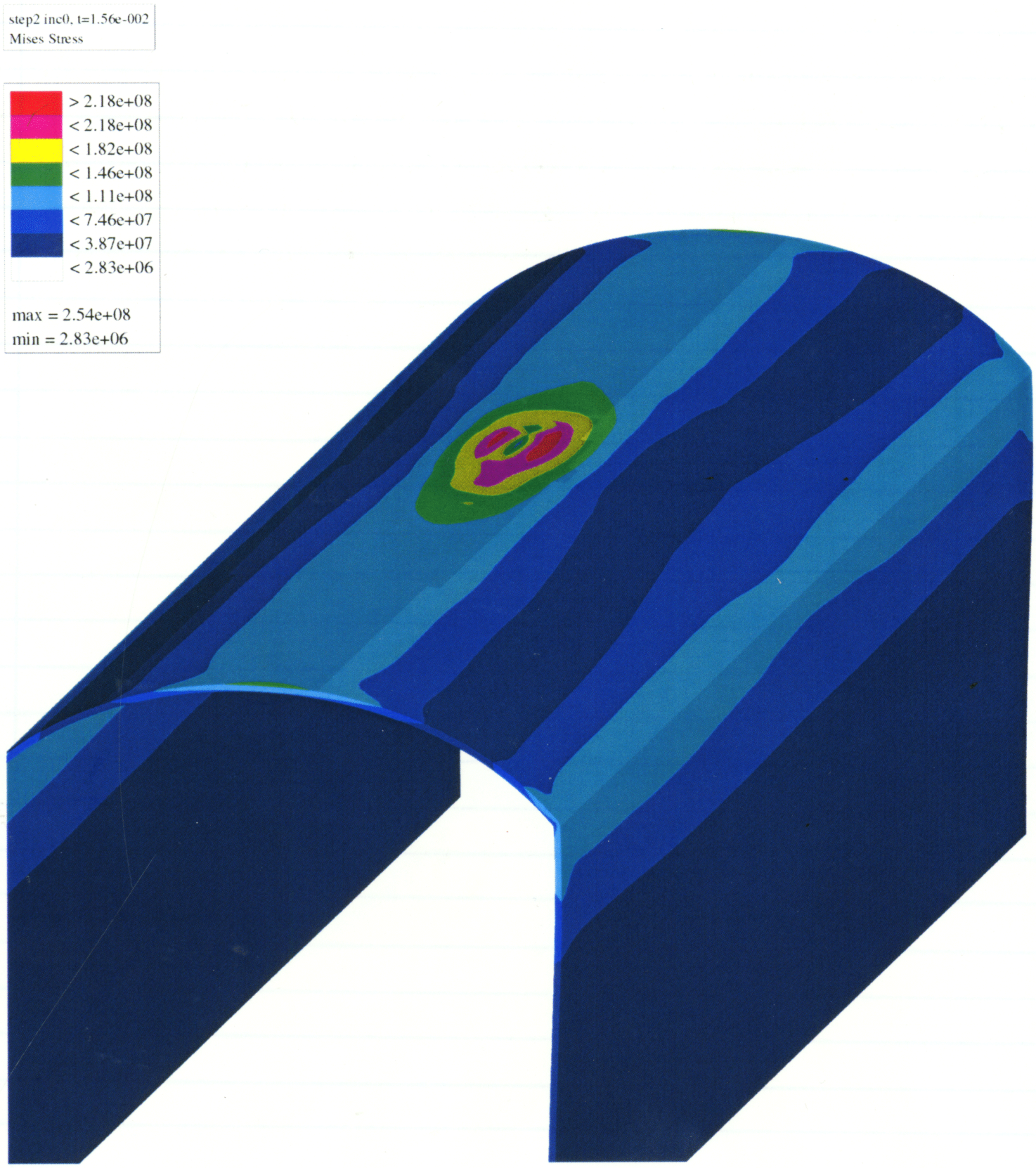


Von Mises stress (N/m^2) contour plot for the 2-tonne rock block, coarse mesh, and 1 m/s ground motion just before premature termination of the simulation.

Doug Stute 4/28/2000

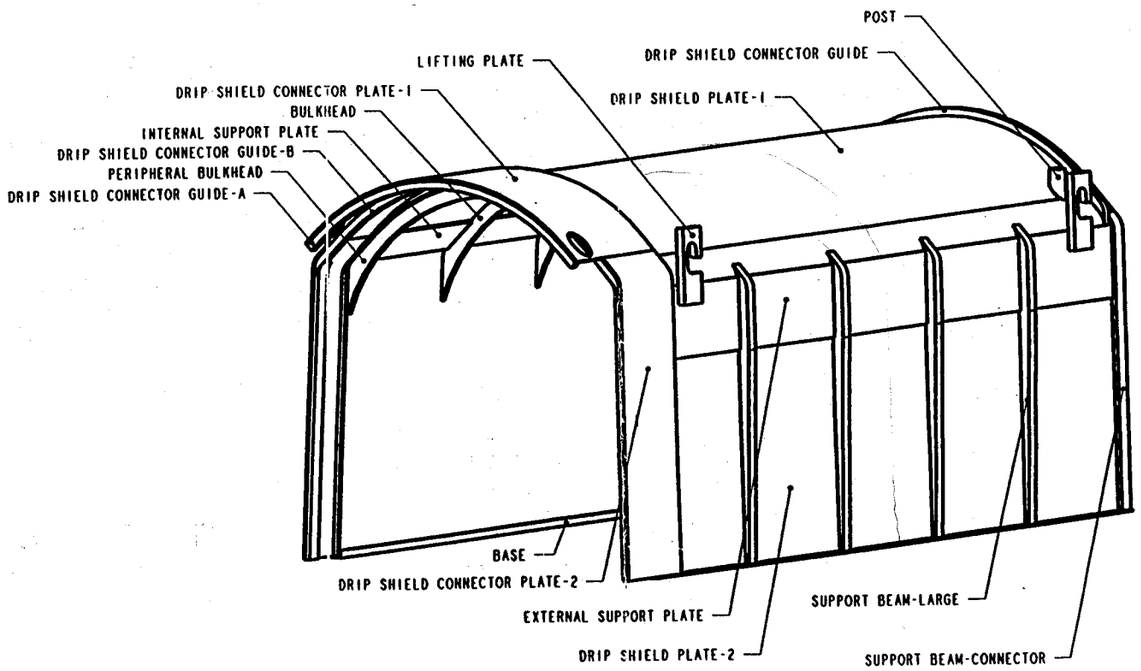
DA 6/21/2000

The results of the DS and ~~to~~ rock block study to date have been documented in the "Process-Level Waste Package Study for Input to SEISMO Module of TPA Code" RDTME KTI IM No. 20.01402.671.070. The report was entitled "Assessment of Mechanical Response of Drip Shields Under Repository Environment - Progress Report." The electronic files are presently stored on the vscr3 scratch drive of the Vulcan workstation. They will be transferred to a DVD medium as soon as they become available.

Doug Ante 5/23/2000

Material Properties for Titanium Grade 5

As per the design details provided in the "Rock Fall on Drip Shield" report provided by DOE (CRWMS, M&O, CAL-EDS-ME-000001. Rev. 00.) DA 6/22/2000 for the drip shield, Titanium Grade 24 will be used for the reinforcing bulkheads and structural stiffeners. A schematic for the new drip shield design is provided below. A bill of materials is also given.



COMPONENT NAME	MATERIAL	THICKNESS	MASS (KG)	QTY ROD
DRIP SHIELD PLATE-1	SB-265 R52400	15	837	1
DRIP SHIELD PLATE-2	SB-265 R52400	15	780	2
BASE	SB-575 N06022	10	55	2
BULKHEAD	SB-265 R56400	38	45	4
PERIPHERAL BULKHEAD	SB-265 R56400	48	56	2
POST	SB-265 R56400	100	5.6	2
INTERNAL SUPPORT PLATE	SB-265 R52400	12.7	16	10
EXTERNAL SUPPORT PLATE	SB-265 R52400	12.7	27	10
LIFTING PLATE	SB-265 R56400	50	17	4
SUPPORT BEAM-CONNECTOR	SB-265 R56400	102	27	6
SUPPORT BEAM-LARGE	SB-265 R56400	76	37	8
DRIP SHIELD CONNECTOR GUIDE	SB-265 R52400	50	30	2
DRIP SHIELD CONNECTOR PLATE-1	SB-265 R52400	15	142	1
DRIP SHIELD CONNECTOR PLATE-2	SB-265 R52400	15	89	2
DRIP SHIELD CONNECTOR GUIDE-A	SB-265 R52400	50	26	1
DRIP SHIELD CONNECTOR GUIDE-B	SB-265 R52400	50	31	1
DRIP SHIELD ASSEMBLY	-	-	4203	1

Because Titanium Grades 5 and 24 only differ by the 0.04 to 0.08% of palladium added to Titanium Grade 24, they are expected to exhibit the same mechanical characteristics (i.e., mechanical properties). Mechanical properties for Titanium Grades 5 or 24 are not contained in the ASME B&PV Code. Mechanical properties are available in the U.S. Department of Defense "Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures," MIL-HDBK-5H. The following figures were obtained from this reference

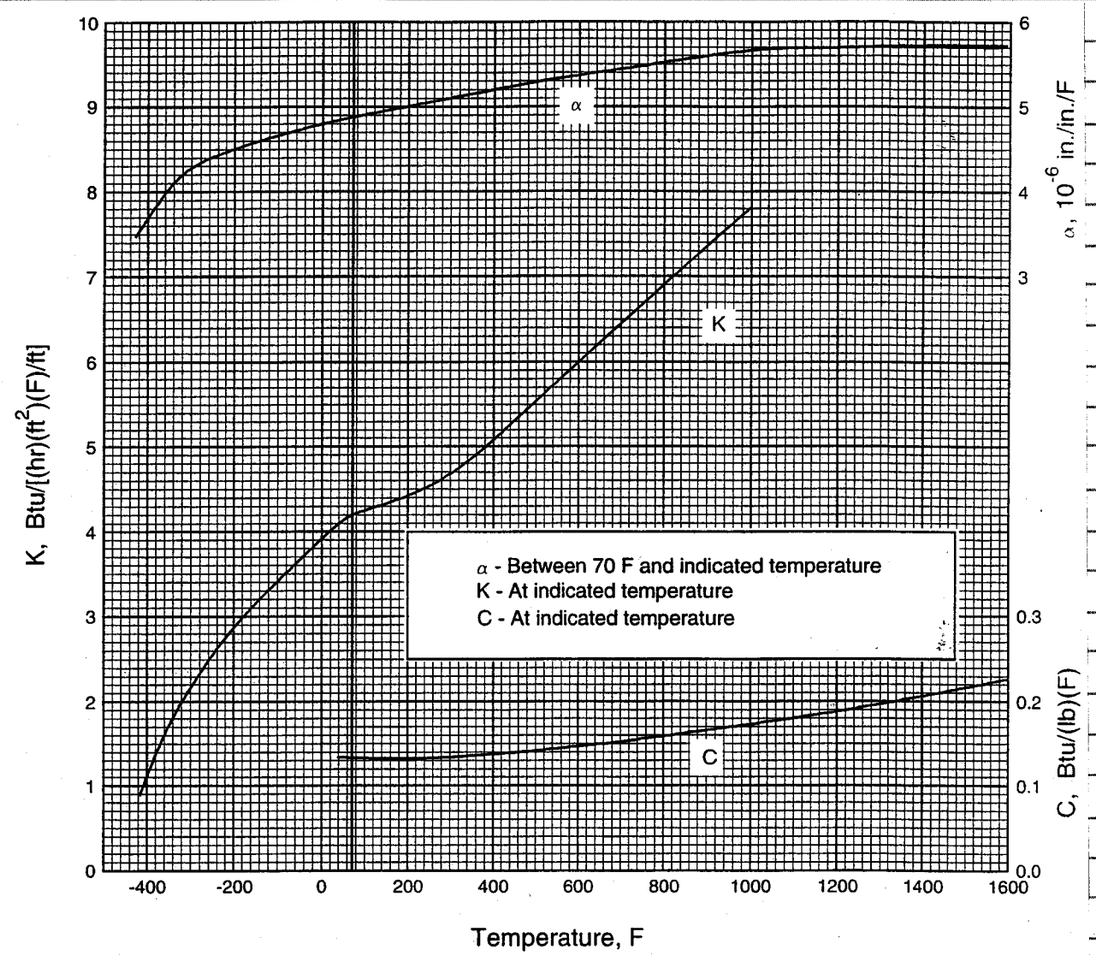


Figure 5.4.1.0. Effect of temperature on the physical properties of Ti-6Al-4V alloy (wrought products).

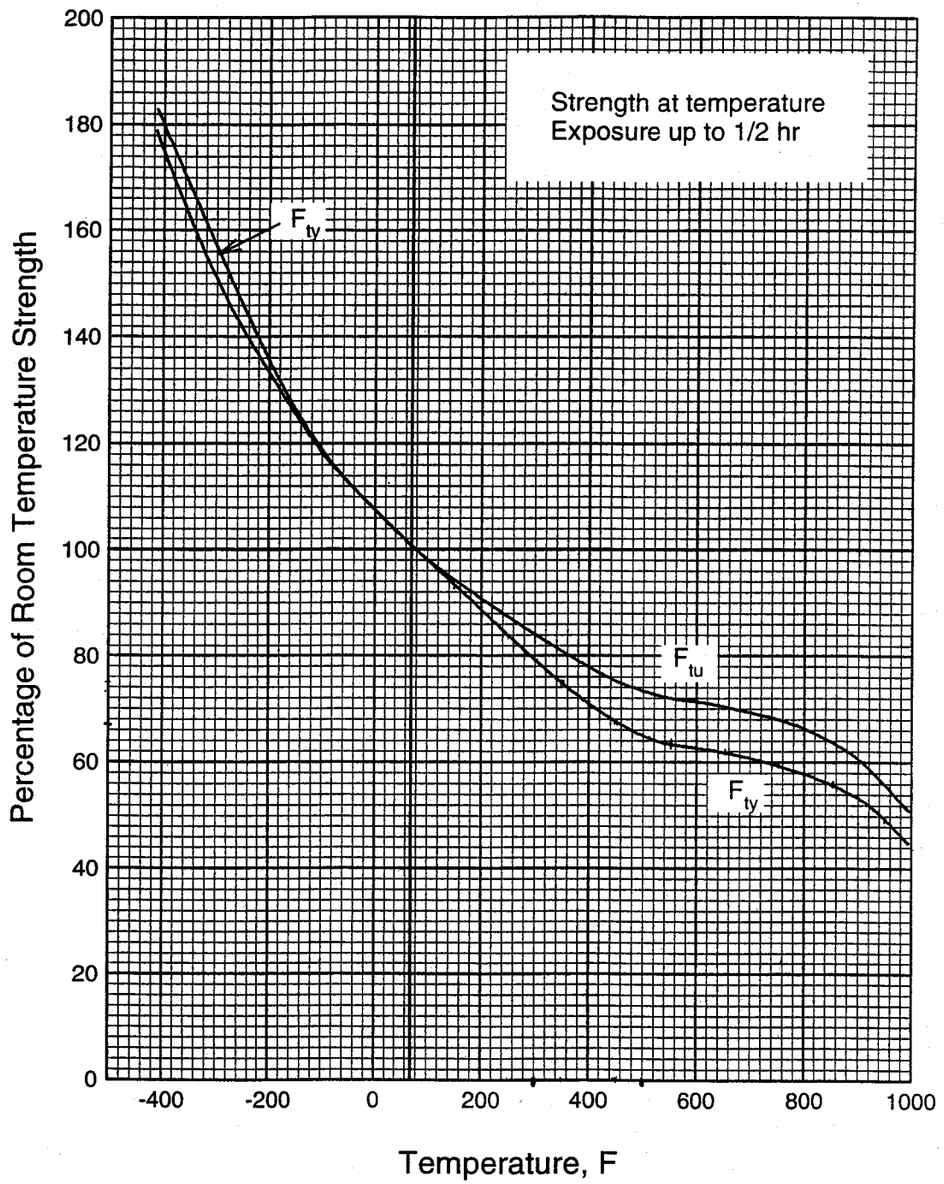


Figure 5.4.1.1.1. Effect of temperature on the tensile ultimate strength (F_{tu}) and the tensile yield strength (F_{ty}) of annealed Ti-6Al-4V alloy (all wrought products).

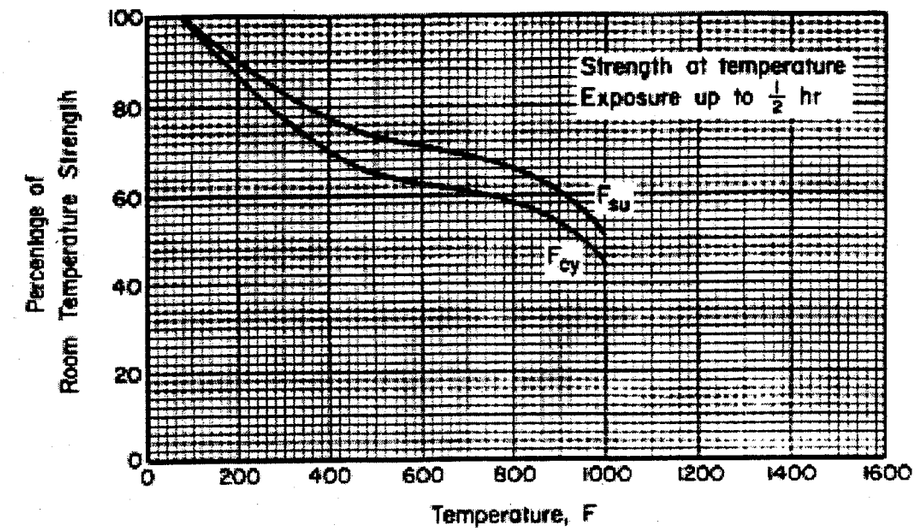


Figure 5.4.1.1.2. Effect of temperature on the compressive yield strength (F_{cy}) and the shear ultimate strength (F_{su}) of annealed Ti-6Al-4V alloy (all wrought products).

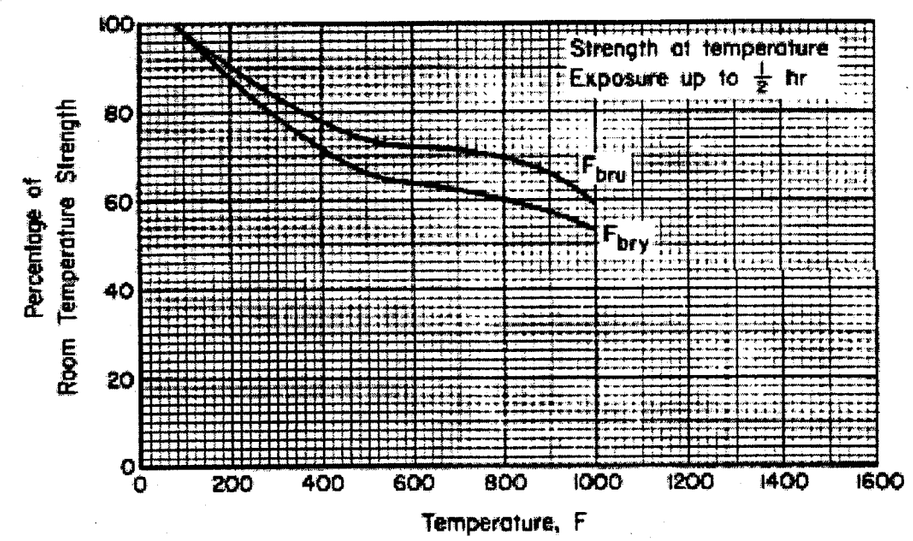


Figure 5.4.1.1.3. Effect of temperature on the bearing ultimate strength (F_{bru}) and the bearing yield strength (F_{bry}) of annealed Ti-6Al-4V alloy (all wrought products).

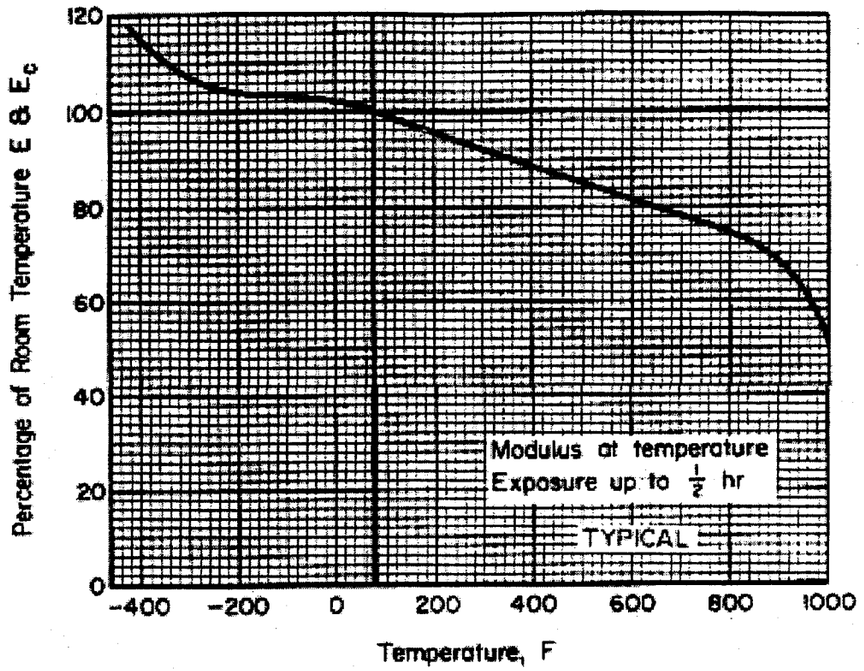


Figure 5.4.1.1.4. Effect of temperature on the tensile and compressive moduli (E and E_c) of annealed Ti-6Al-4V alloy sheet and bar.

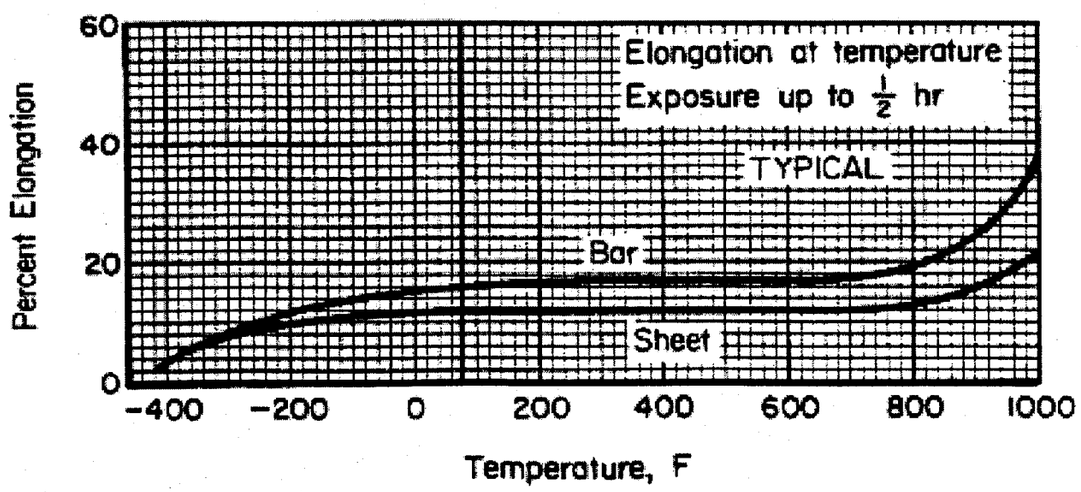


Figure 5.4.1.1.5. Effect of temperature on the elongation of annealed Ti-6Al-4V alloy sheet and bar.

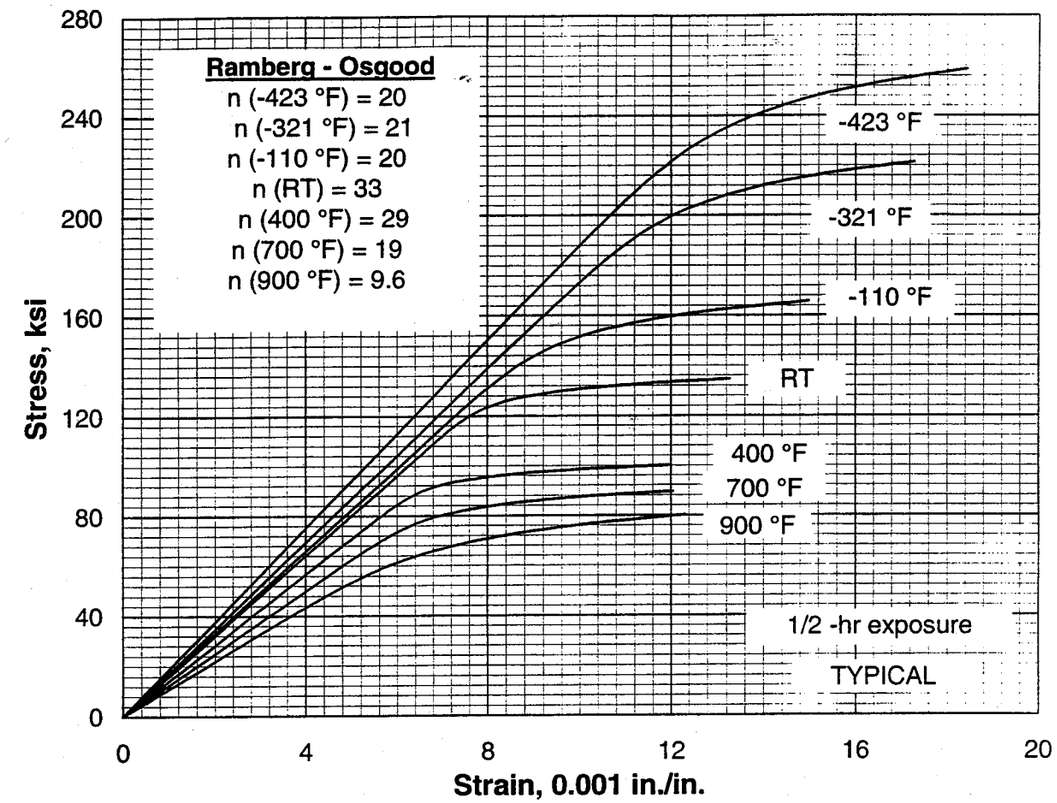


Figure 5.4.1.1.6(a). Typical tensile stress-strain curves at cryogenic, room, and elevated temperatures for annealed Ti-6Al-4V alloy extrusion.

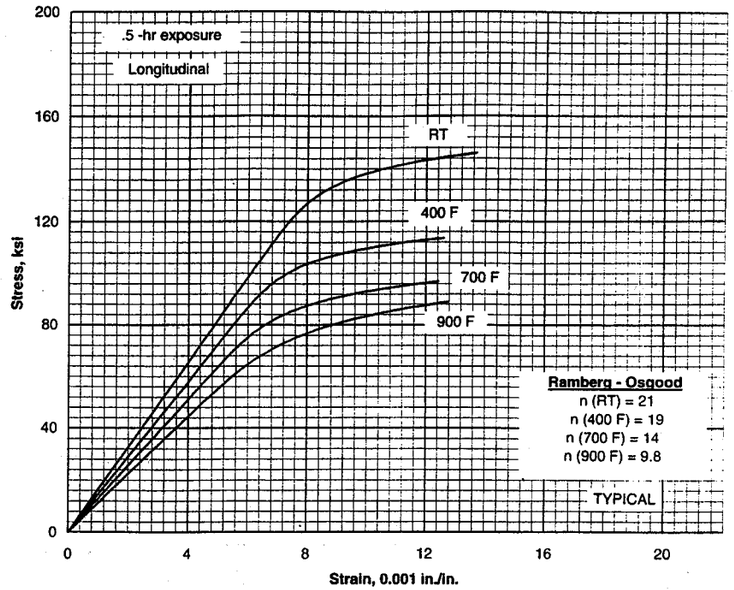


Figure 5.4.1.1.6(b). Typical compressive stress-strain curves at room and elevated temperatures for annealed Ti-6Al-4V alloy extrusion.

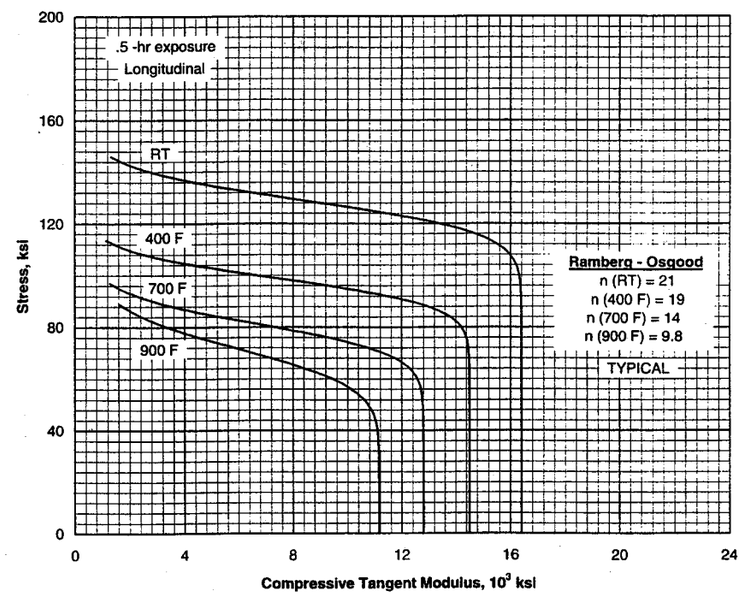


Figure 5.4.1.1.6(c). Typical compressive tangent-modulus curves at room and elevated temperatures for annealed Ti-6Al-4V alloy extrusion.

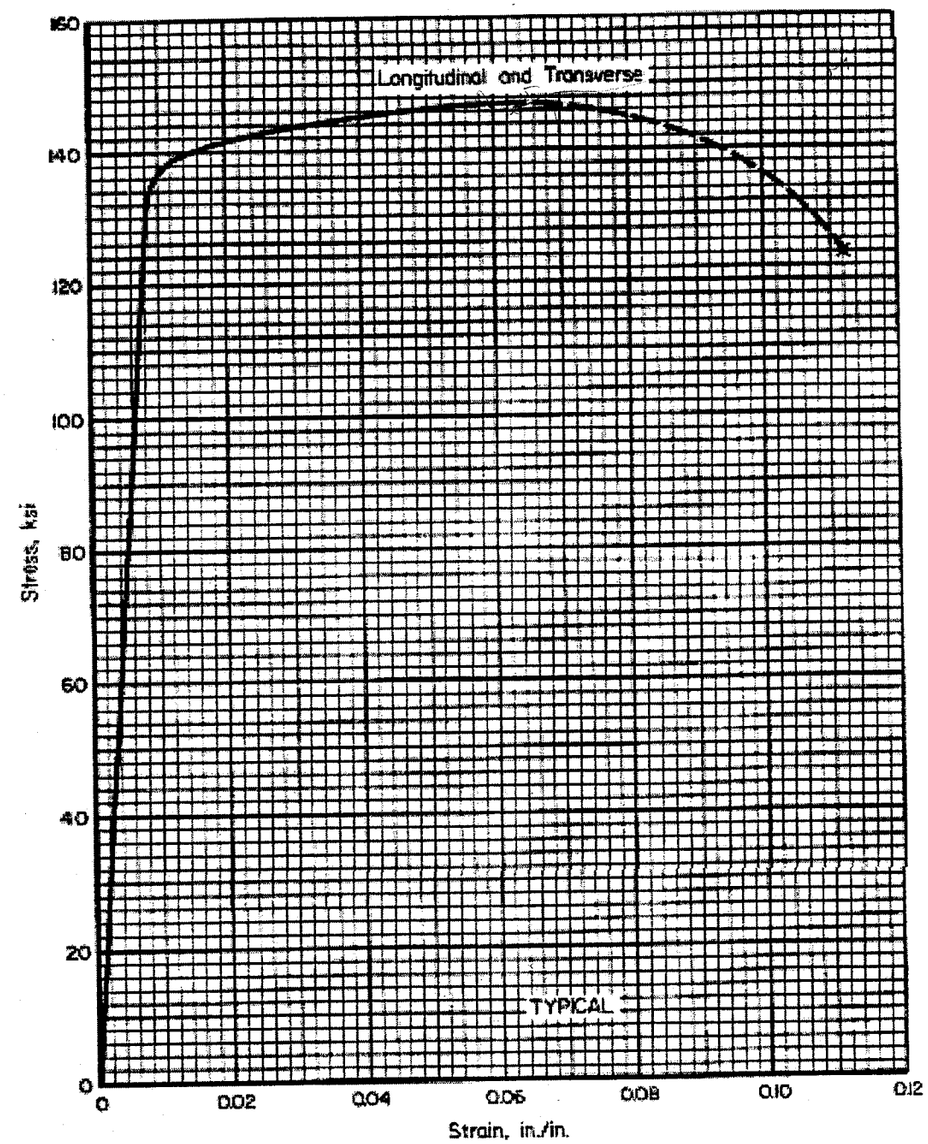


Figure 5.4.1.1.6(d). Typical tensile stress-strain curves (full range) for annealed Ti-6Al-4V sheet at room temperature.

According to ASTM B 265-98, "Standard Specification for Titanium and Titanium Alloy Strip, Sheet, and Plate," the room temperature values for yield stress, ultimate strength, and minimum elongation are

DJ 6/22/2000 Min. Yield Stress Min. Ultimate Strength Minimum Elongation

Information potentially subject to copyright protection was redacted from this location.

The redacted material is from the information listed above.

Note that all the properties are identical, as expected.

Using these refence values and the data extracted from Figure 5.4.1.1.1 DJ 6/22/2000 on p. 60 of this scientific notebook the following temperature dependent values for Yield Stress and Ultimate Strength for Titanium Grade 5 can be obtained.

Temp. °F (°C)	Correction Factor (from Fig. 5.4.1.1.1)	Min. Yield Stress Ksi (MPa)	Correction Factor (from Fig. 5.4.1.1.1)	Min. Ultimate Strength Ksi (MPa)
200 (93)	0.88	105.6 (728.6)	0.91	118.3 (814.5)
400 (204)	0.71	85.2 (587.9)	0.78	101.4 (698.1)
600 (316)	0.62	74.4 (513.4)	0.72	93.6 (644.4)
800 (427)	0.58	69.6 (480.2)	0.66	85.8 (590.7)
1000 (538)	0.44	52.8 (364.3)	0.51	66.3 (456.5)
300 (149)	0.79	94.8 (654.1)	0.84	109.2 (751.8)
500 (260)	0.65	78.0 (538.2)	0.74	96.2 (662.3)

From Table 5.4.1.0 (C.) Design Mechanical and Physical Properties of Ti-6Al-4V Bar (i.e., Ti-5) of the "Military Handbook: Metallic Materials and Elements for Aerospace Vehicle Structures," the Young's Modulus = $16.9(10^3)$ Ksi at room temperature. Using the correction factors extracted from Fig. 5.4.1.1.4 on p. 62 of this scientific notebook, Young's Modulus as a function of temperature can be obtained.

Temp. °F (°C)	Correction Factor (from Fig. 5.4.1.1.4)	Young's Modulus Ksi	~~(MPa)~~ DJ 6/22/2000 (GPa)
RT	1.0	$16.9(10^3)$	(116.5)
200 (93)	0.96	$16.2(10^3)$	(111.8)
300 (~~149~~) DJ 6/22/2000	0.92	$15.5(10^3)$	(107.2)
400 (204)	0.88	$14.9(10^3)$	(102.5)
500 (260)	0.85	$14.4(10^3)$	(99.0)
600 (316)	0.81	$13.7(10^3)$	(94.4)

Doug Date 6/22/2000

Revised Material Pr

Information potentially subject to copyright protection was redacted from this location.
The redacted material is from the 1995 and 1998 ASME B&PV Code, Section II,
Part D-Properties,

* 1995 ASME B&PV Code, Section II, Part D, Table Y-1
† No values published
‡ 1995 ASME B&PV Code, Section II, Part D, Table TM-5

DJ 6/28/2000

According ~~th~~ to the 1998 Version,

Information potentially subject to copyright protection was redacted from this location.

The redacted material is from the information listed above.

* 1998 ASME B&PV Code, Section II, Part D, Table Y-1
† 1998 ASME B&PV Code, Section II, Part D, Table U
‡ 1998 ASME B&PV Code, Section II, Part D, Table TM-5

Doug [illegible] 6/28/2000

Bi-Linear Stress-Strain Curves for Titanium Grades 5 and 7 and Alloy 22.

I. Assuming 150°C Material Temperatures

A. Titanium Grade 5, Engineering Stress and Engineering Strain Values

See page 66 of this notebook

$S_y = 654.1\ MPa$; Engineering Yield Stress
$S_u = 751.8\ MPa$; Engineering Ultimate Tensile Strength
$E = 107.2\ GPa$; Modulus of Elasticity (Young's Modulus)
Min. Elongation = 0.10

B. Titanium Grade 5, Conversion to True Stress and Logarithmic Strain

At the yield point,

$$\sigma_{true} = \sigma_{nom}(1+\epsilon_{nom})$$
$$\epsilon_{ln}^{Pl} = \ln(1+\epsilon_{nom}) - \frac{\sigma_{true}}{E}$$

$$\therefore \sigma_{true} = (654.1\ MPa)\left[1 + \frac{(654.1\ MPa)}{(107{,}200\ MPa)}\right] \quad ; \epsilon_{nom} = \frac{S_y}{E}$$
$$= 658.1\ MPa$$
$$\therefore \epsilon_{ln}^{Pl} = 0.000$$

At the ultimate strength point,

$$\therefore \sigma_{true} = (751.8\ MPa)(1+0.10) \quad ; \epsilon_{nom} \equiv \text{Min. Elongation}$$
$$= 826.98\ MPa$$
$$\simeq 827\ MPa$$
$$\therefore \epsilon_{ln}^{Pl} = \ln(1+0.10) - \frac{(827\ MPa)}{(107{,}200\ MPa)}$$
$$= 0.087596$$

Revised Material Properties for Titanium Grade 7

It was found that the yield stress of Titanium Grade 7 as reported in the 1995 and 1998 ASME B&PV Code, Section II, Part D - Properties, Table Y-1 are not in agreement. The yield stress values published in the 1995 version are assumed to be correct. According to the 1995 Version,

Temperature °F (°C)	Yield Stress* Ksi (MPa)	Ultimate Tensile Strength† Ksi (MPa)	Young's Modulus‡ Ksi (GPa)
-20 to 100 (-29 to 38)	40.0 (275.8)	...	15.5×10^3 (106.9)
200 (93)	32.2 (222.0)	...	15.0×10^3 (103.4)
300 (149)	25.2 (173.8)	...	14.6×10^3 (100.7)
400 (204)	18.6 (128.2)	...	14.0×10^3 (96.5)
500 (260)	14.1 (97.2)	...	13.3×10^3 (91.7)
600 (316)	11.4 (78.6)	...	12.6×10^3 (86.9)

* 1995 ASME B&PV Code, Section II, Part D, Table Y-1
† No values published
‡ 1995 ASME B&PV Code, Section II, Part D, Table TM-5

DJ 6/28/2000

According ~~th~~ to the 1998 Version,

Temperature °F (°C)	Yield Stress* Ksi (MPa)	Ultimate Tensile Strength† Ksi (MPa)	Youngs Modulus‡ Ksi (GPa)
-20 to 100 (-29 to 38)	40.0 (275.8)	50.0 (344.8)	15.5 (10^3) (106.9)
200 (93)	~~32.2 (222.0)~~ DJ 6/28/2000 40.0 (275.8)	43.6 (300.6)	15.0 (10^3) (103.4)
300 (149)	DJ 6/28/2000 ~~25~~ 40.0 (275.8)	36.2 (249.6)	14.6 (10^3) (100.7)
400 (204)	40.0 (275.8)	30.9 (213.1)	14.0 (10^3) (96.5)
500 (260)	40.0 (275.8)	26.6 (183.4)	13.3 (10^3) (91.7)
600 (316)	40.0 (275.8)	22.8 (157.2)	12.6 (10^3) (86.9)

* 1998 ASME B&PV Code, Section II, Part D, Table Y-1
† 1998 ASME B&PV Code, Section II, Part D, Table U
‡ 1998 ASME B&PV Code, Section II, Part D, Table TM-5

Doug [illegible] 6/28/2000

Bi-Linear Stress-Strain Curves for Titanium Grades 5 and 7 and Alloy 22.

I. Assuming 150°C Material Temperatures

A. Titanium Grade 5, Engineering Stress and Engineering Strain Values

See page 66 of this notebook

$S_y = 654.1$ MPa ; Engineering Yield Stress
$S_u = 751.8$ MPa ; Engineering Ultimate Tensile Strength
$E = 107.2$ GPa ; Modulus of Elasticity (Young's Modulus)
Min. Elongation = 0.10

B. Titanium Grade 5, Conversion to True Stress and Logarithmic Strain

At the yield point,

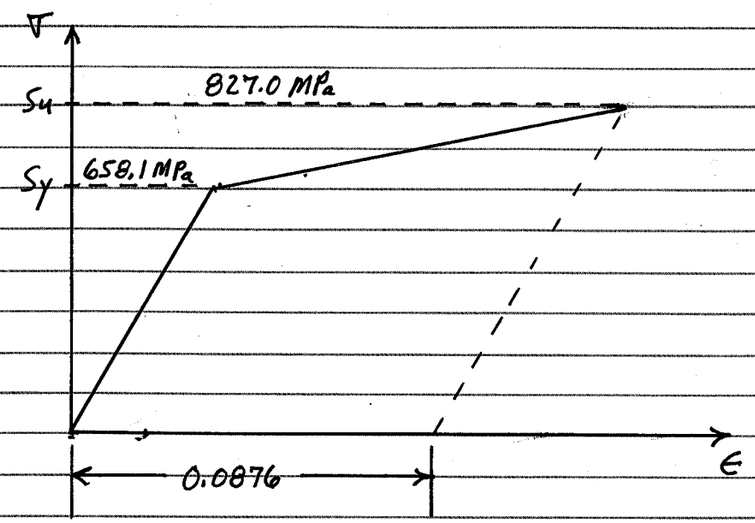
$$\sigma_{true} = \sigma_{nom}(1 + \epsilon_{nom})$$
$$\epsilon_{ln}^{pl} = \ln(1 + \epsilon_{nom}) - \frac{\sigma_{true}}{E}$$

$$\therefore \sigma_{true} = (654.1\ MPa)\left[1 + \frac{(654.1\ MPa)}{(107{,}200\ MPa)}\right] \quad ; \epsilon_{nom} = \frac{S_y}{E}$$
$$= 658.1\ MPa$$
$$\therefore \epsilon_{ln}^{pl} = 0.000$$

At the ultimate strength point,

$$\therefore \sigma_{true} = (751.8\ MPa)(1 + 0.10) \quad ; \epsilon_{nom} \equiv \text{Min. Elongation}$$
$$= 826.98\ MPa$$
$$\simeq 827\ MPa$$
$$\therefore \epsilon_{ln}^{pl} = \ln(1 + 0.10) - \frac{(827\ MPa)}{(107{,}200\ MPa)}$$
$$= 0.087596$$

C. True Stress - Logarithmic Strain for Titanium Grade 5 @ 150 °C



D. Titanium Grade 7, Engineering Stress and Engineering Strain Values

$S_y = 173.8\ MPa$
$S_u = 249.6\ MPa$
$E = 100.7\ GPa$
} from p. 68 of this notebook

Min. Elongation = 0.20 } from p. 23 of this notebook

DJ 6/28/2000

E. ~~Titat~~ Titanium Grade 7, Conversion to True Stress and Logarithmic Strain

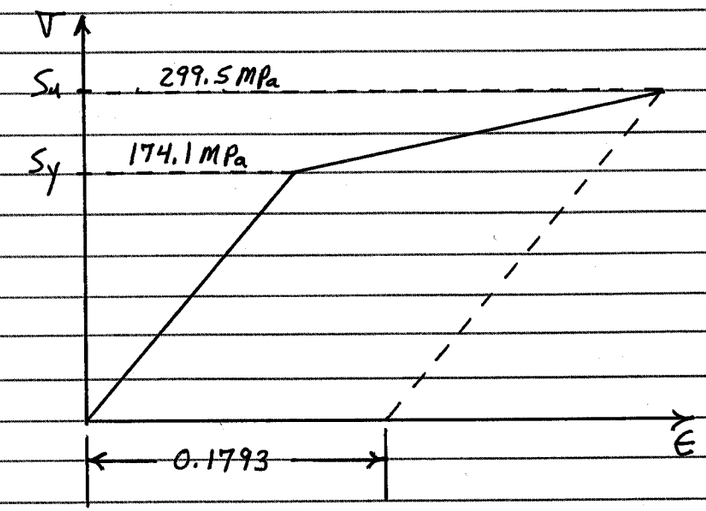
At the yield point,

$$\therefore\ \sigma_{true} = (173.8\ MPa)\left[1 + \frac{(173.8\ MPa)}{(100{,}700\ MPa)}\right]$$
$$= 174.1\ MPa$$
$$\therefore\ \epsilon_{ln}^{pl} = 0.000$$

At the ultimate strength point,

$$\therefore\ \sigma_{true} = (249.6\ MPa)(1 + 0.20)$$
$$= 299.5\ MPa$$
$$\therefore\ \epsilon_{ln}^{pl} = \ln(1 + 0.20) - \frac{(299.5\ MPa)}{(100{,}700\ MPa)}$$
$$= 0.1793$$

F. True Stress - Logarithmic Strain for Titanium Grade 7 @ 150 °C



G. Alloy 22, Engineering Stress and Engineering Strain Values

DJ 6/28/2000

from p. 12 of this notebook
$$S_y = 36.9\ ksi = \left(\frac{36{,}900\ lb}{in^2}\right)\left(\cancel{0.0254\ i}\ \left(\frac{1\ in}{0.0254\ m}\right)^2\left(\frac{4.448222\ N}{lb}\right)\right.$$
$$= 254.4\ MPa$$

from p. 11 of this notebook
$$S_u = 98.5\ ksi = \left(\frac{98{,}500\ lb}{in^2}\right)\left(\frac{1\ in}{0.0254\ m}\right)^2\left(\frac{4.448222\ N}{lb}\right)$$
$$= 679.1\ MPa$$

from p. 15 of this notebook
$$E = 28.6(10^6)\ psi = [28.6(10^6)\ lb/in^2]\left(\frac{1\ in}{0.0254\ m}\right)\left(\frac{4.448222\ N}{lb}\right)$$
$$= 197.2\ GPa$$

~~Min. Elongation = 0.40~~ { ~~from page 18 of this notebook~~ DJ 6/28/2000
Min. Elongation = 0.45 { from ASTM B575-98

H. Alloy 22, Conversion to True Stress and Logarithmic Strain

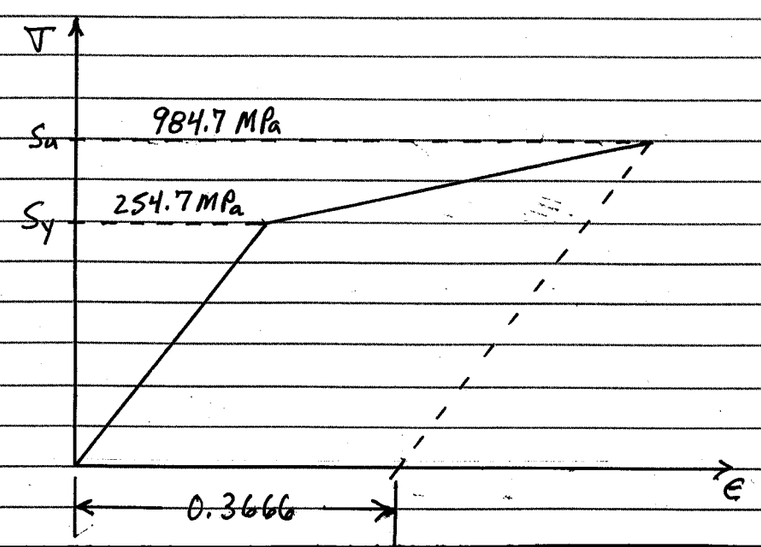
At the yield point,

$$\therefore \sigma_{true} = (254.4\ MPa)\left[1 + \frac{(254.4\ MPa)}{(197{,}200\ MPa)}\right]$$
$$= 254.7\ MPa$$
$$\therefore \epsilon_{ln}^{pl} = 0.000$$

At the ultimate tensile strength pt,

$$\therefore \sigma_{true} = (679.1\ MPa)(1 + 0.45)$$
$$= 984.7\ MPa$$
$$\therefore \epsilon_{ln}^{pl} = \ln(1 + 0.45) - \frac{(984.7\ MPa)}{(197{,}200\ MPa)}$$
$$= 0.3666$$

I. True Stress-Logarithmic Strain for Alloy 22 @ 150°C



II: Assuming 260°C Material Temperatures

A. Titanium Grade 5, Engineering Stress and Engineering Strain Values

$S_y = 538.2\ MPa$
$S_u = 662.3\ MPa$
$E = 99.0\ GPa$
Min. Elongation = 0.10

B. Titanium Grade 5, Conversion to True Stress and Logarithmic Strain

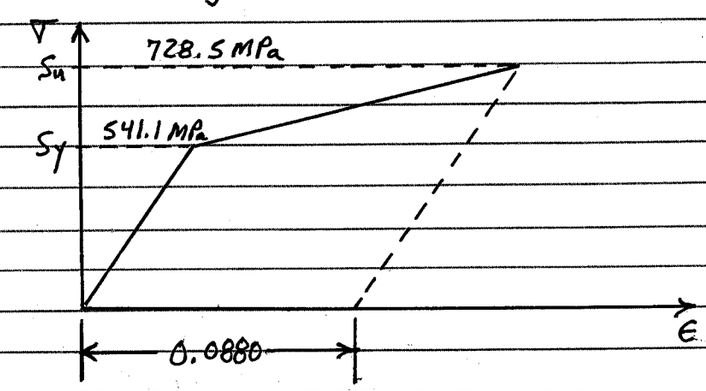
At the yield pt.,

$$\therefore \sigma_{true} = (538.2\ MPa)\left[1 + \frac{(538.2\ MPa)}{(99{,}000\ MPa)}\right]$$
$$= 541.1\ MPa$$
$$\therefore \epsilon_{ln}^{pl} = 0.000$$

At the ultimate tensile strength point,

$$\therefore \sigma_{true} = (662.3\ MPa)(1 + 0.10)$$
$$= 728.5\ MPa$$
$$\therefore \epsilon_{ln}^{pl} = \ln(1 + 0.10) - \frac{(728.5\ MPa)}{(99{,}000\ MPa)}$$
$$= 0.0880$$

C. True Stress-Logarithmic Strain for Titanium Grade 5 @ 260°C



D. Titanium Grade 7, Engineering Stress and Engineering Strain Values

$S_y = 97.2\ MPa$
$S_u = \cancel{26.6}$ DJ 6/28/2000 $183.4\ MPa$
$E = 91.7\ GPa$
Min. Elongation = 0.20

DJ 6/28/2000

E. Titanium Grade 7, Conversion to True Stress and Logarithmic Strain

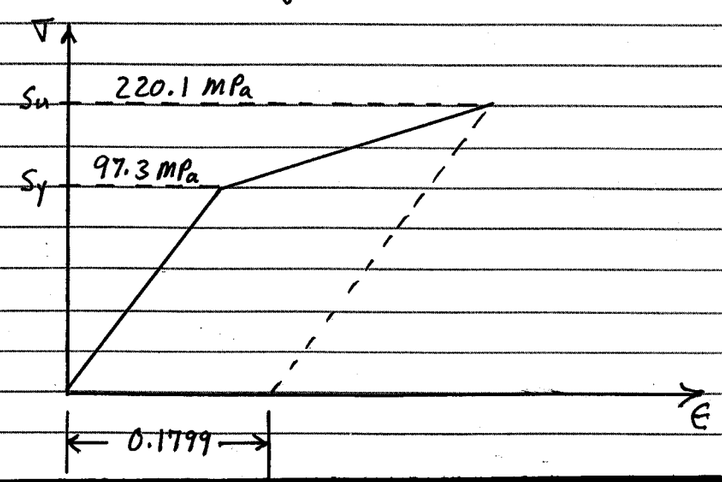
At the yield point,

$$\therefore \sigma_{true} = (97.2\ MPa)\left[1 + \frac{(97.2\ MPa)}{(91{,}700\ MPa)}\right]$$
$$= 97.3\ MPa$$
$$\therefore \epsilon_{ln}^{Pl} = 0.000$$

At the ultimate tensile strength point,

$$\therefore \sigma_{true} = (183.4\ MPa)(1 + 0.20)$$
$$= 220.08\ MPa$$
$$\therefore \epsilon_{ln}^{Pl} = \ln(1 + 0.20) - \frac{(220.1\ MPa)}{(91{,}700\ MPa)}$$
$$= 0.1799$$

F. True Stress - Logarithmic Strain for Titanium Grade 7 @ 260°C



G. Alloy 22, Engineering Stress and Engineering Strain Values

$S_y = 32.2\ ksi = 222.0\ MPa$
$S_u = 92.9\ ksi = 640.5\ MPa$
$E = 27.9(10^6)\ psi = 192.4\ GPa$
Min. Elongation = 0.45

H. Alloy 22, Conversion to True Stress and Logarithmic Strain

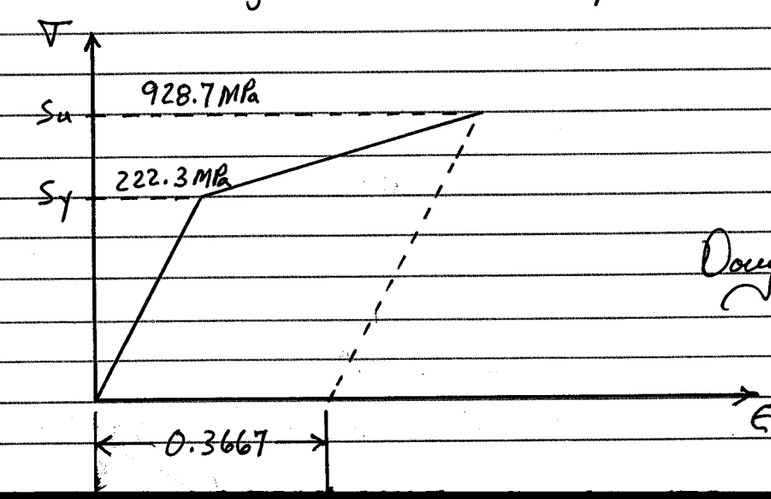
At the yield point,

$$\therefore \sigma_{true} = (222.0\ MPa)\left[1 + \frac{(222.0\ MPa)}{(192{,}400\ MPa)}\right]$$
$$= 222.3\ MPa$$
$$\therefore \epsilon_{ln}^{Pl} = 0.000$$

At the ultimate tensile strength point,

$$\therefore \sigma_{true} = (640.5\ MPa)(1 + 0.45)$$
$$= 928.7\ MPa$$
$$\therefore \epsilon_{ln}^{Pl} = \ln(1 + 0.45) - \frac{(928.7\ MPa)}{(192{,}400\ MPa)}$$
$$= 0.3667$$

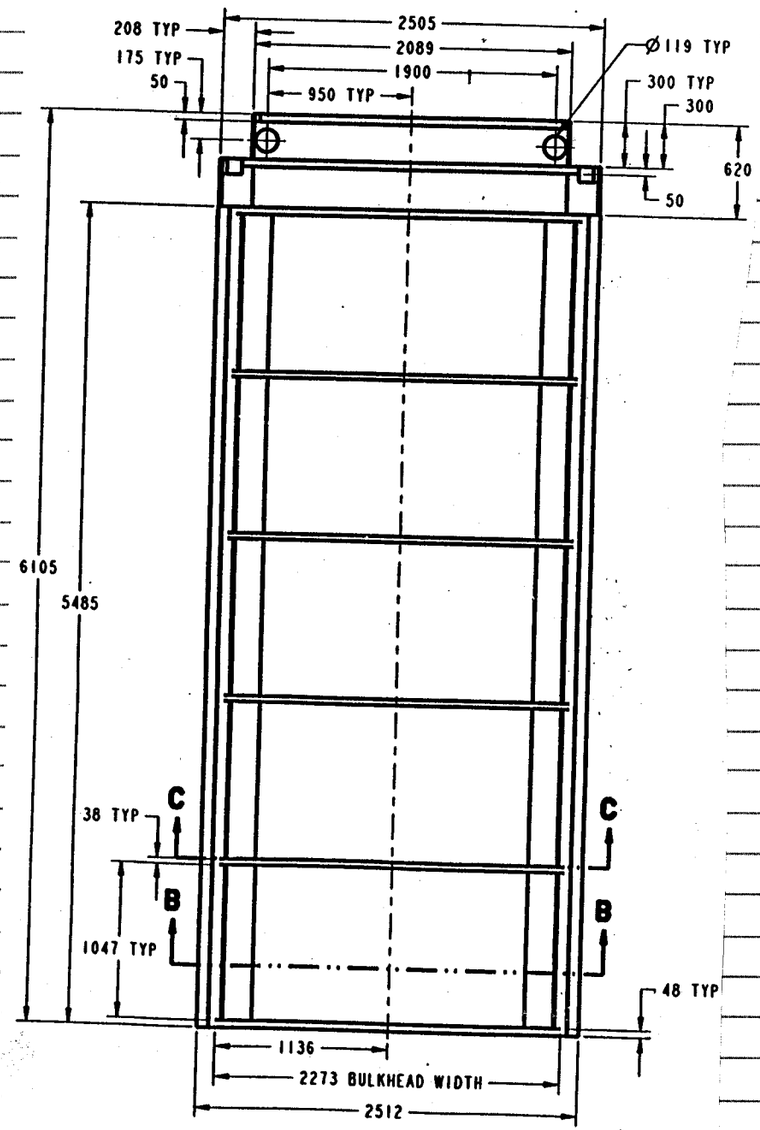
I. True Stress - Logarithmic Strain for Alloy 22 @ 260°C

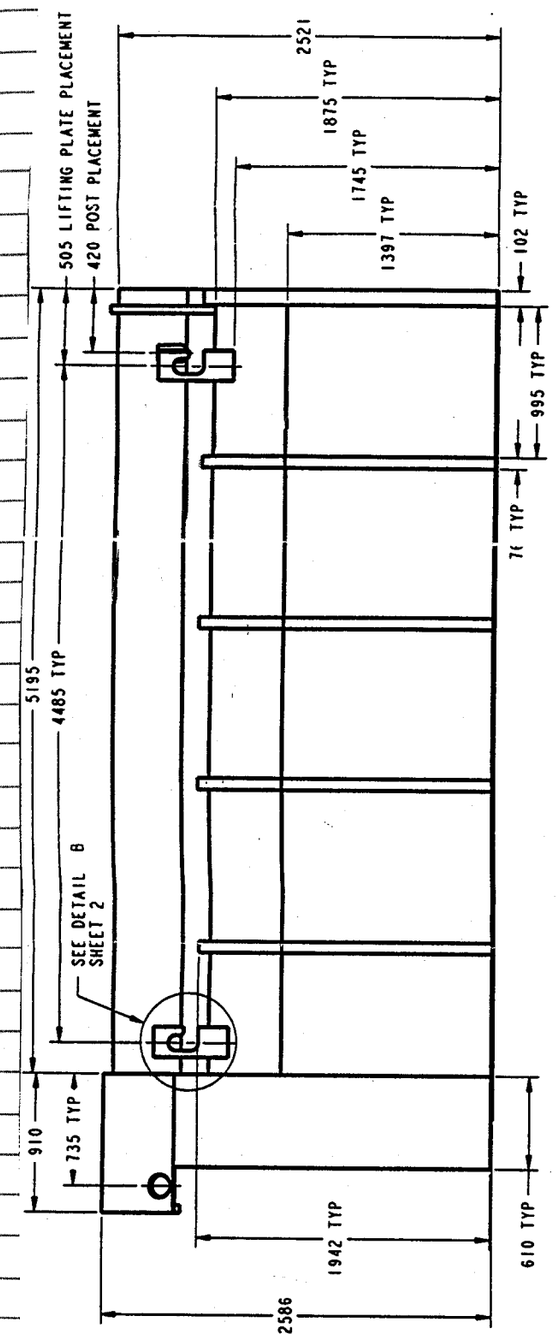


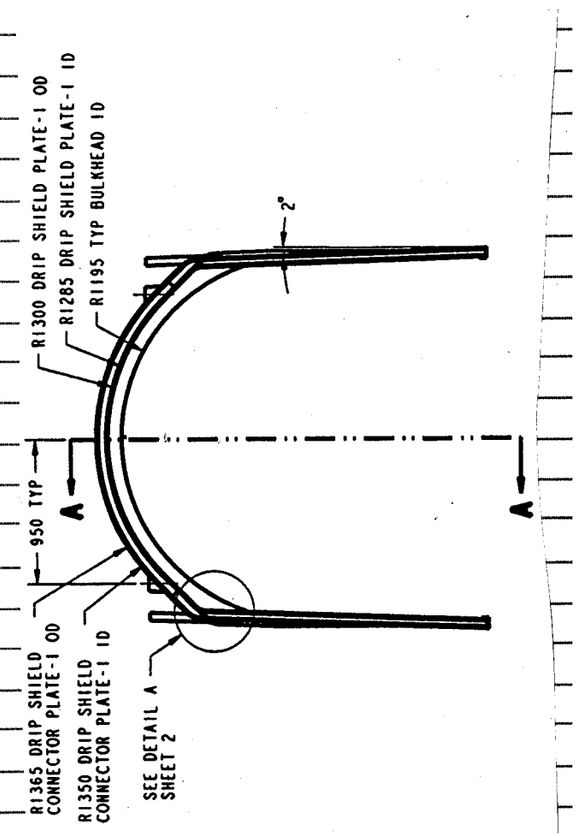
Doug Ende 6/28/2000

Update Drip Shield Dimensions

The following figures were extracted from the "Rock Fall on Drip Shield" report, CAL-EDS-ME-000001 Rev 00, OCRWM.



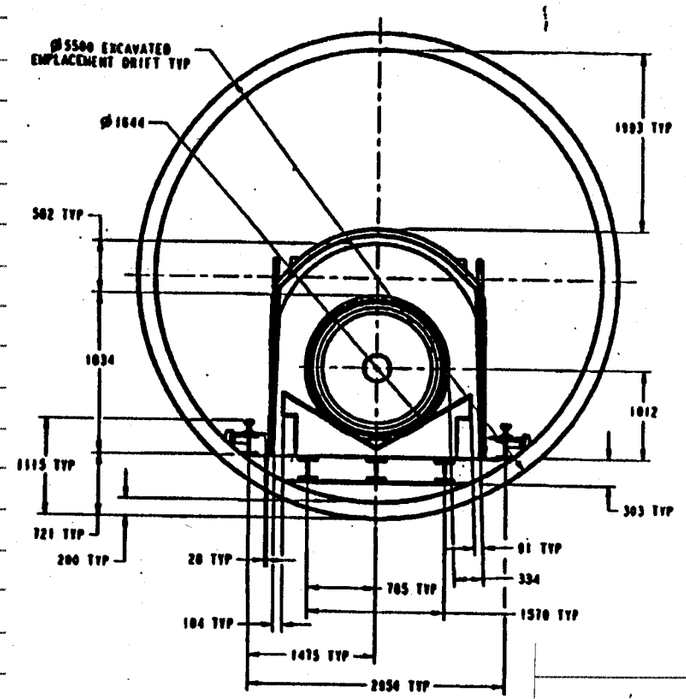




Doug [illegible] 6/30/2000

Emplacement Drift Cross-Section Illustrating the Relative Dimensions of the Drift Invert, Waste Package, and Drip Shield.

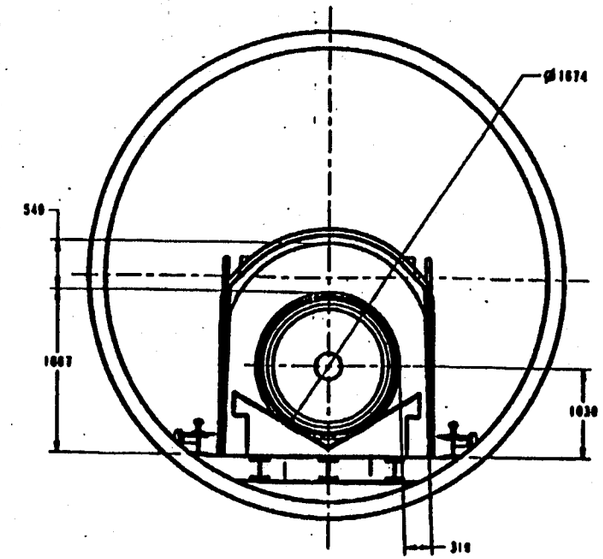
From the OCRWM AMR entitled "Design Analysis for the Ex-Container Components," ANL-XCS-ME-000001 Rev 00, 5/17/00.



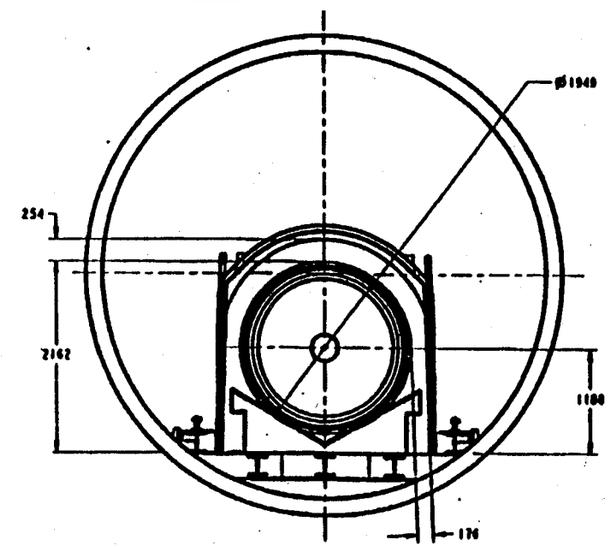
21 PWR

Because the 21PWR WastePackage is the predominant WP to be used at the proposed repository, its dimensions and relative placement will be used in assessing the ability of the drip shield to mitigate the effects of rockfall on it.

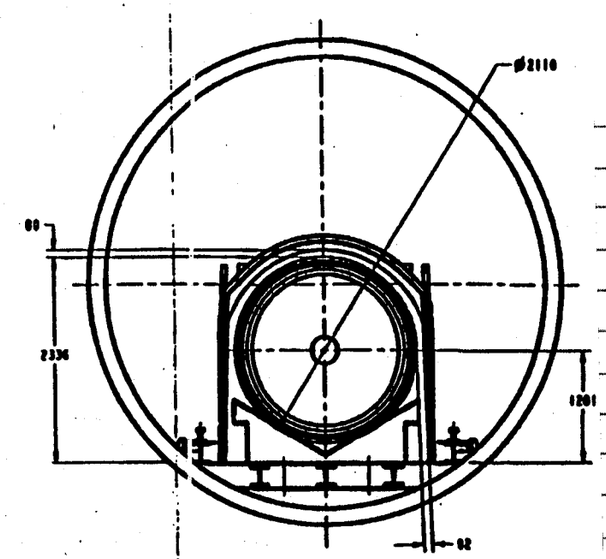
The figures on the following page illustrate the dimensions and relative placement of the other WP types that may be used at the proposed repository.



44 BWR



NAVAL



5 DHLW

Doug [illegible] 7/25/2000

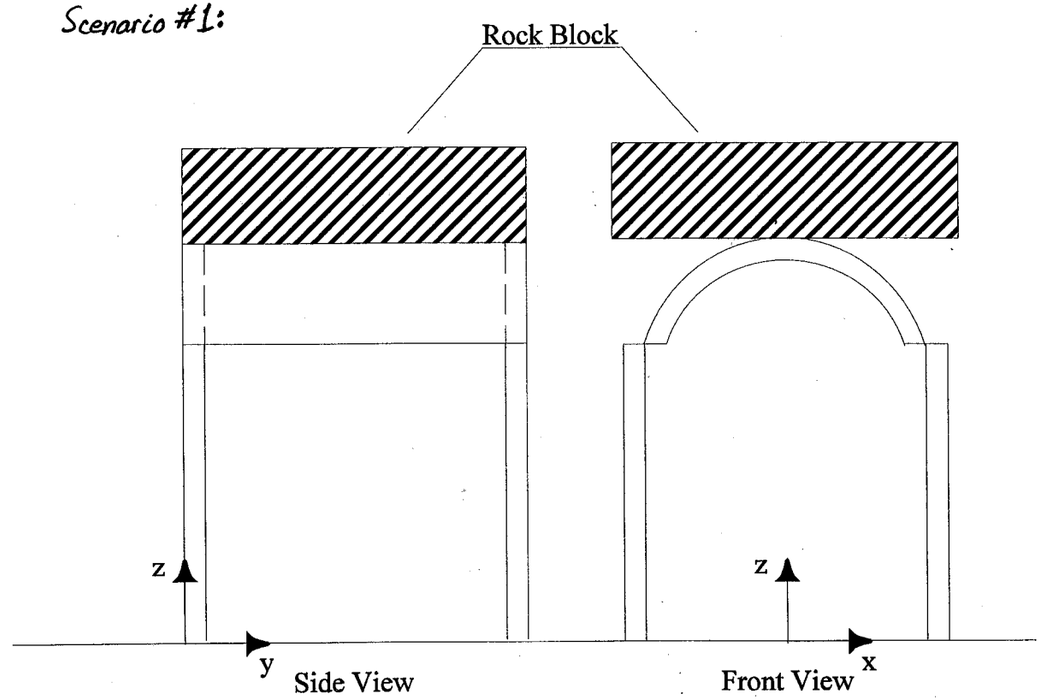
Finite Element Analysis of Drip Shield Using New Design and Updated Material Properties.

The objective of the analysis is to bound the energy dissipation capabilities of the DOE drip shield design documented on pages 76 through 79 of this scientific notebook.

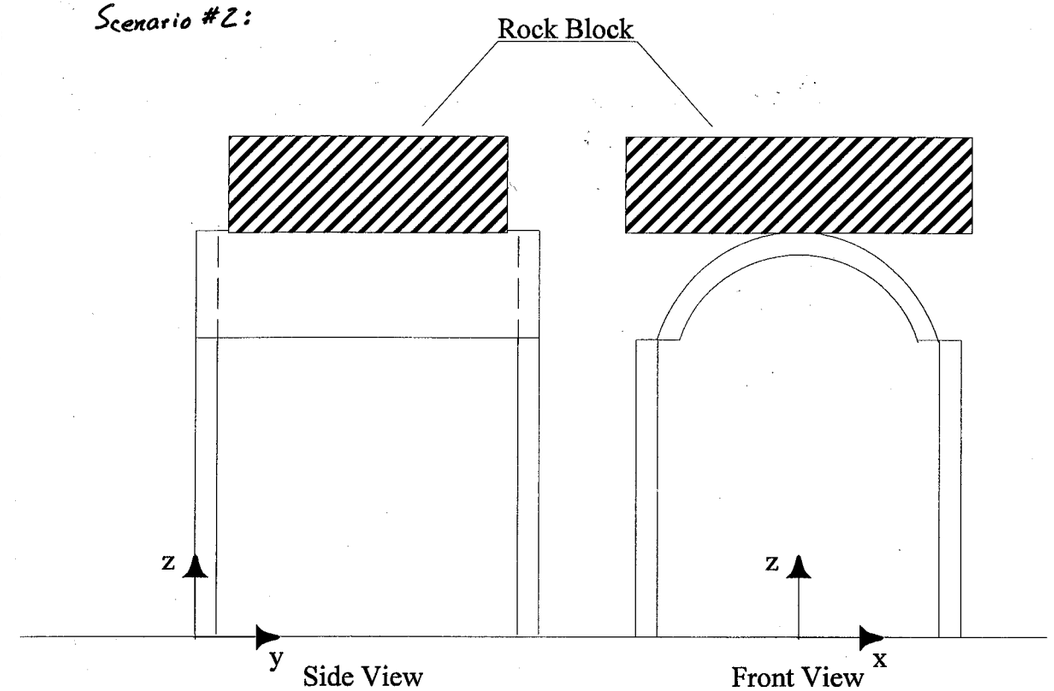
Finite Element (FE) analysis techniques will be used to simulate the response of the drip shield when subjected to rock block impacts. The commercially available FE program ABAQUS/Explicit will be used to perform the simulation. Model units will be Newton, Kilogram, meter, and second.

Two drip shield and rock block impact scenarios will be investigated to establish the bounding energy dissipation capabilities of the drip shield. These scenarios are illustrated schematically as follows:

Scenario #1:



Scenario #2:



Assuming the drip shield is at a uniform temperature of 150°C, the ABAQUS/Explicit definitions for the Titanium Grades 7 and 24 components are as follows:

Titanium Grade 7 @ 150°C (see pages 70 and 71 of this scientific notebook)

```
*MATERIAL, NAME = TI7
*DENSITY
 4512.0
*ELASTIC, TYPE = ISOTROPIC
 100.7E+09, 0.32
*PLASTIC, HARDENING=ISOTROPIC
 174.1E+06, 0.0000
 299.5E+06, 0.1793
```

Titanium Grades 5 and 24 (see pages 69 and 70 of this scientific notebook) @ 150 °C

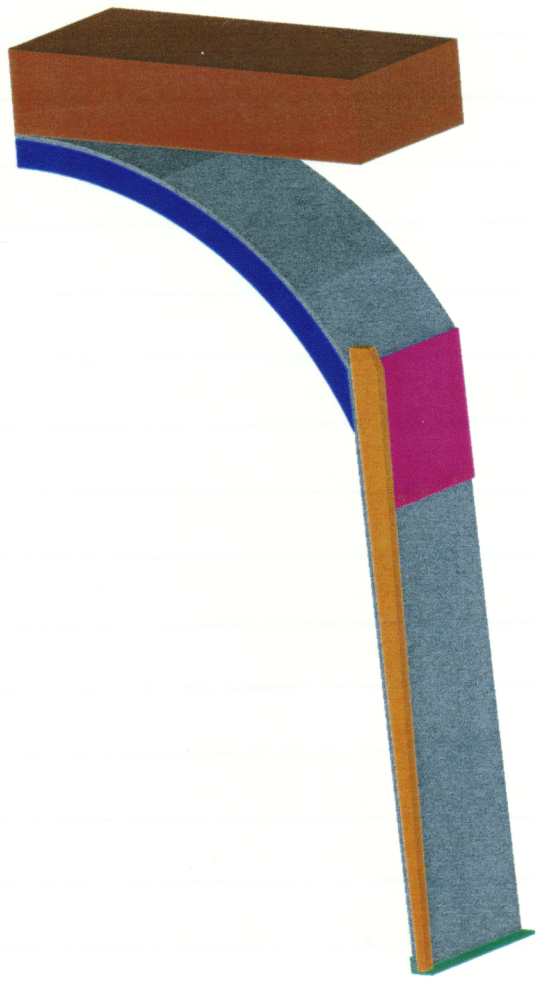
```
*MATERIAL, NAME=TI24
*DENSITY
 4512.0
*ELASTIC, TYPE=ISOTROPIC
 107.2E+09, 0.32
*PLASTIC, HARDENING=ISOTROPIC
 658.1E+06, 0.0000
 827.0E+06, 0.0876
```

Note that the Titanium, regardless of Grade, is represented by a classical metal plasticity model with a Mises yield surface and associated plastic flow rule. It has also been assumed that the minimum elongation of the materials correspond to their ultimate tensile strength. Moreover, due to the lack of definitive data, Poisson's Ratio has been assumed to be temperature independent.

For the sake of simplicity and conservatism, the rock block will be modelled as a simple elastic material. Specifically, within ABAQUS/Explicit, the rock block material constitutive model is defined as follows:

```
*MATERIAL, NAME=ROCK
*DENSITY
 2700.0
*ELASTIC, TYPE=ISOTROPIC
 33.30E+09, 0.21
```

As shown in the figure on page 83 of this scientific notebook, the finite element model of the rock block and drip shield for scenario #1 took advantage of symmetry conditions to reduce the overall size of the model. Using the coordinate axes defined in the figure on page 80 of this scientific notebook, the displacements on the "front" and "back" planes of the model were constrained such that the displacements DJ 11/13/2006 in the y-direction were set to zero. For scenario #1 this constraint was applied to the



rock block and dripshield. In addition, the displacements in the x-direction for the nodes lieing on the X=0 plane were set to zero as well. This was done for both scenarios. Because the drip shield is a free-standing structure, the interaction between the base of the drip shield and the invert was modelled as a frictionless contact. A relatively soft spring having a stiffness of 50 N/m (0.29 lb/in) was used to attach the base of the drip shield to a fixed frame of reference to prevent unconstrained rigid body motion of drip shield and circumvent numerical problems in the FE analysis. A spring was also attached to the rock block for the same purpose. A frictionless contact was also used to define the interaction between the rock block and drip shield. ~~FI~~ DJ 11/13/2000

To approximate the effects of seismic ground motion, the invert (which was modelled as an analytical rigid body surface) was assigned a constant upward velocity of 1 m/s. In addition, both the rock block and drip shield were subjected to gravitational forces throughout the duration of the simulation.

All of the drip shield nodes were assigned an initial upward velocity of 1 m/s. Once the analysis begins, however, the drip shield nodal velocities are allowed to vary and only the invert ~~is~~ DA 11/13/2000 remains moving upward at the constant rate of 1 m/s. Similarly, the rock block nodes are assigned an initial velocity corresponding to ~~a~~ DA 11/13/2000 the assumed fall height. As with the drip shield, the rock block nodal velocities are allowed to vary once the analysis begins.

The finite element analysis permutations for scenario no. 1 (assuming 150°C drip shield temperature) are as follows:

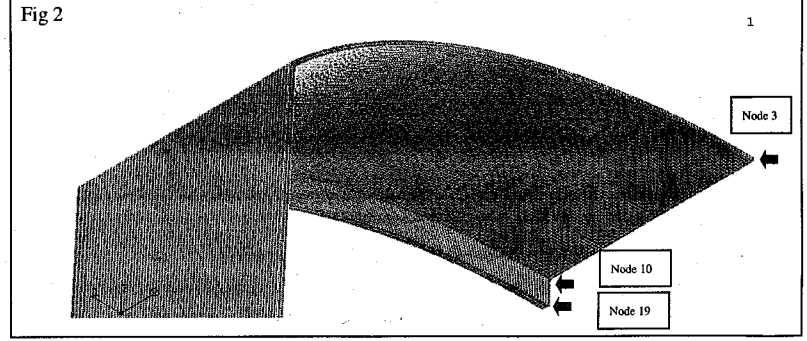
Permutation Number	Rock Block Mass (Kg)	Rock Block Impact Velocity (m/s)	Rock Block Kinetic Energy (J)
1	500	7.0000	12250.
2	500	9.8995	24500.
3	500	14.0000	49000.
4	1000	7.0000	24500.
5	1000	9.8995	49000.
6	1000	14.0000	98000.
7	2000	7.0000	49000.
8	2000	9.8995	98000.
9	2000	14.0000	196000.
10	4000	7.0000	98000.
11	4000	9.8995	196000.
12	4000	2.4749	12250.
13	8000	7.0000	196000.
14	8000	1.7500	12250.
15	8000	2.4749	24500.

See CNWRA scientific notebooks 408 and 409 for additional information pertaining to the FE analyses of the permutations identified in the table above.

Doug Gute
11/13/2000

Summary of Finite Element Analysis Results of Rock Block and Drip Shield Impact (Scenario No. 1 and Updated Design)

Fig 2



DA 11/13/2000

The maximum displacement of node 19 shown in the figure above, relative to the waste package, for the 15 analysis permutations described in the table on page 84 of this scientific notebook were determined to be as follows

Permutation Number	Maximum Vertical Displacement of Node 19 (mm)
1	47.62
2	77.03
3	128.64
4	90.92
5	146.11
6	257.21
7	167.48
8	284.29
9	560.24
10	324.21
11	592.00 (hits the waste package)
12	93.63
13	592.00 (hits the waste package)
14	118.35
15	159.57

Doug Gute 11/13/2000

Predicting the Maximum Drip Shield Displacement in terms of the Rock Block Mass and Impact Velocity (Scenario No. 1 and Updated Design)

Assume the following relationship:

$$\delta_{max} = a_1 M + a_2 M^2 + a_3 M^3 + a_4 MV + a_5 MV^2 \qquad (1)$$

where

$\delta_{max} \equiv$ maximum drip shield displacement (mm)
$M \equiv$ Rock Block Mass (kg)
$V \equiv$ Rock Block Impact Velocity (m/s)
$a_i \equiv$ unknown coefficients to be determined, $i = 1, \ldots, 5$

Using the finite element analysis data provided on page 85 of this scientific notebook,

$$\begin{bmatrix} M_1 & M_1^2 & M_1^3 & M_1V_1 & M_1V_1^2 \\ M_2 & M_2^2 & M_2^3 & M_2V_2 & M_2V_2^2 \\ M_3 & M_3^2 & M_3^3 & M_3V_3 & M_3V_3^2 \\ M_4 & M_4^2 & M_4^3 & M_4V_4 & M_4V_4^2 \\ M_5 & M_5^2 & M_5^3 & M_5V_5 & M_5V_5^2 \\ M_6 & M_6^2 & M_6^3 & M_6V_6 & M_6V_6^2 \\ M_7 & M_7^2 & M_7^3 & M_7V_7 & M_7V_7^2 \\ M_8 & M_8^2 & M_8^3 & M_8V_8 & M_8V_8^2 \\ M_9 & M_9^2 & M_9^3 & M_9V_9 & M_9V_9^2 \\ M_{10} & M_{10}^2 & M_{10}^3 & M_{10}V_{10} & M_{10}V_{10}^2 \\ M_{12} & M_{12}^2 & M_{12}^3 & M_{12}V_{12} & M_{12}V_{12}^2 \\ M_{14} & M_{14}^2 & M_{14}^3 & M_{14}V_{14} & M_{14}V_{14}^2 \\ M_{15} & M_{15}^2 & M_{15}^3 & M_{15}V_{15} & M_{15}V_{15}^2 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{Bmatrix} = \begin{Bmatrix} 1\delta_{max} \\ 2\delta_{max} \\ 3\delta_{max} \\ 4\delta_{max} \\ 5\delta_{max} \\ 6\delta_{max} \\ 7\delta_{max} \\ 8\delta_{max} \\ 9\delta_{max} \\ 10\delta_{max} \\ 12\delta_{max} \\ 14\delta_{max} \\ 15\delta_{max} \end{Bmatrix} \qquad (2)$$

Note that the results for permutations 11 and 13 were not included in the curve fit because the drip shield impacts the waste package before it reached its maximum displacement. Equation 2 can be written more simply as

$$[A]\{a\} = \{\delta_{max}\} \qquad (3)$$

Multiplying Equation (3) by $[A]^T$ gives

$$[A]^T[A]\{a\} = [A]^T\{\delta_{max}\} \qquad (4)$$

Note that it can be shown that $[A]^T[A]$ gives a square, positive definite result. As a consequence, an inverse for $([A]^T[A])$ exists.

$$\therefore \{a\} = ([A]^T[A])^{-1}[A]^T\{\delta_{max}\} \qquad (5)$$

$$\begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \end{Bmatrix} = \begin{Bmatrix} 1.5959(10^{-2}) \\ 1.3335(10^{-7}) \\ -1.0710(10^{-10}) \\ 6.4485(10^{-4}) \\ 1.2692(10^{-3}) \end{Bmatrix} \qquad (6)$$

The plot on the next page (i.e., page 88) of this scientific notebook illustrates the approximation level achieved from the assumed function given in Equation (1) using the coefficients obtained in Equation (6).

Doug [illegible] 11/16/2000

Rock Block Kinetic Energy at the Time of Impact With the Drip Shield

- Kinetic Energy = 12,250 Joules
- Kinetic Energy = 24,500 Joules
- Kinetic Energy = 49,000 Joules
- Kinetic Energy = 98,000 Joules
- Kinetic Energy = 196,000 Joules

Drip Shield Temperature = 150 °C

Rock Block Velocity, $v = \sqrt{2gh}$

Rock Block Kinetic Energy $= \frac{1}{2} M v^2$

Ground Motion Velocity = 1m/s (upward)

M = **Rock Block Mass (kg/m)**

h = **Rock Block Fall Height (m)**

g = **Acceleration Due To Gravity (m/s²)**

$$\delta_{max} \cong 1.5959(10^{-2})M + 1.3335(10^{-7})M^2 - 1.0710(10^{-10})M^3 + 6.4485(10^{-4})Mv + 1.2692(10^{-3})Mv^2$$

11/16/2000

SUMMARY OF FINITE ELEMENT ANALYSIS OF ROCK BLOCK AND DRIP SHIELD IMPACT
(Scenario #2 on updated design)

Analyses were performed using ABAQUS/Explicit Version 5.8-16. Verification of this software is documented in the vendor's (Hibbitt, Karlsson & Sorensen, Inc.) quality program. The figures below illustrate the model and shows the location of the nodes tracked for deflection relative to the waste package. Deflection values reported below is the Z deflection of node 123490 minus node 96965.

6 MAR 2002

Electronic files have been archived to 8mm magnetic tape. A summary of the archived data is shown in the table below:

		Case 01	Case 02	Case 03	Case 04	Case 05	Case 06	Case 07	Case 08	Case 09	Case 10	Case 11	Case 12	Case 13	Case 14	Case 15	Case 16	Case 17
Mass	(kg)	500	500	500	1000	1000	1000	2000	2000	2000	4000	4000	4000	8000	8000	8000	4000	4000
Velocity	(m/s)	7	10	14	7	10	14	7	10	14	7	10	2	7	1	2	7	7
abaqus.env	(Bytes)	125	124	124	124	124	124	0	124	124	124	124	124	124	124	124	124	124
.abq	(GB)	0.7	0.7	0.1	0.7	0.7	0.7	0.0	0.7	0.7	1.9	0.6	0.6	0.7	0.7	0.7	0.6	0.6
.com	(Bytes)	2465	2713	2713	4062	4069	4066	0	4066	4066	2765	4066	4060	4060	1700	2715	2723	4078
.dat	(MB)	10.5	10.5	10.5	9.2	9.4	9.4	0.0	9.4	9.4	12.4	9.1	9.1	9.6	9.6	9.6	9.1	9.1
.fil	(GB)	2.0	4.0	4.0	2.0	2.0	0.5	0.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	2.0	1.6	2.0
.inp	(MB)	15.3	n/a	n/a	15.2	15.2	15.2	0.0	15.2	15.2	15.3	15.3	15.3	15.5	n/a	15.5	15.3	15.3
.log	(Bytes)	480	n/a	n/a	1134	1136	301	0	1136	1136	730	1136	1133	1133	n/a	700	705	1142
.msg	(Bytes)	0	n/a	n/a	0	0	0	0	0	0	2	0	0	0	n/a	0	0	0
.odb	(GB)	1.3	n/a	n/a	1.4	0.9	n/a	0.0	1.3	1.6	0.9	1.9	1.3	1.9	n/a	1.6	1.6	1.6
.pac	(MB)	101.0	n/a	n/a	208.4	208.6	208.6	0.0	209.1	209.1	472.1	100.1	100.1	211.9	n/a	211.9	100.1	100.1
.res	(GB)	1.0	n/a	n/a	0.1	0.1	1.0	0.0	0.1	0.1	1.0	0.1	0.1	0.1	n/a	1.0	1.0	0.1
.sel	(GB)	1.0	n/a	n/a	1.0	0.7	1.0	0.0	1.0	1.2	1.9	1.4	1.0	1.4	n/a	1.2	0.6	1.2
.sta	(MB)	0.2	n/a	n/a	0.2	0.2	0.2	0.0	0.2	0.2	0.2	0.2	0.2	0.2	n/a	0.2	n/a	n/a
.pstrs.rslts	(MB)	109.2	n/a	n/a	n/a	n/a	n/a	0.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
.sed.rslts	(MB)	71.9	n/a	n/a	n/a	n/a	n/a	0.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
.stress.rslts	(MB)	165.2	n/a	n/a	n/a	n/a	n/a	0.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
.von.rslts	(MB)	178.3	n/a	n/a	n/a	n/a	n/a	0.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
command.cmf	(Bytes)	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a	56547	9498	17084	193	n/a
hmmenu.set	(KB)	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a	356	354	355	354	n/a
mac.cmf	(Bytes)	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a	102	102	102	102	n/a
.hm	(Bytes)	n/a	n/a	n/a	n/a	n/a	n/a	0	n/a	n/a	n/a	n/a	n/a	1E+07	n/a	1E+07	n/a	n/a
TOTAL	(GB)	**6.6**	**4.7**	**4.1**	**5.3**	**4.6**	**3.3**	**0.0**	**5.2**	**5.7**	**8.1**	**6.2**	**5.1**	**6.3**	**4.7**	**6.7**	**5.5**	**5.6**
Errors		a, b													c		d, e, f	
																TOTAL	(GB)	87.9

Error Codes				
a	tar: tape read error			
b	did not ask for second tape			
c	tar: directory checksum error (hopefully prevented using i with tar command)	black	backed up on tape	
d	tar: Unexpected EOF on archive file	red	**not** backed up on tape	
e	tar: Error exit delayed from previous errors			
f	tar: Skipping to next file header			

Tapes are labeled with case number, rock mass, rock velocity and tape sequence number. All tapes are dated Dec 2001. A sample label would be:

Case01 0.5 MT 7 m/s 1/2
Dec 2001

6 MAR 2002

The following table summarizes maximum deflection relative to the waste package from Scenario #1 and #2 for the 15 permutations described on page 84 of this scientific notebook. Case16 and Case17 were added to explore the effects of a simply supported base (Case16) and a fixed base (Case17) with the 4000 kg rock at 7 m/s impact velocity. No conclusions are drawn for Case16 and Case17 but they are use to aid the engineers understanding of the drip shield's structural characteristics.

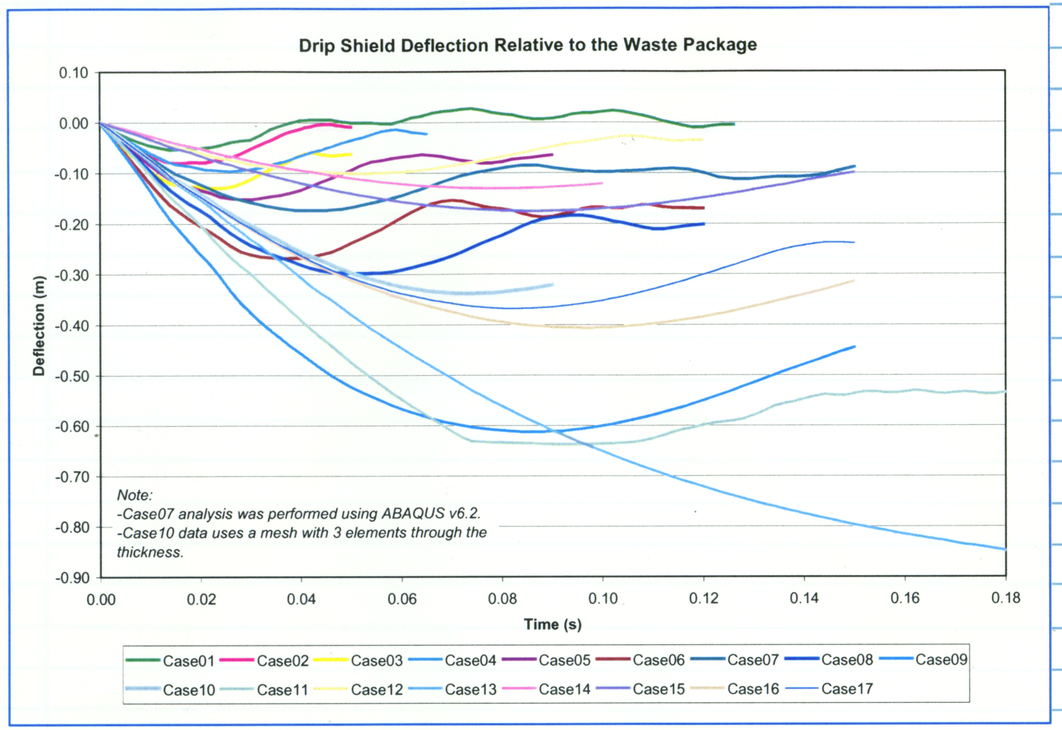
Deflection Comparison Between Scenario #1 and #2				
Case#	Deflection (mm)		% Diff.	Scenario #2 Time (ms)
	Scenario #1	Scenario #2		
1	47.62	54.30	14.0%	14.0
2	77.03	80.30	4.2%	17.0
3	128.64	129.54	0.7%	24.0
4	90.92	96.62	6.3%	26.0
5	146.11	152.89	4.6%	30.0
6	257.21	268.40	4.3%	38.0
7	167.48	173.73	3.7%	42.0
8	284.29	298.40	5.0%	52.0
9	560.24	613.27	9.5%	86.0
10	324.21	338.25	4.3%	73.0
11	592.00	638.30	7.8%	92.0
12	93.63	100.71	7.6%	52.0
~~13*~~	~~592.00~~	~~848.83~~	~~43.4%~~	~~180.0~~
14	118.35	130.47	10.2%	80.0
15	159.57	175.42	9.9%	86.0
16	N/A	406.53	N/A	96.0
17	N/A	172.01	N/A	24.0

* Maximum Deflection not achieved in simulation

A comparison of simulations for Scenario #1 and #2 revealed that Scenario #1 has used an erroneous and non-conservative method to model the physical parameters of the rock block. First, density of the Scenario #1 rock block is modified to increase the mass between permutations while rock block geometry is held constant. In contrast, the Scenario #2 is more realistic because rock block mass is increased by changing the geometric dimensions of the rock block. Second, the Scenario #1 rock block has a very large width when compared to height. In contrast, the Scenario #2 rock block has a square cross section. The large width in Scenario #1 effectively softens the impact on the drip shield. The combined effect is that Scenario #1 deflections are non-conservative and therefore predicted values are too low. It is expected that a Scenario #1 rock fall impact would result in larger deflections relative to the waste package when compared to Scenario #2.

Two considerations differentiate Scenario #1 and Scenario #2. First the rock is expected to fracture when it contacts the stiff section of the bulkhead. Therefore, Scenario #2 is more realistic. Second, the partial rock segment will maximize shear stress in the drip shield plate and induce the earliest onset of stress failure. Therefore, Scenario #2 is more conservative for plate stress. For these reasons Scenario #1 will not be corrected and run again. Scenario #1 data will not be used in further rock block and drip shield impact studies.

The following chart illustrates relative deflection between nodes 123490 and 96965 versus simulation time. The simulated condition is Scenario #2 shown on page 81 of this scientific notebook. Note that Case07 data was generated using ABAQUS version 6.2. This should not affect the results. Also, data for Case10 was not available due to an unknown error in the backup process. Case10 data is reported from a simulation of the same geometry but with a new mesh of 3 elements through the thickness (other data has two through the thickness). The differences in models run with 2 versus 3 elements in the plate thickness show insignificant changes in the deflection profile.



Additional data can be found on CDROM disks.

6 MAR 2002

DJ (4/16/02)

The abstraction methodology described on pages 86 and 87 of this scientific notebook is applied to the determination of maximum deflection (δ), von Mises stress (σ_{vm}), Tresca stress (σ_{tr}) and equivalent plastic strain (PEEQ). MathCAD 2000 (a commercially available symbolic math program) was used to assemble and solve the matrix equations. The table below summarizes the values used for input to the MathCAD worksheet:

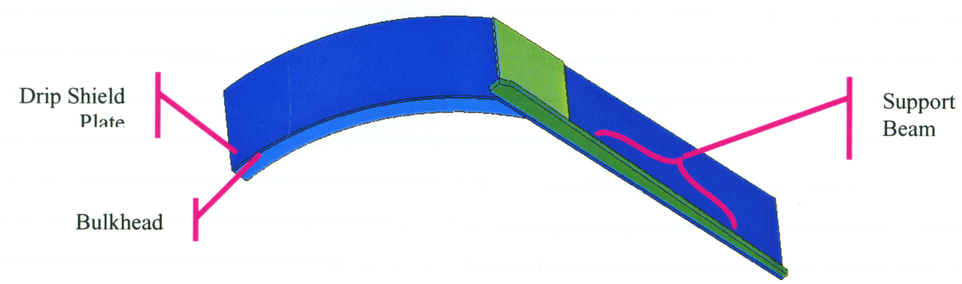
	Drip Shield			Bulkhead			Support Beam		
Case #	Max PEE	Max Mises	Max Tresca	Max PEEQ	Max Mises	Max Tresca	Max PEEQ	Max Mises	Max Tresca
1	0.4%	1.77E+08	2.03E+08	0.6%	6.68E+08	6.71E+08	3.5%	6.11E+08	7.04E+08
2	0.7%	1.78E+08	2.05E+08	1.5%	6.85E+08	6.86E+08	5.2%	6.84E+08	7.63E+08
3	1.2%	1.82E+08	2.10E+08	3.5%	7.25E+08	7.27E+08	0.9%	6.75E+08	7.49E+08
4	5.5%	2.12E+08	2.44E+08	2.5%	7.06E+08	7.07E+08	4.8%	6.89E+08	7.76E+08
5	9.3%	2.38E+08	2.75E+08	4.7%	7.38E+08	7.40E+08	0.4%	6.60E+08	6.92E+08
6	16.2%	2.87E+08	3.27E+08	8.2%	8.12E+08	8.13E+08	1.9%	6.95E+08	7.21E+08
7	12.4%	2.60E+08	2.86E+08	5.7%	7.63E+08	7.65E+08	1.1%	6.61E+08	6.65E+08
8	18.5%	3.00E+08	3.44E+08	8.8%	8.26E+08	8.27E+08	2.3%	7.01E+08	7.56E+08
9	18.9%	3.00E+08	3.42E+08	11.7%	8.27E+08	8.34E+08	4.5%	7.44E+08	7.50E+08
10	3.6%	1.79E+08	2.02E+08	9.6%	8.27E+08	8.28E+08	1.1%	6.79E+08	7.60E+08
11	22.1%	3.00E+08	3.40E+08	22.4%	8.27E+08	9.55E+08	3.0%	7.15E+08	7.21E+08
12	4.7%	2.07E+08	2.34E+08	3.4%	7.21E+08	7.21E+08	0.4%	5.27E+08	5.28E+08
~~13*~~	~~28.5%~~	~~3.00E+08~~	~~3.46E+08~~	~~14.0%~~	~~8.27E+08~~	~~8.39E+08~~	~~6.2%~~	~~7.78E+08~~	~~7.82E+08~~
14	7.6%	2.27E+08	2.62E+08	4.4%	7.41E+08	7.42E+08	0.2%	5.62E+08	5.62E+08
15	13.8%	2.71E+08	3.09E+08	5.9%	7.73E+08	7.73E+08	0.4%	5.94E+08	5.95E+08
~~16*~~	~~11.3%~~	~~2.53E+08~~	~~2.90E+08~~	~~9.5%~~	~~8.27E+08~~	~~8.28E+08~~	~~3.1%~~	~~7.18E+08~~	~~7.33E+08~~
~~17*~~	~~15.5%~~	~~2.82E+08~~	~~3.20E+08~~	~~10.0%~~	~~8.27E+08~~	~~8.30E+08~~	~~2.9%~~	~~7.14E+08~~	~~7.94E+08~~

*** Data not used in abstraction calculations**

The pages 94 and 95 of this scientific notebook illustrate the layout of the calculation sheet for Drip Shield Plate equivalent plastic strain (PEEQ). Stress and strain abstractions are created for each component (Drip Shield Plate, Bulkhead and Support Beam) while one deflection abstraction is performed for the entire Drip Shield. The calculation sheets are archived on CDROM in the files:

Scenario#1and#2Deflection.mcd	deflection abstraction
Scenario#2PEEQAbstraction.mcd	equivalent plastic strain abstractions
Scenario#2SvmAbstraction.mcd	von Mises stress abstractions
Scenario#2StrAbstraction.mcd	tresca stress abstractions

Stress and strain abstractions are based on element output data of select elements from each component (see illustration below). Scripted routines (macros) in ABAQUS/CAE and MS Excel were created to facilitate data processing.



Location of Abstraction Elements

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Mathcad Calculation Sheets for Scenario #2 Drip Shield Maximum Deflection

M := rock mass vector
v := rock velocity at contact vector
d := maximum deflection vector from FEA
A1 := deflection equation matrix
a := coefficients of the deflection equation
d_{max} := deflection equation
$dmax_i$:= correlation vector
err_i := error between equation and FEA

$$M := \begin{pmatrix} 500 \\ 500 \\ 500 \\ 1000 \\ 1000 \\ 1000 \\ 2000 \\ 2000 \\ 2000 \\ 4000 \\ 4000 \\ 4000 \\ 8000 \\ 8000 \end{pmatrix} \quad v := \begin{pmatrix} 7 \\ 9.8995 \\ 14 \\ 7 \\ 9.8995 \\ 14 \\ 7 \\ 9.8995 \\ 14 \\ 7 \\ 9.8995 \\ 2.4749 \\ 1.75 \\ 2.4749 \end{pmatrix} \quad A1 := \begin{bmatrix} M_0 & (M_0)^2 & (M_0)^3 & M_0 \cdot v_0 & M_0 \cdot (v_0)^2 \\ M_1 & (M_1)^2 & (M_1)^3 & M_1 \cdot v_1 & M_1 \cdot (v_1)^2 \\ M_2 & (M_2)^2 & (M_2)^3 & M_2 \cdot v_2 & M_2 \cdot (v_2)^2 \\ M_3 & (M_3)^2 & (M_3)^3 & M_3 \cdot v_3 & M_3 \cdot (v_3)^2 \\ M_4 & (M_4)^2 & (M_4)^3 & M_4 \cdot v_4 & M_4 \cdot (v_4)^2 \\ M_5 & (M_5)^2 & (M_5)^3 & M_5 \cdot v_5 & M_5 \cdot (v_5)^2 \\ M_6 & (M_6)^2 & (M_6)^3 & M_6 \cdot v_6 & M_6 \cdot (v_6)^2 \\ M_7 & (M_7)^2 & (M_7)^3 & M_7 \cdot v_7 & M_7 \cdot (v_7)^2 \\ M_8 & (M_8)^2 & (M_8)^3 & M_8 \cdot v_8 & M_8 \cdot (v_8)^2 \\ M_9 & (M_9)^2 & (M_9)^3 & M_9 \cdot v_9 & M_9 \cdot (v_9)^2 \\ M_{10} & (M_{10})^2 & (M_{10})^3 & M_{10} \cdot v_{10} & M_{10} \cdot (v_{10})^2 \\ M_{11} & (M_{11})^2 & (M_{11})^3 & M_{11} \cdot v_{11} & M_{11} \cdot (v_{11})^2 \\ M_{12} & (M_{12})^2 & (M_{12})^3 & M_{12} \cdot v_{12} & M_{12} \cdot (v_{12})^2 \\ M_{13} & (M_{13})^2 & (M_{13})^3 & M_{13} \cdot v_{13} & M_{13} \cdot (v_{13})^2 \end{bmatrix} \quad d := \begin{pmatrix} 54.30 \\ 80.30 \\ 129.54 \\ 96.62 \\ 152.89 \\ 268.40 \\ 173.73 \\ 298.40 \\ 613.27 \\ 338.25 \\ 638.30 \\ 100.71 \\ 130.47 \\ 175.42 \end{pmatrix}$$

$$a := \left(A1^T \cdot A1\right)^{-1} \cdot A1^T \cdot d \qquad a = \begin{pmatrix} 7.720 \times 10^{-3} \\ 3.402 \times 10^{-6} \\ -3.544 \times 10^{-10} \\ 1.041 \times 10^{-4} \\ 1.443 \times 10^{-3} \end{pmatrix}$$

$$d_{max}(Mass, Vel) := a_0 \cdot Mass + a_1 \cdot Mass^2 + a_2 \cdot Mass^3 + a_3 \cdot Mass \cdot Vel + a_4 \cdot Mass \cdot Vel^2$$

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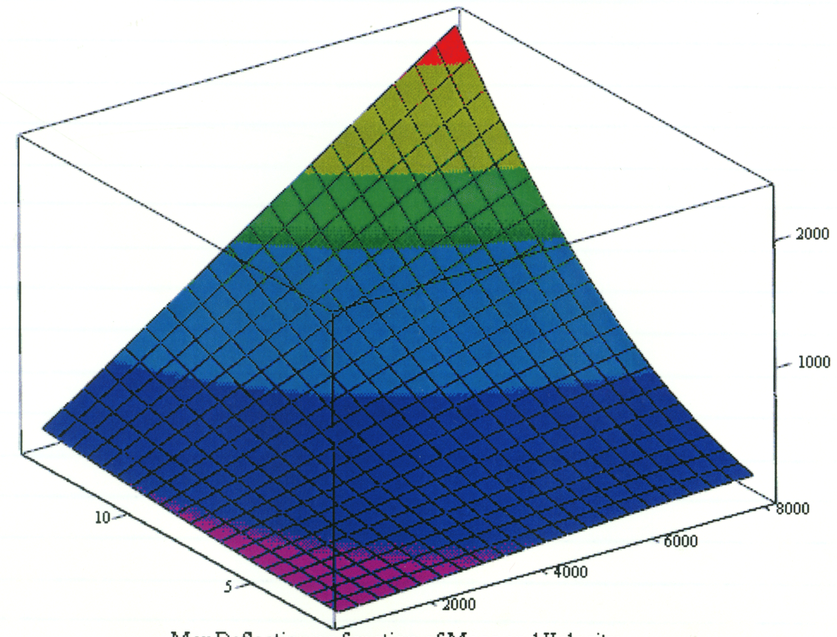

Max Deflection as function of Mass and Velocity

$$i := 0..13 \qquad dmax_i := a_0 \cdot M_i + a_1 \cdot (M_i)^2 + a_2 \cdot (M_i)^3 + a_3 \cdot M_i \cdot v_i + a_4 \cdot M_i \cdot (v_i)^2$$

$$diff_i := dmax_i - d_i \qquad err_i := \frac{(dmax_i - d_i)}{d_i}$$

d =

	0
0	54.30
1	80.30
2	129.54
3	96.62
4	152.89
5	268.40
6	173.73
7	298.40
8	613.27
9	338.25
10	638.30
11	100.71
12	130.47
13	175.42

dmax =

	0
0	40.38
1	75.89
2	146.81
3	82.20
4	153.21
5	295.06
6	169.09
7	311.11
8	594.79
9	348.38
10	632.42
11	99.02
12	134.87
13	170.83

diff =

	0
0	-13.92
1	-4.41
2	17.27
3	-14.42
4	0.32
5	26.66
6	-4.64
7	12.71
8	-18.48
9	10.13
10	-5.88
11	-1.69
12	4.40
13	-4.59

err =

	0
0	-25.63
1	-5.49
2	13.33
3	-14.92
4	0.21
5	9.93
6	-2.67
7	4.26
8	-3.01
9	3.00
10	-0.92
11	-1.68
12	3.38
13	-2.61

%

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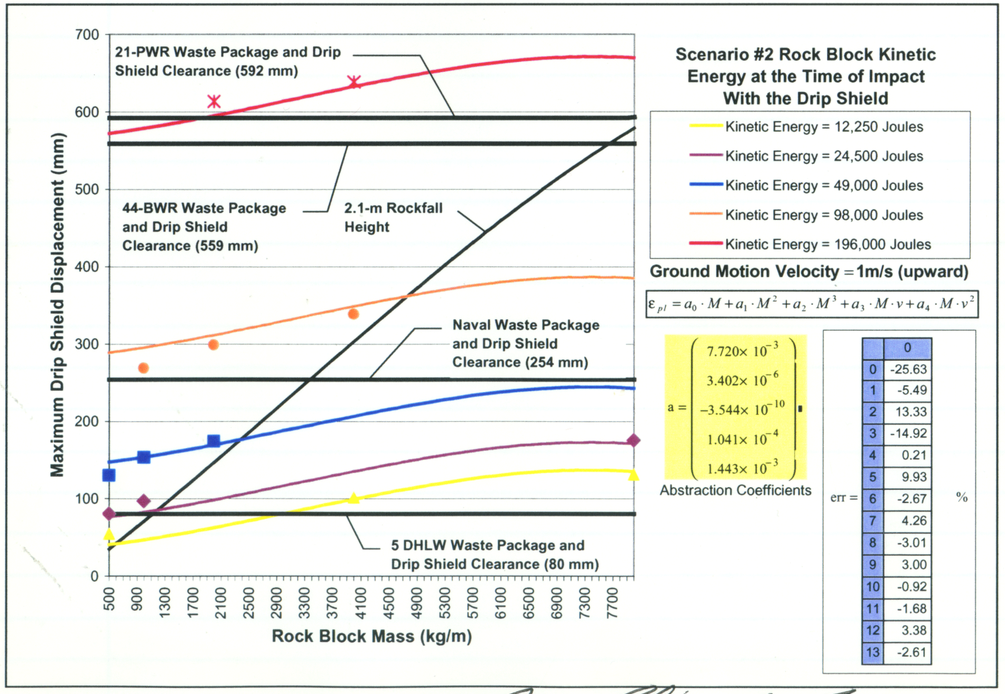
The following figures summarize each abstraction. Case13 is not included any these calculations because the drip shield buckles under this load and maximum deflection is not achieved. Case16 and Case17 are for information only. The abstraction formulation was change for PEEQ, σ_{vm} and σ_{tr} to gain a better match. In addition, the cases where failure stress was exceeded were excluded from calculation because the perfectly plastic post yield behavior makes the abstraction discontinuous. Each figure below indicates the actual formula used as well as the abstraction coefficients. Also, the percent error of the abstraction calculation versus FE data is indicated. The data correlates to case values according to the table below. Finally, the abstractions for the support beam are shown but will never be used because noisy FE data prevents an accurate abstraction. This is not a concern because Support Beam stresses are well below failure for all simulations used for abstraction.

Position in MathCAD Formula	Deflection Case Number	Stress and Strain Case Number
0	1	1
1	2	2
2	3	3
3	4	4
4	5	5
5	6	6
6	7	7
7	8	12
8	9	14
9	10	15
10	11	n/a
11	12	n/a
12	14	n/a
13	15	n/a



	0
0	-25.63
1	-5.49
2	13.33
3	-14.92
4	0.21
5	9.93
6	-2.67
7	4.26
8	-3.01
9	3.00
10	-0.92
11	-1.68
12	3.38
13	-2.61

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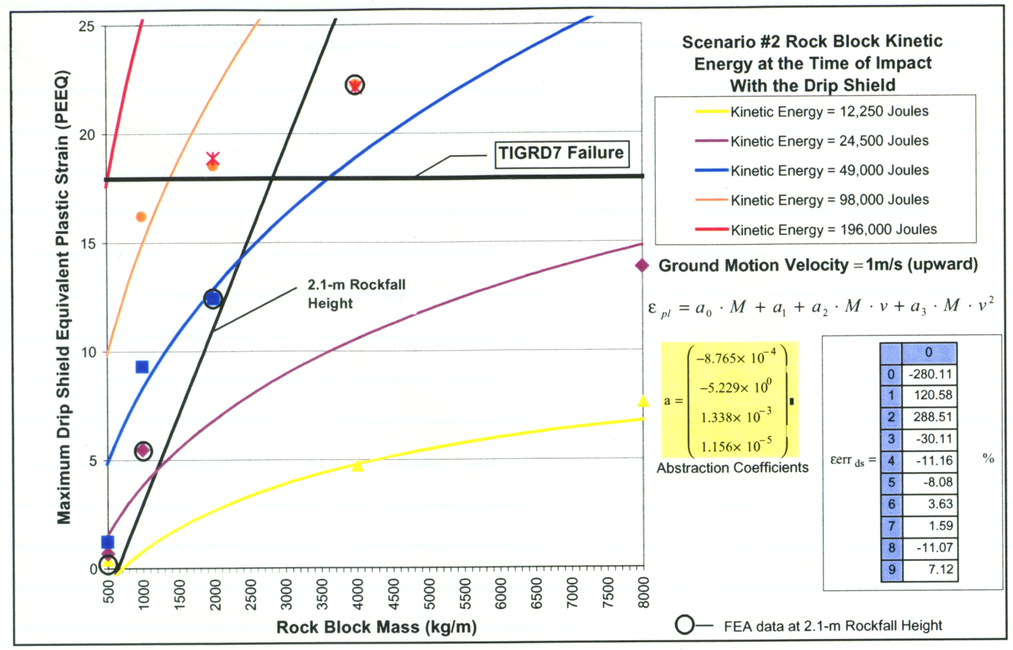
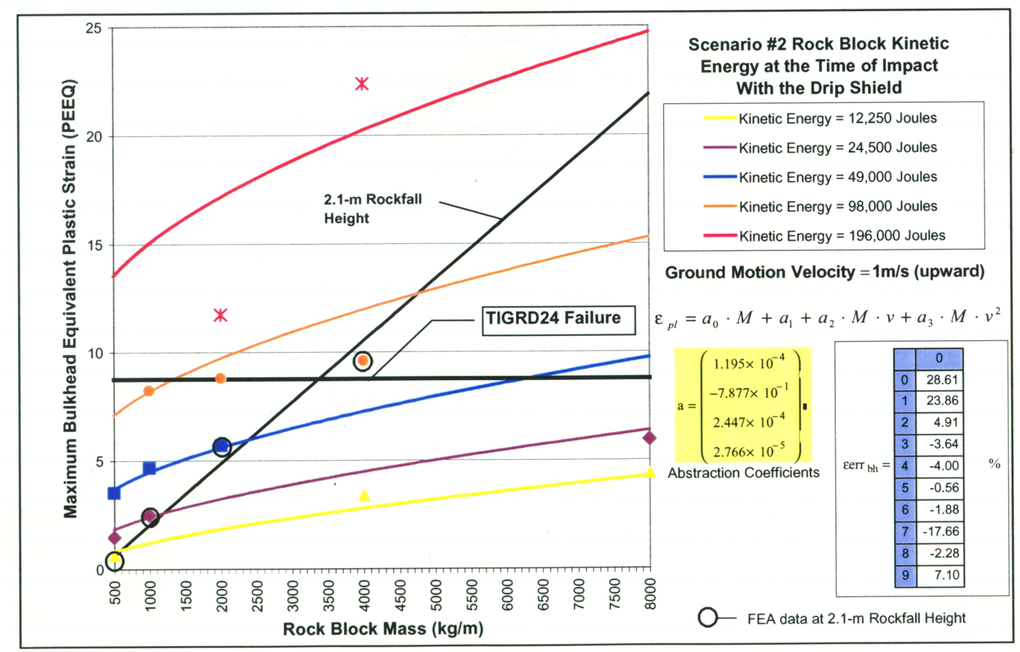
PEEQ failure lines are total (log normal) plastic strain.



	0
0	-280.11
1	120.58
2	288.51
3	-30.11
4	-11.16
5	-8.08
6	3.63
7	1.59
8	-11.07
9	7.12

Drip Shield and Bulkhead PEEQ abstractions show good correlation, especially at the failure line.



	0
0	28.61
1	23.86
2	4.91
3	-3.64
4	-4.00
5	-0.56
6	-1.88
7	-17.66
8	-2.28
9	7.10

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