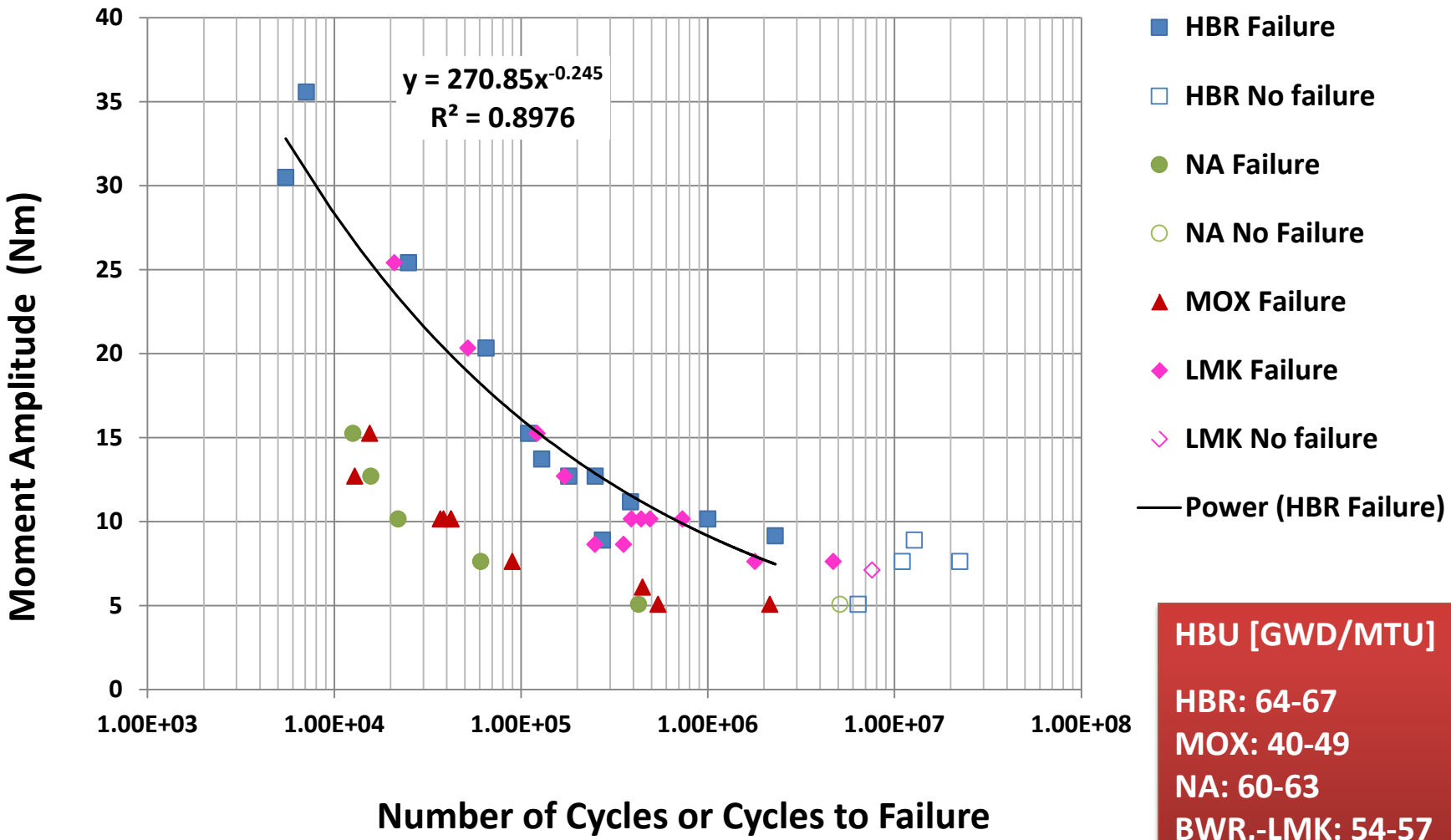
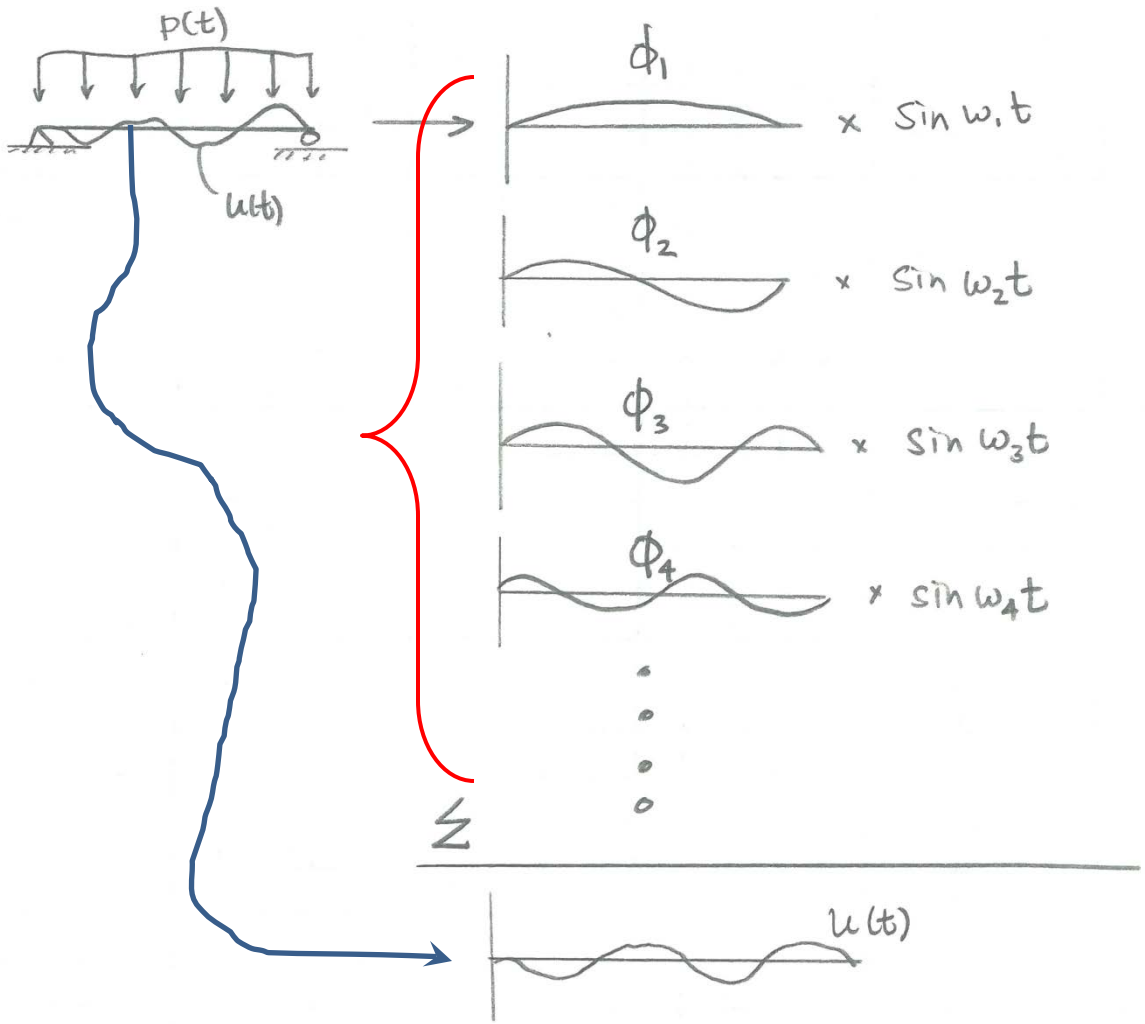
CIRFT bending load vs fatigue life data reveals large data scatter



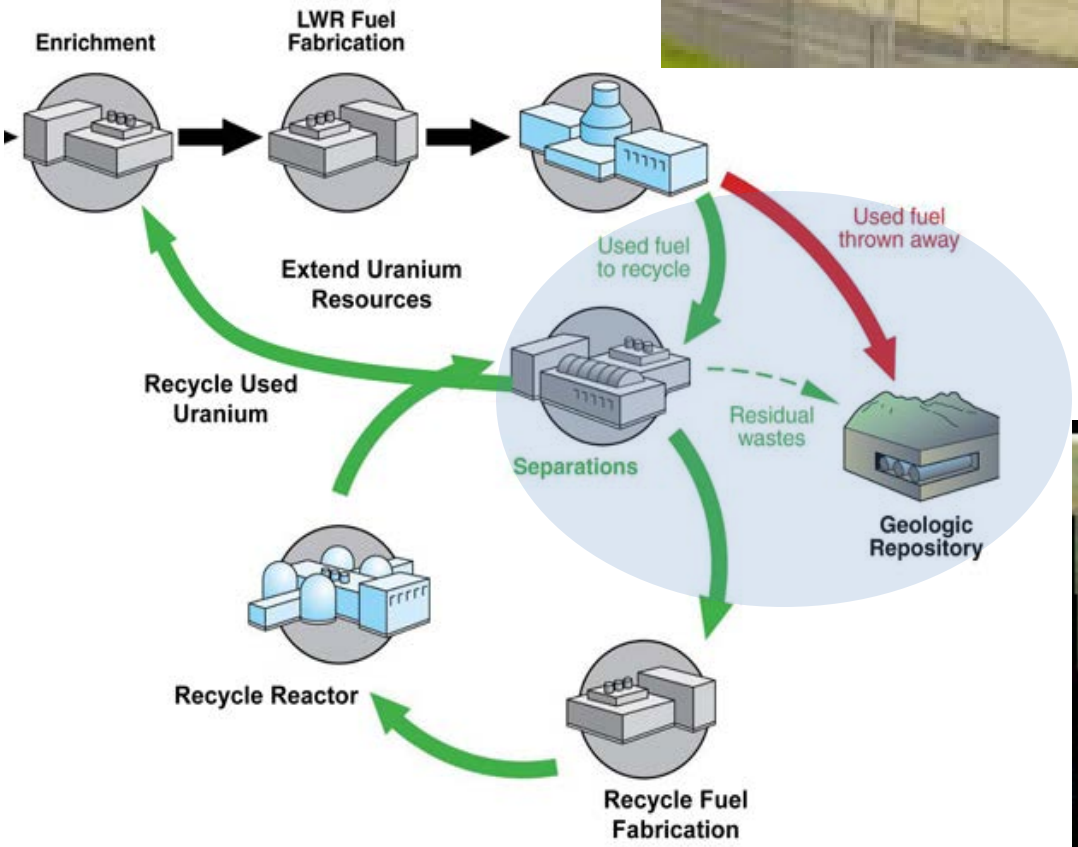
HBU [GWD/MTU]

HBR: 64-67
MOX: 40-49
NA: 60-63
BWR,-LMK: 54-57

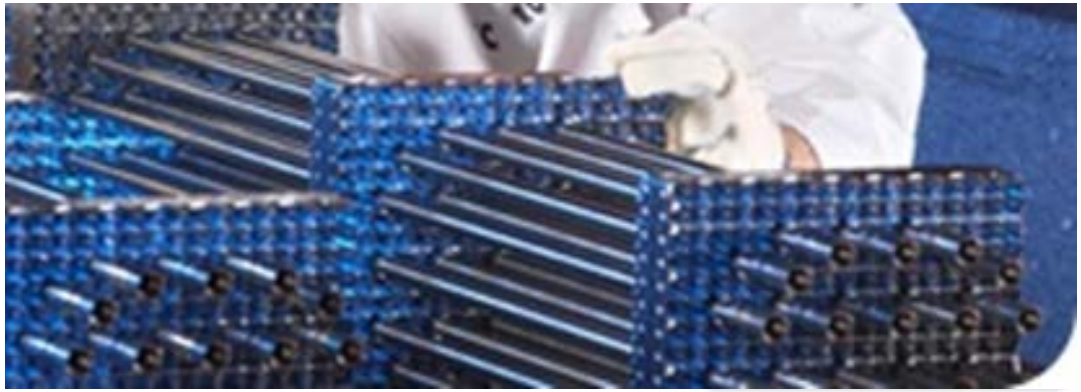
Complex vibration can be constructed or formed by modal shape functions

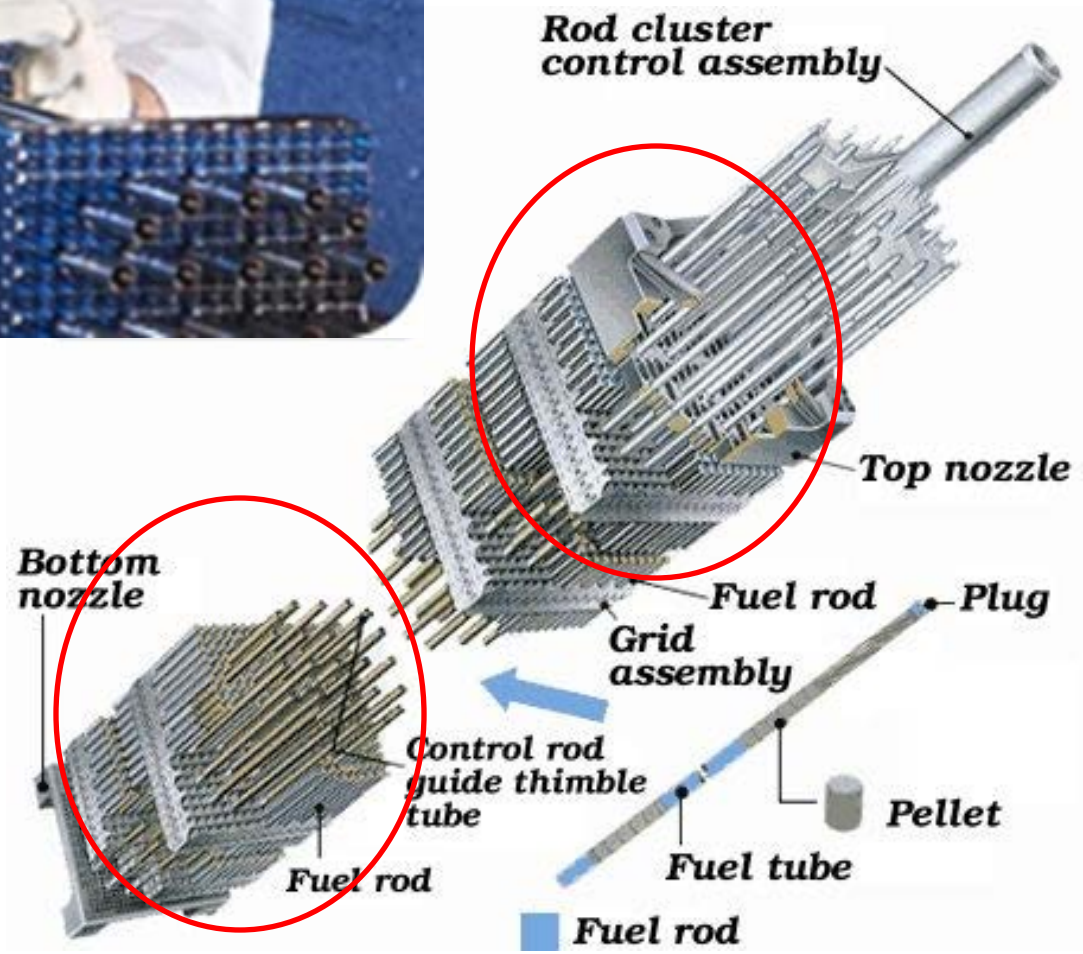


SNF transport reliability investigation plays a critical role in the back end fuel cycle initiative

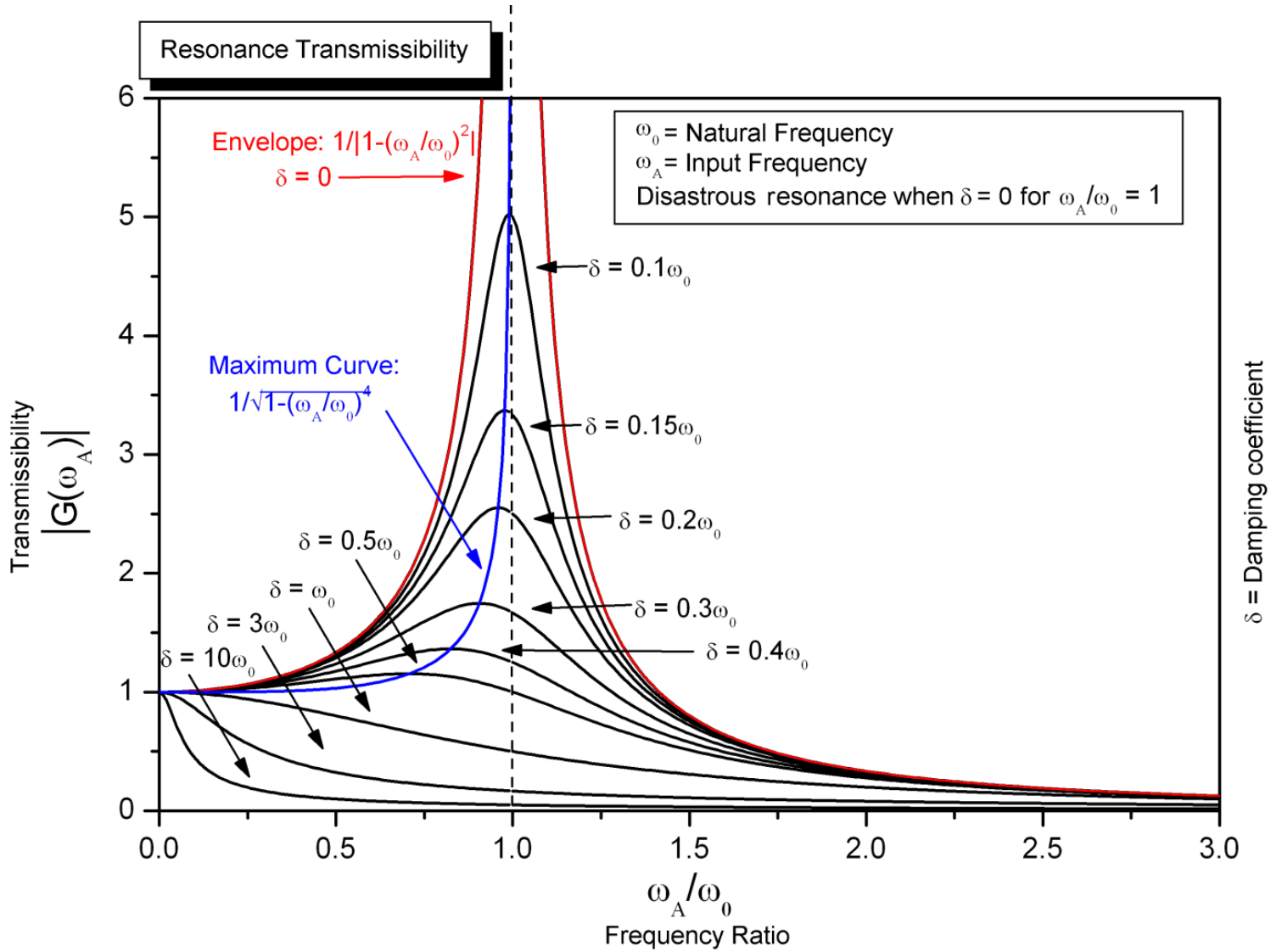


Skelton of fuel assembly is formed by guide thimble tubes and spacer grids





System damping can critical affect the system amplification factors



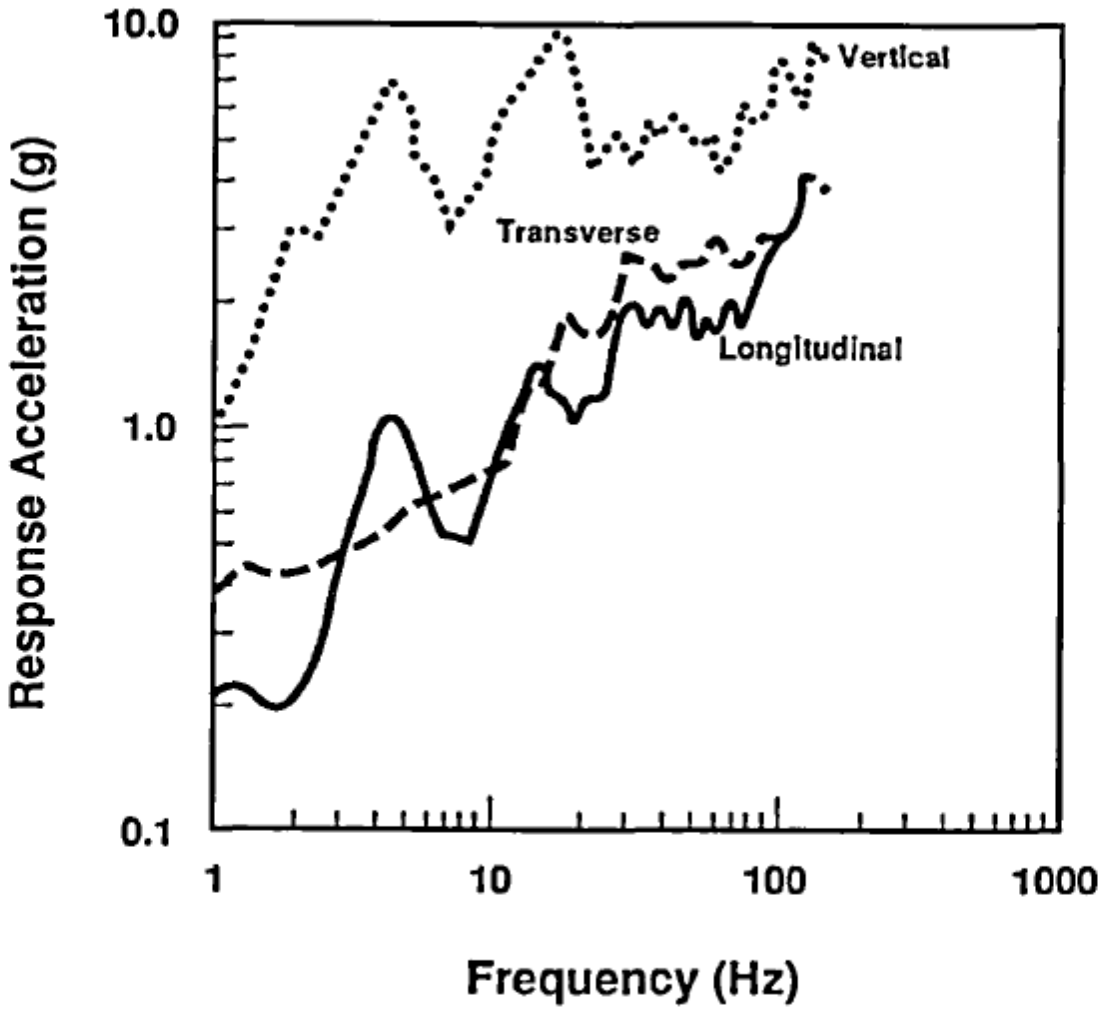


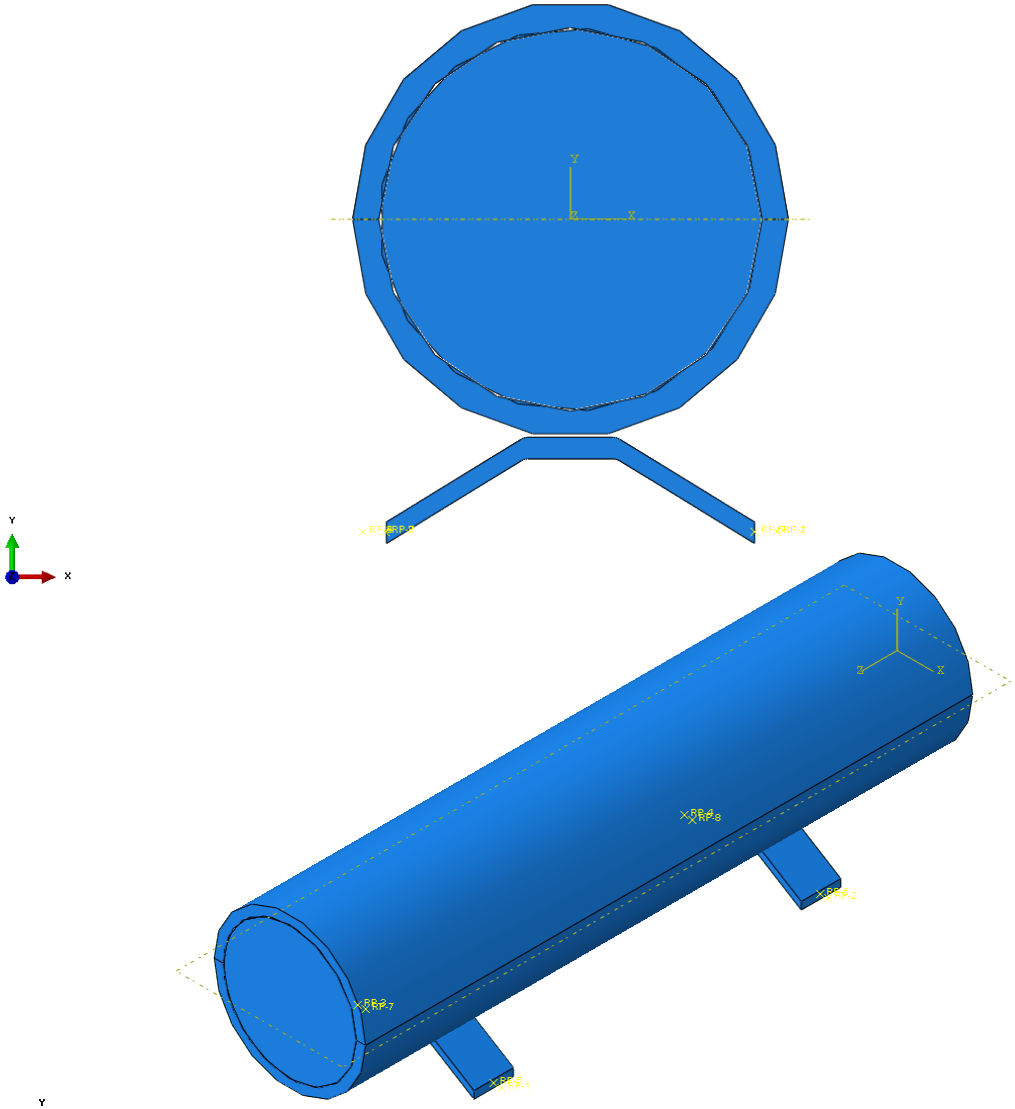
Figure II-71. Truck Superimposed Shock Response Envelopes with 3% Damping [MA77a]

Table II-14

Truck Vibration Data [MA77a]

Frequency Band (Hz)	Measurements on Cargo Floor (g) 99% Level of Zero to Peak Amplitude		
	Longitudinal Axis	Transverse Axis	Vertical Axis
0-5	0.10	0.10	2.00
5-10	0.08	0.06	1.04
10-20	0.84	0.15	1.68
20-40	0.51	0.24	1.20
40-80	0.36	0.42	0.50
80-120	0.24	0.27	0.87
120-180	1.23	0.21	0.63
180-240	0.87	0.12	0.87
240-350	0.24	0.15	0.63
350-500	0.24	0.15	0.42
500-700	0.87	0.15	0.87
700-1000	1.50	0.87	1.17
1000-1400	0.87	1.17	1.17
1400-1900	0.39	0.24	0.87

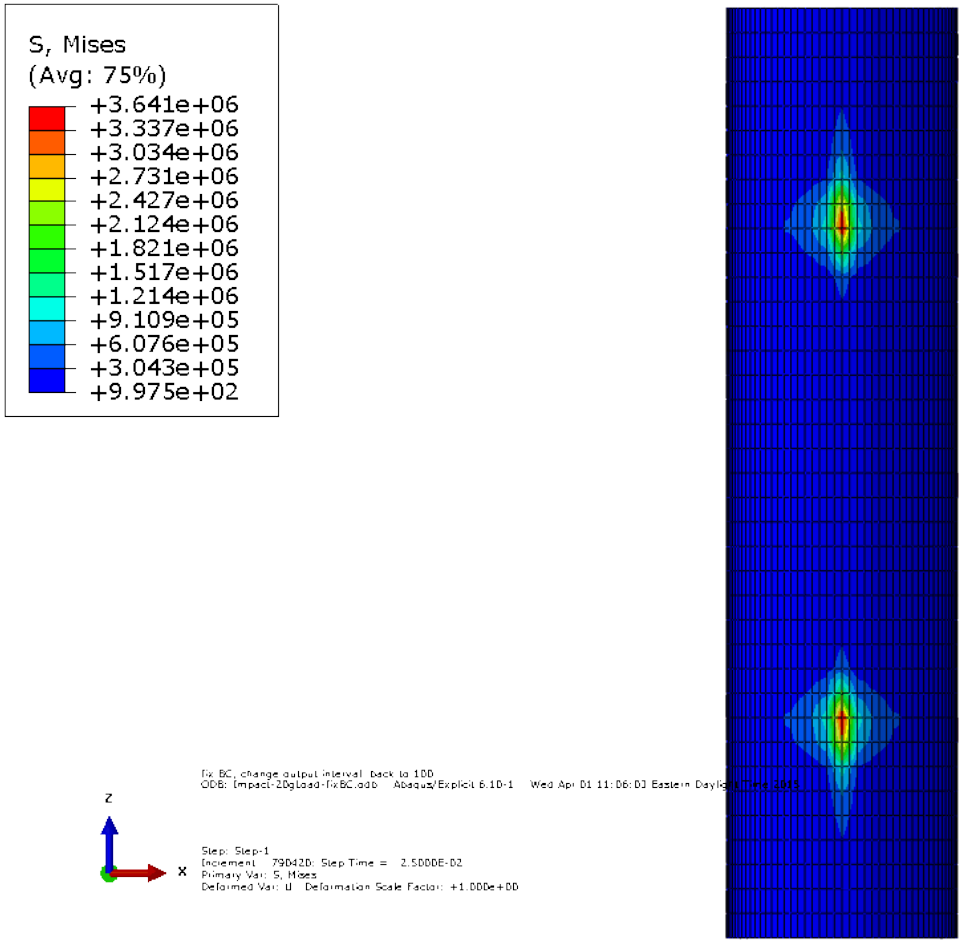
Fuel Rod Section with Two Dimples Model



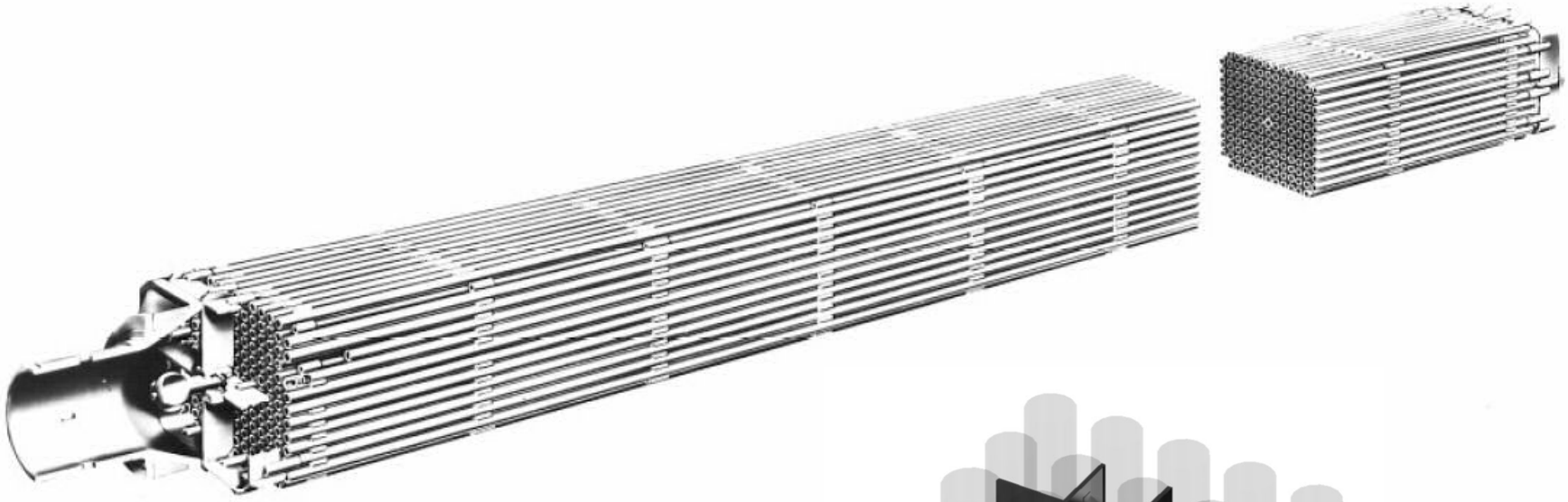
- 3-D model
- Model clad as full fuel rod with length 38mm
- Model two dimples
- Dynamic explicit
- Define general contact between clad and dimple surfaces
- Define clad initial velocity upon impacting dimple 0.25mm/s~0.62mm/s as estimated
- Both clad and dimple with material Zircaloy-4

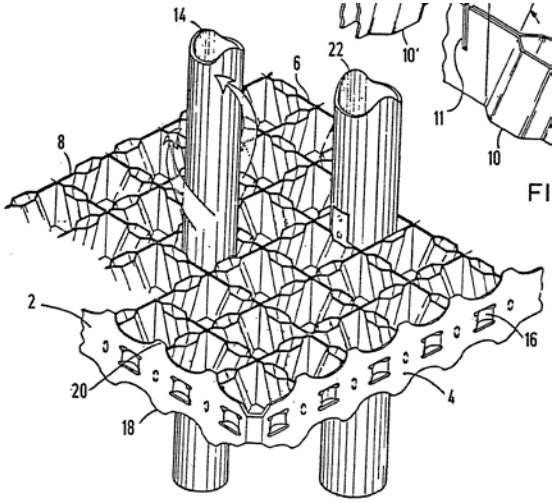
Managed by UT-Battelle
for the U.S. Department of Energy

Impact 20g Load



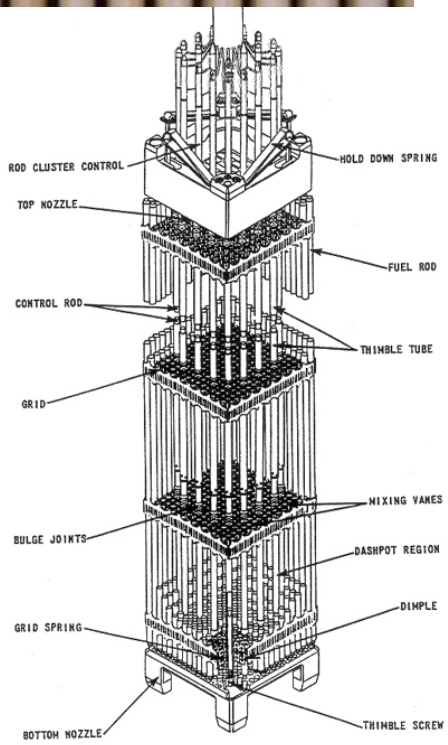
Impact location max stress 3.641 MPa

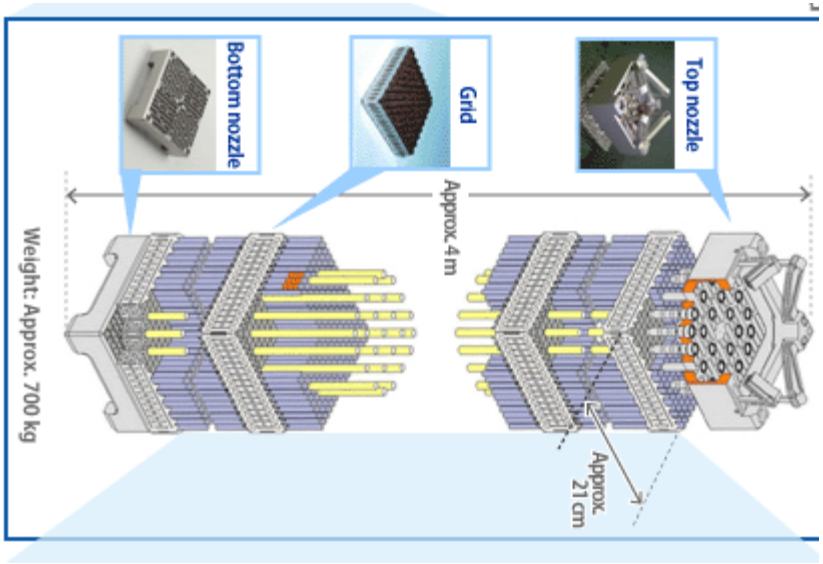



14
22
10'
6
11
8
10
FI
2
16
20
4
18

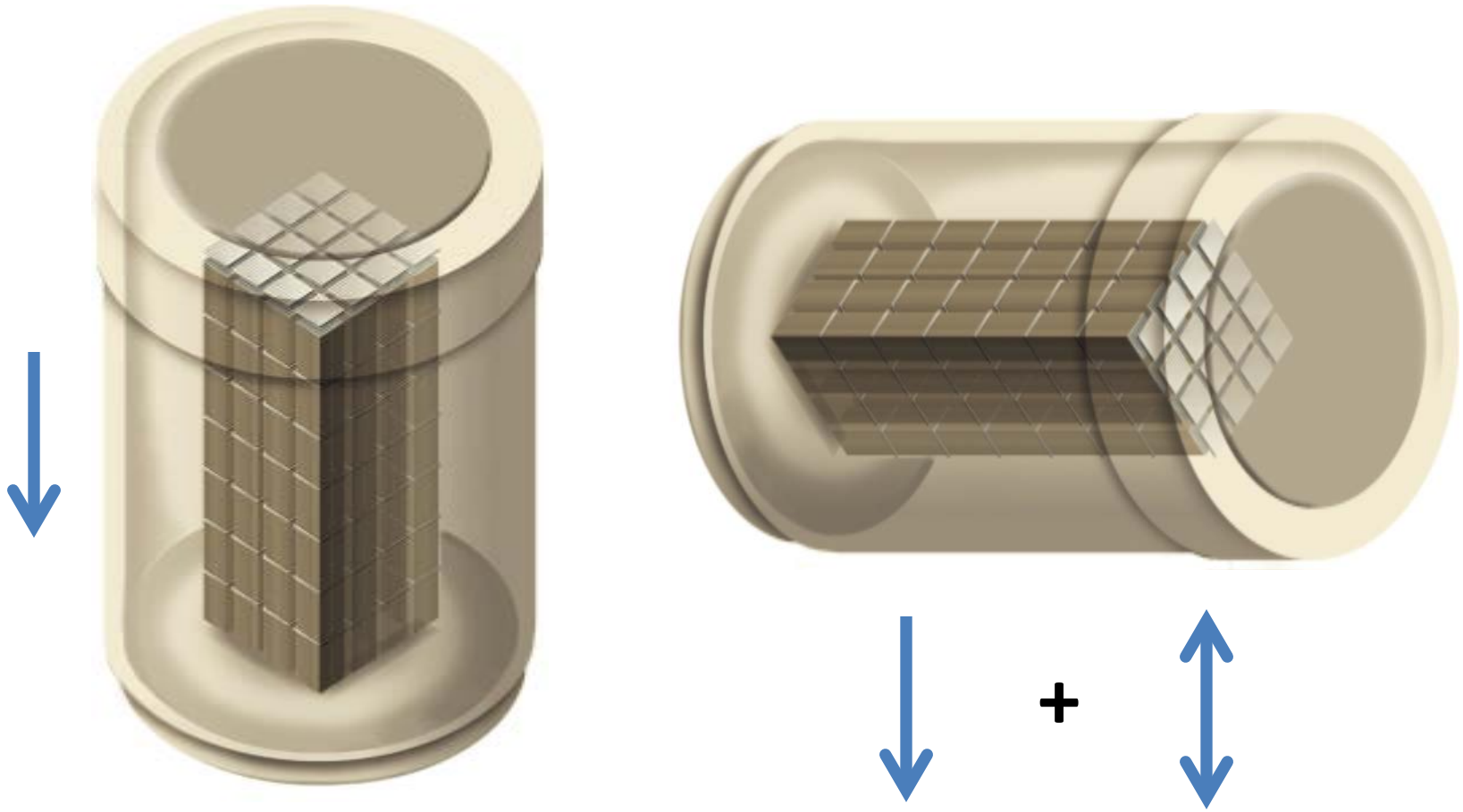
ENZYME

5 FACE 1

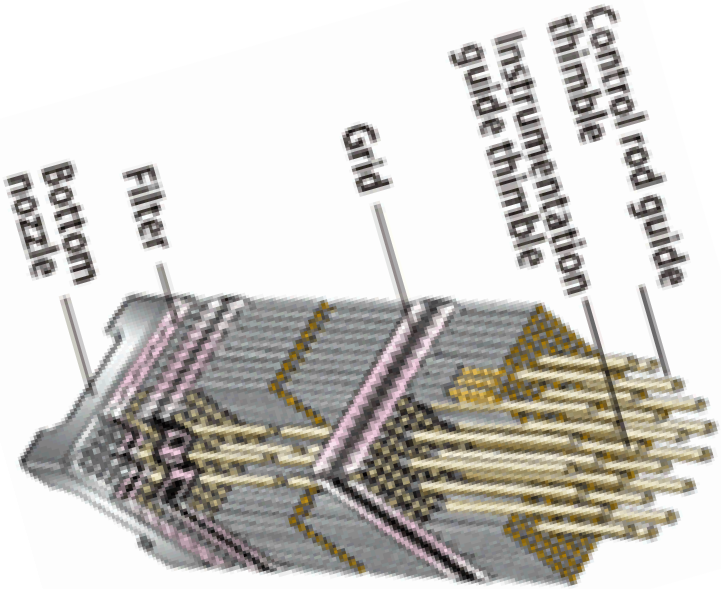

ROD CLUSTER CONTROL
TOP NOZZLE
CONTROL ROD
GRID
BULGE JOINTS
GRID SPRING
BOTTOM NOZZLE
HOLD DOWN SPRING
FUEL ROD
THIMBLE TUBE
MIXING VANES
DASHPOT REGION
DIMPLE
THIMBLE SCREW

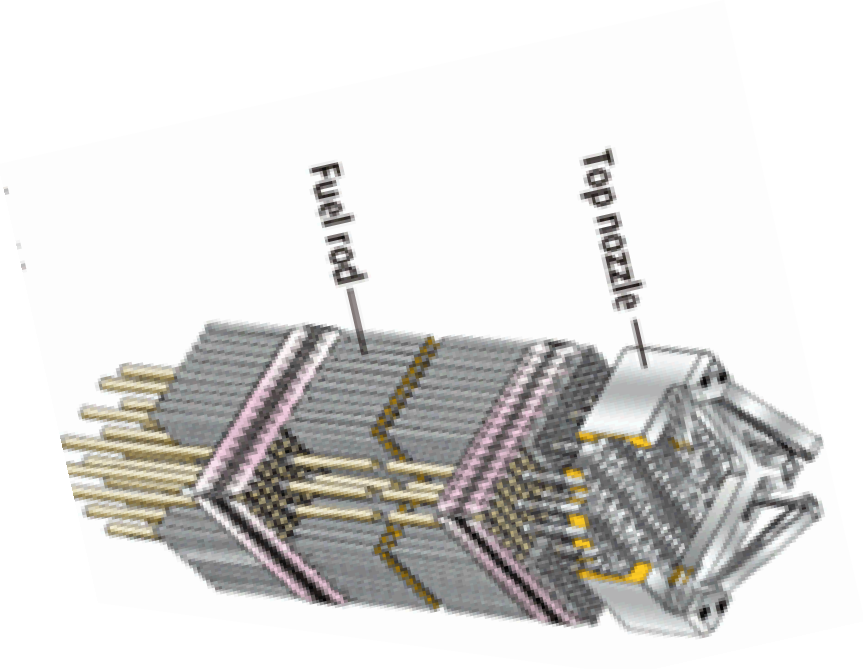

Top nozzle
Grid
Bottom nozzle
Approx. 4 m
Approx. 21 cm
Weight: Approx. 700 kg

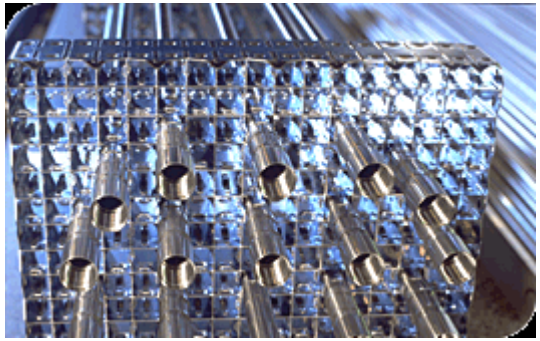
Canister design can significantly affect SNF system vibration reliability



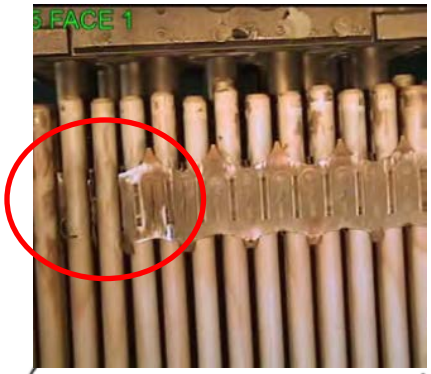
Guide tube and spacer grids become load bearing in horizontal set-up under NCT

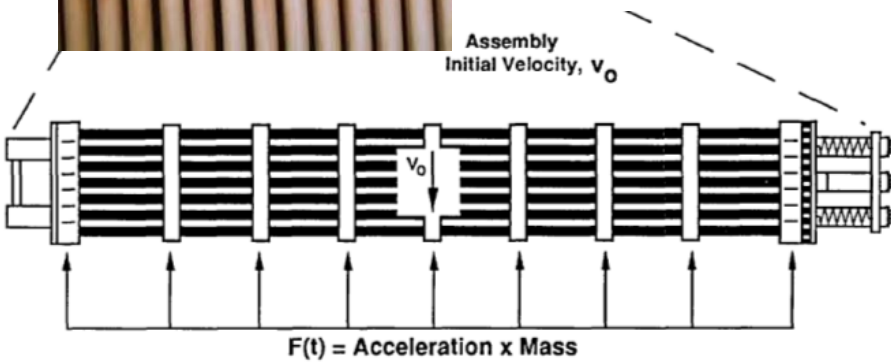


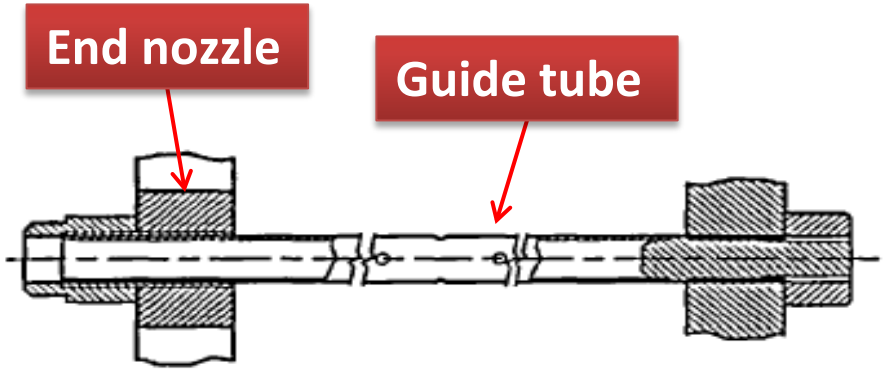




SNF fuel assembly vibration intensity depends on aging skeleton integrity







Guide Tube Assembly - Details

- Due to SNF horizontal installation for transport, guide tubes & spacer grids are now become bending load bearing members for fuel rods static & dynamic loads;
- Fuel assembly skeleton, formed by guide tubes & spacer grids, **is responsible** for **LOAD** transferring mechanism within the fuel assembly during transport.
- Thus, the integrity of guide tube & spacer grids will critically affect SNF vibration intensity during transport.

Transient Shocks and Vibration Environments Encountered During Normal Rail Transportation of Heavy Cargo (SAND82-0819, TTC-0298, August 1982)

Shock and vibraton environments were measured during rail transport of a 45-tonne (50-ton) cargo mounted on a railroad flat car. The cargo was transported by regular railroad methods from Denver, Colorado to Albuquerque, New Mexico.

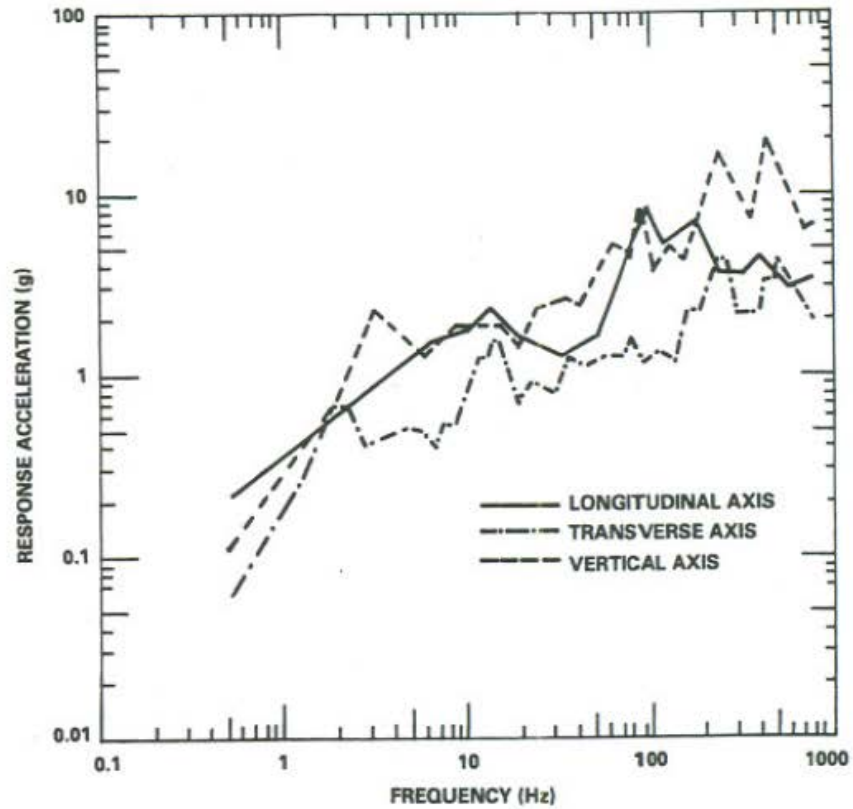
The maxima of the 99 percentile levels of acceleration amplitude vibration for a 45-tonne (50-ton) cargo over the frequency range of 0 to 750 Hz were

Peak Normal Vibration

Axis	Zero-to-Peak Acceleration (g)
Longitudinal	0.10
Transverse	0.19
Vertical	0.52

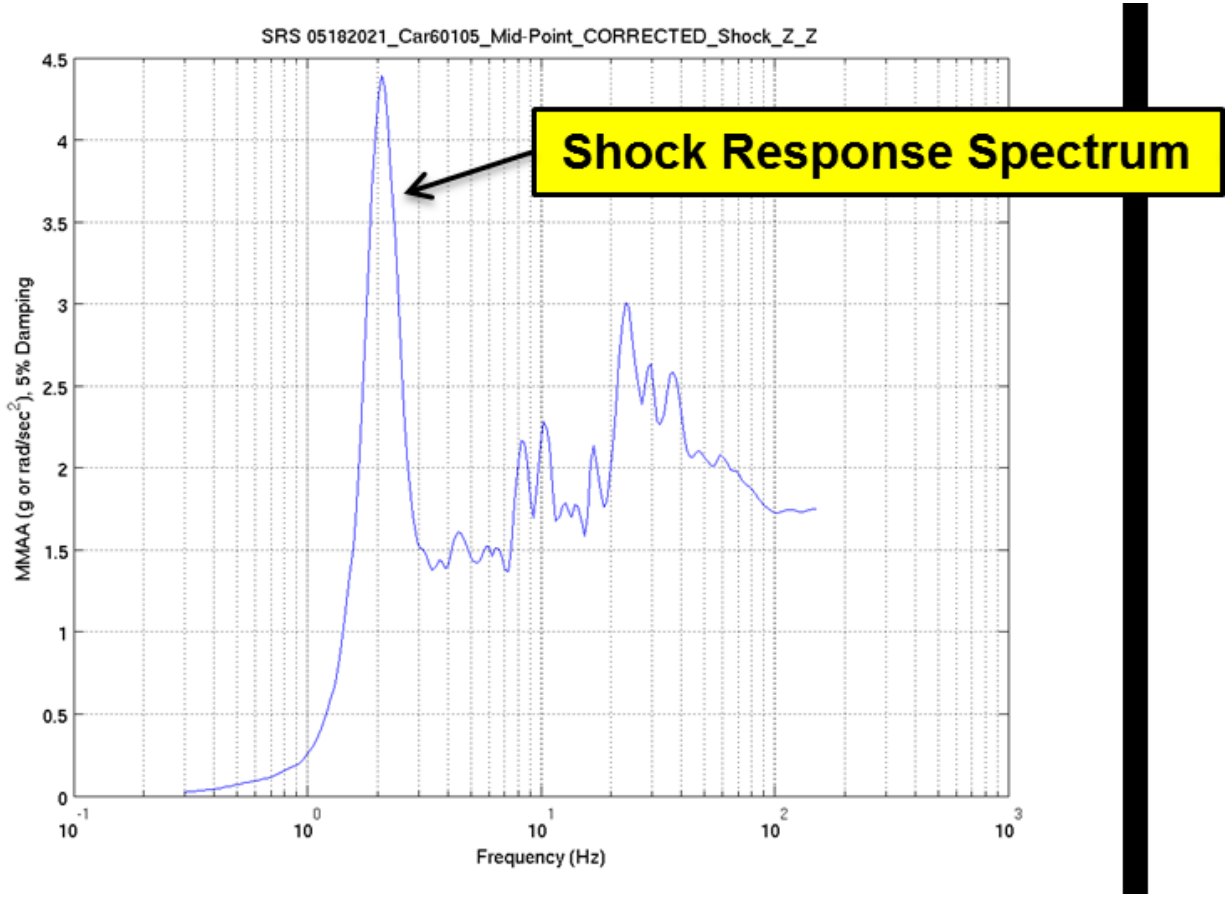
The shock response spectra, using 3% damping, are shown in the following figure.

Transient Shocks of NCT



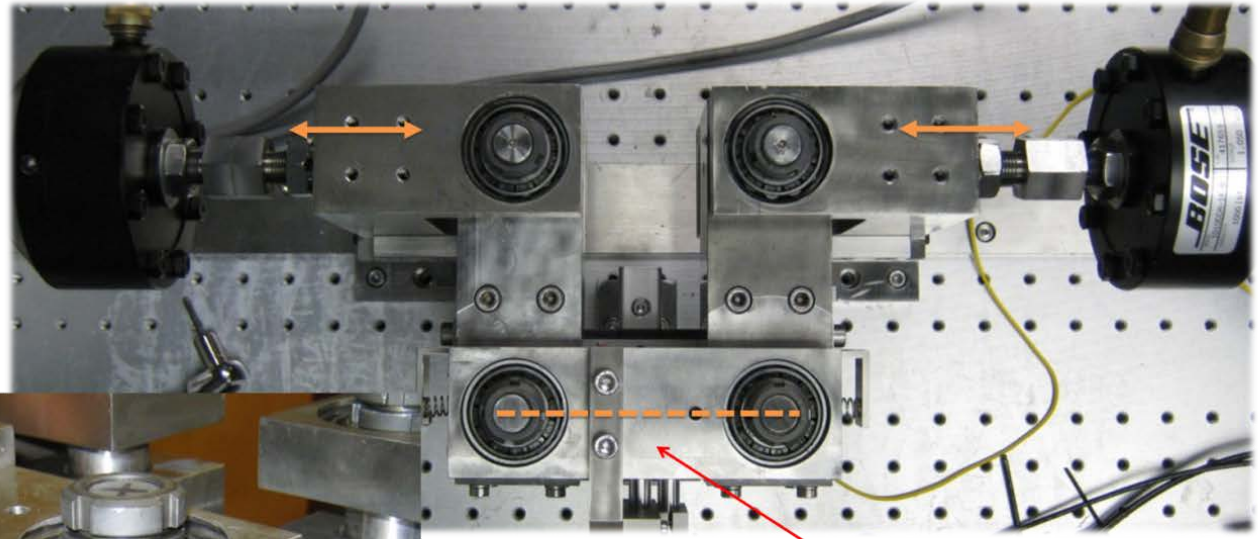
Mean Plus Three Standard Deviation Amplitude Envelopes of Shock Response Spectra; 3% Damping

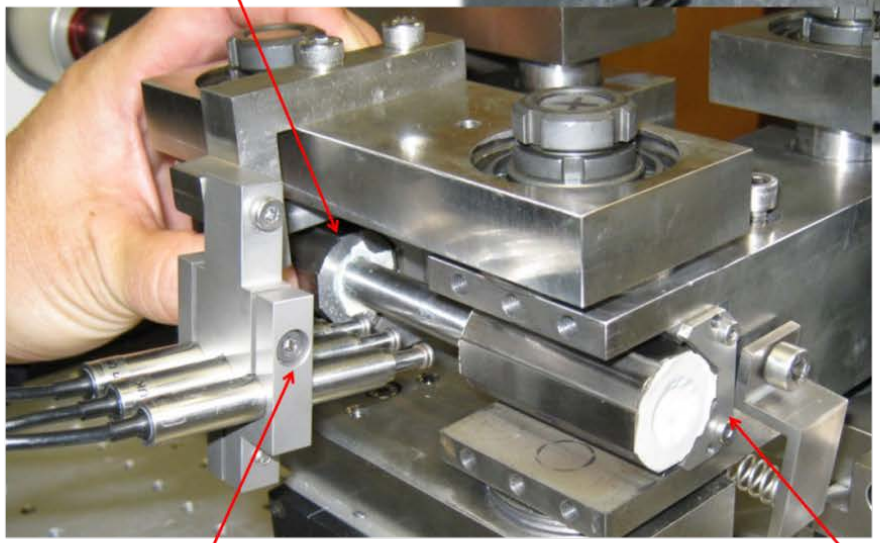
TTCI rail study vibration spectrum provided in FCRD-UFD-2013-000325 (2013)



Unique design concepts of CIRFT testing protocol are illustrated below

Design concept eliminates the need for a machined gauge section and the testing of SNF in "as-found" condition



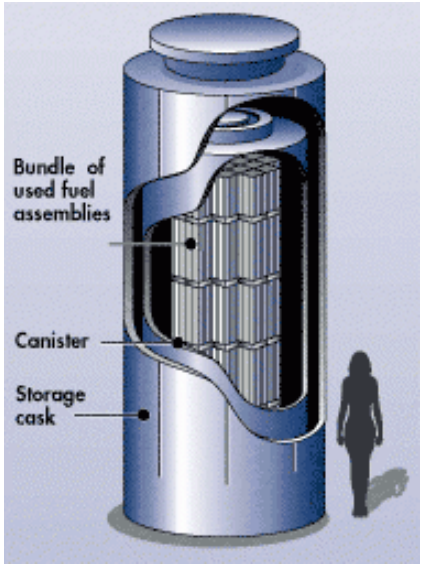


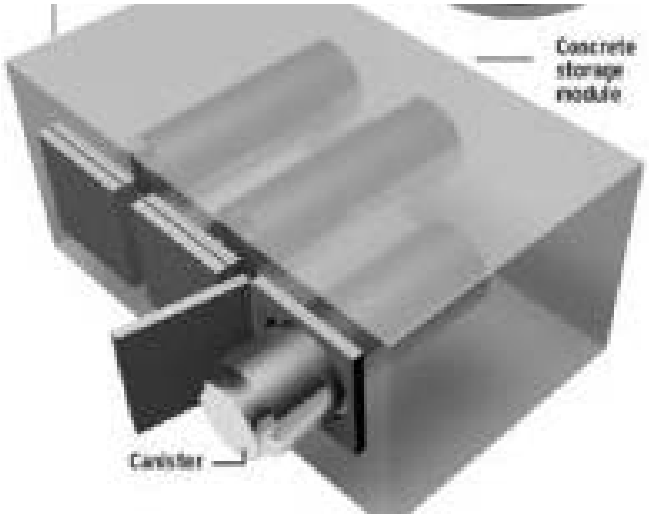
Sample location.
Push-pull force of linear motors translates to bending moment using unique U-frame design.

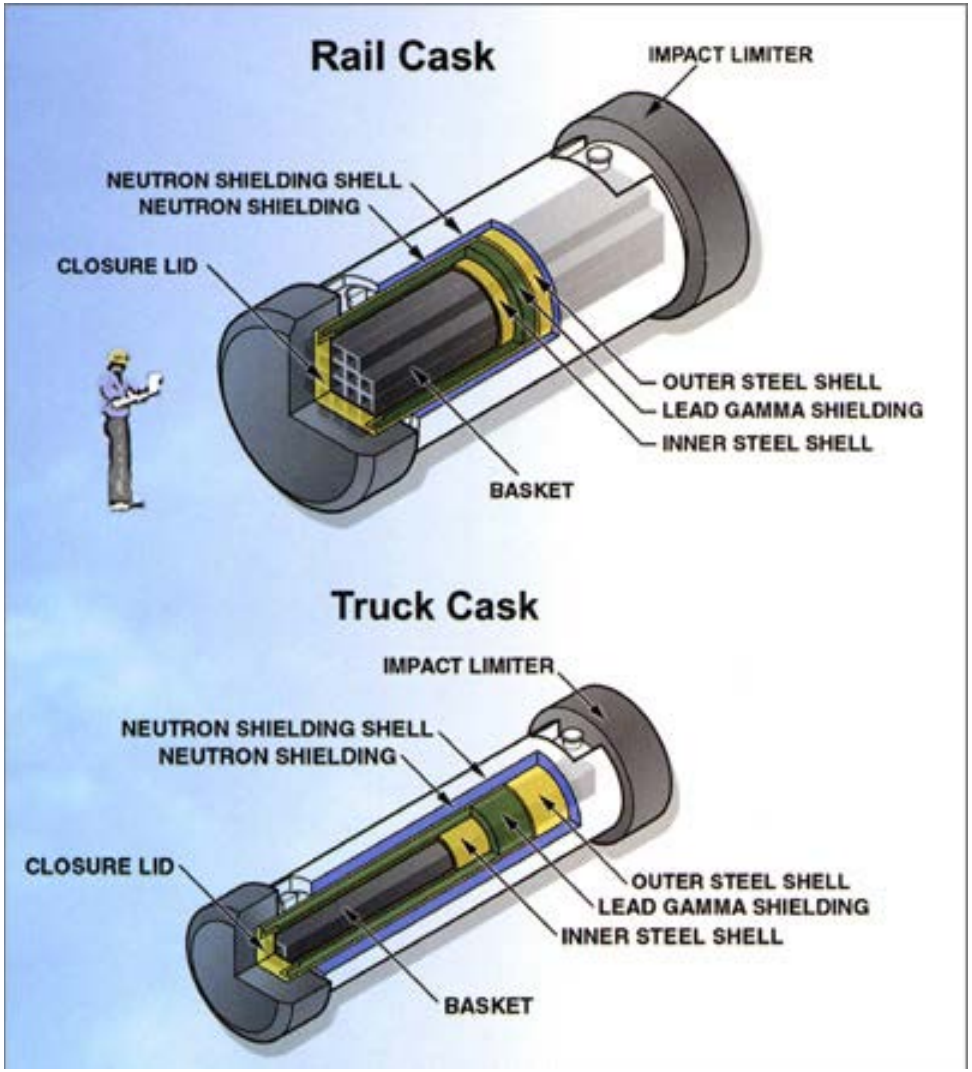
Real-time, direct monitoring with three LVDT setup

Frictionless grip, in combination with roller bearing design, allows for lateral movement, eliminating an axial tensile loading during bending.

Canister orientations can affect static/dynamic loads transfer mechanism within a fuel assembly

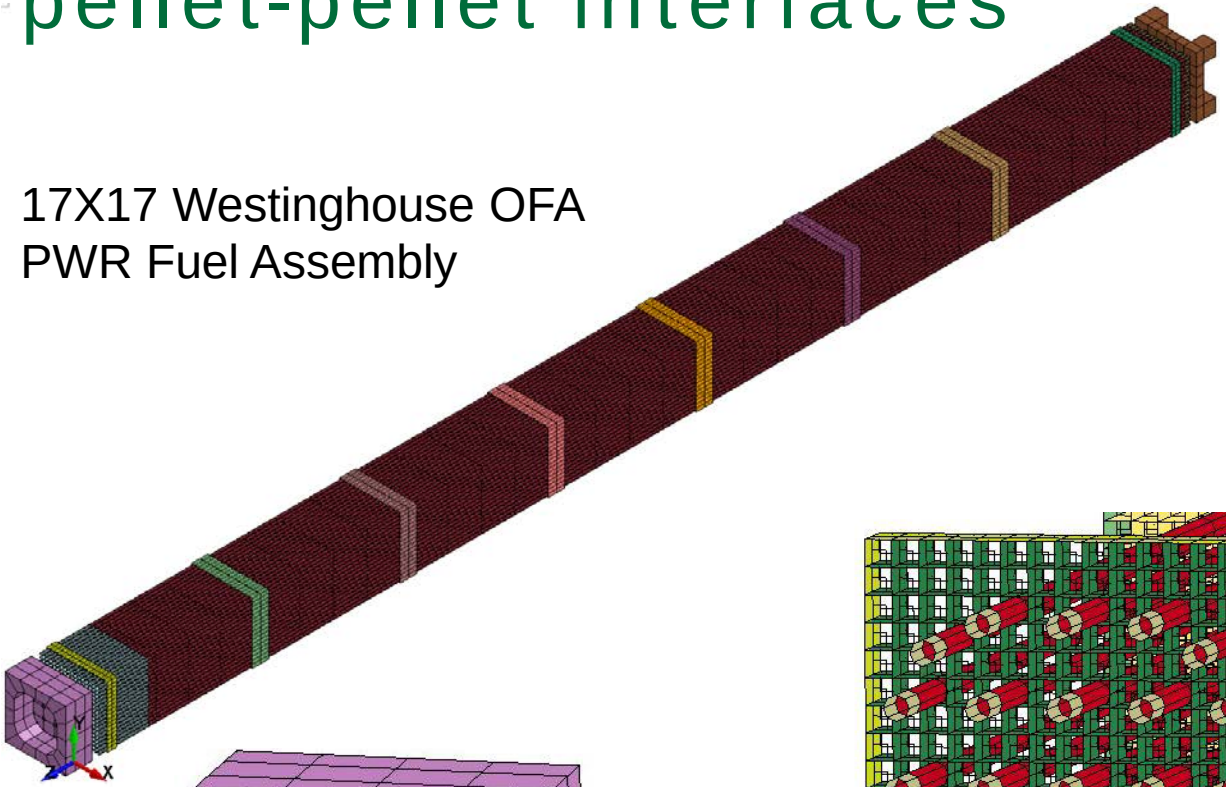


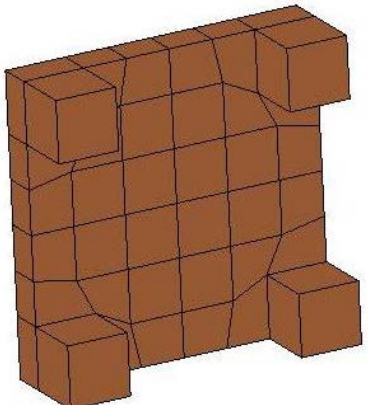




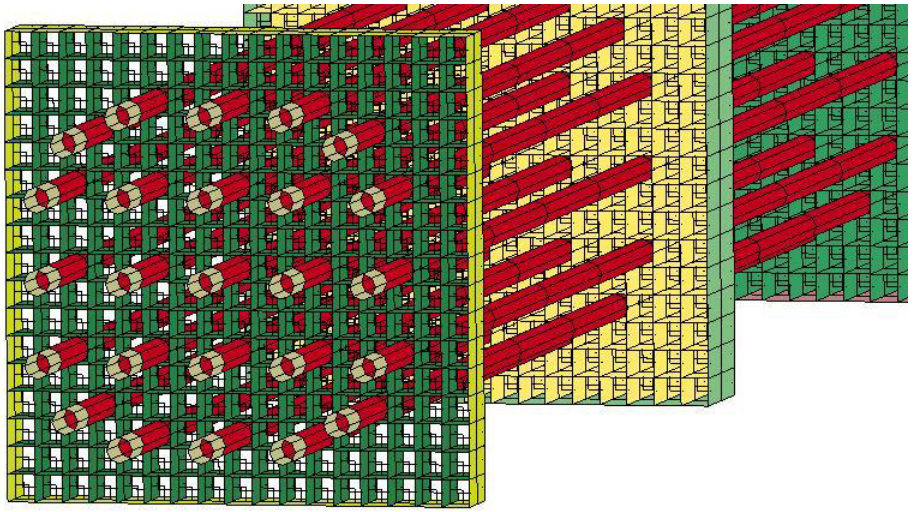
Global PNNL SNF assembly FEM – no pellet-pellet interfaces

17X17 Westinghouse OFA
PWR Fuel Assembly

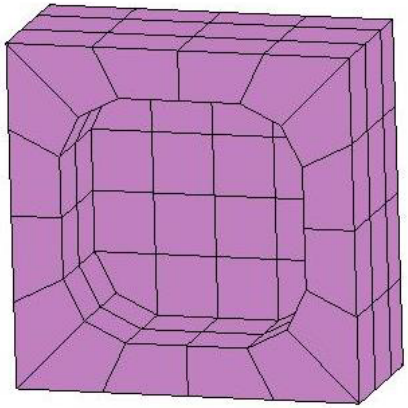




Lower Tie Grids/Nozzles



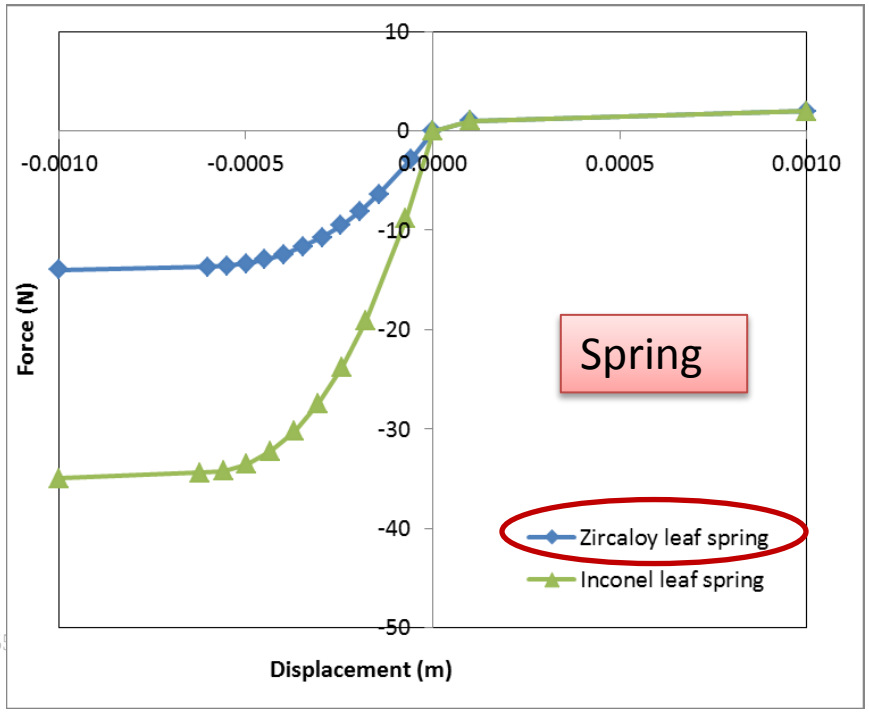
Spacer Grids Rigidly Attached to the Guide Tubes

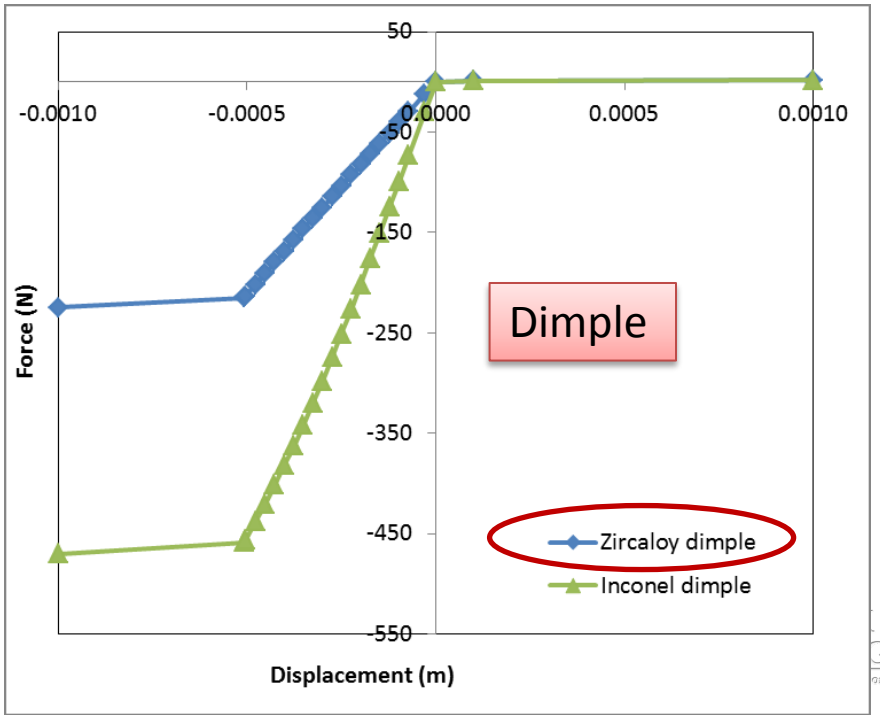


Upper Tie Grids/Nozzles

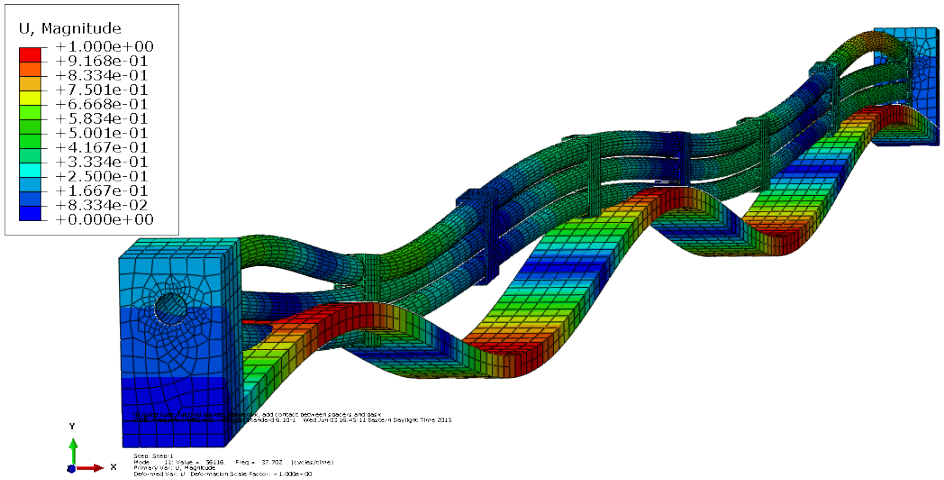
Fuel rod, skeleton, and basket wall material properties

Material	Density (lb/in^3)	Young's Modulus (psi)	Poisson's ratio	Yield strength (psi)
UO_2	0.396	2.92e7	0.32	3.11e5
Zircaloy-4	0.237	1.32e7	0.33	1.31e5
Inconel	0.296	3.06e7	0.284	1.432e5
Stainless steel	0.2901	2.8e7	0.3	4.206e4

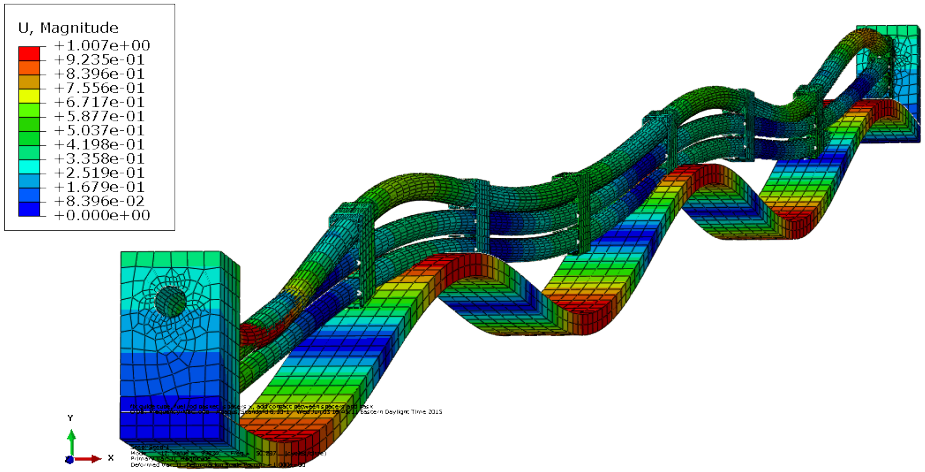




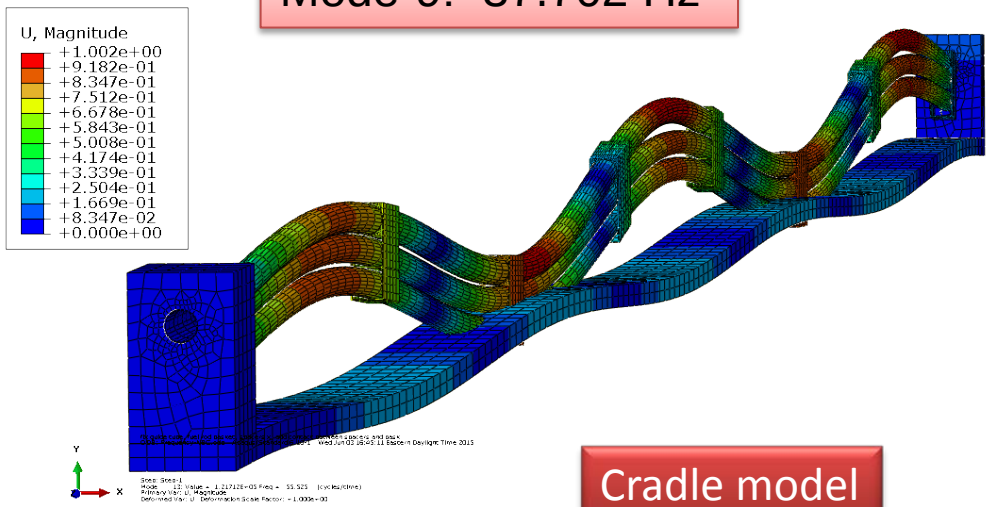
Modal Analysis--Mode and Frequency Cont.



Mode-9: 37.702 Hz

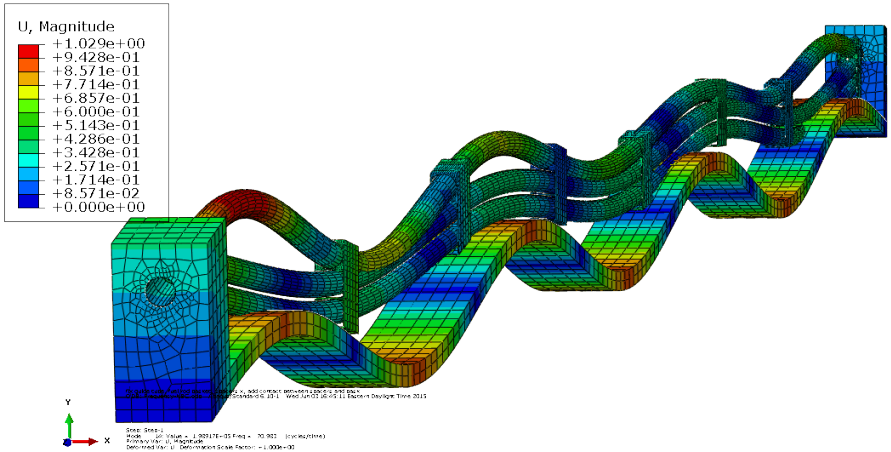


Mode-10: 50.287 Hz



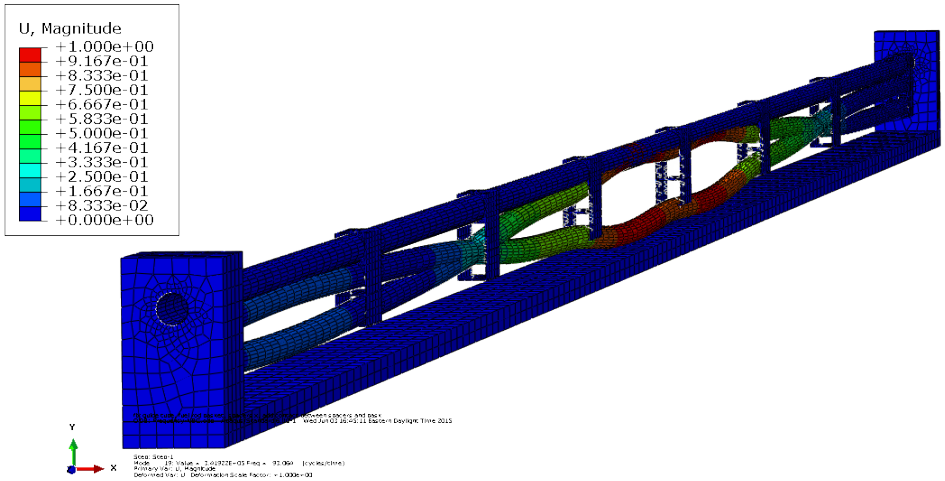
Cradle model

Mode-11: 55.525 Hz

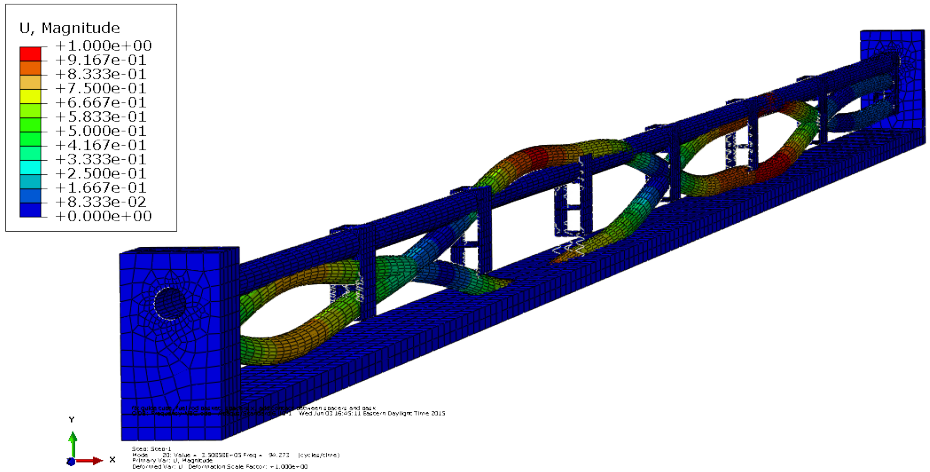


Mode-12: 70.983 Hz

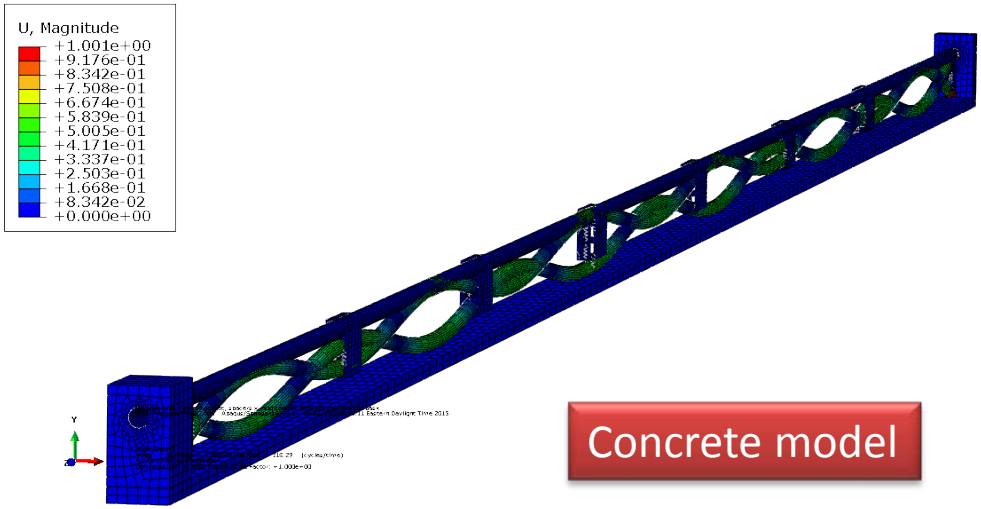
Modal Analysis--Mode and Frequency Cont.



Mode-17: 93.064 Hz

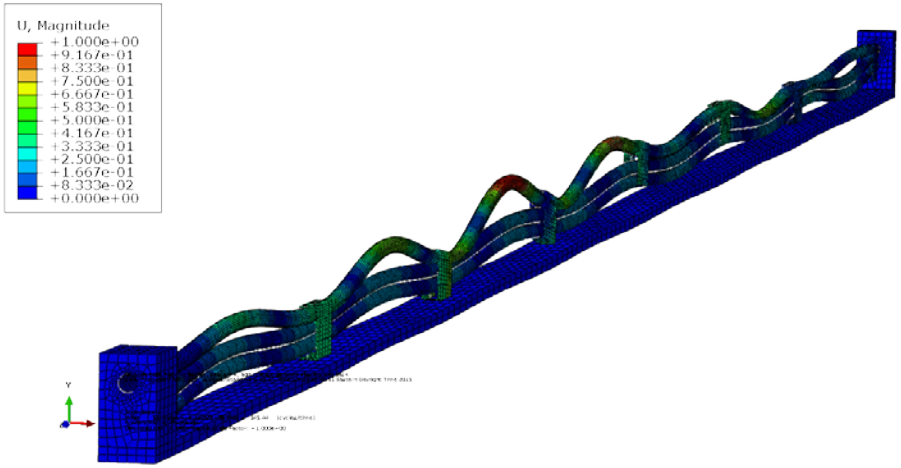


Mode-18: 94.273 Hz



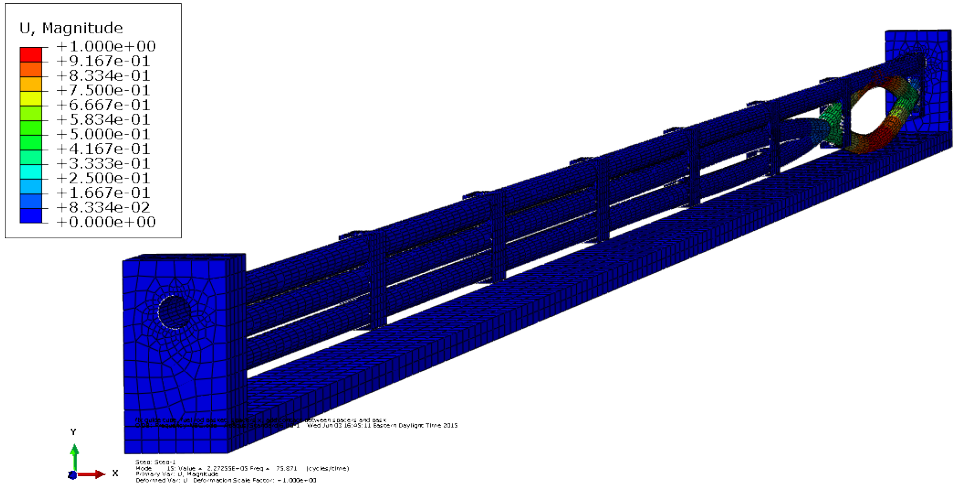
Concrete model

Mode-49: 318.29 Hz

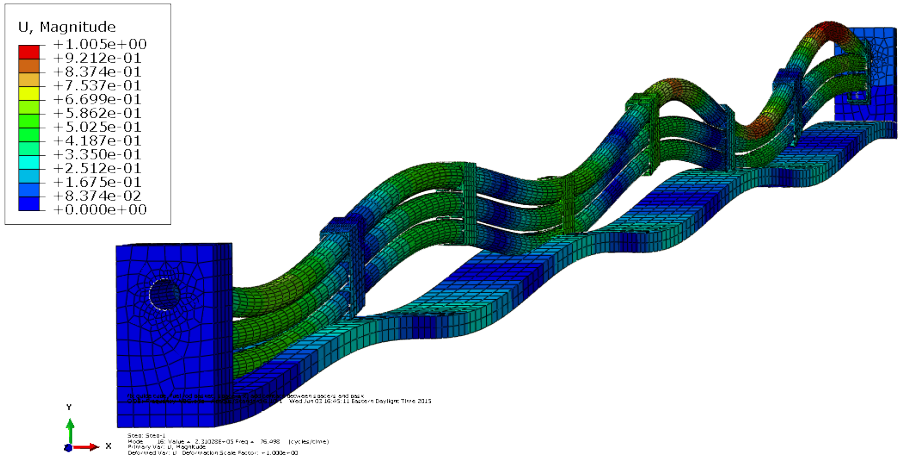


Mode-51: 345.44 Hz

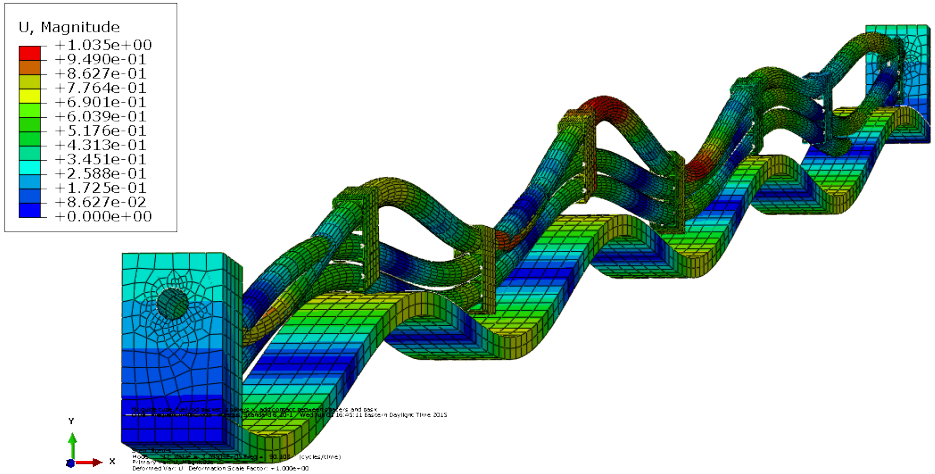
Modal Analysis--Mode and Frequency Cont.



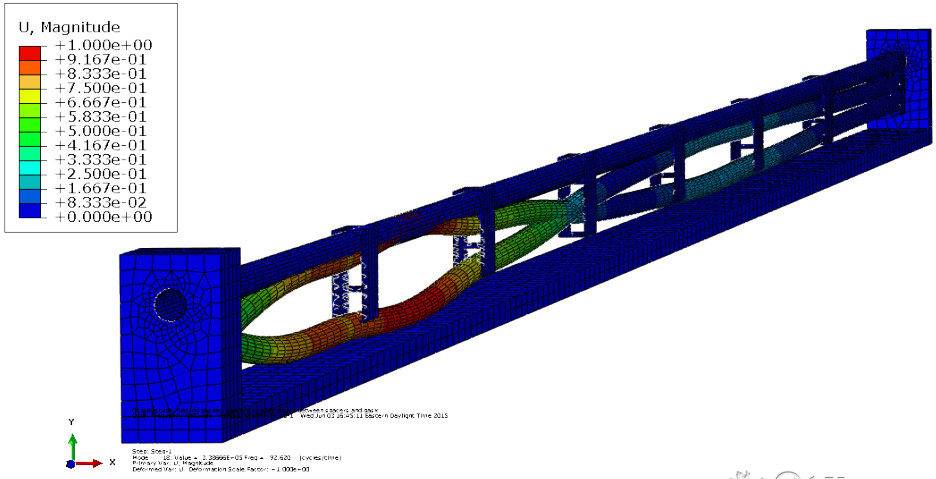
Mode-13: 75.871 Hz



Mode-14: 76.498 Hz

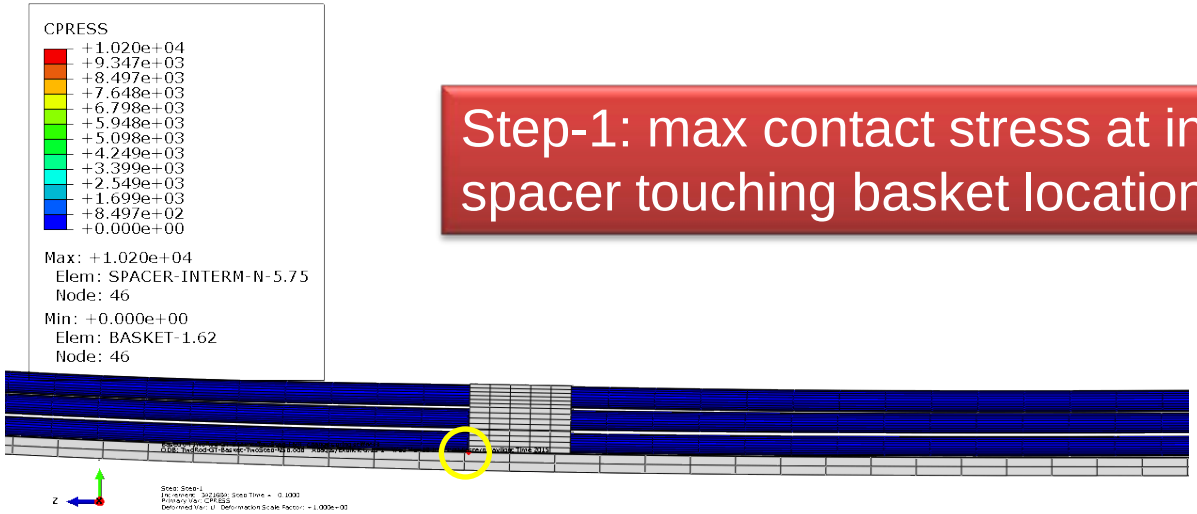


Mode-15: 90.103 Hz



Mode-16: 92.62 Hz

Contact Stress



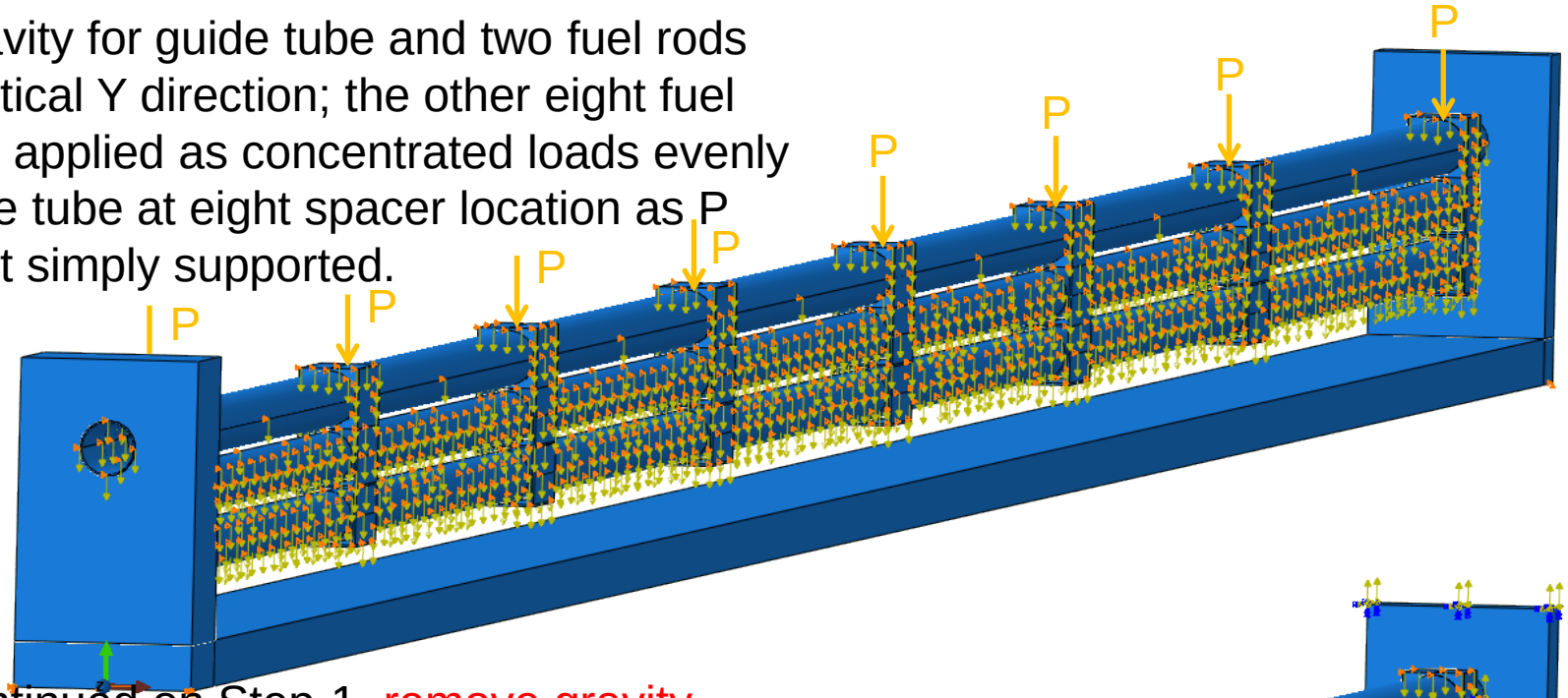
Step-1: max contact stress at intermediate spacer touching basket location

Step-2: max contact stress at clad contacting guide tube

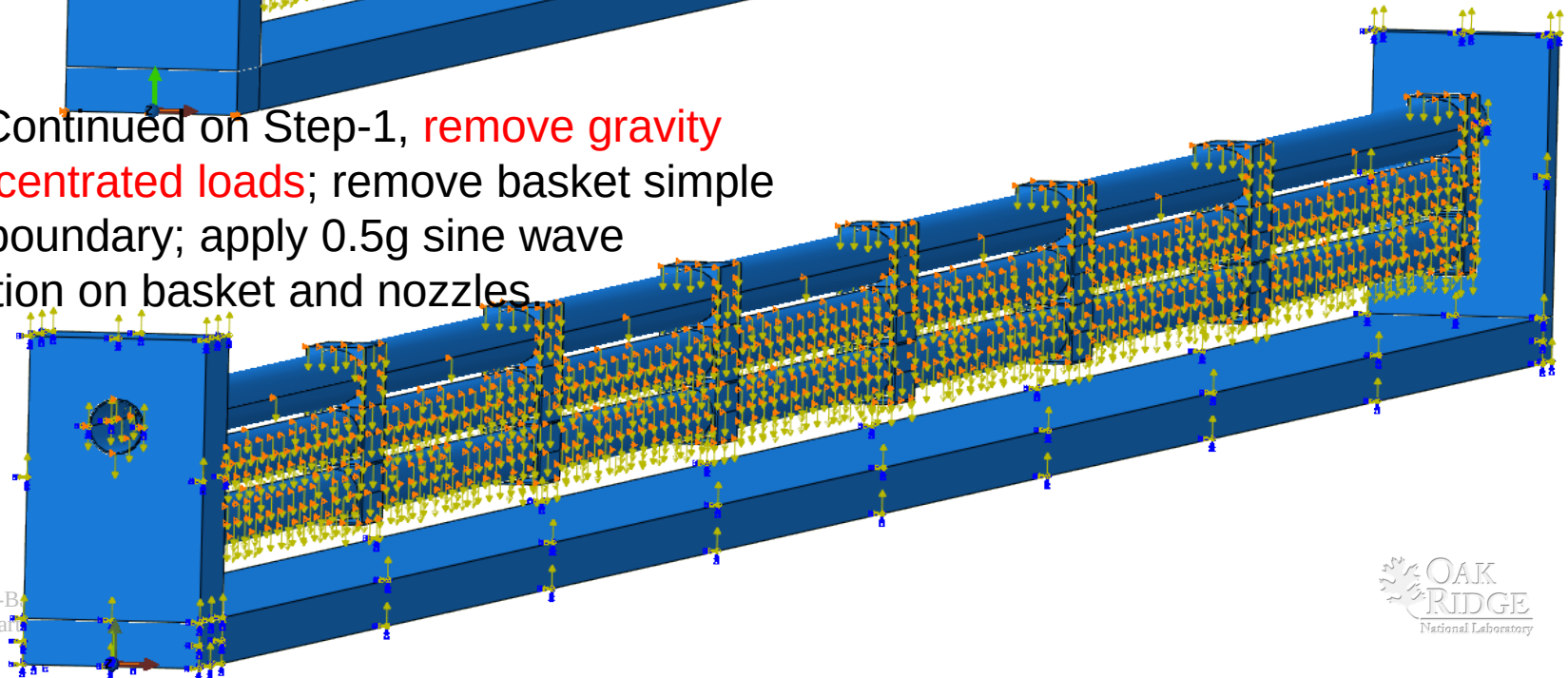
Load and Boundary- Case 2

Step-1: Gravity for guide tube and two fuel rods down in vertical Y direction; the other eight fuel rod weights applied as concentrated loads evenly on the guide tube at eight spacer location as P load; basket simply supported.

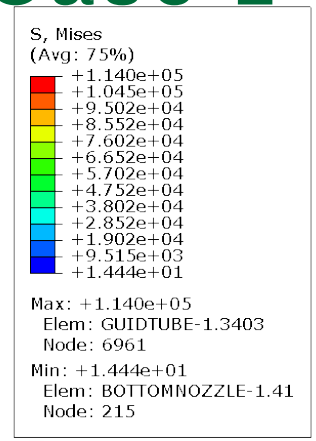
P=4.94 lb



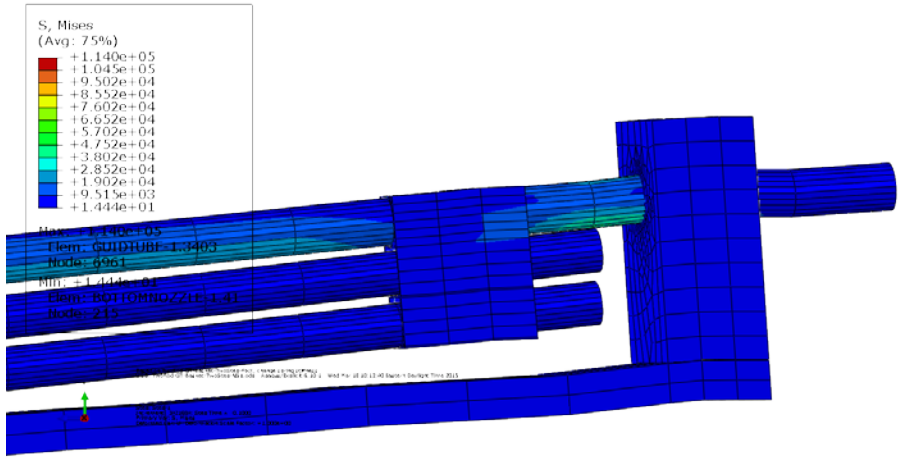
Step-2: Continued on Step-1, remove gravity and concentrated loads; remove basket simple support boundary; apply 0.5g sine wave acceleration on basket and nozzles.

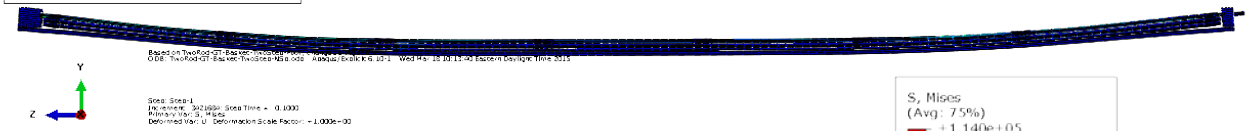


Step-1: Under Gravity Loads--Same as Case 1



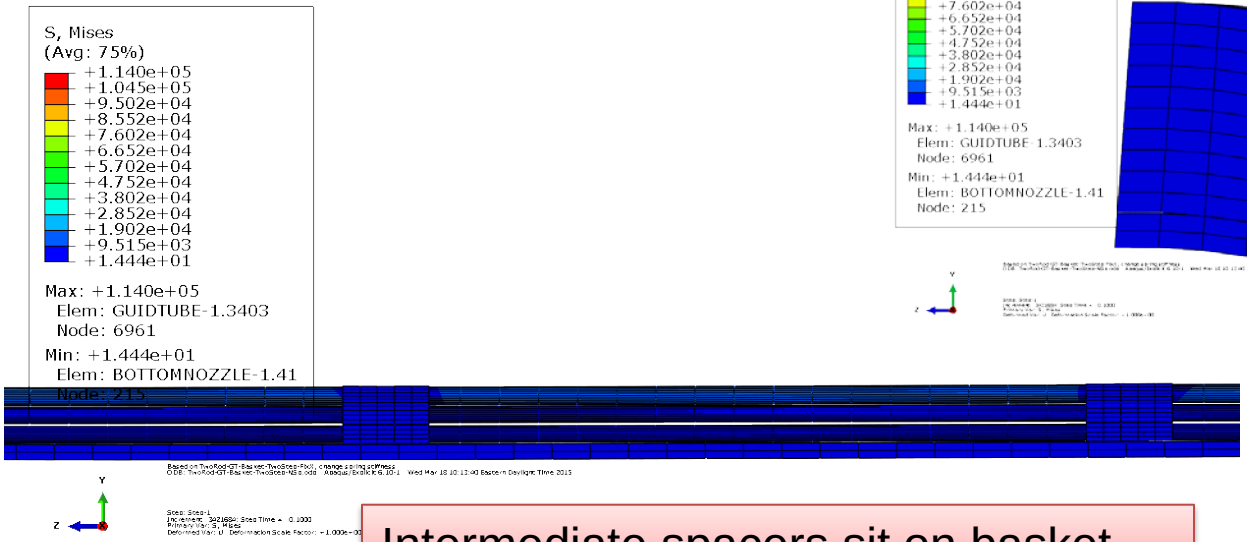
Guide tube and fuel rods sag in the middle; Max stress on guide tube, no yielding





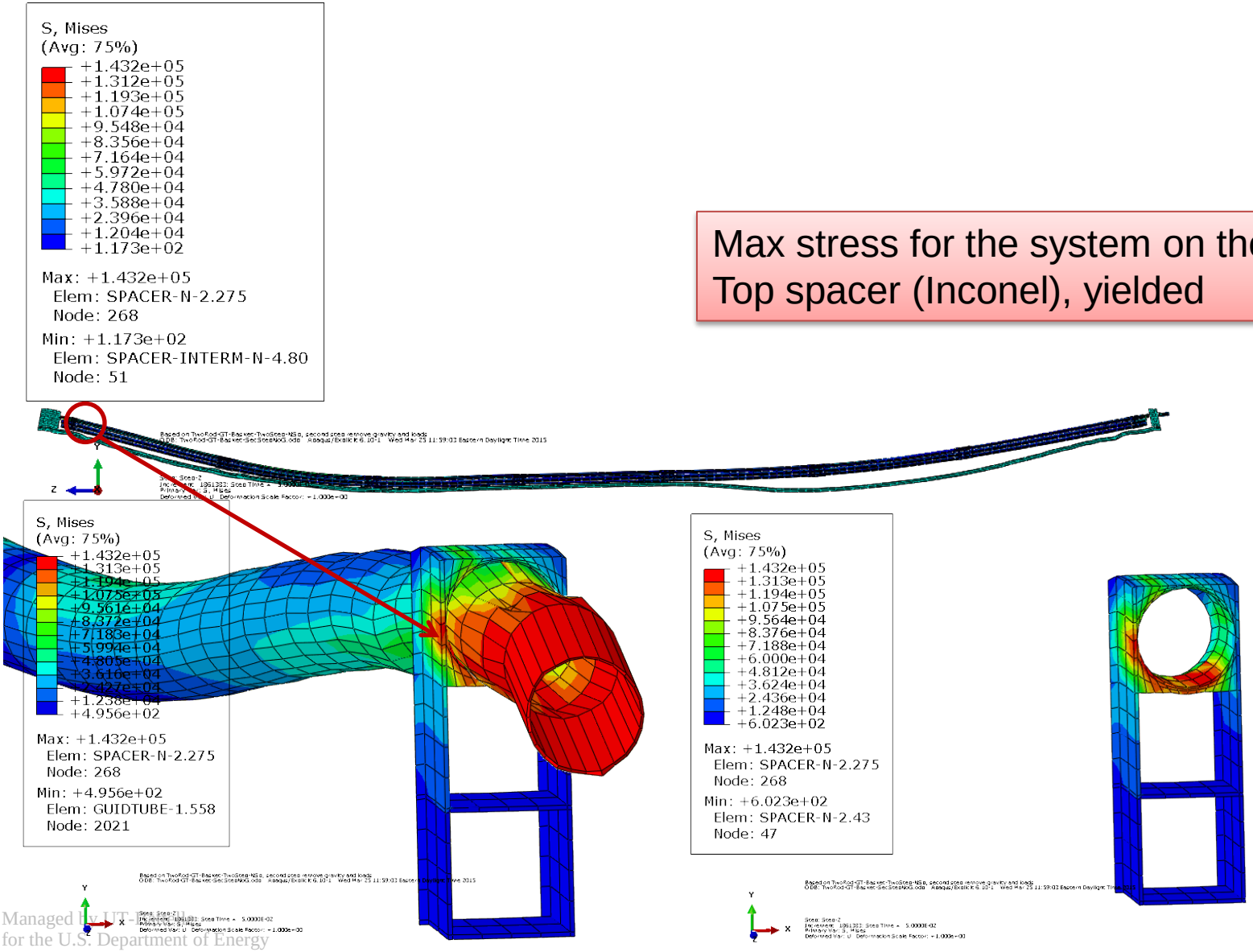
Bottom spacer doesn't contact basket

Top spacer doesn't contact basket



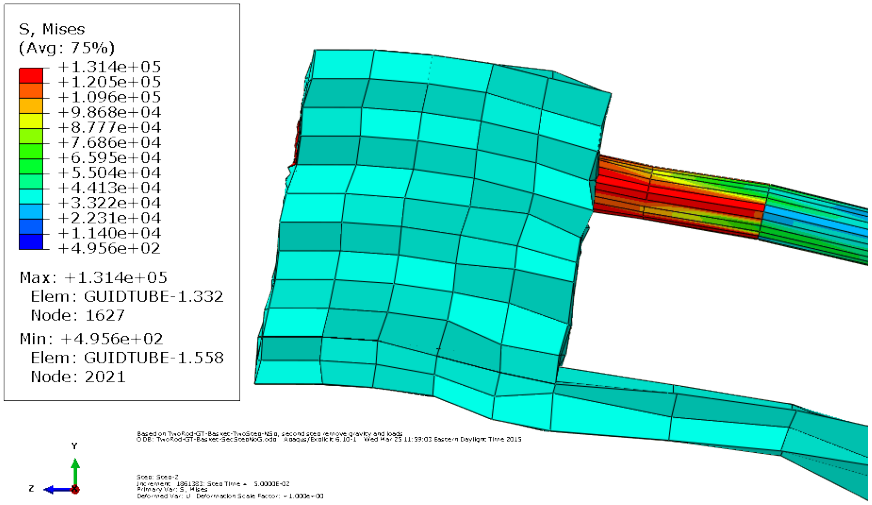
Intermediate spacers sit on basket

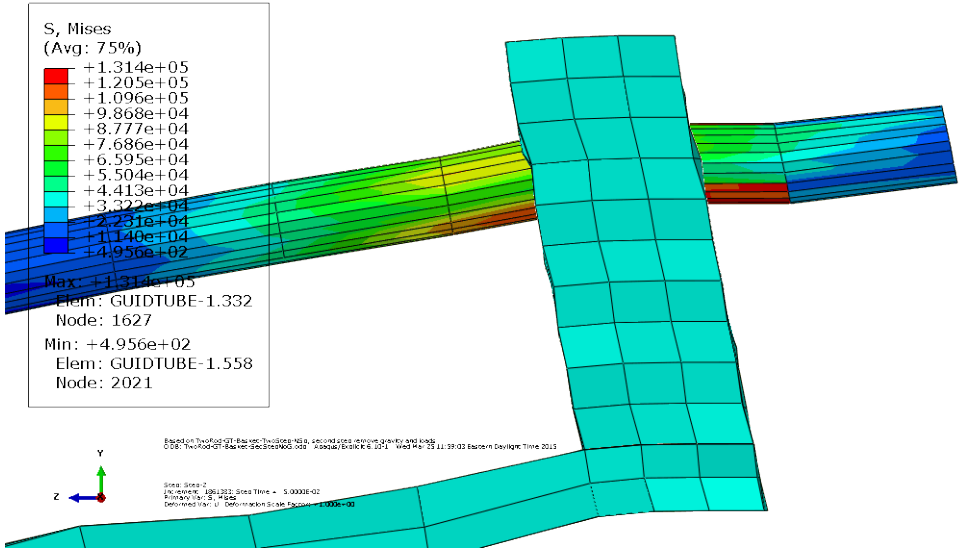
Step-2: Acceleration 0.5g Sine Wave

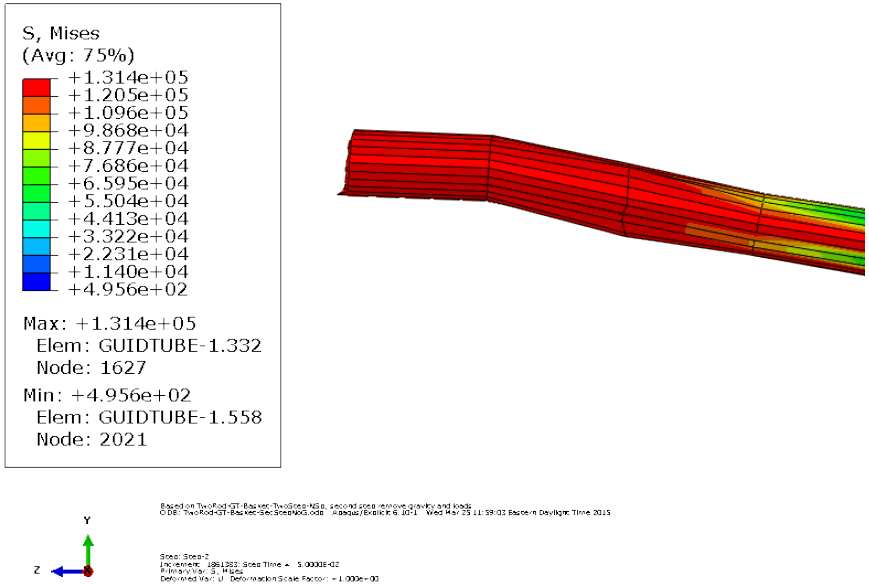


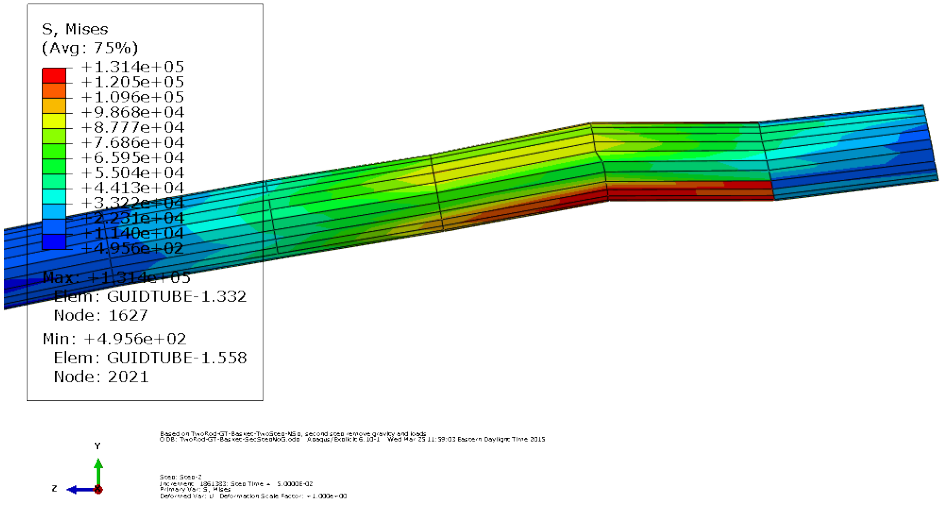
Max stress for the system on the Top spacer (Inconel), yielded

Step-2: Guide Tube Response on 0.5g Acceleration



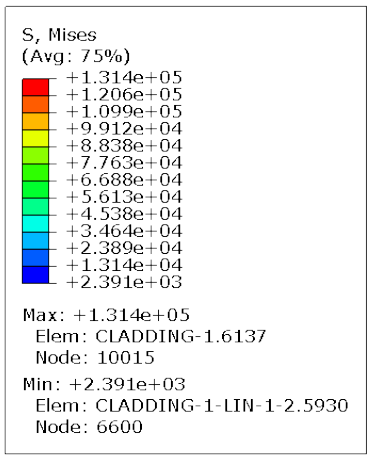


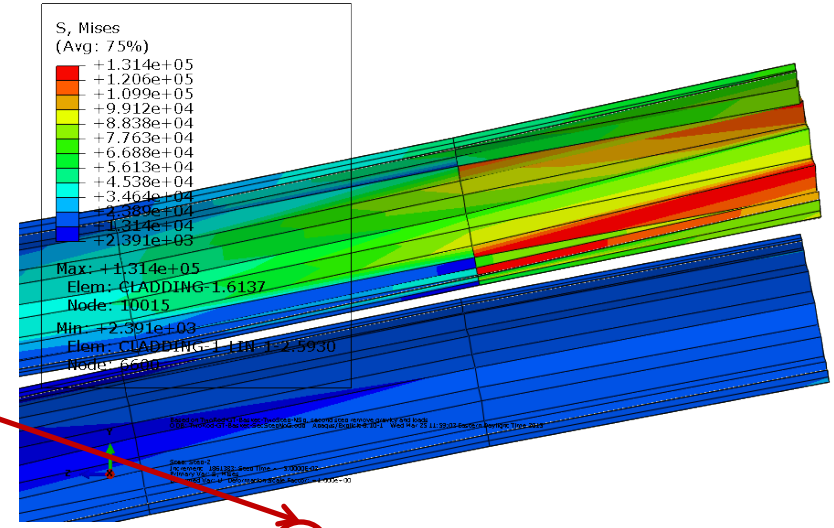




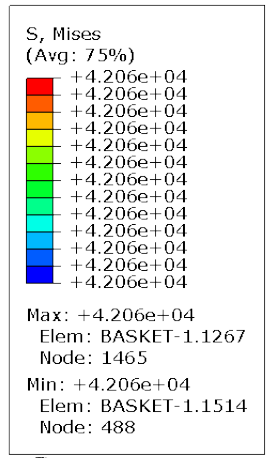
Guide tube yielded at top and bottom nozzle location

Step-2:Clad, Basket and Nozzles Response



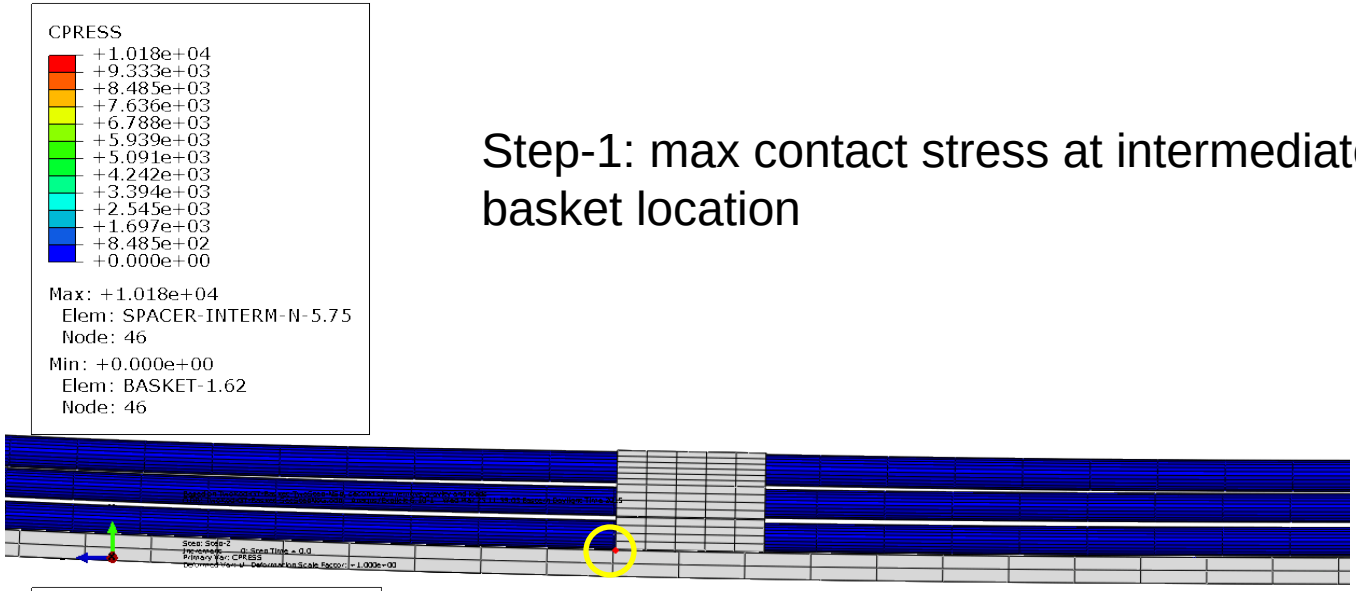


Clad yield at spacer grip

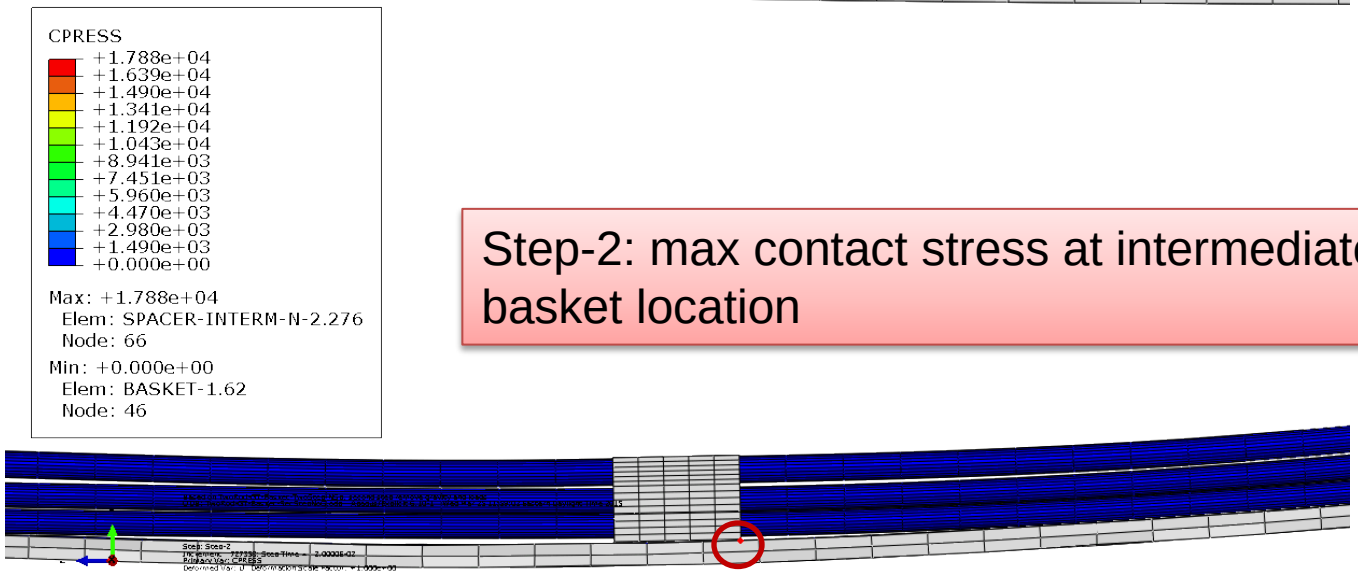


Basket and nozzles yielded

Contact Stress



Step-1: max contact stress at intermediate spacer touching basket location



Step-2: max contact stress at intermediate spacer touching basket location