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SOLID PROPELLANT BEHAVIOR IN RADIOISOTOPE POWER SYSTEMS ACCIDENT SEQUENCE MODELING. D. J. Clayton[1], G. M. Lucas[2], [1]Sandia National Laboratories, Mail Stop 0747, P.O. Box 5800, Albuquerque, New Mexico 87185. djclayt@sandia.gov. [2]Sandia National Laboratories, Mail Stop 0747, P.O. Box 5800, Albuquerque, New Mexico 87185. glucas@sandia.gov.

Introduction: An extensive safety analysis is required to launch a radioisotope power system (RPS) into space. Due to the hazardous material that can be released during a launch accident, the potential health risk of an accident must be quantified. Threatening environments that result from a launch accident can be severe and complicated. Accidents are generally initiated by a flight destruct explosion which effectively spreads out the liquid rocket propellant and breaks the solid rocket boosters (SRBs) into smaller pieces. Large pieces of solid propellant can still remain and they could impact or land near the RPS.

The sequence of a launch accident is modeled using the Launch Accident Sequence Evaluation Program (LASEP) [1]. LASEP evaluates all potential threats to the RPS during the launch accident. The simulation starts with an Accident Initiating Condition and continues through in-air blast environments, fragment fields, ground impact, subsequent debris and fragment insults, and solid propellant fragment fires. This paper focuses on solid propellant modeling within the launch safety analysis.

Solid Propellant Modeling: Many launches incorporate SRBs, and the high-temperature fires from the solid propellant fragments can vaporize some of the RPS fuel and increase mission risk. The solid propellant fire model in LASEP evaluates the effects of solid propellant fragments that land within a defined distance from the RPS. This distance is typically five fragment radii. So the larger a fragment is, the further away it can be and still be evaluated as a threat.

Observations from accident videos have enabled a closer look into the solid propellant processes that occur during a launch accident. In the baseline model [2], the masses of the solid propellant fragments are modeled using a lognormal distribution. Recent analyses indicate that a normal distribution of masses may be more appropriate [3]. Furthermore, the baseline model assumed that once the solid propellant fragments impact the ground, they remain in place and burn. Observations from accidents, however, show secondary fragmentation of the faster, larger pieces upon impact. These alternative models were implemented in the LASEP code.

In this paper, two alternatives are evaluated with respect to the effect on the accident source term: 1) use of a normal distribution for the solid propellant fragments instead of the lognormal mass distribution; and 2) the effect of including the secondary fragmentation process. Overall, solid propellant ground impacts and fires are high consequence, low probability events. Hence, changes to the solid propellant modeling are only observed in the high consequence, low probability portion of the source term complementary cumulative distribution function (CCDF). The CCDF displays the total probability of exceeding a given source term value. Releases are shown as normalized effective mass. The effective mass is the mass of particles with less than a 10-μm physical diameter released. The effective mass is important due to the respirability of the particles. The effective mass was then normalized to the total inventory for comparison purposes.

Fragment Distribution. The normal distribution of fragment masses is based upon a cube with the dimensions of the web-thickness of the solid propellant motor. As solid propellant is a relatively "weak" material, fragments with larger aspect ratios (e.g. 10 to 1) are hard to maintain in the explosion. The total energy available to generate fragments is limited which reduces the potential to generate thousands of tiny fragments. A normal distribution centered on a web-thickness cube appears to capture these qualities of the solid propellant mass distribution.

Figure 1 shows the CCDF of the normalized effective mass released for the baseline case which utilizes a lognormal distribution for the solid propellant fragments and the case using a normal distribution.

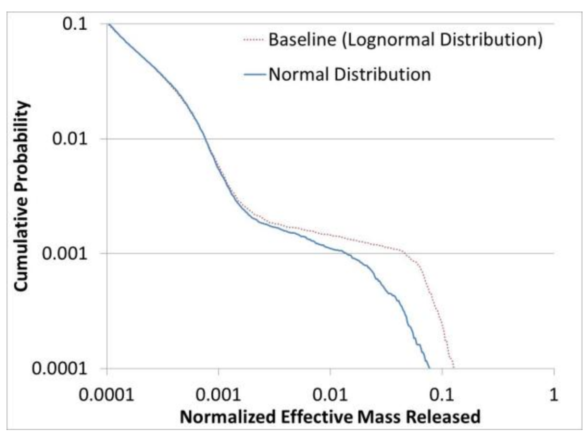

Figure 1. Comparison of Source Term CCDF for Lognormal and Normal Solid Propellant Fragment Distributions

As seen in Figure 1, the effective mass released is lower using a normal distribution compared with a lognormal distribution. In general, the larger releases are due to larger solid propellant fragments. The number of larger aspect ratio fragments is reduced in the normal distribution, which in turn reduced the low probability, high releases seen in the baseline case. Another effect of using the normal distribution is that it reduces the total number of fragments by removing the thousands of tiny solid propellant fragments, which in turn reduces the total computation time required for the calculation.

Secondary Fragmentation. To include secondary fragmentation into the calculations, a model of the behavior of solid propellant fragment ground impacts was implemented into the LASEP code. In the secondary fragmentation model, the yield from the solid propellant fragment ground impact is calculated from 1) the mass and velocity of the primary solid propellant fragment, and 2) the impacting surface type. This is done through the use of an empirical correlation that was developed from the analysis of solid rocket motor impacts, which includes a minimum impact velocity cutoff. Observations of solid propellant ground impacts during launch accidents show that the slower fragments did not fragment upon impact. The ground impact data also show that the minimum impact velocity cutoff value is surface dependent. Lower velocities show secondary fragmentation on "hard" surfaces with no secondary fragmentation on "soft" surfaces.

Once the explosive yield of the solid propellant impacting the ground has been determined, the properties of the secondary fragments can be established. The masses of the resulting secondary fragments are assumed to be of a lognormal distribution with a cumulative total equal to the primary fragment mass. The explosion imparts velocity to the secondary fragments, which travel from the point of impact in any direction. The secondary fragment trajectories are calculated and any secondary fragments that are within the five fragment radii distance of the RPS are subsequently used to determine a potential release. Furthermore, if a solid propellant fragment explodes near the RPS, the resulting blast wave from the ground impact is calculated. The overpressure decreases with increasing distance from the point of impact.

Figure 2 shows the CCDF of the normalized effective mass releases for the baseline case and the case which incorporates secondary fragmentation. As seen in Figure 2, the normalized effective mass decreased for the secondary fragmentation case in the range between 0.001 and 0.1 compared to the baseline case. In general, secondary fragmentation reduced the larger primary fragments into smaller fragments which appears to have decreased the probability of a high release. The increase in release at the low probability is due to the additional effect of the secondary fragmentation blast, which was not included in the modeling for the baseline case.

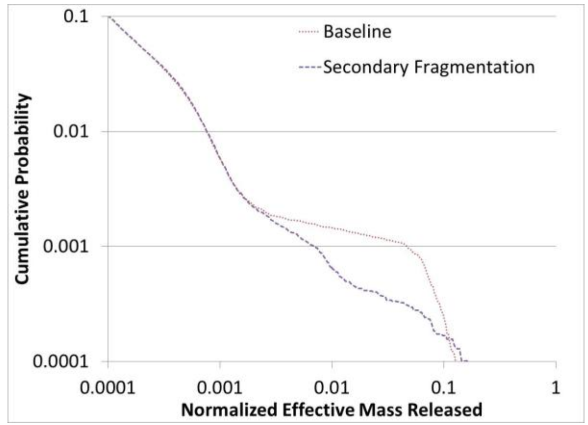

Figure 2. Comparison of Source Term CCDF with and without Secondary Fragmentation

Conclusions: Large pieces of solid propellant can impact or land near the RPS. Observations from accident videos have enabled an improved approach to the solid propellant modeling. The effects on the accident source term of using a normal distribution for the solid propellant fragment masses and including the secondary fragmentation process were analyzed. Using a normal distribution and including secondary fragmentation lowered the normalized effect mass released. Including these changes to the solid propellant modeling into the source term analysis allows the calculation to reflect observations from accident videos.

References:

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