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ON THE NATURE OF THE RESPONSE OF THE GENERAL PURPOSE HEAT SOURCE TO THE IMPACT OF LARGE SOLID ROCKET MOTOR CASING FRAGMENTS

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ON THE NATURE OF THE RESPONSE OF THE GENERAL PURPOSE HEAT SOURCE TO THE IMPACT OF LARGE SOLID ROCKET MOTOR CASING FRAGMENTS

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The General Purpose Heat Source (GPHS) was developed by U.S. Department of Energy (DOE) personnel and their contractors to provide a safe and mass efficient method of packaging the radioactive isotope Pu-238 for use in space power systems. The characteristics of this heat source and its development history are well documented in numerous reports and papers and will not be revisited here.

Most of the GPHS Safety Verification Tests (SVT) focused on demonstrating the ability of the modules to survive launch abort explosions and fires, reentry heating, and post-reentry impact on rigid surfaces. The Challenger (STS-51L) accident demonstrated that Solid Rocket Motor (SRM) casing failure could produce large, high velocity, fragments. At the time of the accident, the ability of the GPHS modules to withstand impacts of fragments of this caliber and velocity had not been demonstrated either by analysis or test. Once the magnitude of this problem was assessed, DOE management initiated a program to determine the response of the GPHS-RTG to the impact of SRM casing fragments of the type and velocity witnessed in the 51L event[(1),(2)]. This program required the designers to use analysis and test in a serial manner to make the best use of the available hardware and test facilities. Using existing gas gun facilities, the maximum velocity at which Pu-238 fueled capsules could be tested in a constrained module configuration was 120 m/s. The maximum fragment size which could be tested was 30.5 × 40.6 cm. The 51L event showed that SRM quadrant sized fragment having velocities of approximately 200 m/s were generated at a Mission Elapsed Time (MET) of 110 seconds. The rocket sleds which were available to test fragments of this size were not in contained facilities; hence, they could not be used to test Pu-238 fueled modules.

The subject of this paper is the process used to perform macro calibrations of analytical models and their application to predict the GPHS modules' response to serially increasing levels of test

Table 1. Summary of Material Properties Used in the SRM Fragment Impact Analyses

MATERIAL	EQUATION OF STATE						YIELD MODEL				DATA SOURCE
	TYPE	(a)	BULK MODULUS KBAR	Y1 KBAR	Y2 KBAR	REF. DENSITY (ρo) gm/cc	TYPE	SHEAR MODULUS KBAR	YIELD STRENGTH KBAR	SPALL STRENGTH KBAR	
WEAK PLUTONIA (PU2H6H)	P-α	0.84	730.	0.677	1.33	11.5	VON MISES	270.	0.677	0.200	LOS ALAMOS DATA SHEETS MAY 1986
STRONG PLUTONIA (PU4H13H)	P-α	0.84	730.	1.30	1.33	11.5	VON MISES	270.	1.30	0.400	
WEAK URANIA (U6H11H)	P-α	0.87	1370.	1.10	1.22	11.0	VON MISES		1.10	0.600	LOS ALAMOS DATA SHEETS MAY 1986
STRONG URANIA (U8H12H)	P-α	0.87	1370.	1.20	1.22	11.0	VON MISES	598.	1.20	0.800	
POCO GRAPHITE	POLY-NOMIAL	-	301.			1.98	VON MISES	20.	0.50	1.0	W.W. TARBELL (1979)
3-D GRAPHITE	SHOCK	-	25.9			1.95	VON MISES	20.	1.00	1.0	AFWL-TR-79-38
IRIDIUM	POLY-NOMIAL	-	3510.			22.5	VON MISES	1618.	2.00	1000.	ORNL-5611 APRIL 1980 (c) FSAR GESP 7200 AUGUST 1985
INSULATION-T/E	P-α	0.59	8.9			0.90	VON MISES	6.7	1.00	0.1	GE MEMO (b) C.J. EARDLEY 1/7/88
ALUMINIUM	POLY-NOMIAL	-	765.			2.77	VON MISES	294.0	6.50	1000.	BAKKEN & ANDERSON, SANDIA
D6A STEEL	POLY-NOMIAL	-	1670.			7.86	VON MISES	816.0	12.9	1000.	LADISH DATA SHEET FSCM # 07703 (1987)

(a) $\alpha = \frac{\text{DENSITY OF UNCOMPACTED MATERIAL}}{\text{DENSITY OF COMPACTED MATERIAL}}$

(b) DERIVED FROM EXPERIMENTS CONDUCTED AT GE AND MODIFIED BY FSC PERSONNEL TO ACCOUNT FOR THERMOELECTRIC ELEMENT INITIAL COMPRESSIVE STRENGTH

(c) YIELD CORRECTED FOR THE BIAXIAL TENSION CREATED BY THE ALMOST SPHERICAL NATURE OF THE IRIDIUM SHELL.

environment complexity. The first step in this process was to develop a set of material constituative equations for plutonia and urania which would bracket the results obtained from the planned experiments. Table 1 shows the material properties used in the subsequent analyses. The terms "weak" and "strong" describe the material property sets which provided upper and lower bounds to the capsule deformation response observed in the experimental program. The protocols for the experimental program required that an analytical prediction be made prior to performing a test. As a result, with the exception of the 54 m/s Bare Capsule Impact (BCI) test series, the authors made their analytical predictions before they knew the corresponding experimental results. This was purposely done to provide a single blind experiment.

A comparison of the analytical and experimental results for the impact of a bare GPHS urania fueled capsule on a 2.54 cm thick steel target is shown in Figure 1. The geometric time history of the impact of a urania-fueled capsule with an initial velocity of 76 m/s on a 2.54 cm thick steel target is shown in Figure 2. Comparisons of the predicted and measured end-point geometry of the event shown in Figure 2 are presented in Figure 3 for the urania fuel and Figure 4 for the plutonia fuel. This agreement was considered adequate for the required purposes and the calibration exercise moved to the next level of complexity.

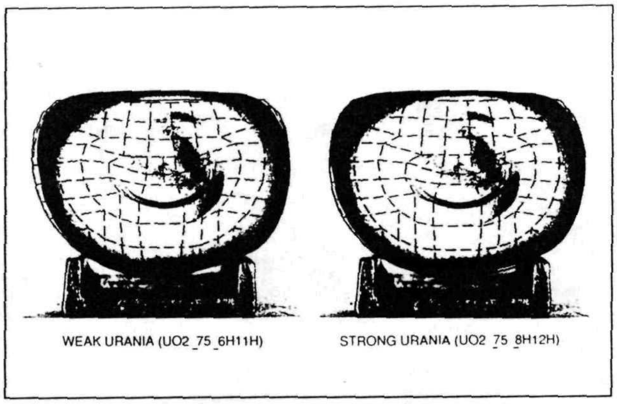

Figure 1. **Effect of Simulant Properties on the Predicted Post Impact Geometry Resulting from a Urania Fueled-Capsule Impact on a 2.54 cm Steel Target at 75 m/s in the BCI Geometry**

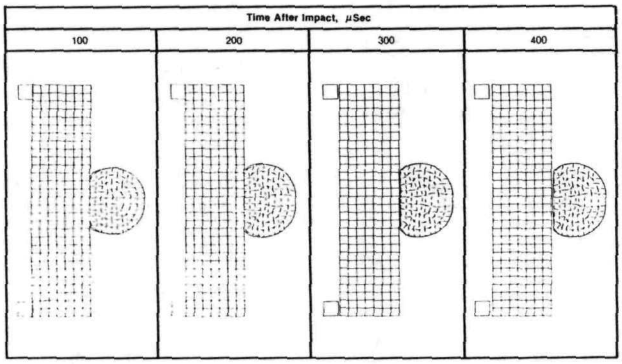

Figure 2. **Predicted Response of a Urania-Fueled Capsule in the BCI 21 Event (76 m/s 2.54 cm Thick Steel Target)**

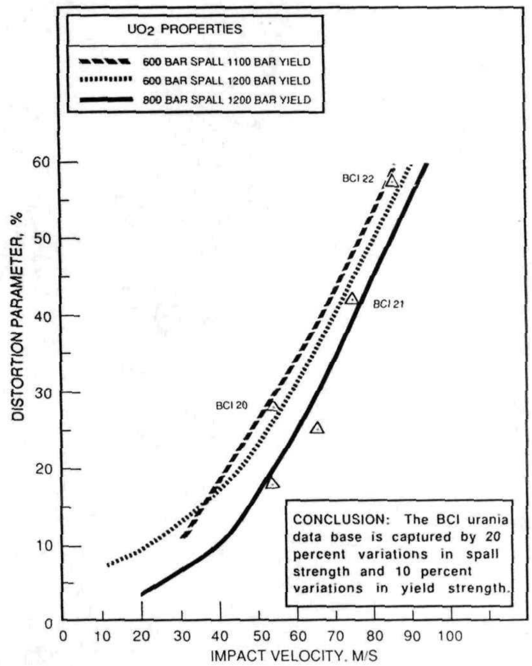

Figure 3. **Bare Urania-Fueled Capsule Response to Impact on a 2.54 cm Thick Steel Plate (BCI Geometry)**

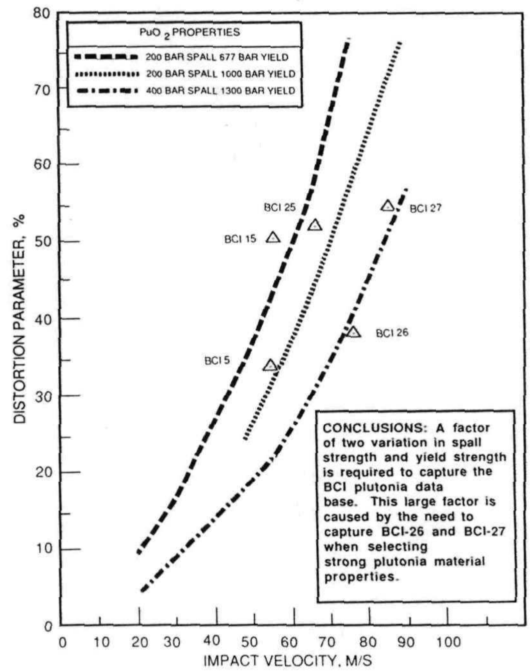

Figure 4. **Plutonia-Fueled Bare GPHS Capsule Response to Impact on a 2.54 cm Thick Steel Target (BCI Geometry)**

The Fragment Gun Tests (FGT) were performed in the same closed facility at Los Alamos National Laboratory (LANL) which was used for the BCI tests. Both urania and plutonia were used in this series as was the case in the BCI series. The accelerated test article consisted of a prototypical urania or plutonia fueled module sandwiched between two module mass simulants (molybdum in POCO graphite), a simulated thermoelectric insulation package and a simulated generator housing section. This assembly was fired into a 30 × 40 cm section of an STS-SRM casing at 100 and 120 m/s. A comparison of predicted and observed fueled capsule distortion resulting from the FGT environment is shown in Figure 5. A predicted geometric time-history of a plutonia fueled GPHS module assembly of the type described above impacting at 100 m/s is shown in Figure 6. A comparison of the observed and predicted (weak plutonia) post-impact geometries from FGT-2 is shown in Figure 7. Based on the above, the model was judged calibrated and was then used to predict the results of the planned Large Fragment Tests (LFT).

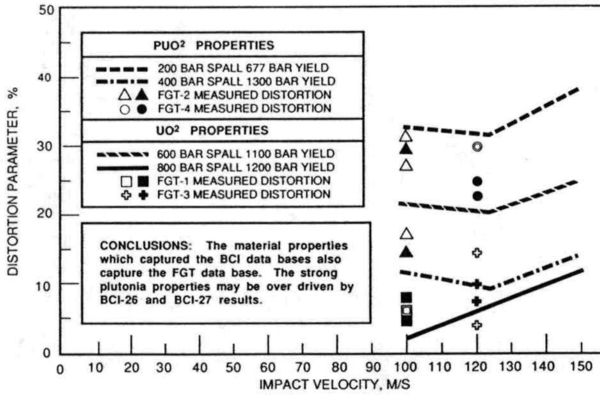

Figure 5. Effect of Fuel Properties, Impact Velocity, and Target Thickness on Predicted Forward GIS Fueled Capsule Deformation in FGT-Type Events

The LFT test article could not be fueled since no contained facility which could accommodate the required fragment size and provide the required fragment velocity was available. Because of this, analysis was used to connect the expected plutonia response to the observed urania response. A model of the type shown in Figure 8 was devised to represent the test article used in the LFT. The test article in this case was a 1/2 length section of the GPHS engineering test unit. This unit was impacted with a 142 × 142 cm square section of STS-SRM casing at 115 and 212 m/s. The results of these and the previously described tests are summarized in Table 2. Typical

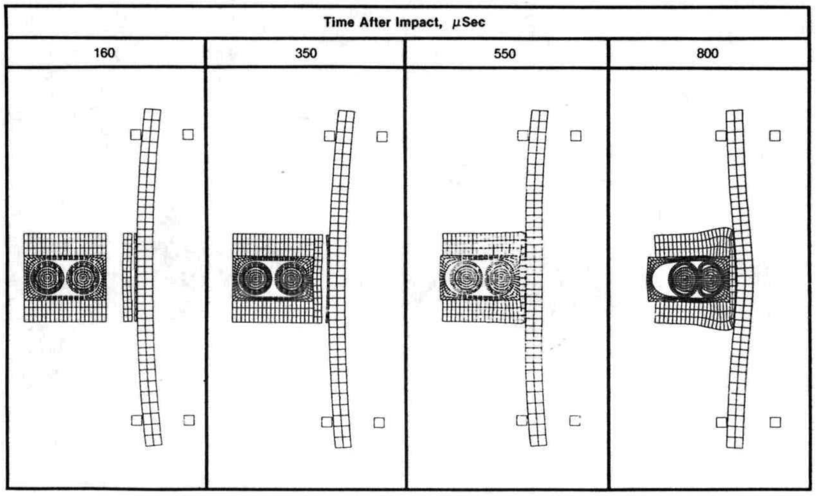

Figure 6. Predicted Response of the FGT-2 Stack to Impact at 100 m/s on a 30 × 40 × 1.26 cm D6A Steel Target

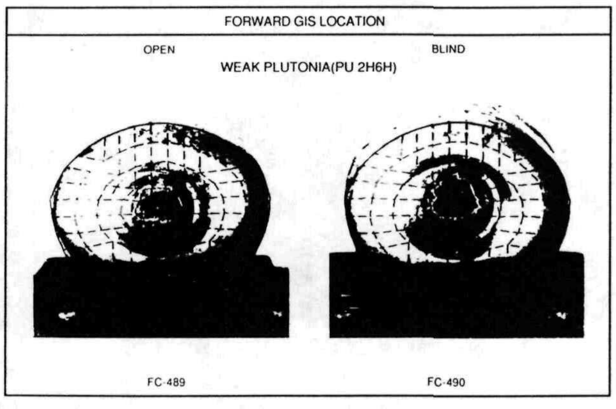

Figure 7. Comparison of Predicted and ObservedPost FGT-2 Impact Fueled-Capsule Geometry (100 M/S On a 30 × 40 × 1.26 cm D6A Steel Target, Weak Plutonia)

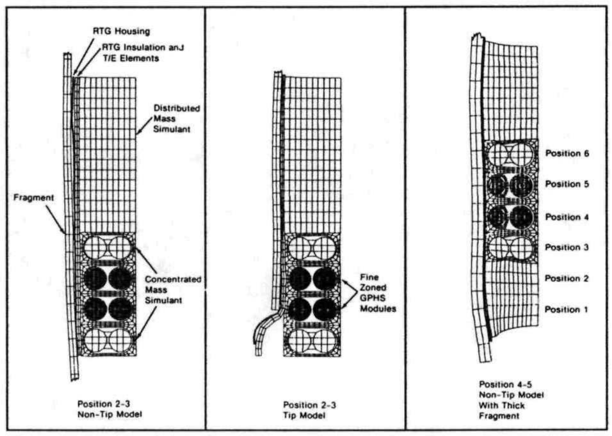

Figure 8. Models Used in Developing the SRM Fragment Data Base

agreement obtained between predicted and observed results is shown in Figure 9 and Figure 10. It should be noted that simple extrapolation of the 120 m/s FGT results would have produced very different answers than were predicted for the LFT results. The serial predictor/corrector approach used by the experimentalists and analysts was critical to obtaining the maximum possible information from the available hardware and facilities. It is hoped that the predictive power of analysis is found useful in selecting test conditions for future programs.

Table 2. Summary of the Large Fragment Test (LFT) Results[3]

FORWARD CAPSULE RESPONSE TO LFT EVENTS								
Stack Position 2								
IMPACT VELOCITY	115				212			
LOCATION	STRAIN				STRAIN			
	DIAMETER %	HEIGHT %	LENGTH %	PARAMETER %	DIAMETER %	HEIGHT %	LENGTH %	PARAMETER %
OPEN VENT CUP	0.9	−2.9	1.0	3.9	1.3	−10.8	10.3	13.5
OPEN SOLID CUP	0.9	−2.1		3.1	1.3	−11.2		14.0
BLIND VENT CUP	0.2	−2.6	0.6	2.9	.6	− 9.1	8.1	6.0
BLIND SOLID CUP	0.9	−2.3		3.2	—	—	—	—
Stack Position 5								
OPEN VENT CUP	2.9	−2.8	2.0	5.9	.3	− 8.5	4.3	9.7
OPEN SOLID CUP	3.1	−2.8		6.1	.9	− 3.4		4.4
BLIND VENT CUP	2.8	−4.9	1.8	8.2	.6	− 4.3	8.4	7.0
BLIND SOLID CUP	2.2	−2.1		4.4	.3	− 4.3		4.8
AFT CAPSULE RESPONSE TO LFT ENVIRONMENT								
Stack Position 2								
OPEN VENT CUP	2.9	−1.5	2.1	4.4	0.1	− 1.8	−1.1	1.9
OPEN SOLID CUP	2.6	−5.7		8.8	−0.1	− 2.4		2.4
BLIND VENT CUP	0.3	−0.6	−1.3	0.9	0.9	− 2.6	0.2	3.7
BLIND SOLID CUP	0.2	−1.3		1.5	0.6	− 3.2		4.0
Stack Position 5								
OPEN VENT CUP	0.6	−0.1	0.9	1.6	0.7	− 2.6	0.0	3.4
OPEN SOLID CUP	0.8	−2.6		3.6	1.0	− 3.1		4.2
BLIND VENT CUP	0.4	−0.6	−0.7	1.0	0.5	− 2.3	−0.9	2.9
BLIND SOLID CUP	0.3	−0.9		1.1	0.9	− 3.3		4.3

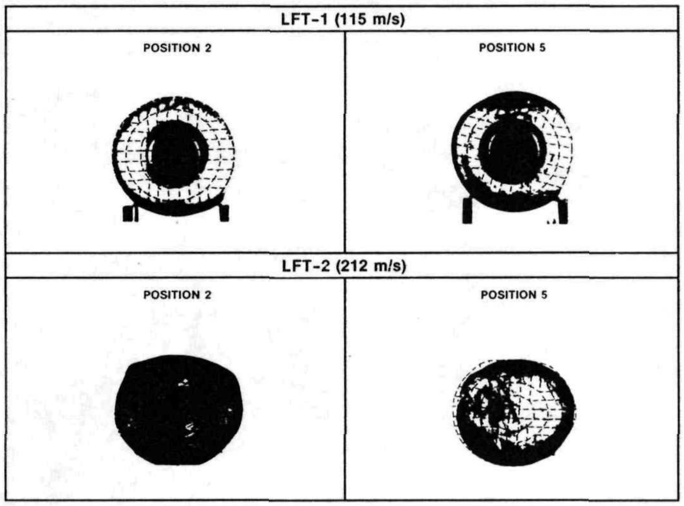

Figure 9. Forward Capsule Post Impact Geometry for the LFT-1 and LFT-2 Events

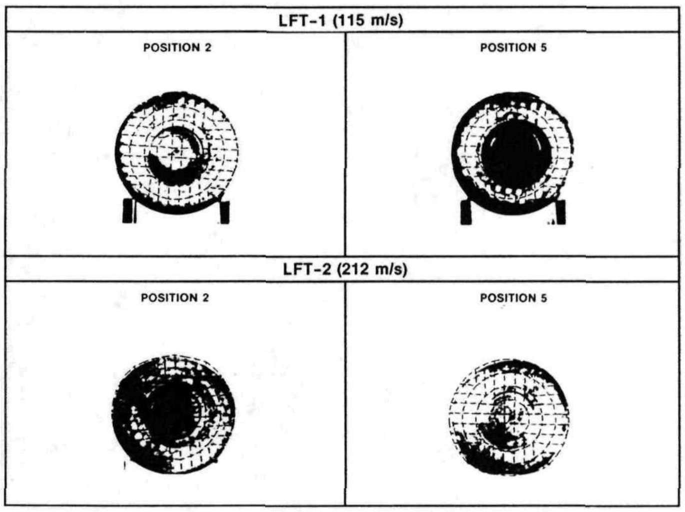

Figure 10. Aft Fueled Clad Post Impact Geometry for the LFT-1 and LFT-2 Events

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