RESULTING SOURCE TERM FROM THE MARS SCIENCE LABORATORY SAFETY ANALYSIS.

D. J. Clayton[1], G. M. Lucas[2], and T. E. Radel[3], [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. [3]Madison, WI 53701. teradel@yahoo.com.

Introduction: The National Aeronautics and Space Administration's (NASA's) Mars Science Laboratory (MSL) Project plans to send a rover to the surface of Mars with a launch in the fall of 2011. The MSL mission is being designed to conduct a Mars habitability investigation, with habitability defined as the "capacity of the environment to sustain life" (i.e., the potential of a given environment to support life at some time, past or present). The MSL rover design uses a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) to provide continuous power on the Martian surface. The MMRTG will be provided by the U.S. Department of Energy (DOE) and contains 4.8 kg of plutonium-238 (Pu-238). Due to the radioactive material in the MMRTG and the potential for accidents involving some of its release to the environment, safety is an inherent consideration in all steps from mission design through launch.

Safety Analysis: The DOE is responsible for quantifying the risks associated with potential launch accidents through a Safety Analysis Report, prepared in accordance with DOE Directives and a formal Launch Approval Process subject to the requirements of Presidential Directive/National Security Council Memorandum 25. An updated Final Safety Analysis Report was prepared for the MSL launch. A summary of the results of the source term analysis from the updated Final Safety Analysis Report are presented here.

The risk analysis considers those accidents that can occur from the time of MMRTG attachment to the spacecraft through spacecraft injection into the interplanetary trajectory. The analysis is separated into phases to aid in the calculation setup and the subsequent assessment. The Prelaunch phase begins once the MMRTG is installed on the spacecraft and ends at launch. The Early Launch phase begins at launch and ends once the spacecraft has reached an altitude such that there is no potential for land impact. Next, the Late Launch phase ends once the spacecraft has reached an altitude of 100,000 ft. Subsequently, the Suborbital phase continues until the end of the first stage burn. After the end of the first stage burn, the Orbital phase lasts until spacecraft separation. The Long Term phase includes the possibility of reentry into Earth's atmosphere if the spacecraft does not land on Mars and continues in an Earth orbit crossing trajectory. During these phases, potential accidents could lead to damage of the MMRTG and its components by overpressure, fragment impact, ground impact, or thermal environments.

The variability in the time and strength of the explosion or fires, along with the variability in the response of the MMRTG to the overpressure, fragment impact, ground impact, and thermal environments, require a probabilistic approach to response modeling. Whenever a value is required for a quantity, which has a probability distribution, a random number distributed according to that probability distribution is generated and used. The simulation is repeated thousands of times for each accident scenario. The set of results from all the repetitions (trials) provides probability distributions of the possible outcomes for each accident scenario.

This simulation process is embodied in a computer code entitled the Launch Accident Sequence Evaluation Program (LASEP). [1] This code consists of a number of subroutines, which calculate the effects of various damaging environments (e.g., explosion blast, fragment collision, ground collision, and fire) on the fueled clads. As events occur, the accident environment is determined and the resulting damage to the fueled clads is calculated.

Modeling Results: A summary of the launch accident source term by mission phase is provided in Table 1. The mean accident probability is the sum of the mean probability of the various accident scenarios for each mission phase. The release probability represents the conditional probability that, given a failure, a release of Pu-238 will occur. The total probability is calculated as the product of the mean accident probability and release probability. The mean total mass is the mean mass released, given that a release occurs. The mean effective mass is the mean mass of particles with less than a 10-µm physical diameter that were released. The effective mass is important due to the respirability of the particles.

As seen in Table 1, the total mission probability of an accident that could influence Earth population or environment is 0.031. The total mission probability of release is 0.0032 and the mean release for the mission is about 7.3 g of Pu-238 out of a total of 4.8 kg. The largest total probability of release and mean release occur for the Early Launch phase. The Early Launch phase is the most significant contributor to the source term. Figure 1 provides the source term complementary cumulative distribution functions (CCDFs) for the launch accidents, grouped by mission phase. Figure 1 also shows how the Early Launch phase dominates the overall potential for release. The Long Term and Late Launch phases are relatively insignificant compared with the total mission.

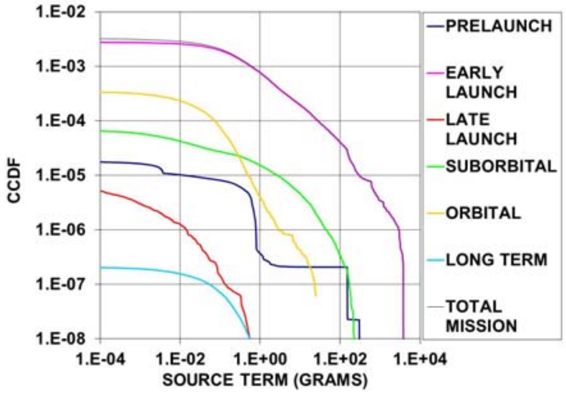

Figure 1. CCDF of Source Term by Mission Phase

Table 2 summarizes the source of the launch accident releases for each phase, by displaying the fraction of the total release that results from each type of release shown in the table. As seen in Table 2, overpressure releases are relatively minor compared with other sources. The dominate release for the Early Launch, Suborbital, Orbital and Long Term phases is ground impact releases. As the spacecraft is over water during the Late Launch phase, ground impacts are not possible and hence do not contribute to the release for that mission phase. The Prelaunch phase has very few ground impact releases because of the short distance to the ground before the spacecraft launch. Thermal releases dominate the Prelaunch phase. No releases during reentry are predicted, only those from post-reentry ground impact.

References:

[1] Radel T. E and Robinson D. G. (2008) "Launch Safety Analysis Code for Radioisotope Power Systems," Proc. PSA 2008, Knoxville, Tennessee, Sept. 7-11, 2008, American Nuclear Society.

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Table 1. Launch Accident Source Term by Mission Phase.

Phase	Mean Accident Probability	Release Probability	Total Probability	Mean Total Release (g)	Mean Effective Release (g)
Prelaunch	3.01E-05	5.95E-01	1.79E-05	2.26E+00	4.91E-01
Early Launch	7.88E-03	3.53E-01	2.78E-03	8.33E+00	1.09E+00
Late Launch	6.10E-03	1.11E-03	6.78E-06	9.94E-03	2.06E-03
Suborbital	1.39E-02	4.77E-03	6.65E-05	2.92E+00	2.09E-01
Orbital	3.06E-03	1.10E-01	3.36E-04	1.18E-01	1.85E-02
Long Term	1.17E-06	1.73E-01	2.03E-07	1.48E-01	3.29E-02
Total Mission	3.10E-02	1.04E-01	3.21E-03	7.30E+00	9.56E-01

Table 2. Fraction of Total Release.

Phase	Overpressure Releases	In-Air Fragment Releases	Ground Impact Releases	Thermal Releases
Prelaunch	0.000	0.000	0.006	0.994
Early Launch	0.002	0.131	0.708	0.160
Late Launch	0.000	1.000	0.000	0.000
Suborbital	0.002	0.424	0.574	0.000
Orbital	0.000	0.000	1.000	0.000
Long Term	0.000	0.000	1.000	0.000