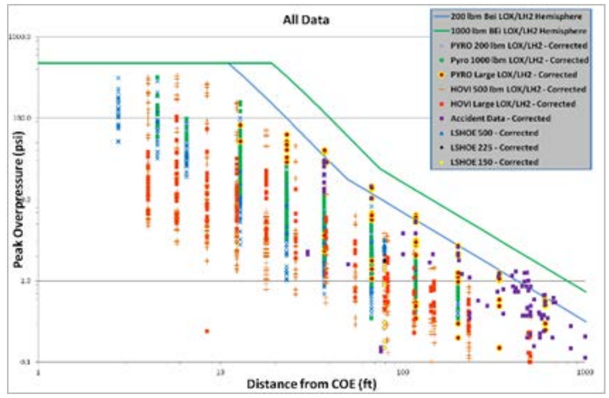
Applying Current Crew Survivability Efforts to Improve Safety of Radioisotope Payloads During Launch.
M. E. Bangham and J. M. Blackwood, Bangham Engineering, Inc., 1300 Meridian Street/Suite 11, Huntsville Ala 35801 mike.bangham@banghamengineering.com, [2]Bangham Engineering, Inc. 1300 Meridian Street/Suite 11, Huntsville, Ala, 35801 james.blackwood@banghamengineering.com.

Introduction: This paper proposes to extend the ongoing efforts to characterize launch vehicle explosion environments for human space flight to application of safe launch of Radioisotope Space Power Generators. At present a team led by MSFC consisting of personnel from MSFC, ARC, and Bangham Engineering Inc. are performing research into launch vehicle explosions and have begun to characterize the underlying physics of the blast waves and to characterize how a vehicle generates fragments. Some of the findings to date indicate that the use of TNT to represent a blast is fundamentally wrong since the underlying physics of Launch Vehicle blasts are different from those of TNT. This is especially true in the near field where radioisotope payloads are located. As the automotive industry started to do in the late 50's with automobile crash testing, the team is producing the knowledge and tools to enable designers to mitigate the effects of explosions and significantly increase the chance of survival. This knowledge can be applied to the design of the next generation of radioisotope power systems and the configuration of the launch vehicle used to place it in orbit so that the payload can remain safe during the event of a catastrophic launch vehicle explosion. This paper outlines the initial steps in that direction.

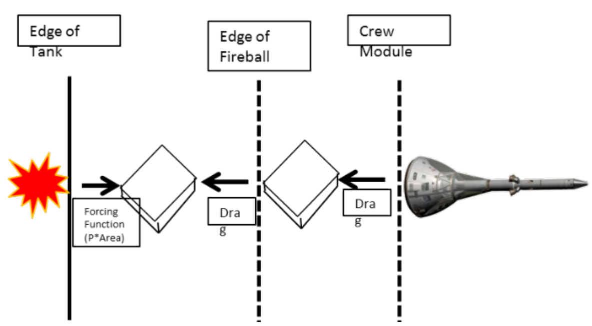
Launch Vehicle Blasts: Research into prior launch vehicle accidents has provided a very interesting insight in that there is currently no evidence of any payload that has been destroyed by the initial explosion. This has led the team to study cryogenic and solid rocket explosions in detail by initially reviewing work performed by JSC-White Sands Test Facility, KSC, MSFC and the Air Force. JPL efforts are now being incorporated as well. The team is now conducting fundamental physical characterization of blast waves and coupling that model to the generation and acceleration of the launch vehicle explosion fragments. The knowledge learned is being fed into both engineering level and computational models. It should be noted that the work is still ongoing and in most cases a three pronged approach is being used where engineering models are built, computational models are developed, and focused testing is being conducted to help characterize the resulting explosions and fragment dynamics.

Liquid Rockets. The team recently proposed a new blast model shown below. This model establishes an upper limit on the magnitude of the overpressure and



defines the radius of rapid combustion or deflagration. This zone of rapid deflagration is a key to defining the amount of kinetic energy that is imparted to the fragments. Further work is being conducted to add a probabilistic prediction to the overpressure blast model. This will allow Monte Carlo-type simulations to simulate a broad range of explosion scenarios.

Fragments represent the most significant risk to the crew. The primary risk expected to be the same for radioisotope power system payloads as well. The figure below shows one approach being used to simulate the fragment propagation. This particular approach is considered an engineering level model while computational efforts are underway as well. These tools are being compared to accident data that was collected post-explosion as a means of validation.



Solid Rockets. Solid rocket explosions can also produce a blast wave and even more dangerous fragments. On average fragments generated by solid rocket motors have three orders of magnitude higher kinetic energy than fragments generated from liquid rocket explosions. The solid fragments tend to have a directionality to them based on the location of the initial failure (linear shaped charge destruct or a case burst).

Spacecraft / Radioisotope Power Systems Considerations: The knowledge being developed can be applied to make the spacecraft and radioisotope power source even safer than before. The payload fairing and area directly below the payload represent the first line of defense from the explosion effects. The next layer is the spacecraft itself and then the containment system for the plutonium. Each layer provides a "crash zone" to provide for the deflection or absorption of the fragments and then ultimately absorb the energy from a possible ground impact. Once validated, the knowledge being gained from the computational work using fluid-solid interaction simulations on the ARC supercomputers will provide tools to assess the design details and ability to protect the containment system. Engineering level tools can provide immediate first level assessments.

Launch Vehicle Configurations: The insights being gained from the human spaceflight safety indicate that some vehicle configurations will produce lower energy explosions. The largest threat would appear to be the high-speed impact of the rocket into the ground with the payload still attached. This produces much higher energy blasts than are being considered by the current program. One goal could be to ensure that the payload is removed from the rocket body prior to ground impact. Assured destruction of the stages is another path or high reliability payload separation/escape systems that simply separate the payload from the rocket may be a better approach.

The blast wave produced when propellants are forced together from high speed ground impact can be many times larger than an in-flight explosion. This scenario can be mitigated by reasonable design choices for radioisotope power system, spacecraft and launch vehicle configuration selection.

Observations / Recommendations: Design for Safety has been one of the tools used to enhance the safety of the radioisotope power system. This paper advocates that this approach should be applied to the entire system including the launch vehicle, spacecraft, fairings, and potential escape systems. Careful design trades will enable larger power sources to be safely flown.

The automobile industry has been studying vehicle crash tests since the 1950's. The knowledge and tools gained have produced automobiles that are much safer today than what the public had access to in the 50's. A representative example is the crash test done in 2010 of a 1959 Chevy Belair and a 2009 Chevy Malibu. The Belair is considerably heavier than the Malibu yet the safety systems, the crash impact zones and passenger restraint system make the lighter vehicle an order of magnitude safer as shown by the crash test video found on line. The photo below shows the crash, in which the hypothetical passenger in the Malibu would walk away while the Belair passenger would be carried away with major or fatal injuries.

With knowledge of the launch vehicle explosions, the designers of the next generation nuclear power system can significantly reduce the risk to the public.

References: Bangham, M. E., Blackwood J. M., Jackson, A. P., Hays, M. J., Skinner, T (2013) Final report NESC assessment of Launch Vehicle Accidents environments release pending, Lawrence, S., et al, "Blast Overpressure Modeling Enhancements for Application to Risk-Informed Design of Human Space Flight Launch Vehicles," The Annual Reliability and Maintainability Symposium, Las Vegas, NV, January 2008. Space Shuttle Data for Planetary Mission Radioisotope Thermoelectric Generator (RTG) Safety Analysis, NSTS 08116, NASA JSC, Initial Release February 1985.