ATTACHMENT (1)

NUH32P+.0203, REVISION 0, 32P+ TRANSFER CASK IMPACT ONTO THE CONCRETE PAD LS-DYNA ANALYSIS (80 INCH END DROP)

AREVA TRANSNUCLEAR INC.	Form 3.2-1 Calculation Cover Sheet TIP 3.2 (Revision 4)	Calculation No.:	NUH32P+.0203
		Revision No.:	0
		Page: 1 of 24	

DCR NO (if applicable) :	PROJECT NAME: NUH32P+ Dry Fuel Storage Project for CCNPP
PROJECT NO: NUH32P+	CLIENT: Calvert Cliff Nuclear Power Plant (CCNPP)

CALCULATION TITLE:

32P+ Transfer Cask Impact onto the Concrete Pad LS-DYNA Analysis (80 inch End Drop)

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation determines the rigid body acceleration time history of the 32P+ Cask during impact on a concrete pad with subgrade soil. The cask will be analyzed for the end drop with a drop height of 80".

2) Storage Media Description

Secure network initially, then redundant tape backup

If original issue, is licensing review per TIP 3.5 required?

Yes ☐ No ☒ (explain below) Licensing Review No.: ____________

This calculation is prepared to support a Site Specific License Application by CCNPP that will be reviewed and approved by the NRC. Therefore, a 10CFR72.48 licensing review per TIP 3.5 is not applicable.

Software Utilized (subject to test requirements of TIP 3.3):	**Version:**
LS-DYNA	ls971s R4.2 Rev. 50638
Calculation is complete: Abhijit Honrao [signature] Originator Name and Signature:	Date: 3/2/10
Calculation has been checked for consistency, completeness and correctness: Devon Wilson Checker Name and Signature: [signature]	Date: 3/2/10
Calculation is approved for use: Kamran Tavassoli Project Engineer Name and Signature: [signature]	Date: 3/4/10

REVISION SUMMARY

REV.	DESCRIPTION OF CHANGES	AFFECTED PAGES	AFFECTED Computational I/O
0	Initial Issue	All	All

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 PURPOSE

This calculation analyzes the rigid body acceleration time histories for the 32P+ cask in the end drop with a drop height of 80". A dynamic finite element analysis program is used to determine the time histories. Rigid body time histories of the cask body and cask bottom plates/resin are extracted from the results.

2 REFERENCES

2.1. LS-DYNA Keyword User's Manual, Volumes 1 & 2, Version ls971s R4.2, Livermore Software Technology Corporation.

2.2. U.S. Nuclear Regulatory Commision NUREG/CR-6608, "Summary and Evaluation of Low-Velocity Impact Tests of Solid Steel Billet Onto Concrete Pads", February 1998.

2.3. ASME Boiler and Pressure Vessel Code, Section II, "Materials Specifications," Parts A, B, C and D, 1998 edition with all addenda up to and including 1999 Addenda.

2.4. TN Calculation No. 1095-1, Rev. 1, "NUHOMS 32P – Weight Calculation of DSC/TC System".

2.5. TN Calculation 10494-66, Rev. 0, "NUHOMS-32PTH, OS187H Transfer Cask Dynamic Impact Analysis".

2.6. Structural Design of Concrete Storage Pads for Spent Fuel Casks, Electric Power Research Institute, EPRI NP-7551, RP 2813-28, April 1993.

2.7. BNL-NUREG-71196-2003-CP, "Impact Analysis of Spent Fuel Dry Casks Under Accidental Drop Scenarios," Brookhaven National Laboratory, 2003.

3 ASSUMPTIONS

3.1 NUH32P+ DSC design is identical to NUH32P DSC design. NUH32P weight properties are used for NUH32P+ weight.

3.2 Static and dynamic coefficient of friction of 0.25 is assumed between all sliding surfaces.

3.3 Strain rate effects on all material properties are neglected.

3.4 Mass of DSC is evenly distributed as a homogenous solid.

3.5 A uniform temperature of 350°F is used for the end drop analysis.

4 METHODOLOGY

LS-DYNA, a dynamic finite element analysis program, is used to determine the rigid body acceleration time history of the NUH32P+ cask caused by a hypothetical accident end drop condition. Because of the complexity of the analysis, a simplified model of the cask and DSC is necessary. The cask model does not include trunnions and other details; however, the mass of these unmodeled items is accounted for. The DSC structure is modeled as an isotropic elastic material with properties approximately equivalent to that of the structure as a whole. This is the same method used in Reference [2.2].

The model consists of the cask, the simplified DSC structure, a concrete impact pad, and the subgrade soil. Only ½ of the cask, DSC structure, concrete and soil are modeled as the entire arrangement is symmetric about the X-Y plane. The section of concrete modeled is 16'-8" long, 6'-8" wide, and 3' thick. The soil section is 66'-8" long, 18'-9" wide, and 39'-2" deep. The concrete and soil dimensions are based on the dimensions used in Reference [2.2]. All lower faces of the soil are fixed except for the symmetry plane. All elements are modeled with fully integrated S/R solid elements.

The finite element model is developed with ANSYS Rev. 11.0 and transferred to LS-DYNA. Modifications were made to the LS-DYNA input files to add the material definitions, non-reflecting boundaries and initial conditions into LS-DYNA, since these input variables are not available through ANSYS. The end drop is analyzed at 350°F. The 32P+ Cask finite element model is shown in Figures 5-1.

5 COMPUTATIONS

5.1 MATERIAL PROPERTIES

The following tables, Table 5-1 through Table 5-3, list stainless steel or carbon steel material properties available in the model material database. The material properties are based on ASME BPV Code, Section II, 1992 [2.3].

Table 5-1 Material Properties of Stainless Steel SA 240 Type 304

Stainless Steel SA 240 Type 304 (18cr-8ni) -ASME 1992									
Temperature	[°F]	0	70	200	300	400	500	600	700
Sy	[psi]	30000	30000	25000	22500	20700	19400	18200	17700
Su	[psi]	75000	75000	71000	66000	64400	63500	63500	63500
Sm	[psi]	20000	20000	20000	20000	18700	17500	16400	16000
E	[psi]	2.87E+07	2.83E+07	2.76E+07	2.70E+07	2.65E+07	2.58E+07	2.53E+07	2.48E+07

Table 5-2 Material Properties of Stainless Steel SA 182 Type F304N

Stainless Steel SA 182 Type F304N (18cr-8ni-n)-ASME 1992									
Temperature	[°F]	0	70	200	300	400	500	600	700
Sy	[psi]	35000	35000	28700	25000	22500	20900	19800	19100
Su	[psi]	80000	80000	80000	75900	73200	71200	69700	68600
Sm	[psi]	23300	23300	23300	22500	20300	18800	17800	17200
E	[psi]	2.87E+07	2.83E+07	2.76E+07	2.70E+07	2.65E+07	2.58E+07	2.53E+07	2.48E+07

Table 5-3 Material Properties of Carbon Steel SA 516 Type 70

Carbon Steel SA516 Type 70 - ASME 1992									
Temperature	[°F]	0	70	200	300	400	500	600	700
Sy	[psi]	38000	38000	34600	33700	32600	30700	28100	27400
Su	[psi]	70000	70000	70000	70000	70000	70000	70000	70000
Sm	[psi]	23300	23300	23100	22500	21700	20500	18700	18300
E	[psi]	2.98E+07	2.95E+07	2.88E+07	2.83E+07	2.77E+07	2.73E+07	2.67E+07	2.55E+07

5.1.1 CASK MATERIAL

The cask material properties are the same at those used in Section 5.1 except the outer shell density is adjusted to account for unmodeled cask parts. The cask weight is calibrated to the weight computed in Reference [2.4]. All cask materials are modeled as elastic.

Table 5-4: Cask Material Properties

Cask Component	Elastic Modulus (psi)	Density (lb-sec^2/in^4)	Poisson's Ratio
Top Lid	$26.75\text{X}10^6$	$9.7878\text{x}10^{-4}$	0.3
Shell Flanges and Ram Access Ring	$26.75\text{X}10^6$	$7.4017\text{x}10^{-4}$	0.3
Outer Shell	$28.0\text{X}10^6$	$15.133\text{x}10^{-4}$	0.3
Lead	$1.91\text{X}10^6$	$10.637\text{x}10^{-4}$	0.45
Inner Shell	$26.75\text{X}10^6$	$11.102\text{x}10^{-4}$	0.3
Bottom Plates	$26.75\text{X}10^6$	$7.4017\text{X}10^{-4}$	0.3
Resin	$1.6\text{X}10^5$	$1.646\text{X}10^{-4}$	0.2

The modeled weight of the empty cask is 61,099 lbs since it is a half model, therefore the total modeled weight is 122,198 lbs. The total calculated empty cask weight (121,458 lbs) in Reference [2.4]. The percentage difference in calculated weight and the modeled weight is 0.58%

5.1.2 DSC STRUCTURE MATERIAL

The DSC structure material properties are the same as those used in Reference [2.2] except for the density. The density of the DSC structure is adjusted to calibrate the overall weight of the canister, basket, and fuel assembly [2.4]. The DSC structure is modeled as elastic.

$E = 2.8\text{x}10^6$ psi
$v = 0.3$
$\rho = 4.0062\text{x}10^{-4}$ lb sec^2/in^4

Total modeled weight of the DSC structure is 47,390 lbs since it is a half model. Therefore the total modeled weight is 94,780 lbs. Total actual weight of the DSC per Reference [2.4] is 90,976 lbs.

5.1.3 SOIL MATERIAL

The Lawrence Livermore National Labs report [2.2] and Brookhaven National Laboratory report [2.7] indicates that the stiffness of the soil has little impact on the peak accelerations predicted in the cask. Thus, the same soil model as that used in the Livermore report [2.2] is assumed. The soil is modeled as elastic.

E = 6,000 psi
ν = 0.45
$\rho = 2.0368\times10^{-4}$ lb sec^2/in^4

5.1.4 CONCRETE MATERIAL

The concrete is modeled using Material Law 16 in LS-DYNA [Ref. 2.1], which was developed specifically for granular type materials. All properties are the same as those used in Reference [2.2] except when noted. A summary of the input used in the analysis is as follows.

Yield stress versus pressure:

$$\sigma_{\max} = a_0 + \frac{P}{a_1 + a_2 P}$$

$$\sigma_{failed} = a_{0f} + \frac{P}{a_{1f} + a_2 P}$$

$\rho = 2.09675\times10^{-4}$ lb. sec.^{2} / in.^{4}
ν = 0.22
a_0 = 1606 psi [2.5]
a_1 = 0.418
$a_2 = 8.35\times10^{-5}$ psi^{-1}
b_1 = 0
a_{0f} = 0.0 psi.
a_{1f} = 0.385

The yield stress versus pressure curve is defined by

$$\sigma_{yield} = \sigma_{failed} + \eta\left(\sigma_{\max} - \sigma_{failed}\right)$$

The scale factor η is shown in Table 5-2. The values listed in Table 5-2 are taken directly from Reference [2.2] and not scaled.

Table 5-5: Effective Plastic Strain vs. Scale Factor for Concrete Material

Effective Plastic Strain	Scale Factor, η
0	0
0.00094	0.289
0.00296	0.465
0.00837	0.629
0.01317	0.774
0.0234	0.893
0.04034	1.0
1.0	1.0

The maximum principal stress tensile failure cutoff is set at 870 psi [2.2]. Strain rate effects are neglected in the analysis.

The pressure-volume behavior of the concrete is modeled with the following tabulated pressure versus volumetric strain relationship shown in Table 5-3 using the equation of state feature in LS-DYNA [Ref. 2.2].

Table 5-6: Tabulated pressures vs. volumetric strain for concrete material

Volumetric Strain, ε	Pressure (psi) [2.2]
0	0
-0.006	4,600
-0.0075	5,400
-0.01	6,200
-0.012	6,600
-0.02	7,800
-0.038	10,000
-0.06	12,600
-0.0755	15,000
-0.097	18,700

An unloading bulk modulus of 700,000 psi is assumed to be constant at any volumetric strain, as was assumed in Reference [2.2].

One percent deformation is assumed in the concrete pad to account for the pad reinforcement. The one percent reinforcement is also used in the analyses presented in EPRI [2.6].

The material properties used for the reinforcing bar are as follows.

$E = 30\times10^{6}$ psi
$v = 0.3$
$S_y = 30{,}000$ psi
Tangent Modulus, $E_T = 30\times10^{4}$ psi

5.2 BOUNDARY CONDITIONS

Only ½ of the cask is modeled with symmetry boundary conditions used to simulate the full structure. Non-reflecting boundaries are applied to the bottom and sides of the modeled soil not aligned with the plane of symmetry (bottom, left side, right side, and back) to prevent artificial stress waves from reflecting back into the model. Both dilatation and shear waves are damped as described in the LS-DYNA *BOUNDARY command [Ref. 2.1].

An automatic surface to surface (contact_automatic_single_surface) contact definition is applied between all parts except the soil. The contact definition has a 0.5 penalty stiffness scale factor to prevent excessive contact stiffness leading to unrealistic part accelerations. A surface to surface (contact_surface_to_surface) contact definition is applied between the concrete and the soil. Both contact definitions have soft contact option 2 as this is necessary for contact between materials that have very different material stiffness. A conservatively low coefficient of friction (static and kinetic) of 0.25 is applied between all contact surfaces. It is conservative to use a low value for the coefficient of friction because less energy is absorbed due to friction resulting in greater impact acceleration forces.

5.3 INITIAL CONDITIONS AND LOADING

The analysis begins with a 1.5" gap between the cask and concrete to allow for at least 5 ms of zero acceleration other than gravity (this allows for appropriate filtering of the data). An initial velocity is applied to all parts of the cask model. The initial velocity is computed by equating potential and kinetic energies. Due to the initial 1.5" gap and gravitational acceleration, initial velocities are computed 1.5" shorter than the total 80" drop height.

V = potential energy = mgh
T = kinetic energy = $\frac{1}{2}mv^2$

For a 80" Drop:
$mgh = \frac{1}{2}mv^2$
$\Rightarrow v = \sqrt{2gh} = \sqrt{2(386.4)(80-1.5)} =$ 246.3 in./sec.

A gravitational acceleration of 386.4 in/sec^2 is applied to the cask and DSC model.

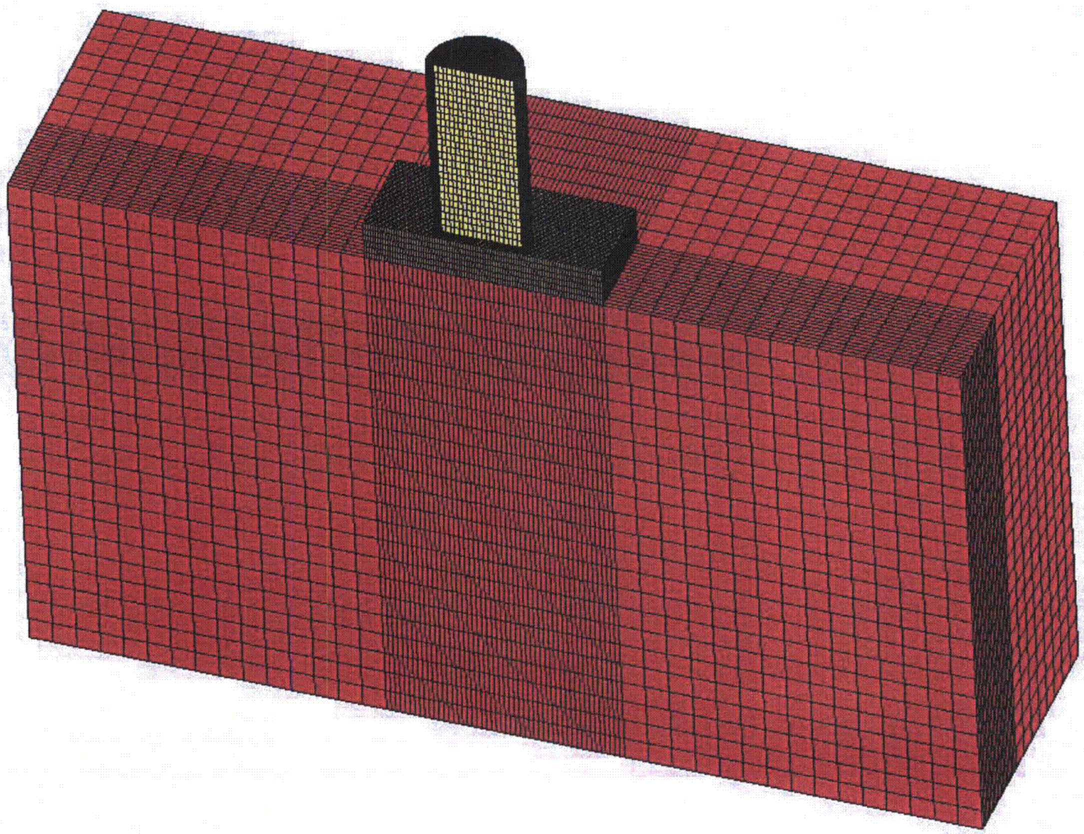

Figure 5-1: Overview of 32P+ Cask Finite Element Model

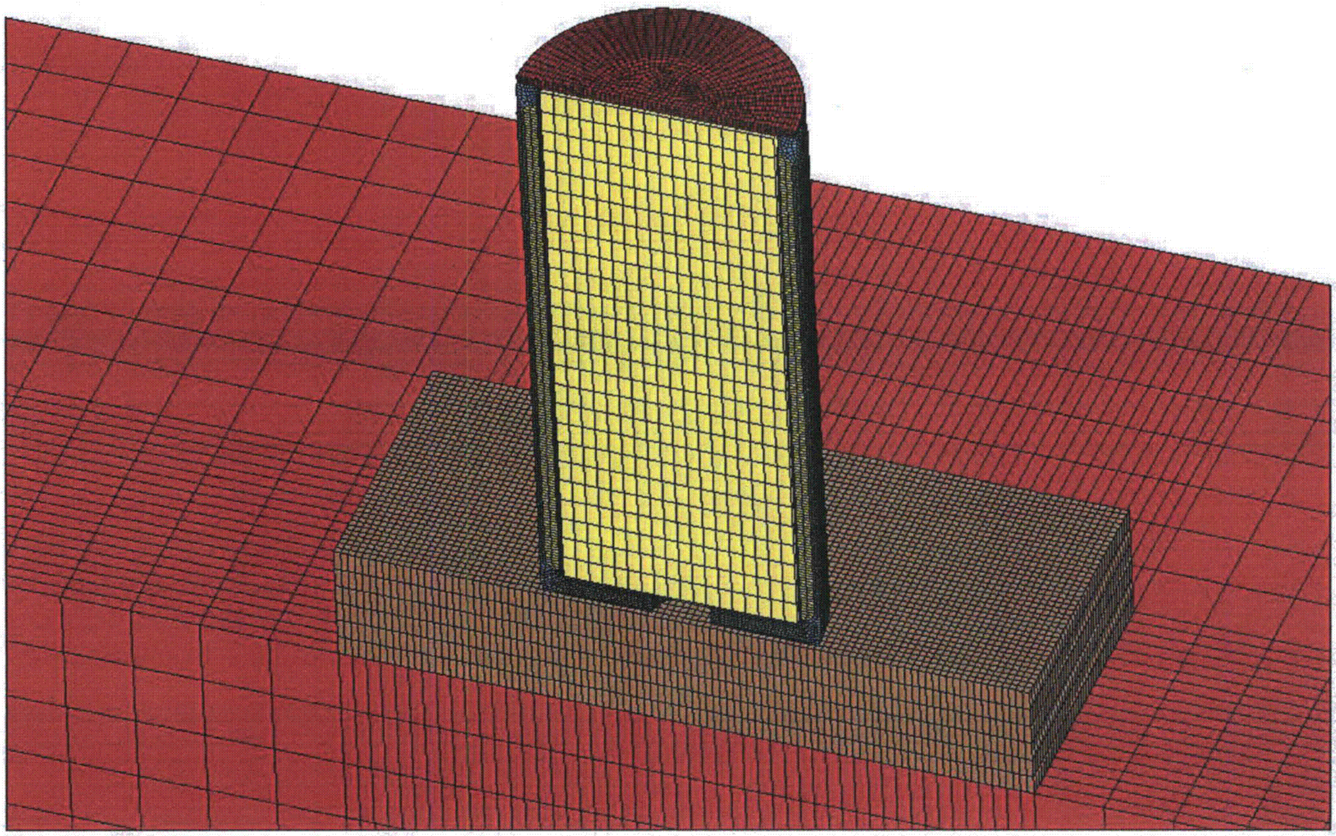

Figure 5-2: 32P+ Cask Finite Element Model

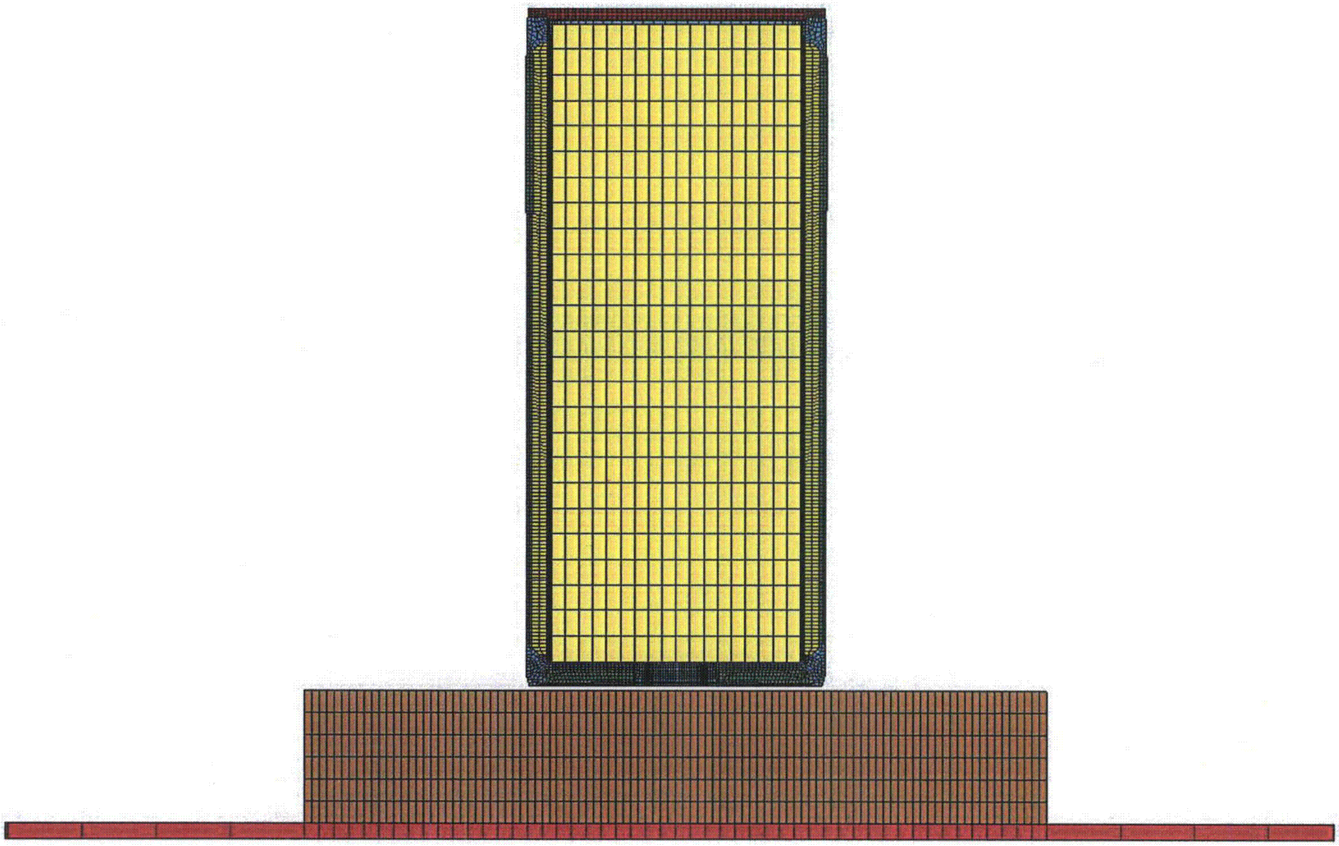

Figure 5-3: 32P+ Finite Element Model Symmetry Plane End Drop Condition

6 DATA REDUCTION

The analyses are run for a duration of 0.08 seconds. The time step was set at 1.17×10^{-6} which resulted in a negligible weight increase of about 9 lbs.

6.1 CASK NODAL ACCELERATION SECTIONS EVALUATED

The resulting rigid body acceleration time histories are computed by LS-DYNA. The rigid body accelerations are computed for the bottom plates + resin and the circumferential shell. The parts can be seen in Figure 6-1.

6.2 RAW DATA FILTERING

LS-DYNA reports the nodal accelerations at 100 μsec intervals. Therefore, by the Nyquist theorem, the frequency content of the nodal acceleration data, refined by LS-DYNA, ranges from zero Hz, up to the following maximum frequency, f_{max}.

$$f_{max} = \frac{1}{2}\frac{1}{100 \times 10^{-6}\ \text{sec}} = 5\ \text{kHz}$$

The natural frequencies of the 32P+ cask model, which can be excited by an impact event, are much lower than this. These natural modes of the cask involve small displacements (and therefore low stresses) at frequencies higher than that of the rigid body motion of the cask. These high frequency accelerations mask the true rigid body motion of the cask, because both the low frequency rigid body acceleration and the high frequency natural vibration accelerations superimpose. The net acceleration is contained in the raw data computed by LS-DYNA. Therefore, filtering is necessary to remove these high frequency accelerations.

The rigid body acceleration for each part is filtered using an 8^{th} order low pass Butterworth filter forwards and backwards with a cutoff frequency of 180Hz. This frequency is based on Fourier spectral analyses shown in Figures 7-1 through 7-4. The figures show that the 180Hz cutoff will still conservatively include some of the cask's natural modes. The impact durations are all over 0.03 seconds, so the minimum frequency to capture rigid body motion would be $2 \times \frac{1}{0.03} = 66.67$ Hz.

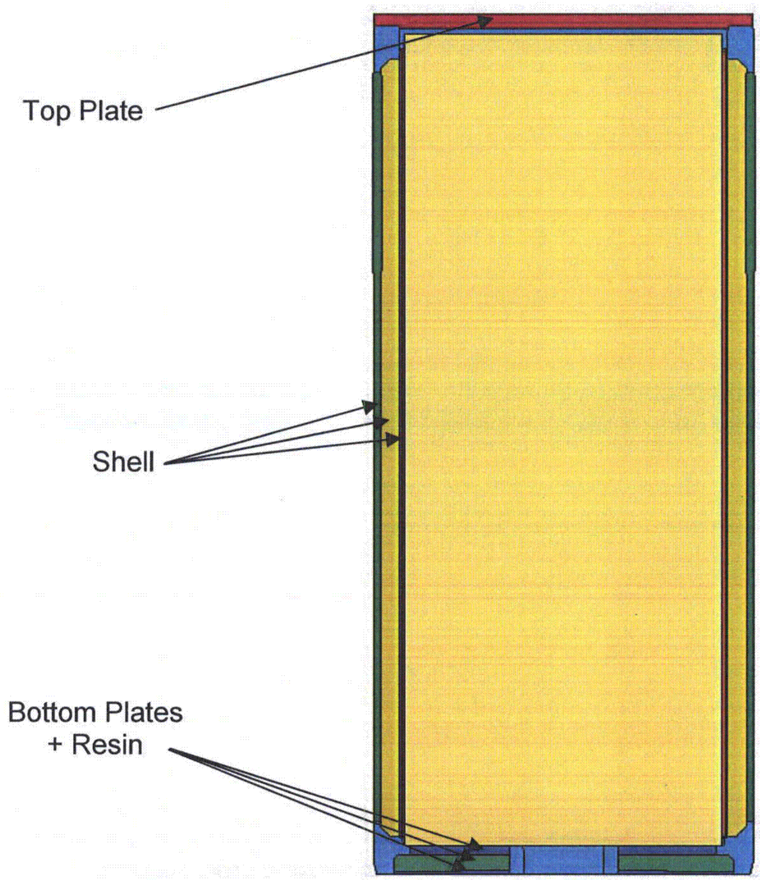

Figure 6-1: Parts Analyzed for Acceleration Time History

7 RESULTS

Table 7-1 lists the peak filtered accelerations and corresponding time history plot for different parts of the 32P+ cask. All results are filtered with an 8th order low pass butterworth filter with a 180Hz cutoff frequency. Figure 8-1 through 8-2 shows the filtered acceleration time histories. Figure 8-3 through 8-4 shows the Fourier spectral analyses of the acceleration time histories before and after filtering.

Table 7-1: Filtered Results Summary

Drop Scenario	Part	Peak Acceleration (g)	Time History Figure Number
End Drop	Circumferential Shell	43.5	7-1
	Bottom Plates + Resin	48.8	7-2

8 LISTING OF ANSYS COMPUTER FILES

Below is a listing of all files used in LS-DYNA, all Analysis performed on Computer HEA0105A, Dual Intel Xeon 3.2GHz, Windows XP SP2, LS-DYNA ver. ls971s R4.2 Revision 50638.

Run Description	File Names	Date Stamp
Ansys Model	32PHB.db	7/9/09 9:15 AM
8th Order Butterworth Filter	low_pass_butter.m	10/6/09 5:08PM
80" End Drop Input Files	32PHB_End_Drop.k	7/10/09 1:37 PM
	Constraints.k	7/9/09 9:22 PM
	Elements.k	9/16/09 1:13 PM
	Nodes.k	9/16/09 1:20 PM
	NodeSets.k	7/9/09 2:27 PM
	SegSets.k	7/9/09 10:19 AM
80" End Drop Output Files	d3plot	9/19/09 9:58 PM
	d3plot01-d3plot162	9/19/09 10:01 PM – 9/20/09 6:41 AM
	messag	9/20/09 6:41 AM
	End_Shell.csv	10/7/09 10:26 AM
	End_Bottom.csv	10/7/09 10:24 AM

Note: Date & time (EST) for main runs are from the listing at the end of the output file. For other files (e.g., .db files), dates & times are reported by the OS on the report issue date, these values may be changed by Windows depending on time of the year (e.g., daylight savings time) and time zones.

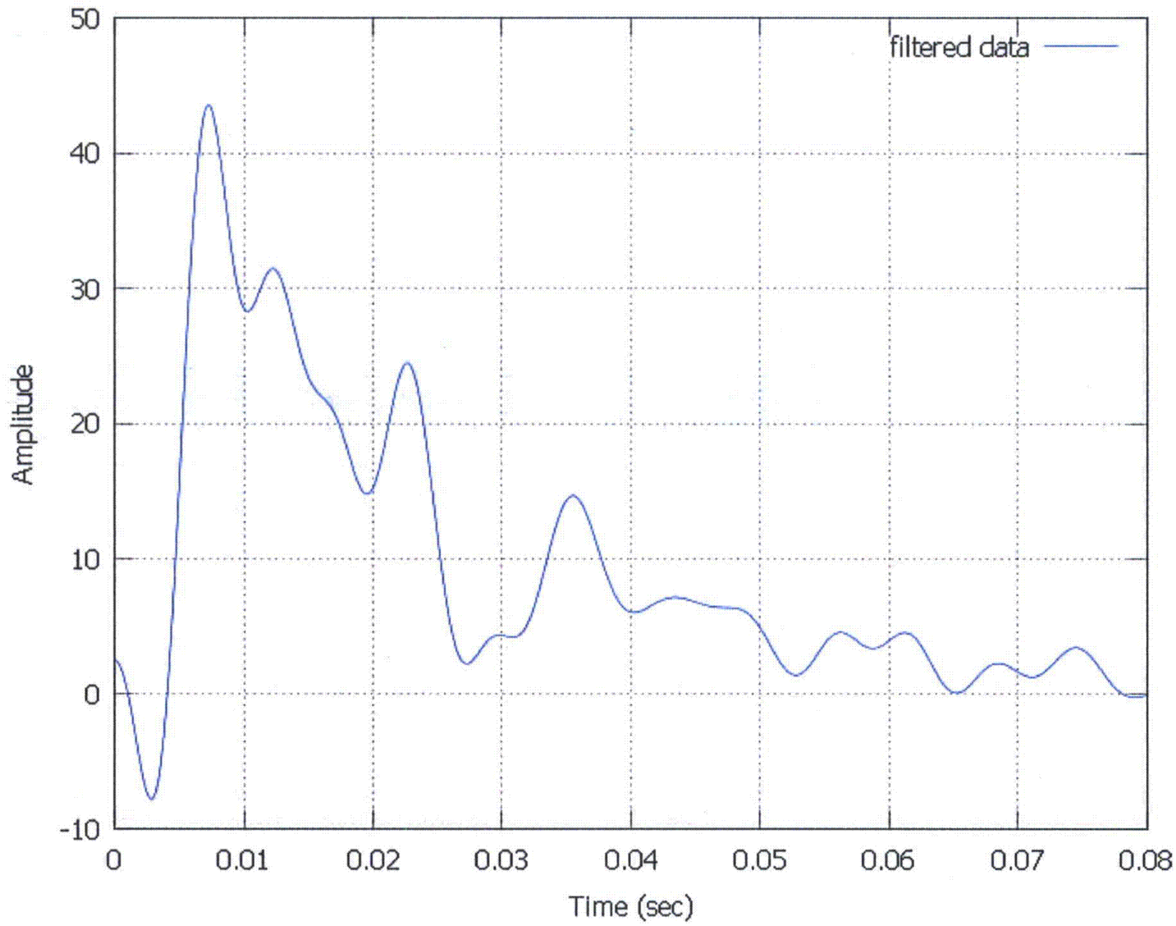

Figure 8-1: End Drop Cask Shell Acceleration (g) Time History 180Hz Filter

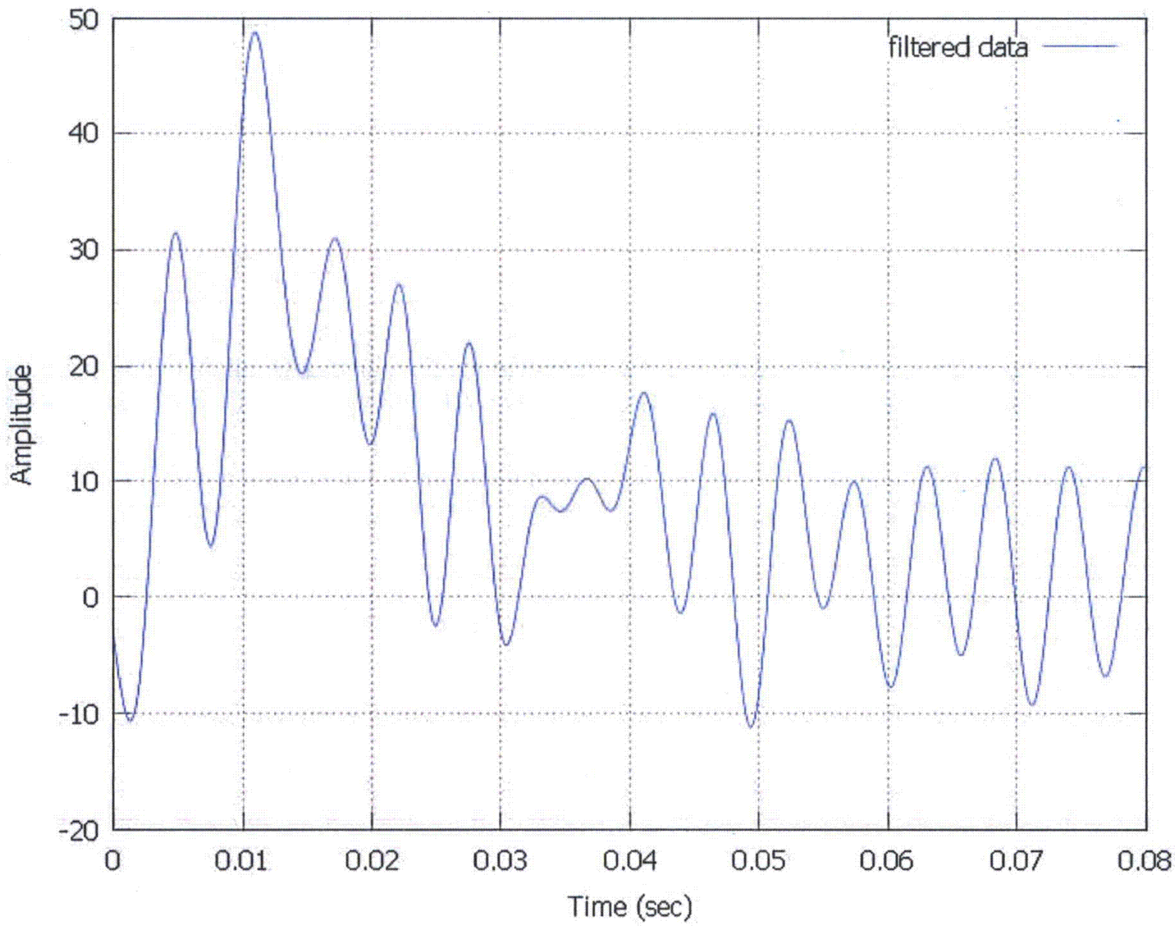

Figure 8-2: End Drop Cask Bottom Plates and Resin Acceleration (g) Time History 180Hz Filter

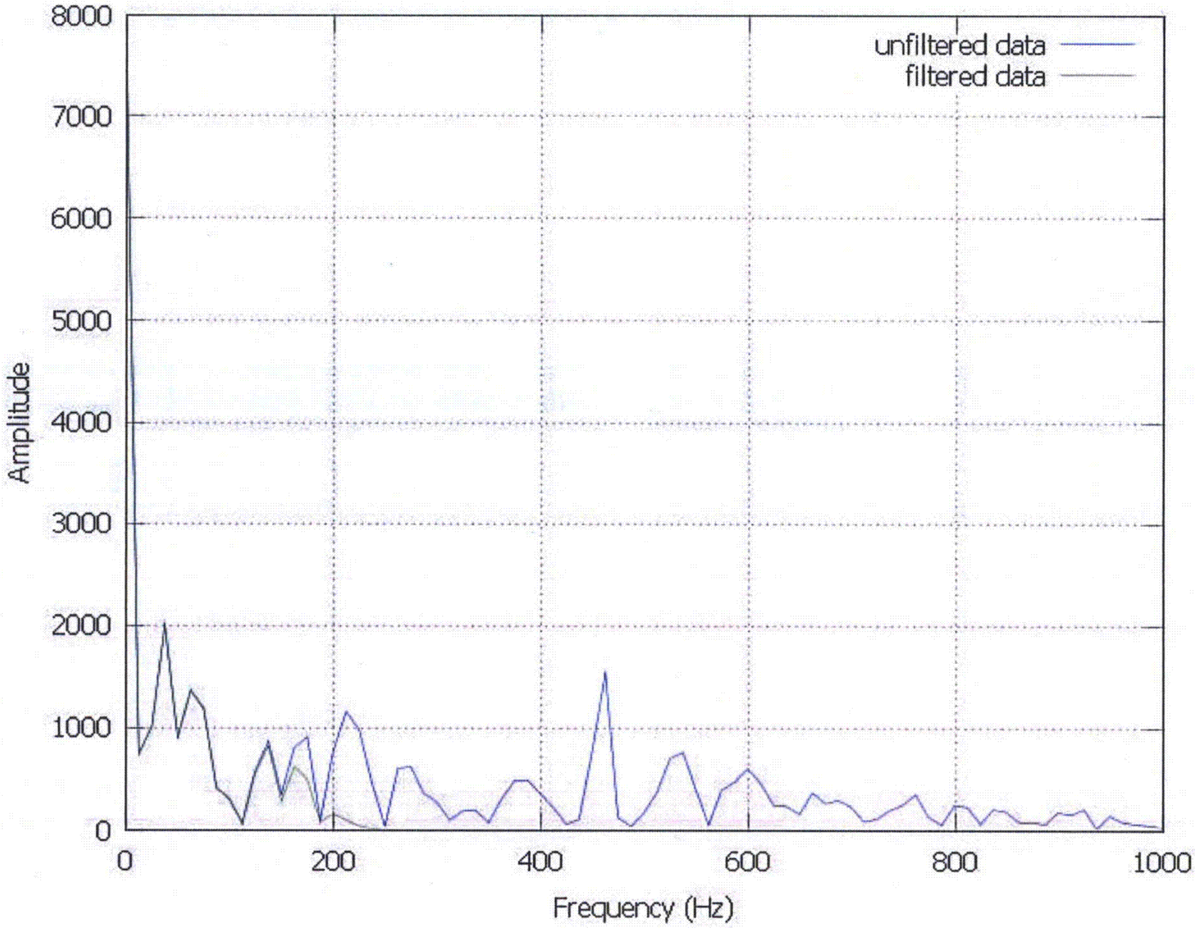

Figure 8-3: End Drop Cask Shell Fourier Spectral Analysis Before and After Filter

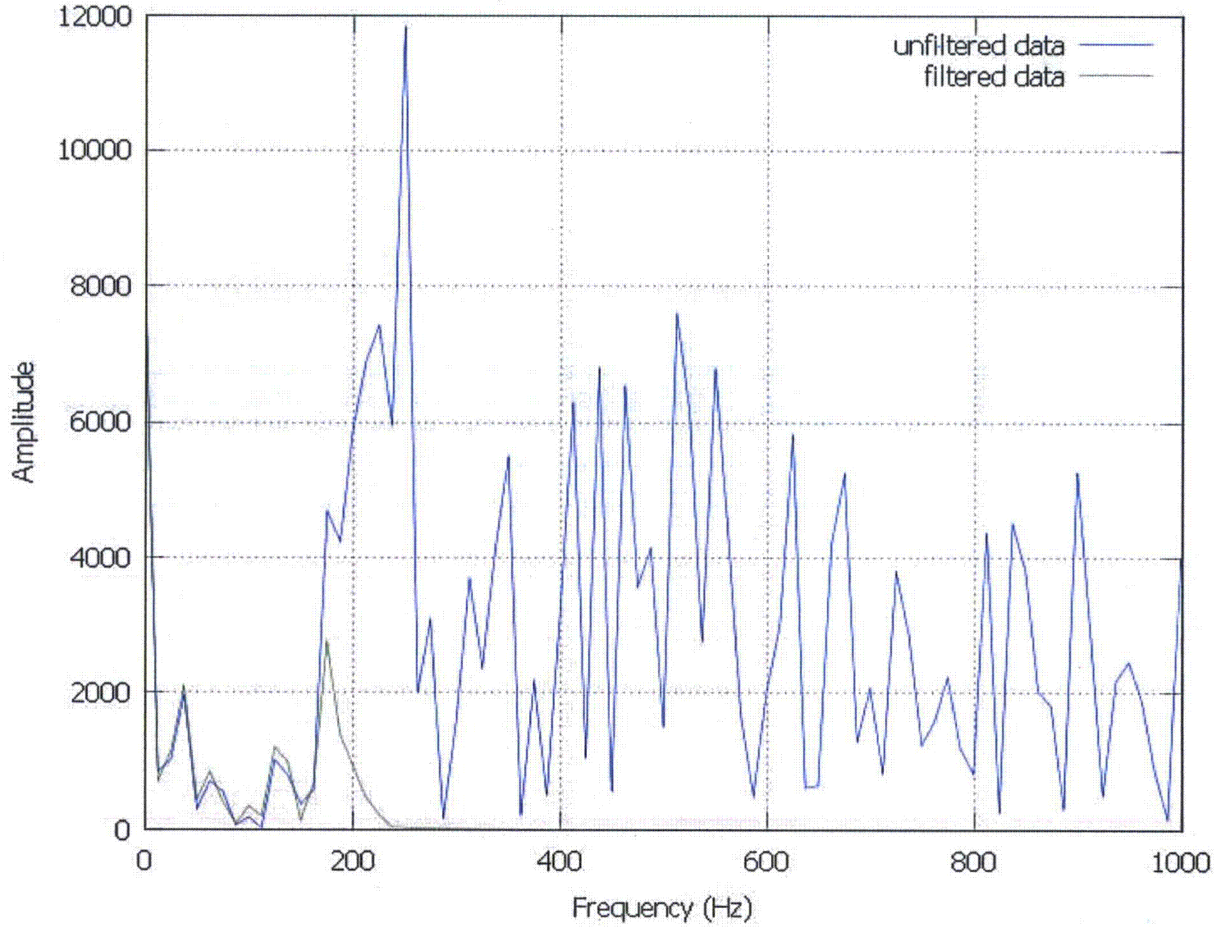

Figure 8-4: End Drop Cask Bottom Plates + Resin Fourier Spectral Analysis Before and After Filter

9 APPENDIX A – BUTTERWORTH FILTER VERIFICATION

The butterworth filter used in this analysis is based on the program Octave, an open source code program used for solving linear and nonlinear problems. An 8th order low pass butterworth filter is run forward and backward as described in NUREG/CR-6608. To verify the filter functions properly, the filtered and unfiltered fourier spectrum plot of the NUREG/CR-6608 is compared to the fourier spectrum plots of this analysis. Figure A1 shows a NUREG/CR-6608 data set which was filtered at 450Hz. The plots of this analysis show good correlation to Figure A1. In addition, Figure A2 shows the frequency response of the 8th order butterworth filter at 450Hz run forward and backward in this analysis. It can be seen that the frequency response coincides with the attenuation pattern seen in the NUREG/CR-6608 data set.

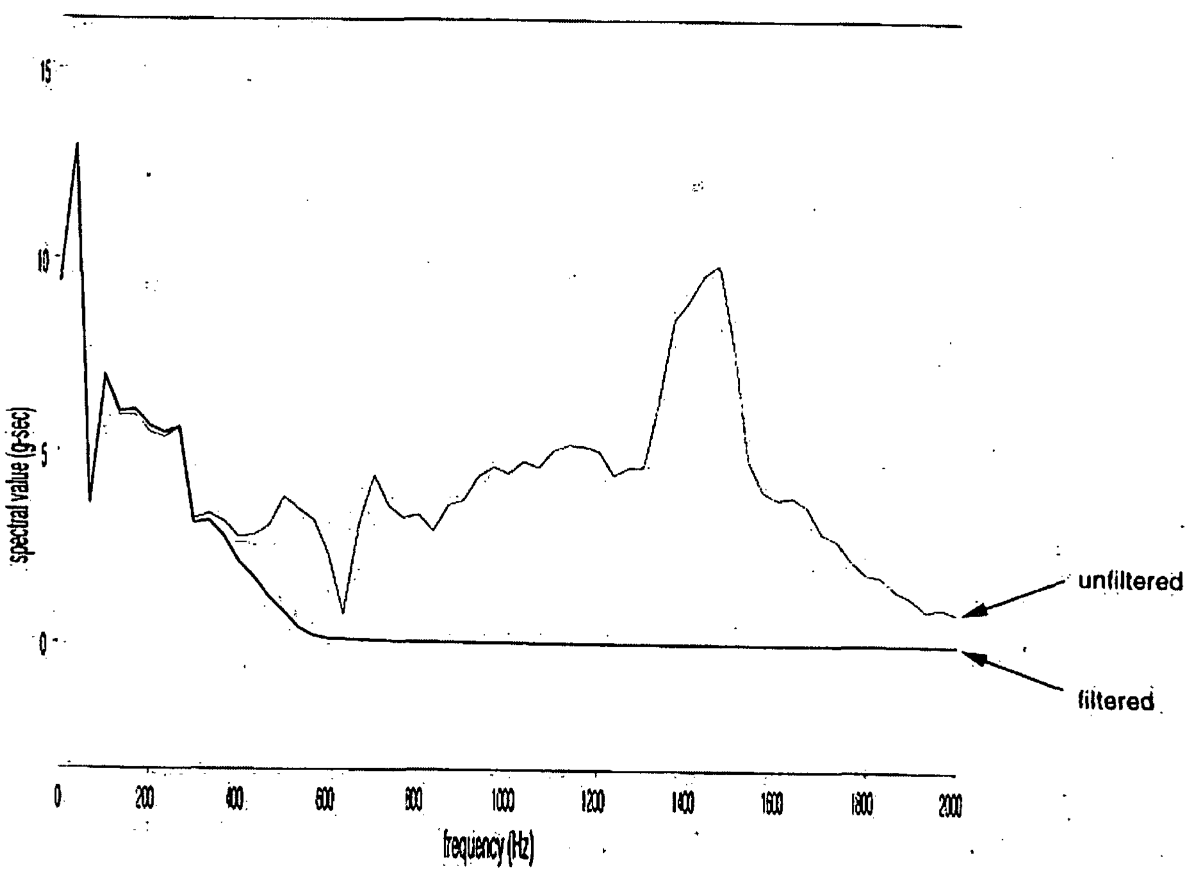

Figure A1 - Impulse Response of 8th Order Butterworth Filter Forward and Backward

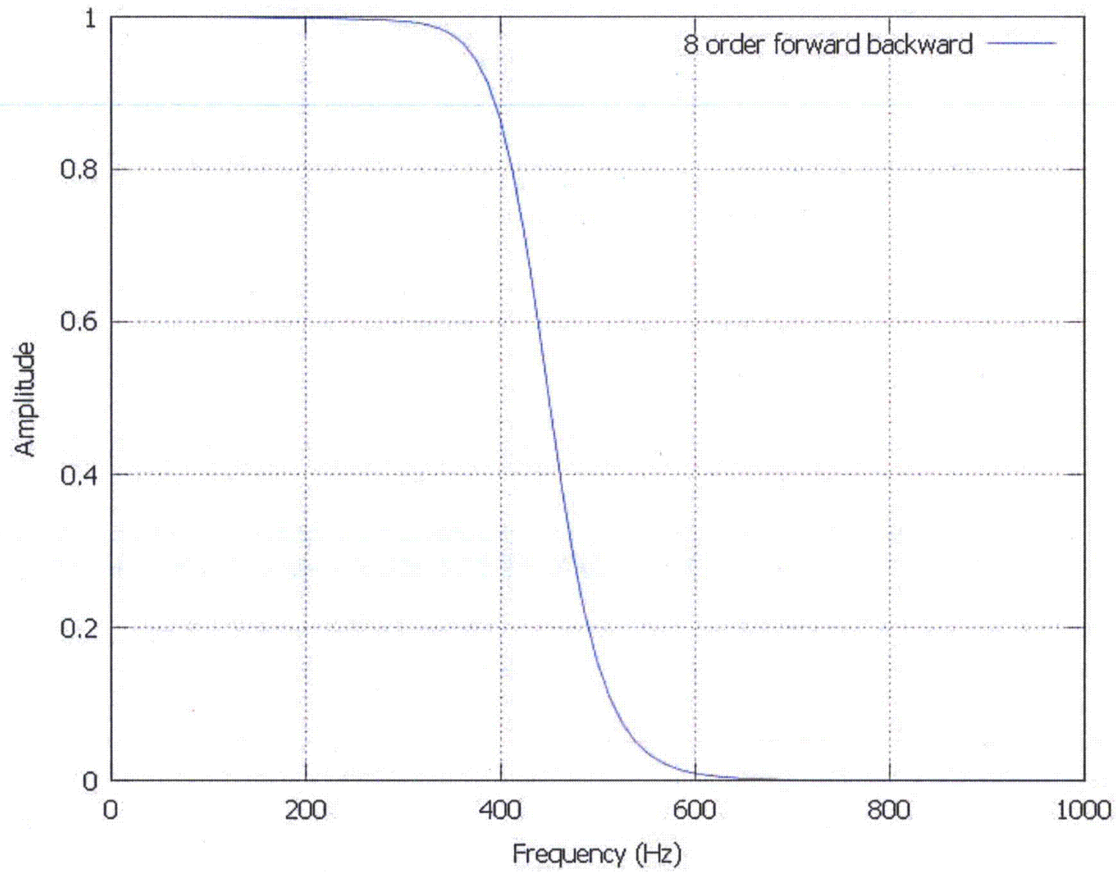

Figure A2 –Frequency Response of 8th Order Butterworth Filter Forward and Backward

ENCLOSURE (1)

The File Listing for Three DVDs Containing LS-DYNA Files for NUH32P+.0203

These DVDs have been provided to J. M. Goshen (NRC, NMSS)

Disk 1		Disk 2		Disk 3	
d3plot	d3plot31	d3plot61	d3plot91	d3plot121	d3plot151
d3plot1	d3plot32	d3plot62	d3plot92	d3plot122	d3plot152
d3plot2	d3plot33	d3plot63	d3plot93	d3plot123	d3plot153
d3plot3	d3plot34	d3plot64	d3plot94	d3plot124	d3plot154
d3plot4	d3plot35	d3plot65	d3plot95	d3plot125	d3plot155
d3plot5	d3plot36	d3plot66	d3plot96	d3plot126	d3plot156
d3plot6	d3plot37	d3plot67	d3plot97	d3plot127	d3plot157
d3plot7	d3plot38	d3plot68	d3plot98	d3plot128	d3plot158
d3plot8	d3plot39	d3plot69	d3plot99	d3plot129	d3plot159
d3plot9	d3plot40	d3plot70	d3plot100	d3plot130	d3plot160
d3plot10	d3plot41	d3plot71	d3plot101	d3plot131	d3plot161
d3plot11	d3plot42	d3plot72	d3plot102	d3plot132	d3plot162
d3plot12	d3plot43	d3plot73	d3plot103	d3plot133	32PHB_End_Drop.k
d3plot13	d3plot44	d3plot74	d3plot104	d3plot134	Constraints.k
d3plot14	d3plot45	d3plot75	d3plot105	d3plot135	Elements.k
d3plot15	d3plot46	d3plot76	d3plot106	d3plot136	Messag
d3plot16	d3plot47	d3plot77	d3plot107	d3plot137	Nodes.k
d3plot17	d3plot48	d3plot78	d3plot108	d3plot138	NodeSets.k
d3plot18	d3plot49	d3plot79	d3plot109	d3plot139	SegSets.k
d3plot19	d3plot50	d3plot80	d3plot110	d3plot140	
d3plot20	d3plot51	d3plot81	d3plot111	d3plot141	
d3plot21	d3plot52	d3plot82	d3plot112	d3plot142	
d3plot22	d3plot53	d3plot83	d3plot113	d3plot143	
d3plot23	d3plot54	d3plot84	d3plot114	d3plot144	
d3plot24	d3plot55	d3plot85	d3plot115	d3plot145	
d3plot25	d3plot56	d3plot86	d3plot116	d3plot146	
d3plot26	d3plot57	d3plot87	d3plot117	d3plot147	
d3plot27	d3plot58	d3plot88	d3plot118	d3plot148	
d3plot28	d3plot59	d3plot89	d3plot119	d3plot149	
d3plot29	d3plot60	d3plot90	d3plot120	d3plot150	
d3plot30					

ATTACHMENT (2)

NUH32P+.0204, REVISION 0, FUEL END DROP ANALYSIS FOR NUH32P+ USING LS-DYNA, NON-PROPRIETARY VERSION

Calvert Cliffs Nuclear Power Plant, LLC
March 31, 2010

Non-PROPRIETARY Version

AREVA
TRANSNUCLEAR INC.

Form 3.2-1
Calculation Cover Sheet
TIP 3.2 (Revision 4)

Calculation No.:	NUH32P+.0204
Revision No.:	0
Page: 1 of 24	

DCR NO (If applicable): N/A

PROJECT NAME: NUH32P+ Dry Fuel Storage Project for CCNPP

PROJECT NO: NUH32P+

CLIENT: CENG - Calvert Cliff Nuclear Power Plant (CCNPP)

CALCULATION TITLE:

Fuel End Drop Analysis for NUH32P+ Using LS-DYNA

SUMMARY DESCRIPTION:

1) Calculation Summary

The purpose of this calculation is to evaluate the structural adequacy of NUH32P+ 14x14 fuel assembly Zircaloy-4 clad exposed to 80 inch end drop event conditions.

2) Storage Media Description

Secure network server initially, then redundant tape backup.

If original issue, is licensing review per TIP 3.5 required?

Yes ☐ No ☒ (explain below) Licensing Review No.:

This calculation is prepared to support a Site Specific License Application by CCNPP that will be reviewed and approved by the NRC. Therefore, a 10CFR72.48 licensing review per TIP 3.5 is not applicable.

Software Utilized (subject to test requirements of TIP 3.3):	Version:
LS-DYNA	ls971s R2 7600.1224

Calculation is complete:

Huan Li

Originator Name and Signature:

Date: 3/5/2010

Calculation has been checked for consistency, completeness and correctness:

Raheel Haroon

Checker Name and Signature:

Date: 3/5/2010

Calculation is approved for use:

Kamran Tavassoli

Project Engineer Name and Signature:

Date: 3/5/10

REVISIONS

REV.	DESCRIPTION OF CHANGES	AFFECTED PAGES	AFFECTED Computational I/O
0	Initial Issue	All	All

Table of Contents

List of Tables

List of Figures

1.0 Purpose

The purpose of this calculation is to evaluate the structural adequacy of 32P+ 14x14 fuel assembly Zircaloy-4 clad fuel rod exposed to 80 inch end drop event conditions with an initial gap of 0.04" between the pin bottom and the cask using LS-DYNA model [2.4] developed according to References [2.1, 2.5].

2.0 References

2.1. Harold E. Adkins, Jr., Brain J. Koeppel and David T. Tang, "Spent Nuclear Fuel Structural Response when Subject to An End Impact Accident". PVP-Vol. 483, Transportation Storage and Disposal of Radioactive Materials, July 25-29, 2004, San Diego, CA, USA.

2.2. Not used.

2.3. TN Calculation, NUH32P-1095-1, Rev. 0, "NUHOMS® 32P Weight Calculation of DSC/TC System".

2.4. TN Calculation, TN40HT-0217, Rev. 0, "TN40HT Fuel End Drop Analysis Using LS-DYNA".

2.5. NUREG-1864, "A Pilot Probabilistic Risk Assessment Of a Dry Cask Storage System At a Nuclear Power Plant". Date published in March 2007.

2.6. TN Calculation, NUH32P+-0203, Rev. 0, "32P+ Transfer Cask Impact onto the Concrete Pad LS-DYNA Analysis (80 inch End Drop)".

2.7. DOE/RW-0184, Vol 3 of 6, "Characteristics of Spent Fuel, High Level Waste and other Radioactive Wastes which require Long Term Isolation – Physical Descriptions of LWR Fuel Assemblies," Appendix 2A, U.S. DOE, December, 1987.

2.8. Not used.

2.9. TN Calculation No. 972-179, Rev. 0, "TN-68 High Burnup Cladding Mechanical Properties".

2.10. CCNPP Calculation, DCALC No. CA06758, "Fuel Performance Data for Calvert Cliffs Dry Storage (ISFSI) Analysis for Batches C1N Through C1T and C2M Through C2S", October 19th, 2006.

2.11. Eric R. Siegmann, J. Kevin McCoy, Robert Howard, "Cladding Evaluation in the Yucca Mountain Repository Performance Assessment," Material Research Society Symp. Proc. Vol. 608, 2000.

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

6.0 Analysis

6.1 Model Geometry and Details

Figure 2 illustrates the finite element model, which is composed of a single fuel rod, a lumped cask mass, springs representing the spacer grids, contact surfaces representing the basket compartment wall, and a spring representing the target stiffness.

Several views of the actual finite element mesh are shown in Figure 3. In this figure, the views shown are: (a) the entire model, (b) top of rod with basket compartment walls and spacer grid spring, (c) top of rod with fuel pellet springs, and (d) bottom of rod with nodes representing the cask and target (concrete).

6.2 Fuel cladding

The fuel cladding geometry and other physical properties are presented in Table 1 and Figure 1.

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

7.0 Results

The analysis results show that the maximum principal strain of fuel rod is 0.89 %, which is less than the yield strain of 0.92%. The maximum principal strain time-history is shown in Figure 9; and correspondingly the maximum principal strain profile is shown in Figure 10.

In addition, the fuel rod and cask velocity and deceleration time histories are shown in Figure 11 and Figure 12, respectively.

8.0 Conclusions

From the above results, the maximum principal strain for the fuel cladding is 0.89%, which is less than the elastic strain of 0.92%. Hence, based on all of the conservatisms in the current analysis [redacted] it can be concluded that there is no plastic deformation in the fuel cladding; and the fuel cladding maintains its structural integrity during the 80 inch end drop event.

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390

Proprietary Information Withheld Pursuant to 10 CFR 2.390