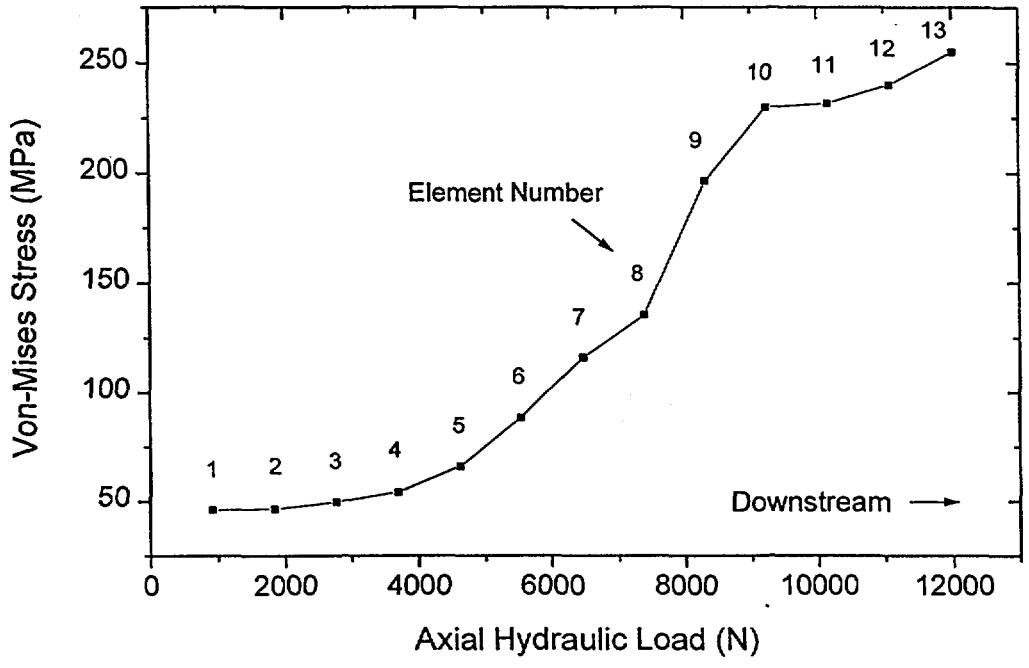


Figure 12 Maximum stress in endplates (CANFLEX bundle 1-13, Double side-stops)

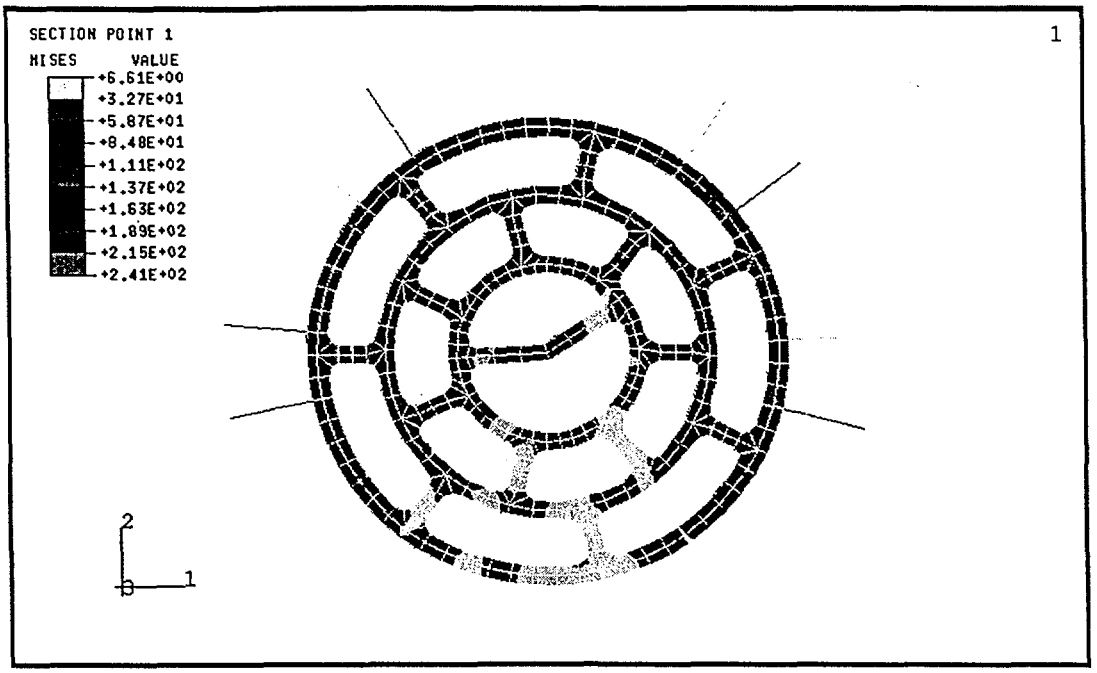


Figure 13 Stress Contour on Endplate of CANFLEX Bundle against double side-stops

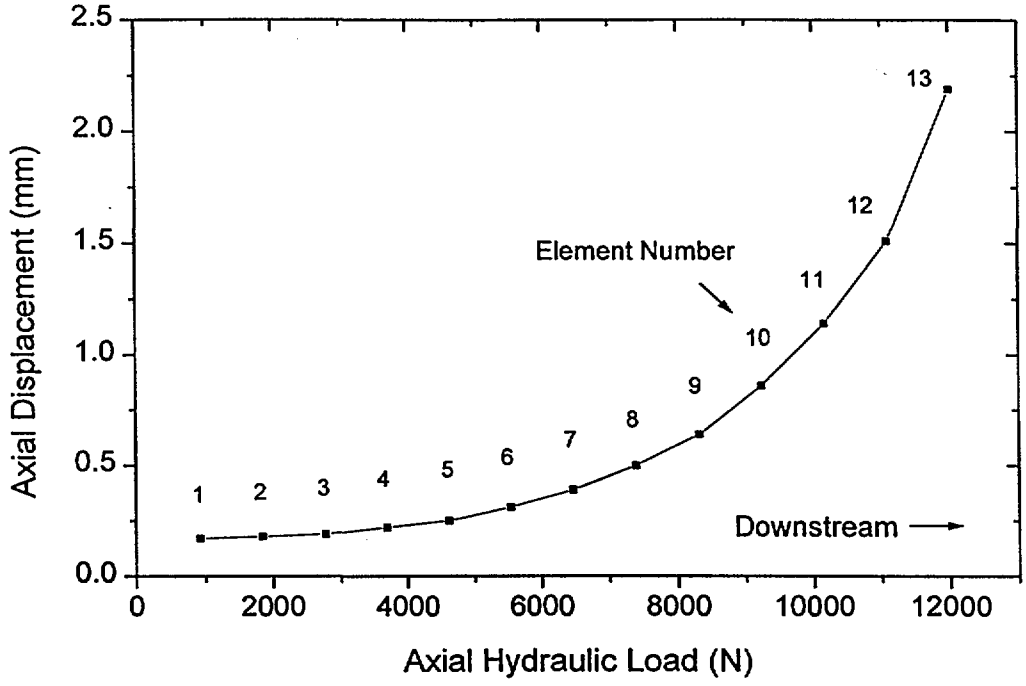


Figure 14 Maximum displacement in endplates (CANFLEX bundle 1-13, Double side-stops)

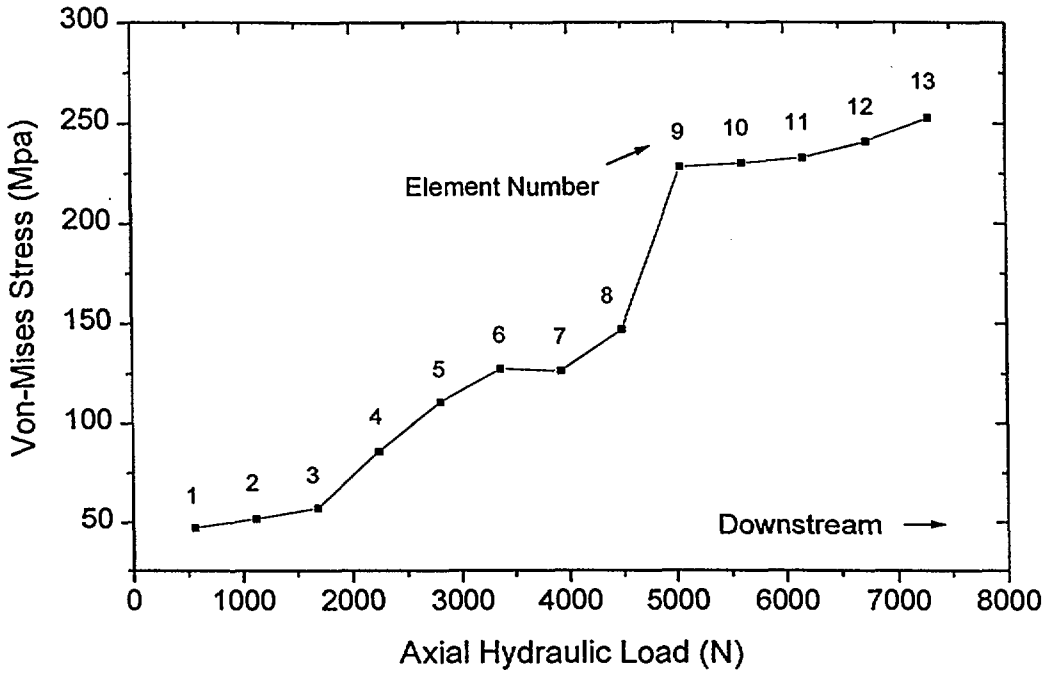


Figure 15 Maximum stress in endplates (CANFLEX bundle 1-13, Single side-stop)

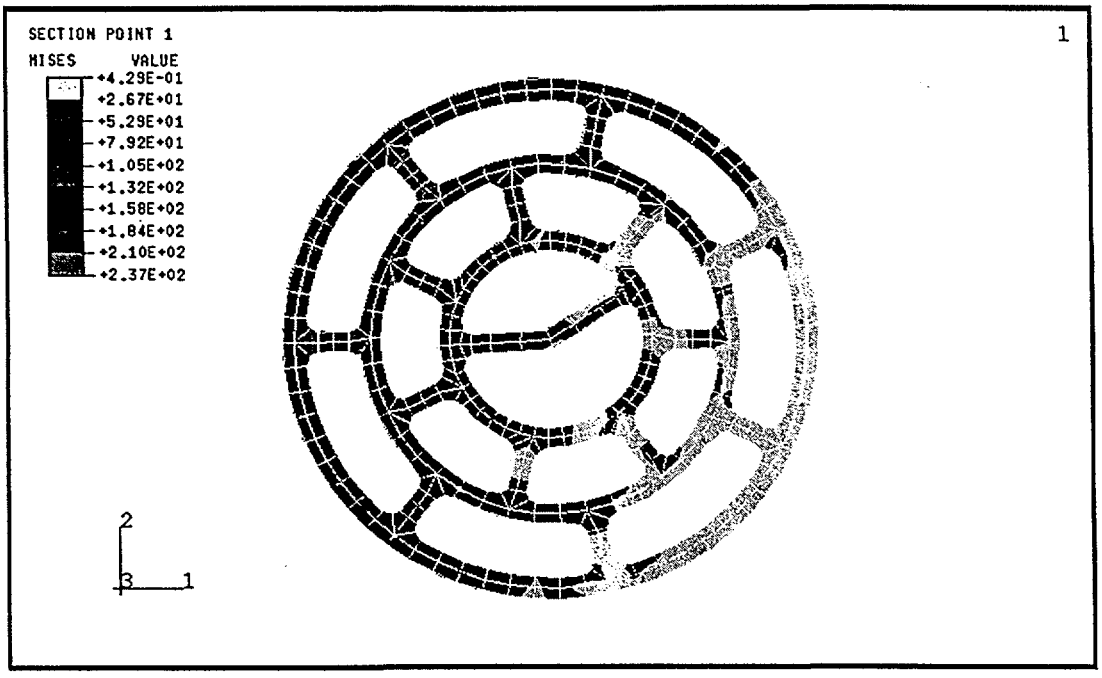


Figure 16 Stress Contour on Endplate of CANFLEX Bundle against single side-stop

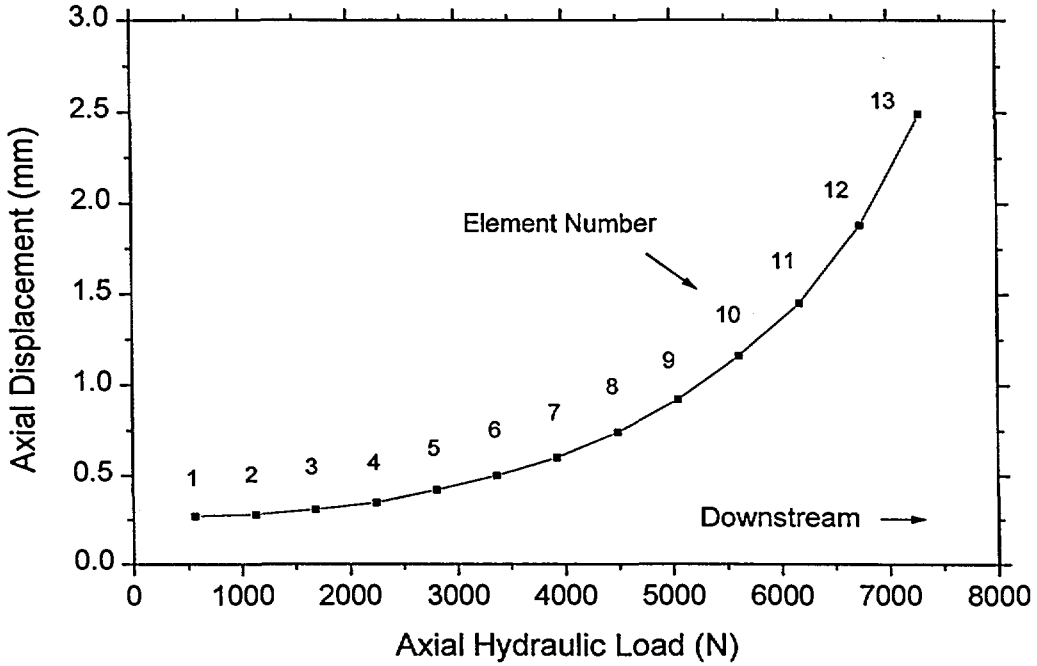


Figure 17 Maximum displacement in endplates (CANFLEX bundle 1-13, Single side-stop)

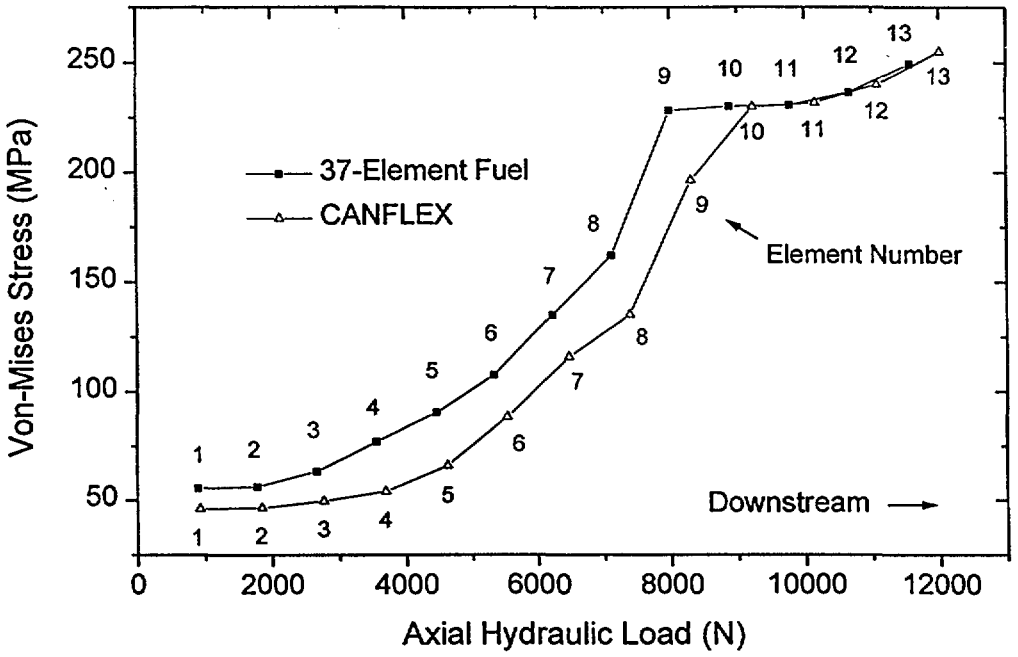


Figure 18 Comparison of maximum stress in endplates between CANFLEX and the 37-element fuel (double side-stops)

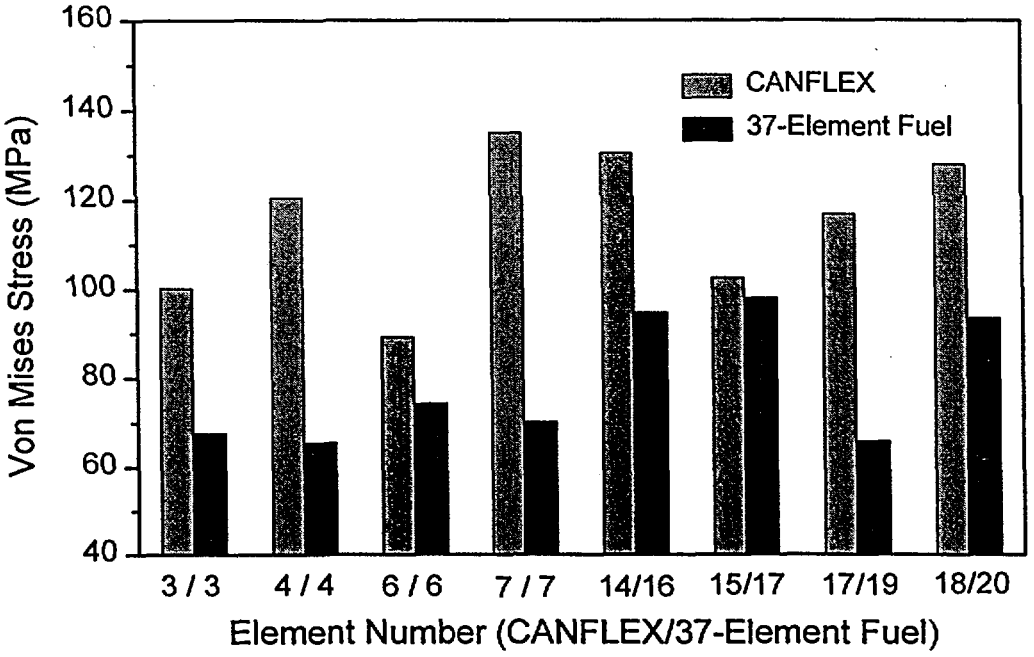


Figure 19 **Comparison of maximum stress in fuel elements against side-stops between CANFLEX and the 37-element fuel**

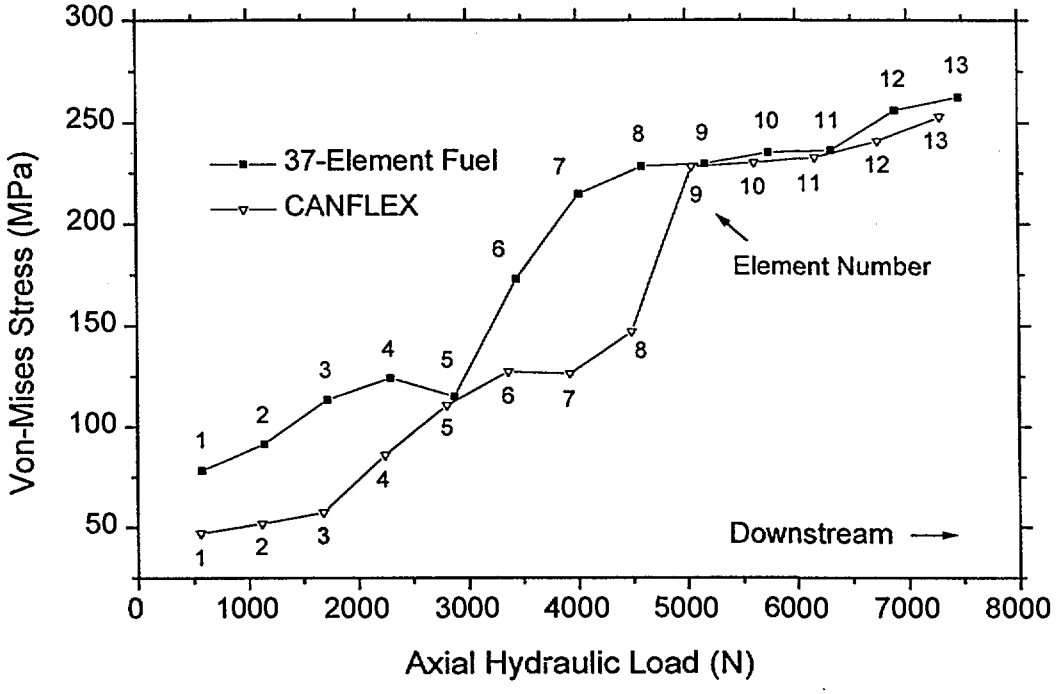


Figure 20 Comparison of maximum stress in endplates between CANFLEX and the 37-element fuel (single side-stop)

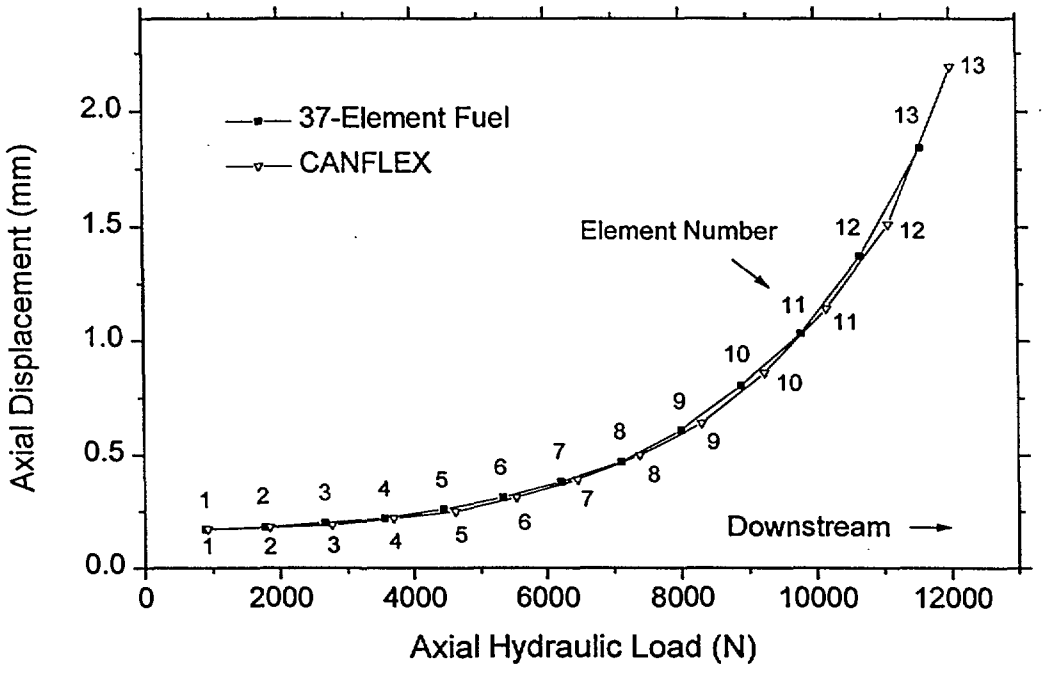


Figure 21 Comparison of maximum displacement in endplates between CANFLEX and the 37-element fuel (double side-stops)

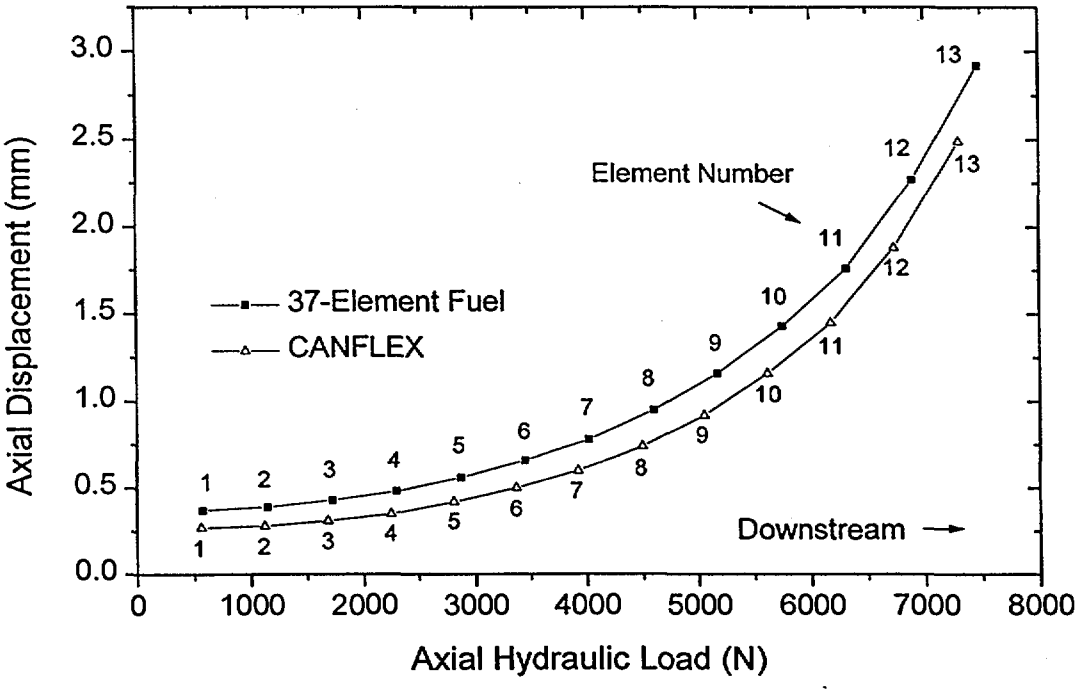


Figure 22 Comparison of maximum displacement in endplates between CANFLEX and the 37-element fuel (single side-stop)

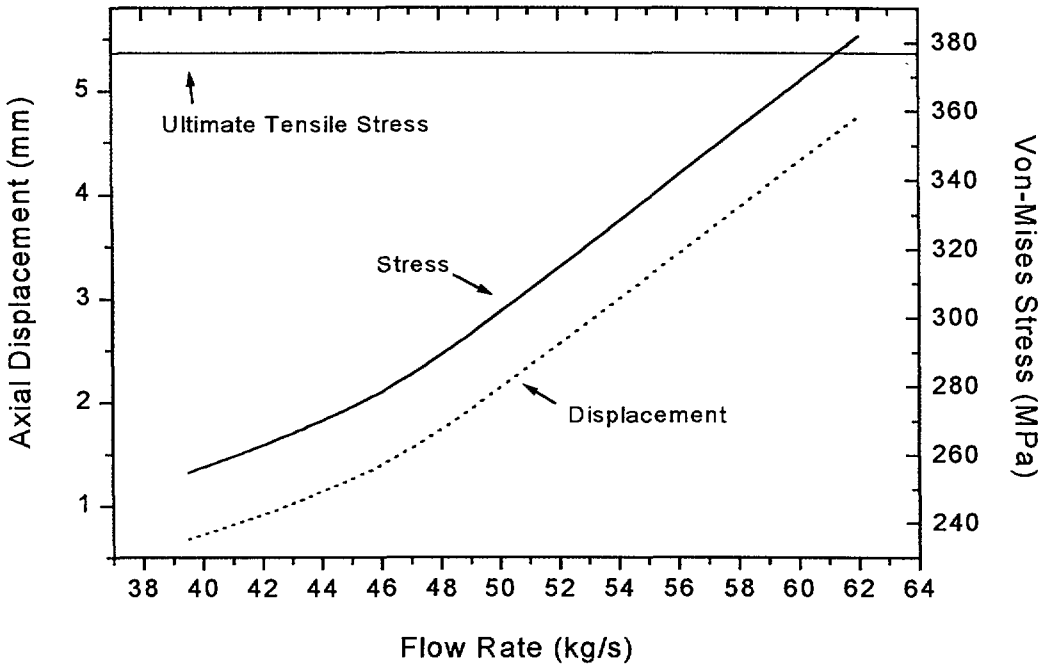


Figure 23 Max. stress and displacement in downstream endplate with varying flow rate (CANFLEX, double side-stops)

부록 1 CANFLEX 핵연료 유한요소해석 입력 자료

```
* HEADING
CANFLEX BUNDLE STRUCTURE ANALYSIS
DOUBLE SIDE-STOPS
SHELL-BEAM MODELLING FOR PLASTIC ANALYSIS
NON-LINEAR MATERIAL PROPERTIES DEFINED
SI UNITS
*PREPRINT,ECHO=NO,MODEL=NO,HISTORY=NO
**
**  Model Definition
**
** SIDE-STOP NODES
*NODE, SYSTEM=C, NSET=NCON
1, 43.84, 54.64285715,  0.0
2, 43.84, 37.50000001,  0.0
3, 43.84, 3.21428572,   0.0
4, 43.84, -13.92857142, 0.0
5, 43.84, -168.2142857, 0.0
6, 43.84, -185.3571428, 0.0
7, 43.84, -219.6428571, 0.0
8, 43.84, -236.7857143, 0.0
*NODE, SYSTEM=C, NSET=N0
11, 61.276, 54.64285715,  0.0
12, 61.276, 37.50000001,  0.0
13, 61.276, 3.21428572,   0.0
14, 61.276, -13.92857142, 0.0
15, 61.276, -168.2142857, 0.0
16, 61.276, -185.3571428, 0.0
17, 61.276, -219.6428571, 0.0
18, 61.276, -236.7857143, 0.0
**
** ENDPLATE
** OUTER RING
** OUTER NODES (N101 - N163)
*NODE, SYSTEM=C, NSET=N1
101, 45.84, 88.92857143, 0.0
*NCOPY, NEW SET=NC1, OLD SET=N1, CHANGE NUMBER=1, SHIFT, MULTIPLE=62
0., 0., 0.
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, SYSTEM=C, NSET=N2
201, 43.84, 88.92857143, 0.0
*NCOPY, NEW SET=NC2, OLD SET=N2, CHANGE NUMBER=1, SHIFT, MULTIPLE=62
0., 0., 0.
0., 0., 0., 0., 0., 1, -5.71428571
*NSET, NSET=NC2
N2, NC2
**
** INNER NODES (N301 - N363)
*NODE, SYSTEM=C, NSET=N3
301, 41.84, 88.92857143, 0.0
*NCOPY, NEW SET=NC3, OLD SET=N3, CHANGE NUMBER=1, SHIFT, MULTIPLE=62
0., 0., 0.
0., 0., 0., 0., 0., 1, -5.71428571
*NSET, NSET=NC3
N3, NC3
**
** OUTER RIB
** OUTER ROOT, LEFT (N401, 403, 405,,, 413)
*NODE, SYSTEM=C, NSET=N4
401, 41.17, 81.058, 0.0
*NCOPY, NEW SET=NC4, OLD SET=N4, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
```

```
*NSET, NSET=NC4
N4, NC4
**
** OUTER ROOT, RIGHT (N402, 404, 406,,, 414)
*NODE, SYSTEM=C, NSET=N5
402, 41.17, 73.942, 0.0
*NCOPY, NEW SET=NC5, OLD SET=N5, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC5
N5, NC5
**
** OUT MIDDLE, LEFT (N421, 423, 425,,, 433)
*NODE, SYSTEM=C, NSET=N6
421, 39.84, 80.015, 0.0
*NCOPY, NEW SET=NC6, OLD SET=N6, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC6
N6, NC6
**
** OUT MIDDLE, RIGHT (N422, 424, 426,,, 434)
*NODE, SYSTEM=C, NSET=N7
422, 39.84, 74.985, 0.0
*NCOPY, NEW SET=NC7, OLD SET=N7, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC7
N7, NC7
**
**OUT MIDDLE, CENTER (N303, 312, 321,,, 357)
**OVERWRITE TO THE PREVIOUS DEFINED NODES
*NODE, SYSTEM=C, NSET=N8
303, 39.84, 77.5, 0.0
*NCOPY, NEW SET=NC8, OLD SET=N8, CHANGE NUMBER=9, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC8
N8, NC8
**
**CENTER MIDDLE, LEFT (N441, 443, 445,,, 453)
*NODE, SYSTEM=C, NSET=N9
441, 37.17, 80.195, 0.0
*NCOPY, NEW SET=NC9, OLD SET=N9, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC9
N9, NC9
**
**CENTER MIDDLE, CENTER (N551 - N557)
*NODE, SYSTEM=C, NSET=N10
551, 37.17, 77.5, 0.0
*NCOPY, NEW SET=NC10, OLD SET=N10, CHANGE NUMBER=1, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC10
N10, NC10
**
**CENTER MIDDLE, RIGHT (N442, 444, 446,,, 454)
*NODE, SYSTEM=C, NSET=N11
442, 37.17, 74.805, 0.0
*NCOPY, NEW SET=NC11, OLD SET=N11, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC11
N11, NC11
**
```

```
**IN MIDDLE, LEFT (N461, 463, 465,,, 473)
*NODE, SYSTEM=C, NSET=N12
461, 34.5, 80.404, 0.0
*NCOPY, NEW SET=NC12, OLD SET=N12, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC12
N12, NC12
**
**IN MIDDLE, RIGHT (N462, 464, 466,,, 474)
*NODE, SYSTEM=C, NSET=N13
462, 34.5, 74.596, 0.0
*NCOPY, NEW SET=NC13, OLD SET=N13, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC13
N13, NC13
**
**INNER ROOT, LEFT (N481, 483, 485,,,,493)
*NODE, SYSTEM=C, NSET=N14
481, 33.17, 81.913, 0.0
*NCOPY, NEW SET=NC14, OLD SET=N14, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC14
N14, NC14
**
**INNER ROOT, RIGHT (N482, 484, 486,,,,494)
*NODE, SYSTEM=C, NSET=N15
482, 33.17, 73.087, 0.0
*NCOPY, NEW SET=NC15, OLD SET=N15, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC15
N15, NC15
**
**INTERMEDIATE RING
**OUTER NODES (N501 - N542)
*NODE, SYSTEM=C, NSET=N16
501, 32.5, 84.64285715, 0.0
*NCOPY, NEW SET=NC16, OLD SET=N16, CHANGE NUMBER=1, SHIFT, MULTIPLE=41
0., 0., 0.
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, SYSTEM=C, NSET=N17
601, 30.75, 84.64285715, 0.0
*NCOPY, NEW SET=NC17, OLD SET=N17, CHANGE NUMBER=1, SHIFT, MULTIPLE=41
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET, NSET=NC17
N17, NC17
**
**INNER NODES (N701 - N742)
*NODE, SYSTEM=C, NSET=N18
701, 29, 84.64285715, 0.0
*NCOPY, NEW SET=NC18, OLD SET=N18, CHANGE NUMBER=1, SHIFT, MULTIPLE=41
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, SYSTEM=C, NSET=N19
502, 34.5, 77.5, 0.0
*NCOPY, NEW SET=NC19, OLD SET=N19, CHANGE NUMBER=6, SHIFT, MULTIPLE=6
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, SYSTEM=C, NSET=N20
801, 28.33, 57.00931428, 0.0
*NCOPY, NEW SET=NC20, OLD SET=N20, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC20
N20, NC20
**
**OUTER ROOT, RIGHT (N802, 804, 806,,, 814)
*NODE, SYSTEM=C, NSET=N21
802, 28.33, 46.56211428, 0.0
*NCOPY, NEW SET=NC21, OLD SET=N21, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC21
N21, NC21
**
**OUT MIDDLE, LEFT (N821, 823, 825,,, 833)
*NODE, SYSTEM=C, NSET=N22
821, 27.3, 55.38031428, 0.0
*NCOPY, NEW SET=NC22, OLD SET=N22, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC22
N22, NC22
**
**OUT MIDDLE, RIGHT (N822, 824, 826,,, 834)
*NODE, SYSTEM=C, NSET=N23
822, 27.3, 48.19111428, 0.0
*NCOPY, NEW SET=NC23, OLD SET=N23, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
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, SYSTEM=C, NSET=N24
705, 27.3, 51.78571428, 0.0
*NCOPY, NEW SET=NC24, OLD SET=N24, CHANGE NUMBER=6, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC24
N24, NC24
**
**CENTER MIDDLE, LEFT (N875, 878, 881,,, 893)
*NODE, SYSTEM=C, NSET=N25
875, 24.3225, 55.8190, 0.0
*NCOPY, NEW SET=NC25, OLD SET=N25, CHANGE NUMBER=3, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC25
N25, NC25
**
**CENTER MIDDLE, CENTER (N876, 879, 882,,, 894)
*NODE, SYSTEM=C, NSET=N26
876, 24.3225, 51.78571428, 0.0
```

```
*NCOPY, NEW SET=NC26, OLD SET=N26, CHANGE NUMBER=3, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC26
N26, NC26
**
**CENTER MIDDLE, RIGHT (N877, 880, 883,,, 895)
*NODE, SYSTEM=C, NSET=N27
877, 24.3225, 47.7524, 0.0
*NCOPY, NEW SET=NC27, OLD SET=N27, CHANGE NUMBER=3, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC27
N27, NC27
**
**IN MIDDLE, LEFT (N841, 843, 845,,, 853)
*NODE, SYSTEM=C, NSET=N28
841, 21.345, 56.37937228, 0.0
*NCOPY, NEW SET=NC28, OLD SET=N28, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC28
N28, NC28
**
**IN MIDDLE, RIGHT (N842, 844, 846,,, 854)
*NODE, SYSTEM=C, NSET=N29
842, 21.345, 47.19205628, 0.0
*NCOPY, NEW SET=NC29, OLD SET=N29, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC29
N29, NC29
**
**INNER ROOT, LEFT (N861, 863, 865,,, 873)
*NODE, SYSTEM=C, NSET=N30
861, 19.7175, 58.76852448, 0.0
*NCOPY, NEW SET=NC30, OLD SET=N30, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC30
N30, NC30
**
**INNER ROOT, RIGHT (N862, 864, 866,,, 874)
*NODE, SYSTEM=C, NSET=N31
862, 19.7175, 44.80290408, 0.0
*NCOPY, NEW SET=NC31, OLD SET=N31, CHANGE NUMBER=2, SHIFT, MULTIPLE=6
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
*NSET, NSET=NC31
N31, NC31
**
**INNER RING
**OUTER NODES (N901 - N942)
*NODE, SYSTEM=C, NSET=N32
901, 19.09, 71.7857, 0.0
*NCOPY, NEW SET=NC32, OLD SET=N32, CHANGE NUMBER=1, SHIFT, MULTIPLE=41
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET, NSET=NC32
N32, NC32
**
** OUTER NODES (N904, 910,,, 940)
*NODE, SYSTEM=C, NSET=N33
904, 19.09, 40.7, 0.0
*NCOPY, NEW SET=NC33, OLD SET=N33, CHANGE NUMBER=6, SHIFT, MULTIPLE=7
0., 0., 0.
0., 0., 0., 0., 0., 1, -51.42857143
```

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*NSET, NSET=NC33
N33, NC33
**
** MIDDLE NODES (N1001 - N1042)
** ELEMENTS LOCATE at 6N+1 (N=0,1,2,3,,,6)
*NODE, SYSTEM=C, NSET=N34
1001, 17.34, 71.7857, 0.0
*NCOPY, NEW SET=NC34, OLD SET=N34, CHANGE NUMBER=1, SHIFT, MULTIPLE=41
0., 0., 0.
0., 0., 0., 0., 0., 1, -8.57142857
*NSET, NSET=NC34
N34, NC34
**
** INNER NODES (N1101 - N1142)
*NODE, SYSTEM=C, NSET=N35
1101, 15.59, 71.7857, 0.0
*NCOPY, NEW SET=NC35, OLD SET=N35, CHANGE NUMBER=1, SHIFT, MULTIPLE=41
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, SYSTEM=C, NSET=N36
903, 21.345, 51.78571428, 0.0
*NCOPY, NEW SET=NC36, OLD SET=N36, CHANGE NUMBER=6, SHIFT, MULTIPLE=6
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, SYSTEM=C, NSET=N37
1104, 14.92, 42.85314286, 0.0
*NCOPY, NEW SET=NC37, OLD SET=N37, CHANGE NUMBER=2, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.292
*NSET, NSET=NC37
N37, NC37
**
*NODE, SYSTEM=C, NSET=N38
1129, 14.92, -166.854, 0.0
*NCOPY, NEW SET=NC38, OLD SET=N38, CHANGE NUMBER=2, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.292
*NSET, NSET=NC38
N38, NC38
**
**N1201 - N1203
*NODE, SYSTEM=C, NSET=N39
1201, 10.4, 42.6987916, 0.0
*NCOPY, NEW SET=NC39, OLD SET=N39, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -9.49164874
*NSET, NSET=NC39
N39, NC39
**
**N1204 - N1206
*NODE, SYSTEM=C, NSET=N40
1204, 10.4, -167.0083513, 0.0
*NCOPY, NEW SET=NC40, OLD SET=N40, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -9.49164874
*NSET, NSET=NC40
```

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N40, NC40
**
**N1207 - N1209
*NODE, SYSTEM=C, NSET=N41
1207, 5.2, 52.46424648, 0.0
*NCOPY, NEW SET=NC41, OLD SET=N41, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.25710362
*NSET, NSET=NC41
N41, NC41
**
**N1210 - N1212
*NODE, SYSTEM=C, NSET=N42
1210, 5.2, -157.2428964, 0.0
*NCOPY, NEW SET=NC42, OLD SET=N42, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -19.25710362
*NSET, NSET=NC42
N42, NC42
**
**N1213, N1215
*NODE, SYSTEM=C, NSET=N43
1213, 1.715, 108.354, 0.0
*NCOPY, NEW SET=NC43, OLD SET=N43, CHANGE NUMBER=2, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -180
*NSET, NSET=NC43
N43, NC43
**
**N1214
*NODE, SYSTEM=C, NSET=N44
1214, 0., 0., 0.
**
** ADDITIONAL NODES FOR "ROUNDNESS" AT JUNCTION BETWEEN
** INNER RING AND INNER RIB (N1216 - N1221)
*NODE, SYSTEM=C, NSET=N45
1216, 13.59, 40.39964286, 0.0
*NCOPY, NEW SET=NC45, OLD SET=N45, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -7.1925
*NSET, NSET=NC45
N45, NC45
**
*NODE, SYSTEM=C, NSET=N46
1219, 13.59, -169.3075, 0.0
*NCOPY, NEW SET=NC46, OLD SET=N46, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
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, NEW SET=N1C2, OLD SET=NC2, CHANGE NUMBER=1100, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=N1C17, OLD SET=NC17, CHANGE NUMBER=763, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
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*NCOPY, NEW SET=N1C34, OLD SET=NC34, CHANGE NUMBER=405, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=N1C44, OLD SET=N44, CHANGE NUMBER=234, SHIFT
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, NEW SET=NA2, OLD SET=NA1, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
**N1701 TO N1848 : NODES BETWEEN 3RD AND 4TH AXIAL SEGMENTS
*NCOPY, NEW SET=NA3, OLD SET=NA2, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
** N1901 TO N2048 : NODES BETWEEN 4TH AND 5TH AXIAL SEGMENTS
*NCOPY, NEW SET=NA4, OLD SET=NA3, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
** N2101 TO N2248 : NODES BETWEEN 5TH AND 6TH AXIAL SEGMENTS
*NCOPY, NEW SET=NA5, OLD SET=NA4, CHANGE NUMBER=200, SHIFT
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
** NODES 501-542, 601-642, 701-742, 801-814, 821-834, 841-854, 861-895
** NODES 901-942, 1001-1042, 1101-1142, 1201-1221
*NCOPY, OLD SET=NPLT1D, NEW SET=NPLT1U, CHANGE NUMBER=3000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,0.
**
** NODALIZATION FOR REMAINING 12 BUNDLES
**
** DOWNSTREAM ENDPLATES 12 MORE
*NCOPY, NEW SET=NPLT2D, OLD SET=NPLT1D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT3D, OLD SET=NPLT2D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT4D, OLD SET=NPLT3D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT5D, OLD SET=NPLT4D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT6D, OLD SET=NPLT5D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT7D, OLD SET=NPLT6D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT8D, OLD SET=NPLT7D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT9D, OLD SET=NPLT8D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
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*NCOPY, NEW SET=NPLT10D, OLD SET=NPLT9D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT11D, OLD SET=NPLT10D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT12D, OLD SET=NPLT11D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT13D, OLD SET=NPLT12D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
**
** SHEATH 12SET MORE
** NODES BETWEEN SEGMENTS
*NCOPY, NEW SET=NAA2, OLD SET=NAA1, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA3, OLD SET=NAA2, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA4, OLD SET=NAA3, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA5, OLD SET=NAA4, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA6, OLD SET=NAA5, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA7, OLD SET=NAA6, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA8, OLD SET=NAA7, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA9, OLD SET=NAA8, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA10, OLD SET=NAA9, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA11, OLD SET=NAA10, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA12, OLD SET=NAA11, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NAA13, OLD SET=NAA12, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
**
** UPSTREAM ENDPLATES 12 MORE
*NCOPY, NEW SET=NPLT2U, OLD SET=NPLT1U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT3U, OLD SET=NPLT2U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT4U, OLD SET=NPLT3U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT5U, OLD SET=NPLT4U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT6U, OLD SET=NPLT5U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
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0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT7U, OLD SET=NPLT6U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT8U, OLD SET=NPLT7U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT9U, OLD SET=NPLT8U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT10U, OLD SET=NPLT9U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT11U, OLD SET=NPLT10U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT12U, OLD SET=NPLT11U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT13U, OLD SET=NPLT12U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.5
0.,0.,0.,0.,0.,1.,0.
**
**
**ELEMENTS
** Side-stop Elements (E1 - E8)
*ELEMENT, TYPE=B31, ELSET=ESTOP
1, 11, 1
2, 12, 2
3, 13, 3
4, 14, 4
5, 15, 5
6, 16, 6
7, 17, 7
8, 18, 8
*BEAM SECTION, ELSET=ESTOP, MATERIAL=MSTOP, SECTION=RECT
9.525, 25.0
*MATERIAL, NAME=MSTOP
*ELASTIC
9.12E7, 0.3
**ENDPLATE
**OUTER RING - OUTER HALF (E9 - E71)
*ELEMENT, TYPE=S4R, ELSET=EPT1D
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
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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
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

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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, TYPE=S4R, ELSET=EPLT1U
*ELCOPY,ELEMENT SHIFT=422,OLD SET=EPT1D,SHIFT NODES=3000,NEW SET=EPLT1U
**
** SHEATH ELEMENTS
** 1ST SEGMENT (EL. 853 - 895)
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES1
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, TYPE=PIPE31, ELSET=ETUBEL1
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, TYPE=PIPE31, ELSET=ETUBES2
896, 1301, 1501
897, 1304, 1504
898, 1307, 1507
899, 1310, 1510
900, 1313, 1513
901, 1316, 1516
902, 1319, 1519
903, 1322, 1522
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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
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, TYPE=PIPE31, ELSET=ETUBES3
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETUBES2, SHIFT NODES=200, NEW SET=ETUBES3
**4th Segment (EL 982-1017) by copying 3rd segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES4
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETUBES3, SHIFT NODES=200, NEW SET=ETUBES4
**5th Segment (EL 1025-1059) by copying 4th segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES5
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETUBES4, SHIFT NODES=200, NEW SET=ETUBES5
**
*ELEMENT, TYPE=PIPE31, ELSET=ETUBEL2
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, TYPE=PIPE31, ELSET=ETUBEL3
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETUBEL2, SHIFT NODES=200, NEW SET=ETUBEL3
**4th Segment (EL 1018-1024) by copying 3rd segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBEL4
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETUBEL3, SHIFT NODES=200, NEW SET=ETUBEL4
**5th Segment (EL 1060-1067) by copying 4th segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBEL5
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETUBEL4, SHIFT NODES=200, NEW SET=ETUBEL5
**
**6TH SEGMENT (EL 1068-1110)
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES6
1068, 2101, 3201
1069, 2104, 3204
1070, 2107, 3207
1071, 2110, 3210
1072, 2113, 3213
1073, 2116, 3216
1074, 2119, 3219
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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
1098, 2191, 3628
1099, 2194, 3631
1100, 2197, 3634
1101, 2200, 3637
1102, 2203, 3640
*ELSET, ELSET=ESTUBE1
ETUBES1,ETUBES2,ETUBES3,ETUBES4,ETUBES5,ETUBES6,
**
*ELEMENT, TYPE=PIPE31, ELSET=ETUBEL6
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=ELTUBE1
ETUBEL1, ETUBEL2, ETUBEL3, ETUBEL4, ETUBEL5, ETUBEL6
**
**SPACER (EL 1111-1201)
*ELEMENT, TYPE=T3D2, ELSET=ESPACER1
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
1125, 1743, 1746
1126, 1746, 1749
1127, 1749, 1752
1128, 1752, 1755
1129, 1755, 1758
1130, 1758, 1761
1131, 1761, 1701
1132, 1764, 1767
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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

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1200, 1803, 1842
1201, 1761, 1803
**
**INTER-BUNDLE ELEMENTS (EL 1202-1244)
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS1
1202, 3201, 10201
1203, 3204, 10204
1204, 3207, 10207
1205, 3210, 10210
1206, 3213, 10213
1207, 3216, 10216
1208, 3219, 10219
1209, 3222, 10222
1210, 3225, 10225
1211, 3228, 10228
1212, 3231, 10231
1213, 3234, 10234
1214, 3237, 10237
1215, 3240, 10240
1216, 3243, 10243
1217, 3246, 10246
1218, 3249, 10249
1219, 3252, 10252
1220, 3255, 10255
1221, 3258, 10258
1222, 3261, 10261
1223, 3601, 10601
1224, 3604, 10604
1225, 3607, 10607
1226, 3610, 10610
1227, 3613, 10613
1228, 3616, 10616
1229, 3619, 10619
1230, 3622, 10622
1231, 3625, 10625
1232, 3628, 10628
1233, 3631, 10631
1234, 3634, 10634
1235, 3637, 10637
1236, 3640, 10640
1237, 4001, 11001
1238, 4007, 11007
1239, 4013, 11013
1240, 4019, 11019
1241, 4025, 11025
1242, 4031, 11031
1243, 4037, 11037
1244, 4214, 11214
**
**Generation of Elements for Bundles #2 - #13 (EL 1245-11372)
**Element Shift=1236 for #2, 844 for others, Shift Nodes:10000
**Bundle #2, Downstream Endplate, EL 1245-1666
*ELEMENT, TYPE=S4R, ELSET=EPLT2D
*ELCOPY, ELEMENT SHIFT=1236, OLD SET=EPT1D, SHIFT NODES=10000, NEW SET=EPLT2D
**Bundle #2, Upstream Endplate, EL 1667-2088
*ELEMENT, TYPE=S4R, ELSET=EPLT2U
*ELCOPY, ELEMENT SHIFT=1236, OLD SET=EPLT1U, SHIFT NODES=10000, NEW SET=EPLT2U
**Bundle #3, Downstream Endplate, EL 2089-2510
*ELEMENT, TYPE=S4R, ELSET=EPLT3D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT2D, SHIFT NODES=10000, NEW SET=EPLT3D
**Bundle #3, Upstream Endplate, EL 2511-2932
*ELEMENT, TYPE=S4R, ELSET=EPLT3U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT2U, SHIFT NODES=10000, NEW SET=EPLT3U
**Bundle #4, Downstream Endplate, EL 2933-3354
*ELEMENT, TYPE=S4R, ELSET=EPLT4D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT3D, SHIFT NODES=10000, NEW SET=EPLT4D
**Bundle #4, Upstream Endplate, EL 3355-3776
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*ELEMENT, TYPE=S4R, ELSET=EPLT4U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT3U, SHIFT NODES=10000, NEW SET=EPLT4U
**Bundle #5, Downstream Endplate, EL 3777-4198
*ELEMENT, TYPE=S4R, ELSET=EPLT5D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT4D, SHIFT NODES=10000, NEW SET=EPLT5D
**Bundle #5, Upstream Endplate, EL 4199-4620
*ELEMENT, TYPE=S4R, ELSET=EPLT5U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT4U, SHIFT NODES=10000, NEW SET=EPLT5U
**Bundle #6, Downstream Endplate, EL 4621-5042
*ELEMENT, TYPE=S4R, ELSET=EPLT6D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT5D, SHIFT NODES=10000, NEW SET=EPLT6D
**Bundle #6, Upstream Endplate, EL 5043-5464
*ELEMENT, TYPE=S4R, ELSET=EPLT6U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT5U, SHIFT NODES=10000, NEW SET=EPLT6U
**Bundle #7, Downstream Endplate, EL 5465-5886
*ELEMENT, TYPE=S4R, ELSET=EPLT7D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT6D, SHIFT NODES=10000, NEW SET=EPLT7D
**Bundle #7, Upstream Endplate, EL 5887-6308
*ELEMENT, TYPE=S4R, ELSET=EPLT7U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT6U, SHIFT NODES=10000, NEW SET=EPLT7U
**Bundle #8, Downstream Endplate, EL 6309-6730
*ELEMENT, TYPE=S4R, ELSET=EPLT8D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT7D, SHIFT NODES=10000, NEW SET=EPLT8D
**Bundle #8, Upstream Endplate, EL 6731-7152
*ELEMENT, TYPE=S4R, ELSET=EPLT8U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT7U, SHIFT NODES=10000, NEW SET=EPLT8U
**Bundle #9, Downstream Endplate, EL 7153-7574
*ELEMENT, TYPE=S4R, ELSET=EPLT9D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT8D, SHIFT NODES=10000, NEW SET=EPLT9D
**Bundle #9, Upstream Endplate, EL 7575-7996
*ELEMENT, TYPE=S4R, ELSET=EPLT9U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT8U, SHIFT NODES=10000, NEW SET=EPLT9U
**Bundle #10, Downstream Endplate, EL 7997-8418
*ELEMENT, TYPE=S4R, ELSET=EPLT10D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT9D, SHIFT NODES=10000, NEW SET=EPLT10D
**Bundle #10, Upstream Endplate, EL 8419-8840
*ELEMENT, TYPE=S4R, ELSET=EPLT10U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT9U, SHIFT NODES=10000, NEW SET=EPLT10U
**Bundle #11, Downstream Endplate, EL 8841-9262
*ELEMENT, TYPE=S4R, ELSET=EPLT11D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT10D, SHIFT NODES=10000, NEW SET=EPLT11D
**Bundle #11, Upstream Endplate, EL 9263-9684
*ELEMENT, TYPE=S4R, ELSET=EPLT11U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT10U, SHIFT NODES=10000, NEW SET=EPLT11U
**Bundle #12, Downstream Endplate, EL 9685-10106
*ELEMENT, TYPE=S4R, ELSET=EPLT12D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT11D, SHIFT NODES=10000, NEW SET=EPLT12D
**Bundle #12, Upstream Endplate, EL 10107-10528
*ELEMENT, TYPE=S4R, ELSET=EPLT12U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT11U, SHIFT NODES=10000, NEW SET=EPLT12U
**Bundle #13, Downstream Endplate, EL 10529-10950
*ELEMENT, TYPE=S4R, ELSET=EPLT13D
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT12D, SHIFT NODES=10000, NEW SET=EPLT13D
**Bundle #13, Upstream Endplate, EL 10951-11372
*ELEMENT, TYPE=S4R, ELSET=EPLT13U
*ELCOPY, ELEMENT SHIFT=844, OLD SET=EPLT12U, SHIFT NODES=10000, NEW SET=EPLT13U
*ELSET, ELSET=EPLATE
EPT1D,EPLT2D,EPLT3D,EPLT4D,EPLT5D,EPLT6D,EPLT7D,EPLT8D,EPLT9D,EPLT10D,EPLT11D,
EPLT12D,EPLT13D,EPLT1U,EPLT2U,EPLT3U,EPLT4U,EPLT5U,EPLT6U,EPLT7U,EPLT8U,EPLT9U,
EPLT10U,EPLT11U,EPLT12U,EPLT13U
*SHELL SECTION, ELSET=EPLATE, MATERIAL=MPLATE
1.60
*MATERIAL, NAME=MPLATE
*ELASTIC
87980.0, 0.42
*PLASTIC
228., 0.0
```

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378., 0.144
**
** Tube Elements for #2 - #13 Bundles (EL 11373-14468)
** SMALL DIA TUBE
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE2
*ELCOPY, ELEMENT SHIFT=10520, OLD SET=ESTUBE1, SHIFT NODES=10000, NEW SET=ESTUBE2
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE3
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE2, SHIFT NODES=10000, NEW SET=ESTUBE3
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE4
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE3, SHIFT NODES=10000, NEW SET=ESTUBE4
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE5
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE4, SHIFT NODES=10000, NEW SET=ESTUBE5
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE6
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE5, SHIFT NODES=10000, NEW SET=ESTUBE6
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE7
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE6, SHIFT NODES=10000, NEW SET=ESTUBE7
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE8
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE7, SHIFT NODES=10000, NEW SET=ESTUBE8
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE9
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE8, SHIFT NODES=10000, NEW SET=ESTUBE9
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE10
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE9, SHIFT NODES=10000, NEW SET=ESTUBE10
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE11
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE10, SHIFT NODES=10000, NEW SET=ESTUBE11
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE12
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE11, SHIFT NODES=10000, NEW SET=ESTUBE12
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE13
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ESTUBE12, SHIFT NODES=10000, NEW SET=ESTUBE13
*ELSET, ELSET=ESTUBE
ESTUBE1, ESTUBE2, ESTUBE3, ESTUBE4, ESTUBE5, ESTUBE6, ESTUBE7, ESTUBE8, ESTUBE9,
ESTUBE10, ESTUBE11, ESTUBE12, ESTUBE13
*BEAM SECTION, ELSET=ESTUBE, MATERIAL=MSTUBE, SECTION=PIPE
5.75, 0.33
1., 0., 0.
*MATERIAL, NAME=MSTUBE
*ELASTIC
89015.0, 0.4
*PLASTIC
403., 0.0
443., 0.144
**
** LARGE DIA TUBE
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE2
*ELCOPY, ELEMENT SHIFT=10520, OLD SET=ELTUBE1, SHIFT NODES=10000, NEW SET=ELTUBE2
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE3
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE2, SHIFT NODES=10000, NEW SET=ELTUBE3
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE4
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE3, SHIFT NODES=10000, NEW SET=ELTUBE4
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE5
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE4, SHIFT NODES=10000, NEW SET=ELTUBE5
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE6
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE5, SHIFT NODES=10000, NEW SET=ELTUBE6
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE7
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE6, SHIFT NODES=10000, NEW SET=ELTUBE7
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE8
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE7, SHIFT NODES=10000, NEW SET=ELTUBE8
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE9
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE8, SHIFT NODES=10000, NEW SET=ELTUBE9
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE10
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE9, SHIFT NODES=10000, NEW SET=ELTUBE10
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE11
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE10, SHIFT NODES=10000, NEW SET=ELTUBE11
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE12
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE11, SHIFT NODES=10000, NEW SET=ELTUBE12
*ELEMENT, TYPE=PIPE31, ELSET=ELTUBE13
*ELCOPY, ELEMENT SHIFT=258, OLD SET=ELTUBE12, SHIFT NODES=10000, NEW SET=ELTUBE13
*ELSET, ELSET=ELTUBE
```

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ELTUBE1, ELTUBE2, ELTUBE3, ELTUBE4, ELTUBE5, ELTUBE6, ELTUBE7, ELTUBE8, ELTUBE9,
ELTUBE10, ELTUBE11, ELTUBE12, ELTUBE13
*BEAM SECTION, ELSET=ELTUBE, MATERIAL=MLTUBE, SECTION=PIPE
6.75, 0.36
1., 0., 0.
*MATERIAL, NAME=MLTUBE
*ELASTIC
89015.0, 0.4
*PLASTIC
403., 0.0
443., 0.144
**
** Spacer Elements for #2 - #13 Bundles (EL 14469-15560)
*ELEMENT, TYPE=T3D2, ELSET=ESPACER2
*ELCOPY, ELEMENT SHIFT=13358, OLD SET=ESPACER1, SHIFT NODES=10000, NEW SET=ESPACER2
*ELEMENT, TYPE=T3D2, ELSET=ESPACER3
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER2, SHIFT NODES=10000, NEW SET=ESPACER3
*ELEMENT, TYPE=T3D2, ELSET=ESPACER4
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER3, SHIFT NODES=10000, NEW SET=ESPACER4
*ELEMENT, TYPE=T3D2, ELSET=ESPACER5
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER4, SHIFT NODES=10000, NEW SET=ESPACER5
*ELEMENT, TYPE=T3D2, ELSET=ESPACER6
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER5, SHIFT NODES=10000, NEW SET=ESPACER6
*ELEMENT, TYPE=T3D2, ELSET=ESPACER7
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER6, SHIFT NODES=10000, NEW SET=ESPACER7
*ELEMENT, TYPE=T3D2, ELSET=ESPACER8
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER7, SHIFT NODES=10000, NEW SET=ESPACER8
*ELEMENT, TYPE=T3D2, ELSET=ESPACER9
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER8, SHIFT NODES=10000, NEW SET=ESPACER9
*ELEMENT, TYPE=T3D2, ELSET=ESPACER10
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER9, SHIFT NODES=10000, NEW SET=ESPACER10
*ELEMENT, TYPE=T3D2, ELSET=ESPACER11
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER10, SHIFT NODES=10000, NEW SET=ESPACER11
*ELEMENT, TYPE=T3D2, ELSET=ESPACER12
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER11, SHIFT NODES=10000, NEW SET=ESPACER12
*ELEMENT, TYPE=T3D2, ELSET=ESPACER13
*ELCOPY, ELEMENT SHIFT=91, OLD SET=ESPACER12, SHIFT NODES=10000, NEW SET=ESPACER13
*ELSET, ELSET=ESPACER
ESPACER1,ESPACER2,ESPACER3,ESPACER4,ESPACER5,ESPACER6,ESPACER7,ESPACER8,ESPACER9,
ESPACER10,ESPACER11,ESPACER12,ESPACER13
*SOLID SECTION, ELSET=ESPACER, MATERIAL=MSPACER
100
*MATERIAL, NAME=MSPACER
*ELASTIC
89015., 0.3
**
** Inter-bundle Elements for #2 - #12 (EL 15561-16033)
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS2
*ELCOPY, ELEMENT SHIFT=14359, OLD SET=ETRUSS1, SHIFT NODES=10000, NEW SET=ETRUSS2
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS3
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS2, SHIFT NODES=10000, NEW SET=ETRUSS3
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS4
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS3, SHIFT NODES=10000, NEW SET=ETRUSS4
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS5
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS4, SHIFT NODES=10000, NEW SET=ETRUSS5
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS6
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS5, SHIFT NODES=10000, NEW SET=ETRUSS6
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS7
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS6, SHIFT NODES=10000, NEW SET=ETRUSS7
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS8
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS7, SHIFT NODES=10000, NEW SET=ETRUSS8
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS9
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS8, SHIFT NODES=10000, NEW SET=ETRUSS9
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS10
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS9, SHIFT NODES=10000, NEW SET=ETRUSS10
*ELEMENT, TYPE=T3D2, ELSET=ETRUSS11
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS10, SHIFT NODES=10000, NEW SET=ETRUSS11
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*ELEMENT, TYPE=T3D2, ELSET=ETRUSS12
*ELCOPY, ELEMENT SHIFT=43, OLD SET=ETRUSS11, SHIFT NODES=10000, NEW SET=ETRUSS12
*ELSET, ELSET=ETRUSS
ETRUSS1,ETRUSS2,ETRUSS3,ETRUSS4,ETRUSS5,ETRUSS6,ETRUSS7,ETRUSS8,ETRUSS9,
ETRUSS10,ETRUSS11,ETRUSS12
*SOLID SECTION, ELSET=ETRUSS, MATERIAL=MTRUSS
100
*MATERIAL, NAME=MTRUSS
*ELASTIC
87980., 0.3
** CONTACT DEFINITION
*SURFACE DEFINITION, NAME=PLATE
EPT1D, SPOS
*CONTACT NODE SET, NAME=TIP
1,2,3,4,5,6,7,8
*CONTACT PAIR, INTERACTION=NOFRIC, SMALL SLIDING
TIP, PLATE
*SURFACE INTERACTION, NAME=NOFRIC
1.5
** APPLY BOUNDARY CONDITIONS
*NSET,NSET=NCNTR,GENERATE
1214,121214,10000
4214,124214,10000
*BOUNDARY
N0, 1, 6
NCNTR, 1, 2
NCNTR, 6
**
** LOADING
*NSET, NSET=NLOAD, GENERATE
1701, 1803, 3
1806, 1848, 6
11701, 11803, 3
11806, 11848, 6
21701, 21803, 3
21806, 21848, 6
31701, 31803, 3
31806, 31848, 6
41701, 41803, 3
41806, 41848, 6
51701, 51803, 3
51806, 51848, 6
61701, 61803, 3
61806, 61848, 6
71701, 71803, 3
71806, 71848, 6
81701, 81803, 3
81806, 81848, 6
91701, 91803, 3
91806, 91848, 6
101701, 101803, 3
101806, 101848, 6
111701, 111803, 3
111806, 111848, 6
121701, 121803, 3
121806, 121848, 6
**
*RESTART,WRITE,FREQ=1000
*STEP,INC=1000
 Step 1
*STATIC
0.001, 1.0
*CLOAD
NLOAD, 3, 21.485
**
*NSET, NSET=NOUTPUT, GENERATE
1, 8, 1
```

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11, 18, 1
201, 261, 3
601, 640, 3
1001, 1037, 6
1214, 1214
*NODE PRINT, NSET=NOUTPUT, FREQ=1000
U
RF
*ELSET, ELSET=EOUTPUT
EPT1D
*ELSET, ELSET=EPIP
855,856,858,859,868,869,871,872
*EL PRINT, ELSET=EPIP, FREQ=1000
SF
*EL PRINT, ELSET=EOUTPUT, FREQ=1000
MISES
*NODE FILE, NSET=NOUTPUT, FREQ=0
U, RF
*PRINT, CONTACT=YES
*CONTACT CONTROLS, AUTOMATIC TOLERANCE
*END STEP
**
*STEP,INC=1000
 Step 2
*STATIC
0.001, 1.0
*CLOAD, OP=NEW
*NODE PRINT, NSET=NOUTPUT, FREQ=1000
U
RF
*EL PRINT, ELSET=EOUTPUT, FREQ=1000
MISES
*NODE FILE; NSET=NOUTPUT, FREQ=0
U, RF
*PRINT, CONTACT=YES
*CONTACT CONTROLS, AUTOMATIC TOLERANCE
*END STEP
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부록 2 37봉 핵연료 유한요소해석 입력 자료

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* HEADING
CANDU BUNDLE STRUCTURE ANALYSIS
DOUBLE SIDE-STOPS
SHELL-BEAM MODELLING FOR PLASTIC ANALYSIS
NON-LINEAR MATERIAL PROPERTIES DEFINED
SI UNITS
*PREPRINT,ECHO=NO,MODEL=NO,HISTORY=NO
**
**  Model Definition
**
** SIDE-STOP NODES
*NODE, SYSTEM=C, NSET=NCON
1, 43.275, -50,  0.0
2, 43.275, -70,  0.0
3, 43.275, -110,  0.0
4, 43.275, -130, 0.0
5, 43.275,  90, 0.0
6, 43.275,  70,  0.0
7, 43.275,  30,  0.0
8, 43.275,  10,  0.0
*NODE, SYSTEM=C, NSET=N0
11, 60.35, -50,  0.0
12, 60.35, -70,  0.0
13, 60.35, -110,  0.0
14, 60.35, -130, 0.0
15, 60.35,  90, 0.0
16, 60.35,  70,  0.0
17, 60.35,  30,  0.0
18, 60.35,  10,  0.0
**
******** ENDPLATE (N101-N988)
*** OUTER RING
*NODE, SYSTEM=C, NSET=A1
101, 45.55, -10, 0.0
*NCOPY, NEW SET=NA1, OLD SET=A1, CHANGE NUMBER=1, SHIFT, MULTIPLE=53
0., 0., 0.
0., 0., 0., 0., 0., 1, -6.666666667
*NODE, SYSTEM=C, NSET=B1
161, 45.55, 7, 0.0
*NCOPY, NEW SET=NB1, OLD SET=B1, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NSET, NSET=NC1
A1, NA1, B1, NB1
** ELEMENTS LOCATE AT 3N+1 (N=0,1,2,3,,,17)
*NODE, SYSTEM=C, NSET=A2
201, 43.275, -10, 0.0
*NCOPY, NEW SET=NA2, OLD SET=A2, CHANGE NUMBER=1, SHIFT, MULTIPLE=53
0., 0., 0.
0., 0., 0., 0., 0., 1, -6.666666667
*NODE, SYSTEM=C, NSET=B2
261, 43.275, 7, 0.0
*NCOPY, NEW SET=NB2, OLD SET=B2, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NSET, NSET=NC2
A2, NA2, B2, NB2
**
*NODE, SYSTEM=C, NSET=A3
301, 41., -10, 0.0
*NCOPY, NEW SET=NA3, OLD SET=A3, CHANGE NUMBER=1, SHIFT, MULTIPLE=53
0., 0., 0.
0., 0., 0., 0., 0., 1, -6.666666667
**
*NODE, SYSTEM=C, NSET=B3
361, 41, 14, 0.0
*NCOPY, NEW SET=NB3, OLD SET=B3, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
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0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NODE, SYSTEM=C, NSET=D3
371, 41, 0., 0.
*NCOPY, NEW SET=ND3, OLD SET=D3, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NODE, SYSTEM=C, NSET=E3
381, 40.4, 11.357, 0.
*NCOPY, NEW SET=NE3, OLD SET=E3, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NODE, SYSTEM=C, NSET=F3
391, 40.4, 2.643, 0.
*NCOPY, NEW SET=NF3, OLD SET=F3, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NSET, NSET=NC3
A3, NA3, B3, NB3, D3, ND3, E3, NE3, F3, NF3
**
*** OUTER RIB
** LOCAL COORDINATE SYSTEM **
*SYSTEM
0, 0, 0, .12186943, -.992546151, 0
*NODE, NSET=A4
401, -1.65, 38.9,   0.
402, -1.65, 35.7375, 0.
403, -1.65, 32.575,  0.
404,  0.,   38.9,    0.
405,  0.,   35.7375, 0.
406,  0.,   32.575,  0.
407,  1.65, 38.9,    0.
408,  1.65, 35.7375, 0.
409,  1.65, 32.575,  0.
*SYSTEM
*NCOPY, NEW SET=NA4, OLD SET=A4, CHANGE NUMBER=9, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NODE, SYSTEM=C, NSET=B4
461, 31.075, 11.857, 0.0
*NCOPY, NEW SET=NB4, OLD SET=B4, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NODE, SYSTEM=C, NSET=D4
471, 31.075, 2.143, 0.0
*NCOPY, NEW SET=ND4, OLD SET=D4, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NSET, NSET=NC4
A4, NA4, B4, NB4, D4, ND4
**
*** MIDDLE RING
*NODE, SYSTEM=C, NSET=A5
501, 30.475, -15, 0.0
*NCOPY, NEW SET=NA5, OLD SET=A5, CHANGE NUMBER=1, SHIFT, MULTIPLE=35
0., 0., 0.
0., 0., 0., 0., 0., 1, -10
*NODE, SYSTEM=C, NSET=B5
541, 30.475, 14, 0.0
*NCOPY, NEW SET=NB5, OLD SET=B5, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
*NODE, SYSTEM=C, NSET=D5
551, 30.475, -3, 0.0
*NCOPY, NEW SET=ND5, OLD SET=D5, CHANGE NUMBER=1, SHIFT, MULTIPLE=5
0., 0., 0.
0., 0., 0., 0., 0., 1, -60
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*NSET, NSET=NC5
A5, NA5, B5, NB5, D5, ND5
*NODE, SYSTEM=C, NSET=A6
601, 28.75, -15, 0.0
*NCOPY, NEW SET=NA6, OLD SET=A6, CHANGE NUMBER=1, SHIFT, MULTIPLE=35
0., 0., 0.
0., 0., 0., 0., 0., 1, -10
*NODE, SYSTEM=C, NSET=A61
611, 28.75, -113, 0.0
*NODE, SYSTEM=C, NSET=A62
623, 28.75, -233, 0.0
*NODE, SYSTEM=C, NSET=A63
635, 28.75, 7, 0.0
*NODE, SYSTEM=C, NSET=D6
651, 28.75, -60, 0.0
*NCOPY, NEW SET=ND6, OLD SET=D6, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NSET, NSET=NC6
A6, NA6, A61, A62, A63, D6, ND6
*NODE, SYSTEM=C, NSET=A7
701, 27.025, -15, 0.0
*NCOPY, NEW SET=NA7, OLD SET=A7, CHANGE NUMBER=1, SHIFT, MULTIPLE=35
0., 0., 0.
0., 0., 0., 0., 0., 1, -10
*NODE, SYSTEM=C, NSET=B7
741, 27.025, 17.62, 0.0
*NCOPY, NEW SET=NB7, OLD SET=B7, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=D7
751, 27.025, -3.62, 0.0
*NCOPY, NEW SET=ND7, OLD SET=D7, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=E7
761, 26.125, 14.33, 0.0
*NCOPY, NEW SET=NE7, OLD SET=E7, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=F7
771, 26.125, -0.3303, 0.0
*NCOPY, NEW SET=NF7, OLD SET=F7, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=G7
781, 27.025, -60, 0.0
*NCOPY, NEW SET=NG7, OLD SET=G7, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120

*NSET, NSET=NC7
A7, NA7, B7, NB7, D7, ND7, E7, NE7, F7, NF7, G7, NG7
**
*** MIDDLE RIB
** LOCAL COORDINATE SYSTEM **
*SYSTEM
0, 0, 0, .12186943, -.992546151, 0
*NODE, NSET=A8
801, -1.65, 24.925,  0.
802, -1.65, 21.825,  0.
803, -1.65, 18.725,  0.
804,  0.,   24.925,  0.
805,  0.,   21.825,  0.
806,  0.,   18.725,  0.
807,  1.65, 24.925,  0.
808,  1.65, 21.825,  0.
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809,  1.65, 18.725,  0.
*SYSTEM
*NCOPY, NEW SET=NA8, OLD SET=A8, CHANGE NUMBER=9, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=B8
831, 17.525, 14.33, 0.0
*NCOPY, NEW SET=NB8, OLD SET=B8, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=D8
841, 17.525, -0.33, 0.0
*NCOPY, NEW SET=ND8, OLD SET=D8, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NSET, NSET=NC8
A8, NA8, B8, NB8, D8, ND8
**
*** INNER RING
*NODE, SYSTEM=C, NSET=A9
901, 16.625, -30, 0.0
*NCOPY, NEW SET=NA9, OLD SET=A9, CHANGE NUMBER=1, SHIFT, MULTIPLE=17
0., 0., 0.
0., 0., 0., 0., 0., 1, -20
*NODE, SYSTEM=C, NSET=B9
921, 16.625, 17.62, 0.0
*NCOPY, NEW SET=NB9, OLD SET=B9, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=D9
931, 16.625, -3.62, 0.0
*NCOPY, NEW SET=ND9, OLD SET=D9, CHANGE NUMBER=1, SHIFT, MULTIPLE=2
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=E9
941, 14.9, -30, 0.0
*NCOPY, NEW SET=NE9, OLD SET=E9, CHANGE NUMBER=1, SHIFT, MULTIPLE=17
0., 0., 0.
0., 0., 0., 0., 0., 1, -20
*NODE, SYSTEM=C, NSET=E91
948, 14.9, -173, 0.0
*NODE, SYSTEM=C, NSET=E92
957, 14.9, 7, 0.0
*NODE, SYSTEM=C, NSET=F9
961, 13.175, -30, 0.0
*NCOPY, NEW SET=NF9, OLD SET=F9, CHANGE NUMBER=1, SHIFT, MULTIPLE=17
0., 0., 0.
0., 0., 0., 0., 0., 1, -20
*NODE, SYSTEM=C, NSET=G9
981, 13.175, 30, 0.0
*NCOPY, NEW SET=NG9, OLD SET=G9, CHANGE NUMBER=1, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -180
*NODE, SYSTEM=C, NSET=H9
983, 13.175, -16, 0.0
*NCOPY, NEW SET=NH9, OLD SET=H9, CHANGE NUMBER=1, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -180
*NODE, SYSTEM=C, NSET=I9
985, 12.5, 20.62, 0.0
*NCOPY, NEW SET=NI9, OLD SET=I9, CHANGE NUMBER=1, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -180
*NODE, SYSTEM=C, NSET=J9
987, 12.5, -6.62, 0.0
*NCOPY, NEW SET=NJ9, OLD SET=J9, CHANGE NUMBER=1, SHIFT, MULTIPLE=1
0., 0., 0.
```

```
0., 0., 0., 0., 0., 1, -180
*NODE, SYSTEM=C, NSET=K9
991, 14.9, -102.38, 0.0
*NCOPY, NEW SET=NK9, OLD SET=K9, CHANGE NUMBER=1, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=L9
993, 14.9, -337.38, 0.0
*NODE, SYSTEM=C, NSET=M9
994, 13.175, -102.38, 0.0
*NCOPY, NEW SET=NM9, OLD SET=M9, CHANGE NUMBER=1, SHIFT, MULTIPLE=1
0., 0., 0.
0., 0., 0., 0., 0., 1, -120
*NODE, SYSTEM=C, NSET=N9
996, 12.675, 23, 0.0
*NSET, NSET=NC9
A9,NA9,B9,NB9,D9,ND9,E9,NE9,E91,E92,F9,NF9,G9,
NG9,H9,NH9,I9,NI9,J9,NJ9,K9,NK9,L9,M9,NM9,N9
**
*** CENTER RIB
** LOCAL COORDINATE SYSTEM **
*SYSTEM
0, 0, 0, .12186943, -.992546151, 0
*NODE, NSET=NC85
851, -1.65, 11.075, 0.
852, -1.65, 7.383, 0.
853, -1.65, 3.692, 0.
854, -1.65, 0., 0.
855, -1.65, -3.692, 0.
856, -1.65, -7.383, 0.
857, -1.65, -11.075, 0.
861, 0., 11.075, 0.
862, 0., 7.383, 0.
863, 0., 3.692, 0.
864, 0., 0., 0.
865, 0., -3.692, 0.
866, 0., -7.383, 0.
867, 0., -11.075, 0.
871, 1.65, 11.075, 0.
872, 1.65, 7.383, 0.
873, 1.65, 3.692, 0.
874, 1.65, 0., 0.
875, 1.65, -3.692, 0.
876, 1.65, -7.383, 0.
877, 1.65, -11.075, 0.
*SYSTEM
**
** Nset of #1 Bundle Downstream Endplate
*NSET, NSET=NPLT1D
NC1,NC2,NC3,NC4,NC5,NC6,NC7,NC8,NC9,NC85
**
** AXIAL SEGMENTS
** NSETS FOR NODES WHERE RODS LOCATE
*NSET, NSET=N200, GENERATE
201, 252, 3
*NSET, NSET=N600, GENERATE
601, 634, 3
*NSET, NSET=N900, GENERATE
941, 956, 3
*NSET, NSET=N864
864
**
**N1001 TO N1109 : NODES BETWEEN 1ST AND 2ND AXIAL SEGMENTS
*NCOPY, NEW SET=N1A, OLD SET=N200, CHANGE NUMBER=800, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=N2A, OLD SET=N600, CHANGE NUMBER=454, SHIFT
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0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=N3A, OLD SET=N900, CHANGE NUMBER=150, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=N4A, OLD SET=N864, CHANGE NUMBER=245, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
*NSET, NSET=NR1
N1A, N2A, N3A, N4A
**
**N1201 TO N1309 : NODES BETWEEN 2ND AND 3RD AXIAL SEGMENTS
*NCOPY, NEW SET=NR2, OLD SET=NR1, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
**N1401 TO N1509 : NODES BETWEEN 3RD AND 4TH AXIAL SEGMENTS
*NCOPY, NEW SET=NR3, OLD SET=NR2, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
** N1601 TO N1709 : NODES BETWEEN 4TH AND 5TH AXIAL SEGMENTS
*NCOPY, NEW SET=NR4, OLD SET=NR3, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
** N1801 TO N1909 : NODES BETWEEN 5TH AND 6TH AXIAL SEGMENTS
*NCOPY, NEW SET=NR5, OLD SET=NR4, CHANGE NUMBER=200, SHIFT
0., 0., -82.55
0.,0.,0.,0.,0.,1.,0.
**
*NSET, NSET=NRA1
NR1, NR2, NR3, NR4, NR5
**
** UPSTREAM ENDPLATE - NPLT1U(N2101-N2996)
*NCOPY, OLD SET=NPLT1D, NEW SET=NPLT1U, CHANGE NUMBER=2000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,0.
**
** NODALIZATION FOR REMAINING 12 BUNDLES
**
** DOWNSTREAM ENDPLATES 12 MORE
*NCOPY, NEW SET=NPLT2D, OLD SET=NPLT1D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,-115
*NCOPY, NEW SET=NPLT3D, OLD SET=NPLT2D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT4D, OLD SET=NPLT3D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT5D, OLD SET=NPLT4D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT6D, OLD SET=NPLT5D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT7D, OLD SET=NPLT6D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT8D, OLD SET=NPLT7D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT9D, OLD SET=NPLT8D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT10D, OLD SET=NPLT9D, CHANGE NUMBER=10000, SHIFT
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0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT11D, OLD SET=NPLT10D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT12D, OLD SET=NPLT11D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT13D, OLD SET=NPLT12D, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
**
** SHEATH 12SET MORE
** NODES BETWEEN SEGMENTS
*NCOPY, NEW SET=NRA2, OLD SET=NRA1, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,-115
*NCOPY, NEW SET=NRA3, OLD SET=NRA2, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,0
*NCOPY, NEW SET=NRA4, OLD SET=NRA3, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA5, OLD SET=NRA4, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA6, OLD SET=NRA5, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA7, OLD SET=NRA6, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA8, OLD SET=NRA7, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA9, OLD SET=NRA8, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA10, OLD SET=NRA9, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA11, OLD SET=NRA10, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA12, OLD SET=NRA11, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NRA13, OLD SET=NRA12, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
**
** UPSTREAM ENDPLATES 12 MORE
*NCOPY, NEW SET=NPLT2U, OLD SET=NPLT1U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,-115
*NCOPY, NEW SET=NPLT3U, OLD SET=NPLT2U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,0.
*NCOPY, NEW SET=NPLT4U, OLD SET=NPLT3U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT5U, OLD SET=NPLT4U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT6U, OLD SET=NPLT5U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
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*NCOPY, NEW SET=NPLT7U, OLD SET=NPLT6U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT8U, OLD SET=NPLT7U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT9U, OLD SET=NPLT8U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT10U, OLD SET=NPLT9U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT11U, OLD SET=NPLT10U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT12U, OLD SET=NPLT11U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
*NCOPY, NEW SET=NPLT13U, OLD SET=NPLT12U, CHANGE NUMBER=10000, SHIFT
0., 0., -495.3
0.,0.,0.,0.,0.,1.,31
**
**ELEMENTS
** Side-stop Elements (E1 - E8)
*ELEMENT, TYPE=B31, ELSET=ESTOP
1, 11, 1
2, 12, 2
3, 13, 3
4, 14, 4
5, 15, 5
6, 16, 6
7, 17, 7
8, 18, 8
*BEAM SECTION, ELSET=ESTOP, MATERIAL=MSTOP, SECTION=RECT
9.525, 25.0
*MATERIAL, NAME=MSTOP
*ELASTIC
9.12E7, 0.3
**ENDPLATE
**OUTER RING - OUTER HALF (E9 - E68)
*ELEMENT, TYPE=S4R, ELSET=EPT1
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, 262, 162
16, 162, 262, 208, 108
17, 108, 208, 209, 109
18, 109, 209, 210, 110
19, 110, 210, 211, 111
20, 111, 211, 212, 112
21, 112, 212, 213, 113
22, 113, 213, 214, 114
23, 114, 214, 215, 115
24, 115, 215, 216, 116
25, 116, 216, 263, 163
26, 163, 263, 217, 117
27, 117, 217, 218, 118
28, 118, 218, 219, 119
29, 119, 219, 220, 120
30, 120, 220, 221, 121
31, 121, 221, 222, 122
32, 122, 222, 223, 123
33, 123, 223, 224, 124
34, 124, 224, 225, 125
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35, 125, 225, 264, 164
36, 164, 264, 226, 126
37, 126, 226, 227, 127
38, 127, 227, 228, 128
39, 128, 228, 229, 129
40, 129, 229, 230, 130
41, 130, 230, 231, 131
42, 131, 231, 232, 132
43, 132, 232, 233, 133
44, 133, 233, 234, 134
45, 134, 234, 265, 165
46, 165, 265, 235, 135
47, 135, 235, 236, 136
48, 136, 236, 237, 137
49, 137, 237, 238, 138
50, 138, 238, 239, 139
51, 139, 239, 240, 140
52, 140, 240, 241, 141
53, 141, 241, 242, 142
54, 142, 242, 243, 143
55, 143, 243, 266, 166
56, 166, 266, 244, 144
57, 144, 244, 245, 145
58, 145, 245, 246, 146
59, 146, 246, 247, 147
60, 147, 247, 248, 148
61, 148, 248, 249, 149
62, 149, 249, 250, 150
63, 150, 250, 251, 151
64, 151, 251, 252, 152
65, 152, 252, 261, 161
66, 161, 261, 253, 153
67, 153, 253, 254, 154
68, 154, 254, 201, 101
** OUTER RING - INNER HALF (69-140)
69, 201, 301, 302, 202
70, 202, 302, 303, 203
71, 203, 303, 304, 204
72, 204, 304, 305, 205
73, 205, 305, 306, 206
74, 206, 306, 362, 207
75, 207, 362, 382, 262
76, 382, 410, 413, 262
77, 262, 413, 416, 392
78, 262, 392, 372, 208
79, 208, 372, 309, 209
80, 209, 309, 310, 210
81, 210, 310, 311, 211
82, 211, 311, 312, 212
83, 212, 312, 313, 213
84, 213, 313, 314, 214
85, 214, 314, 315, 215
86, 215, 315, 363, 216
87, 216, 363, 383, 263
88, 383, 419, 422, 263
89, 263, 422, 425, 393
90, 263, 393, 373, 217
91, 217, 373, 318, 218
92, 218, 318, 319, 219
93, 219, 319, 320, 220
94, 220, 320, 321, 221
95, 221, 321, 322, 222
96, 222, 322, 323, 223
97, 223, 323, 324, 224
98, 224, 324, 364, 225
99, 225, 364, 384, 264
100, 384, 428, 431, 264

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101, 264, 431, 434, 394
102, 264, 394, 374, 226
103, 226, 374, 327, 227
104, 227, 327, 328, 228
105, 228, 328, 329, 229
106, 229, 329, 330, 230
107, 230, 330, 331, 231
108, 231, 331, 332, 232
109, 232, 332, 333, 233
110, 233, 333, 365, 234
111, 234, 365, 385, 265
112, 385, 437, 440, 265
113, 265, 440, 443, 395
114, 265, 395, 375, 235
115, 235, 375, 336, 236
116, 236, 336, 337, 237
117, 237, 337, 338, 238
118, 238, 338, 339, 239
119, 239, 339, 340, 240
120, 240, 340, 341, 241
121, 241, 341, 342, 242
122, 242, 342, 366, 243
123, 243, 366, 386, 266
124, 386, 446, 449, 266
125, 266, 449, 452, 396
126, 266, 396, 376, 244
127, 244, 376, 345, 245
128, 245, 345, 346, 246
129, 246, 346, 347, 247
130, 247, 347, 348, 248
131, 248, 348, 349, 249
132, 249, 349, 350, 250
133, 250, 350, 351, 251
134, 251, 351, 361, 252
135, 252, 361, 381, 261
136, 381, 401, 404, 261
137, 261, 404, 407, 391
138, 261, 391, 371, 253
139, 253, 371, 354, 254
140, 254, 354, 301, 201
** OUTER RIB (141 - 164)
141, 401, 402, 405, 404
*ELGEN, ELSET=EORIB1
141, 2, 1, 1, 2, 3, 2
*ELCOPY, NEWSET=EORIB2, OLDSET=EORIB1, ELEMENT SHIFT=4, SHIFT NODES=9
*ELCOPY, NEWSET=EORIB3, OLDSET=EORIB2, ELEMENT SHIFT=4, SHIFT NODES=9
*ELCOPY, NEWSET=EORIB4, OLDSET=EORIB3, ELEMENT SHIFT=4, SHIFT NODES=9
*ELCOPY, NEWSET=EORIB5, OLDSET=EORIB4, ELEMENT SHIFT=4, SHIFT NODES=9
*ELCOPY, NEWSET=EORIB6, OLDSET=EORIB5, ELEMENT SHIFT=4, SHIFT NODES=9
*ELSET, ELSET= EORIB
EORIB1, EORIB2, EORIB3, EORIB4, EORIB5, EORIB6
** MIDDLE RING - OUTER HALF (165 - 215)
*ELEMENT, TYPE=S4R, ELSET=EPT2
165, 501, 601, 602, 502
166, 502, 602, 603, 503
167, 503, 603, 604, 542
168, 542, 604, 605, 462
169, 412, 462, 605, 415
170, 415, 605, 472, 418
171, 472, 605, 651, 552
172, 552, 651, 606, 506
173, 506, 606, 607, 507
174, 507, 607, 608, 508
175, 508, 608, 609, 509
176, 509, 609, 610, 543
177, 543, 610, 611, 463
178, 421, 463, 611, 424
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179, 424, 611, 473, 427
180, 473, 611, 612, 553
181, 553, 612, 613, 513
182, 513, 613, 614, 514
183, 514, 614, 615, 515
184, 515, 615, 616, 544
185, 544, 616, 617, 464
186, 430, 464, 617, 433
187, 433, 617, 474, 436
188, 474, 617, 652, 554
189, 554, 652, 618, 518
190, 518, 618, 619, 519
191, 519, 619, 620, 520
192, 520, 620, 621, 521
193, 521, 621, 622, 545
194, 545, 622, 623, 465
195, 439, 465, 623, 442
196, 442, 623, 475, 445
197, 475, 623, 624, 555
198, 555, 624, 625, 525
199, 525, 625, 626, 526
200, 526, 626, 627, 527
201, 527, 627, 628, 546
202, 546, 628, 629, 466
203, 448, 466, 629, 451
204, 451, 629, 476, 454
205, 476, 629, 653, 556
206, 556, 653, 630, 530
207, 530, 630, 631, 531
208, 531, 631, 632, 532
209, 532, 632, 633, 533
210, 533, 633, 634, 541
211, 541, 634, 635, 461
212, 403, 461, 635, 406
213, 406, 635, 471, 409
214, 471, 635, 636, 551
215, 551, 636, 601, 501
** MIDDLE RING - INNER HALF (216-260)
216, 601, 701, 702, 602
217, 602, 702, 703, 603
218, 603, 703, 704, 604
219, 604, 704, 705, 605
220, 605, 705, 781, 651
221, 651, 781, 706, 606
222, 606, 706, 707, 607
223, 607, 707, 708, 608
224, 608, 708, 709, 609
225, 609, 709, 742, 610
226, 610, 742, 762, 611
227, 762, 810, 813, 611
228, 611, 813, 816, 772
229, 611, 772, 752, 612
230, 612, 752, 713, 613
231, 613, 713, 714, 614
232, 614, 714, 715, 615
233, 615, 715, 716, 616
234, 616, 716, 717, 617
235, 617, 717, 782, 652
236, 652, 782, 718, 618
237, 618, 718, 719, 619
238, 619, 719, 720, 620
239, 620, 720, 721, 621
240, 621, 721, 743, 622
241, 622, 743, 763, 623
242, 763, 819, 822, 623
243, 623, 822, 825, 773
244, 623, 773, 753, 624

245, 624, 753, 725, 625
246, 625, 725, 726, 626
247, 626, 726, 727, 627
248, 627, 727, 728, 628
249, 628, 728, 729, 629
250, 629, 729, 783, 653
251, 653, 783, 730, 630
252, 630, 730, 731, 631
253, 631, 731, 732, 632
254, 632, 732, 733, 633
255, 633, 733, 741, 634
256, 634, 741, 761, 635
257, 761, 801, 804, 635
258, 635, 804, 807, 771
259, 635, 771, 751, 636
260, 636, 751, 701, 601
** MIDDLE RIB (261 - 272)
261, 801, 802, 805, 804
*ELGEN, ELSET=EMRIB1
261, 2, 1, 1, 2, 3, 2
*ELCOPY, NEWSET=EMRIB2, OLDSET=EMRIB1, ELEMENT SHIFT=4, SHIFT NODES=9
*ELCOPY, NEWSET=EMRIB3, OLDSET=EMRIB2, ELEMENT SHIFT=4, SHIFT NODES=9
*ELSET, ELSET=EMRIB
EMRIB1, EMRIB2, EMRIB3
** INNER RING - OUTER HALF (273-299)
*ELEMENT, TYPE=S4R, ELSET=EPT3
273, 901, 941, 942, 902
274, 902, 942, 943, 903
275, 903, 943, 944, 904
276, 904, 944, 991, 922
277, 922, 991, 945, 832
278, 812, 832, 945, 815
279, 815, 945, 842, 818
280, 842, 945, 946, 932
281, 932, 946, 947, 907
282, 907, 947, 948, 908
283, 908, 948, 949, 909
284, 909, 949, 950, 910
285, 910, 950, 992, 923
286, 923, 992, 951, 833
287, 821, 833, 951, 824
288, 824, 951, 843, 827
289, 843, 951, 952, 933
290, 933, 952, 953, 913
291, 913, 953, 954, 914
292, 914, 954, 955, 915
293, 915, 955, 956, 916
294, 916, 956, 993, 921
295, 921, 993, 957, 831
296, 803, 831, 957, 806
297, 806, 957, 841, 809
298, 841, 957, 958, 931
299, 931, 958, 941, 901
** INNER RING - INNER HALF (300-324)
300, 941, 961, 962, 942
301, 942, 962, 963, 943
302, 943, 963, 964, 944
303, 944, 964, 994, 991
304, 991, 994, 965, 945
305, 945, 965, 966, 946
306, 946, 966, 982, 947
307, 947, 982, 986, 948
308, 867, 948, 986, 877
309, 857, 988, 948, 867
310, 984, 949, 948, 988
311, 949, 984, 970, 950
312, 950, 970, 995, 992

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313, 992, 995, 971, 951
314, 951, 971, 972, 952
315, 952, 972, 973, 953
316, 953, 973, 974, 954
317, 954, 974, 975, 955
318, 955, 975, 981, 956
319, 956, 981, 996, 993
320, 993, 996, 985, 957
321, 985, 851, 861, 957
322, 957, 861, 871, 987
323, 957, 987, 983, 958
324, 958, 983, 961, 941
** CENTER RIB (325~336)
325, 851, 852, 862, 861
*ELGEN, ELSET=ECRIB
325, 6, 1, 1, 2, 10, 6
**GENERATION OF DOWNSTREAM ENDPLATE ELEMENTS
*ELSET, ELSET=EPT1D
EPT1, EPT2, EPT3, EORIB, EMRIB, ECRIB
**
**GENERATION OF UPSTREAM ENDPLATE ELEMENTS (326~654)
*ELEMENT, TYPE=S4R, ELSET=EPLT1U
*ELCOPY,ELEMENT SHIFT=328,OLD SET=EPT1D,SHIFT NODES=2000,NEW SET=EPLT1U
**
** SHEATH ELEMENTS
** 1ST SEGMENT
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES1
741, 201, 1001
742, 204, 1004
743, 207, 1007
744, 210, 1010
745, 213, 1013
746, 216, 1016
747, 219, 1019
748, 222, 1022
749, 225, 1025
750, 228, 1028
751, 231, 1031
752, 234, 1034
753, 237, 1037
754, 240, 1040
755, 243, 1043
756, 246, 1046
757, 249, 1049
758, 252, 1052
759, 601, 1055
760, 604, 1058
761, 607, 1061
762, 610, 1064
763, 613, 1067
764, 616, 1070
765, 619, 1073
766, 622, 1076
767, 625, 1079
768, 628, 1082
769, 631, 1085
770, 634, 1088
771, 941, 1091
772, 944, 1094
773, 947, 1097
774, 950, 1100
775, 953, 1103
776, 956, 1106
777, 864, 1109
**
** 2ND SEGMENT
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES2
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778, 1001, 1201
779, 1004, 1204
780, 1007, 1207
781, 1010, 1210
782, 1013, 1213
783, 1016, 1216
784, 1019, 1219
785, 1022, 1222
786, 1025, 1225
787, 1028, 1228
788, 1031, 1231
789, 1034, 1234
790, 1037, 1237
791, 1040, 1240
792, 1043, 1243
793, 1046, 1246
794, 1049, 1249
795, 1052, 1252
796, 1055, 1255
797, 1058, 1258
798, 1061, 1261
799, 1064, 1264
800, 1067, 1267
801, 1070, 1270
802, 1073, 1273
803, 1076, 1276
804, 1079, 1279
805, 1082, 1282
806, 1085, 1285
807, 1088, 1288
808, 1091, 1291
809, 1094, 1294
810, 1097, 1297
811, 1100, 1300
812, 1103, 1303
813, 1106, 1306
814, 1109, 1309
**Consequtive Copy of Segments
**3rd Segment (815-851) by copying 2nd segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES3
*ELCOPY, ELEMENT SHIFT=37, OLD SET=ETUBES2, SHIFT NODES=200, NEW SET=ETUBES3
**4th Segment (852-888) by copying 3rd segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES4
*ELCOPY, ELEMENT SHIFT=37, OLD SET=ETUBES3, SHIFT NODES=200, NEW SET=ETUBES4
**5th Segment (889-925) by copying 4th segment
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES5
*ELCOPY, ELEMENT SHIFT=37, OLD SET=ETUBES4, SHIFT NODES=200, NEW SET=ETUBES5
**
**6TH SEGMENT (EL 926-962)
*ELEMENT, TYPE=PIPE31, ELSET=ETUBES6
926, 1801, 2201
927, 1804, 2204
928, 1807, 2207
929, 1810, 2210
930, 1813, 2213
931, 1816, 2216
932, 1819, 2219
933, 1822, 2222
934, 1825, 2225
935, 1828, 2228
936, 1831, 2231
937, 1834, 2234
938, 1837, 2237
939, 1840, 2240
940, 1843, 2243
941, 1846, 2246
942, 1849, 2249
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943, 1852, 2252
944, 1855, 2601
945, 1858, 2604
946, 1861, 2607
947, 1864, 2610
948, 1867, 2613
949, 1870, 2616
950, 1873, 2619
951, 1876, 2622
952, 1879, 2625
953, 1882, 2628
954, 1885, 2631
955, 1888, 2634
956, 1891, 2941
957, 1894, 2944
958, 1897, 2947
959, 1900, 2950
960, 1903, 2953
961, 1906, 2956
962, 1909, 2864
*ELSET, ELSET=ESTUBE1
ETUBES1,ETUBES2,ETUBES3,ETUBES4,ETUBES5,ETUBES6
**SPACER
*ELEMENT, TYPE=T3D2, ELSET=ESP1
963, 1401, 1404
964, 1404, 1407
965, 1407, 1410
966, 1410, 1413
967, 1413, 1416
968, 1416, 1419
969, 1419, 1422
970, 1422, 1425
971, 1425, 1428
972, 1428, 1431
973, 1431, 1434
974, 1434, 1437
975, 1437, 1440
976, 1440, 1443
977, 1443, 1446
978, 1446, 1449
979, 1449, 1452
980, 1452, 1401
981, 1455, 1458
982, 1458, 1461
983, 1461, 1464
984, 1464, 1467
985, 1467, 1470
986, 1470, 1473
987, 1473, 1476
988, 1476, 1479
989, 1479, 1482
990, 1482, 1485
991, 1485, 1488
992, 1488, 1455
993, 1491, 1494
994, 1494, 1497
995, 1497, 1500
996, 1500, 1503
997, 1503, 1506
998, 1506, 1491
999, 1401, 1455
1000, 1404, 1455
1001, 1404, 1458
1002, 1407, 1458
1003, 1410, 1461
1004, 1413, 1461
1005, 1413, 1464

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1006, 1416, 1464
1007, 1419, 1467
1008, 1422, 1467
1009, 1422, 1470
1010, 1425, 1470
1011, 1428, 1473
1012, 1431, 1473
1013, 1431, 1476
1014, 1434, 1476
1015, 1437, 1479
1016, 1440, 1479
1017, 1440, 1482
1018, 1443, 1482
1019, 1446, 1485
1020, 1449, 1485
1021, 1449, 1488
1022, 1452, 1488
1023, 1455, 1491
1024, 1458, 1491
1025, 1461, 1494
1026, 1464, 1494
1027, 1467, 1497
1028, 1470, 1497
1029, 1473, 1500
1030, 1476, 1500
1031, 1479, 1503
1032, 1482, 1503
1033, 1485, 1506
1034, 1488, 1506
1035, 1491, 1509
1036, 1494, 1509
1037, 1497, 1509
1038, 1500, 1509
1039, 1503, 1509
1040, 1506, 1509
**
**Generation of Elements for Bundles #2 - #13 (EL 1041-8912)
**Element Shift=1032 for #2, 656 for others, Shift Nodes:10000
**Bundle #2, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT2D
*ELCOPY, ELEMENT SHIFT=1032, OLD SET=EPT1D, SHIFT NODES=10000, NEW SET=EPLT2D
**Bundle #2, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT2U
*ELCOPY, ELEMENT SHIFT=1032, OLD SET=EPLT1U, SHIFT NODES=10000, NEW SET=EPLT2U
**Bundle #3, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT3D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT2D, SHIFT NODES=10000, NEW SET=EPLT3D
**Bundle #3, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT3U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT2U, SHIFT NODES=10000, NEW SET=EPLT3U
**Bundle #4, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT4D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT3D, SHIFT NODES=10000, NEW SET=EPLT4D
**Bundle #4, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT4U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT3U, SHIFT NODES=10000, NEW SET=EPLT4U
**Bundle #5, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT5D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT4D, SHIFT NODES=10000, NEW SET=EPLT5D
**Bundle #5, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT5U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT4U, SHIFT NODES=10000, NEW SET=EPLT5U
**Bundle #6, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT6D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT5D, SHIFT NODES=10000, NEW SET=EPLT6D
**Bundle #6, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT6U
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*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT5U, SHIFT NODES=10000, NEW SET=EPLT6U
**Bundle #7, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT7D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT6D, SHIFT NODES=10000, NEW SET=EPLT7D
**Bundle #7, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT7U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT6U, SHIFT NODES=10000, NEW SET=EPLT7U
**Bundle #8, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT8D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT7D, SHIFT NODES=10000, NEW SET=EPLT8D
**Bundle #8, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT8U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT7U, SHIFT NODES=10000, NEW SET=EPLT8U
**Bundle #9, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT9D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT8D, SHIFT NODES=10000, NEW SET=EPLT9D
**Bundle #9, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT9U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT8U, SHIFT NODES=10000, NEW SET=EPLT9U
**Bundle #10, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT10D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT9D, SHIFT NODES=10000, NEW SET=EPLT10D
**Bundle #10, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT10U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT9U, SHIFT NODES=10000, NEW SET=EPLT10U
**Bundle #11, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT11D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT10D, SHIFT NODES=10000, NEW SET=EPLT11D
**Bundle #11, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT11U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT10U, SHIFT NODES=10000, NEW SET=EPLT11U
**Bundle #12, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT12D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT11D, SHIFT NODES=10000, NEW SET=EPLT12D
**Bundle #12, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT12U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT11U, SHIFT NODES=10000, NEW SET=EPLT12U
**Bundle #13, Downstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT13D
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT12D, SHIFT NODES=10000, NEW SET=EPLT13D
**Bundle #13, Upstream Endplate
*ELEMENT, TYPE=S4R, ELSET=EPLT13U
*ELCOPY, ELEMENT SHIFT=656, OLD SET=EPLT12U, SHIFT NODES=10000, NEW SET=EPLT13U
*ELSET, ELSET=EPLATE
EPT1D,EPLT2D,EPLT3D,EPLT4D,EPLT5D,EPLT6D,EPLT7D,EPLT8D,EPLT9D,EPLT10D,EPLT11D,
EPLT12D,EPLT13D,EPLT1U,EPLT2U,EPLT3U,EPLT4U,EPLT5U,EPLT6U,EPLT7U,EPLT8U,EPLT9U,
EPLT10U,EPLT11U,EPLT12U,EPLT13U
*SHELL SECTION, ELSET=EPLATE, MATERIAL=MPLATE
1.60
*MATERIAL, NAME=MPLATE
*ELASTIC
87980.0, 0.42
*PLASTIC
228., 0.0
378., 0.144
**
** Tube Elements for #2 - #13 Bundles (EL 8913-11576)
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE2
*ELCOPY, ELEMENT SHIFT=8172, OLD SET=ESTUBE1, SHIFT NODES=10000, NEW SET=ESTUBE2
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE3
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE2, SHIFT NODES=10000, NEW SET=ESTUBE3
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE4
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE3, SHIFT NODES=10000, NEW SET=ESTUBE4
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE5
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE4, SHIFT NODES=10000, NEW SET=ESTUBE5
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE6
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE5, SHIFT NODES=10000, NEW SET=ESTUBE6
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*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE7
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE6, SHIFT NODES=10000, NEW SET=ESTUBE7
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE8
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE7, SHIFT NODES=10000, NEW SET=ESTUBE8
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE9
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE8, SHIFT NODES=10000, NEW SET=ESTUBE9
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE10
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE9, SHIFT NODES=10000, NEW SET=ESTUBE10
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE11
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE10, SHIFT NODES=10000, NEW SET=ESTUBE11
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE12
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE11, SHIFT NODES=10000, NEW SET=ESTUBE12
*ELEMENT, TYPE=PIPE31, ELSET=ESTUBE13
*ELCOPY, ELEMENT SHIFT=222, OLD SET=ESTUBE12, SHIFT NODES=10000, NEW SET=ESTUBE13
*ELSET, ELSET=ESTUBE
ESTUBE1, ESTUBE2, ESTUBE3, ESTUBE4, ESTUBE5, ESTUBE6, ESTUBE7, ESTUBE8, ESTUBE9,
ESTUBE10, ESTUBE11, ESTUBE12, ESTUBE13
*BEAM SECTION, ELSET=ESTUBE, MATERIAL=MSTUBE, SECTION=PIPE
6.5, 0.38
1., 0., 0.
*MATERIAL, NAME=MSTUBE
*ELASTIC
89015.0, 0.4
*PLASTIC
403., 0.0
443., 0.144
**
** Spacer Elements for #2 - #13 Bundles (EL 11577-12488)
*ELEMENT, TYPE=T3D2, ELSET=ESP2
*ELCOPY, ELEMENT SHIFT=10614, OLD SET=ESP1, SHIFT NODES=10000, NEW SET=ESP2
*ELEMENT, TYPE=T3D2, ELSET=ESP3
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP2, SHIFT NODES=10000, NEW SET=ESP3
*ELEMENT, TYPE=T3D2, ELSET=ESP4
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP3, SHIFT NODES=10000, NEW SET=ESP4
*ELEMENT, TYPE=T3D2, ELSET=ESP5
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP4, SHIFT NODES=10000, NEW SET=ESP5
*ELEMENT, TYPE=T3D2, ELSET=ESP6
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP5, SHIFT NODES=10000, NEW SET=ESP6
*ELEMENT, TYPE=T3D2, ELSET=ESP7
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP6, SHIFT NODES=10000, NEW SET=ESP7
*ELEMENT, TYPE=T3D2, ELSET=ESP8
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP7, SHIFT NODES=10000, NEW SET=ESP8
*ELEMENT, TYPE=T3D2, ELSET=ESP9
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP8, SHIFT NODES=10000, NEW SET=ESP9
*ELEMENT, TYPE=T3D2, ELSET=ESP10
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP9, SHIFT NODES=10000, NEW SET=ESP10
*ELEMENT, TYPE=T3D2, ELSET=ESP11
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP10, SHIFT NODES=10000, NEW SET=ESP11
*ELEMENT, TYPE=T3D2, ELSET=ESP12
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP11, SHIFT NODES=10000, NEW SET=ESP12
*ELEMENT, TYPE=T3D2, ELSET=ESP13
*ELCOPY, ELEMENT SHIFT=78, OLD SET=ESP12, SHIFT NODES=10000, NEW SET=ESP13
*ELSET, ELSET=ESP
ESP1,ESP2,ESP3,ESP4,ESP5,ESP6,ESP7,ESP8,ESP9,
ESP10,ESP11,ESP12,ESP13
*SOLID SECTION, ELSET=ESP, MATERIAL=MSPACER
100
*MATERIAL, NAME=MSPACER
*ELASTIC
89015., 0.3
**
** CONTACT DEFINITION for side stop
*SURFACE DEFINITION, NAME=PLATE
EPT1D, SPOS
*CONTACT NODE SET, NAME=TIP
1,2,3,4,5,6,7,8
*CONTACT PAIR, INTERACTION=NOFRIC, SMALL SLIDING
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TIP, PLATE
*SURFACE INTERACTION, NAME=NOFRIC
1.5
** DEFINITION FOR 1st CONTACT
*SURFACE DEFINITION, NAME=SURF1U
EPLT1U, SNEG
*SURFACE DEFINITION, NAME=SURF2D
EPLT2D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC1, SMALL SLIDING
SURF1U, SURF2D
*SURFACE INTERACTION, NAME=NOFRIC1
**
** DEFINITION FOR 2nd CONTACT
*SURFACE DEFINITION, NAME=SURF2U
EPLT2U, SNEG
*SURFACE DEFINITION, NAME=SURF3D
EPLT3D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC2, SMALL SLIDING
SURF2U, SURF3D
*SURFACE INTERACTION, NAME=NOFRIC2
**
** DEFINITION FOR 3rd CONTACT
*SURFACE DEFINITION, NAME=SURF3U
EPLT3U, SNEG
*SURFACE DEFINITION, NAME=SURF4D
EPLT4D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC3, SMALL SLIDING
SURF3U, SURF4D
*SURFACE INTERACTION, NAME=NOFRIC3
**
** DEFINITION FOR 4th CONTACT
*SURFACE DEFINITION, NAME=SURF4U
EPLT4U, SNEG
*SURFACE DEFINITION, NAME=SURF5D
EPLT5D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC4, SMALL SLIDING
SURF4U, SURF5D
*SURFACE INTERACTION, NAME=NOFRIC4
**
** DEFINITION FOR 5th CONTACT
*SURFACE DEFINITION, NAME=SURF5U
EPLT5U, SNEG
*SURFACE DEFINITION, NAME=SURF6D
EPLT6D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC5, SMALL SLIDING
SURF5U, SURF6D
*SURFACE INTERACTION, NAME=NOFRIC5
**
** DEFINITION FOR 6th CONTACT
*SURFACE DEFINITION, NAME=SURF6U
EPLT6U, SNEG
*SURFACE DEFINITION, NAME=SURF7D
EPLT7D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC6, SMALL SLIDING
SURF6U, SURF7D
*SURFACE INTERACTION, NAME=NOFRIC6
**
** DEFINITION FOR 7th CONTACT
*SURFACE DEFINITION, NAME=SURF7U
EPLT7U, SNEG
*SURFACE DEFINITION, NAME=SURF8D
EPLT8D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC7, SMALL SLIDING
SURF7U, SURF8D
*SURFACE INTERACTION, NAME=NOFRIC7
**
** DEFINITION FOR 8th CONTACT
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*SURFACE DEFINITION, NAME=SURF8U
EPLT8U, SNEG
*SURFACE DEFINITION, NAME=SURF9D
EPLT9D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC8, SMALL SLIDING
SURF8U, SURF9D
*SURFACE INTERACTION, NAME=NOFRIC8
**
** DEFINITION FOR 9th CONTACT
*SURFACE DEFINITION, NAME=SURF9U
EPLT9U, SNEG
*SURFACE DEFINITION, NAME=SURF10D
EPLT10D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC9, SMALL SLIDING
SURF9U, SURF10D
*SURFACE INTERACTION, NAME=NOFRIC9
**
** DEFINITION FOR 10th CONTACT
*SURFACE DEFINITION, NAME=SURF10U
EPLT10U, SNEG
*SURFACE DEFINITION, NAME=SURF11D
EPLT11D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC10, SMALL SLIDING
SURF10U, SURF11D
*SURFACE INTERACTION, NAME=NOFRIC10
**
** DEFINITION FOR 11th CONTACT
*SURFACE DEFINITION, NAME=SURF11U
EPLT11U, SNEG
*SURFACE DEFINITION, NAME=SURF12D
EPLT12D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC11, SMALL SLIDING
SURF11U, SURF12D
*SURFACE INTERACTION, NAME=NOFRIC11
**
** DEFINITION FOR 12th CONTACT
*SURFACE DEFINITION, NAME=SURF12U
EPLT12U, SNEG
*SURFACE DEFINITION, NAME=SURF13D
EPLT13D, SPOS
*CONTACT PAIR, INTERACTION=NOFRIC12, SMALL SLIDING
SURF12U, SURF13D
*SURFACE INTERACTION, NAME=NOFRIC12
** APPLY BOUNDARY CONDITIONS
*NSET,NSET=NCNTR,GENERATE
864,  120864, 10000
2664, 122864, 10000
*BOUNDARY
N0, 1, 6
NCNTR, 1, 2
NCNTR, 6
**
** LOADING (not gonna be used)
*NSET, NSET=NLOAD, GENERATE
1401, 1509, 3
11401, 11509, 3
21401, 21509, 3
31401, 31509, 3
41401, 41509, 3
51401, 51509, 3
61401, 61509, 3
71401, 71509, 3
81401, 81509, 3
91401, 91509, 3
101401, 101509, 3
111401, 111509, 3
121401, 121509, 3
```

```
**
**Load Transfer Output
*ELSET, ELSET=LOUTPUT, GENERATE
741, 777, 1
8913, 8949, 1
9135, 9171, 1
9357, 9393, 1
9579, 9615, 1
9801, 9837, 1
10023, 10059, 1
10245, 10281, 1
10467, 10503, 1
10689, 10725, 1
10911, 10947, 1
11133, 11169, 1
11355, 11391, 1
*RESTART,WRITE,FREQ=100
*STEP,INC=1000
 Step 1
*STATIC
0.0005, 1.0
*DLOAD
ESTUBE, PZ, 0.04852
**
*NSET, NSET=NOUTPUT, GENERATE
1, 8, 1
11, 18, 1
201, 252, 3
601, 634, 3
941, 956, 3
864, 864
*NODE PRINT, NSET=NOUTPUT, FREQ=100
U
RF
*ELSET, ELSET=EOUTPUT
EPT1D
*EL PRINT, ELSET=EOUTPUT, FREQ=100
MISES
*EL PRINT, ELSET=LOUTPUT, FREQ=100
SF
*NODE FILE, NSET=NOUTPUT, FREQ=0
U, RF
*PRINT, CONTACT=YES
*CONTACT CONTROLS, AUTOMATIC TOLERANCE
*END STEP
**
*STEP,INC=1000
 Step 2
*STATIC
0.0005, 1.0
*DLOAD, OP=NEW
*NODE PRINT, NSET=NOUTPUT, FREQ=100
U
RF
*EL PRINT, ELSET=EOUTPUT, FREQ=100
MISES
*NODE FILE, NSET=NOUTPUT, FREQ=0
U, RF
*PRINT, CONTACT=YES
*CONTACT CONTROLS, AUTOMATIC TOLERANCE
*END STEP
```

서 지 정 보 양 식

수행기관보고서번호	위탁기관보고서번호	표준보고서번호	INIS 주제코드
KAERI/TR-1698/2000			

제목/부제	ABAQUS를 이용한 중수로용 핵연료의 유한요소해석 모델 개발 및 강도 해석
주저자 및 부서명	조문성 (핵연료설계기술개발팀)
연 구 자 및 부 서 명	석호천 (핵연료설계기술개발팀)

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참고사항					

비밀여부	공개(V)	보고서종류	기술보고서
연구위탁기관		계약 번호	

초록 (15-20줄 내외)

상용 구조해석 소프트웨어인 ABAQUS를 이용하여 노외 핵연료 강도시험을 시뮬레이션하기 위한 유한요소 정적 해석모델을 개발하였다. 본 유한요소 모델은 수력적 견인력을 받는 핵연료 연료봉의 변형과, 접합판에 발생하는 응력 및 변위 등을 계산하기 위한 것이다. CANFLEX 43-연료봉과 기존의 37-연료봉 핵연료에 대해 수행된 노외 강도시험의 하중 조건 및 경계조건을 근거로 해석을 수행하였으며 해석결과를 시험결과 측정치와 비교하여 유한요소 모델을 검증하였다. 계산결과는 측정치와 매우 잘 일치하였다. 개발된 유한요소 모델을 이용하여 환봉간의 하중전가, 접합판 립(rib) 효과, 집합체열내 소성변형을 일으키는 수력적 견인력의 크기 및 유량 증가에 따른 영향 등과 같은 핵연료 집합체열의 정적 거동을 분석하였다.

주제명 키워드 (10단어내외)

CANFLEX 핵연료, 37봉 핵연료, 정적 강도해석, 하중전가, 중수 원자로, 수력적 견인력, 접합판 립 효과

BIBLIOGRAPHIC INFORMATION SHEET

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KAERI/TR-1698/2000			

Title/Subtitle	Finite Element Analysis Model Development and Static Strength Analysis for CANDU-6 Reactor Fuel Bundle
Author and Department	Moon-Sung Cho (Nuclear Fuel Design Technology Development Team)
Researcher and Department	Ho Chun Suk (Nuclear Fuel Design Technology Development Team)

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Abstract (15-20 Lines)

A static and finite-element (FE) analysis model was developed to simulate out-reactor fuel string strength tests with use of the structural analysis computer code ABAQUS. The FE model takes into account the deflection of fuel elements and stress and displacement in end-plates subjected to hydraulic drag loads. It was adapted to the strength tests performed for CANFLEX 43-element bundles and the existing 37-element bundles. The FE model was found to be in good agreement with the experiment results. With use of the FE model, the static behavior of the fuel bundle strings, such as load transfer between ring elements, end-plate rib effects, hydraulic drag load incurring plastic deformation in fuel string and hydraulic flow rate effects were investigated.

Subject Keywords (About 10 words)

CANFLEX fuel, 37-element fuel, static strength analysis, load transfer, CANDU-6 reactor, hydraulic drag, end-plate rib effects