

RTG SAFETY TESTS  
SUPPLEMENTAL SCRIPT FOR THE NEWS MEDIA

Radioisotope thermoelectric generators -- RTGs -- have been extensively tested and studied to determine what will happen to them in an accident. For more than nine years engineers at the Department of Energy have subjected RTGs to rigorous tests that simulate potential accident scenarios. The results indicated that the RTGs will perform as expected and contain their plutonium. The probability of any failure of an RTG is extremely low.

For more than 25 years radioisotope thermoelectric generators have provided electrical power for NASA spacecraft that travel to the dark, outer reaches of our solar system. RTGs have powered the Apollo lunar landing experiments, the Viking missions to Mars, the Pioneer missions to Jupiter and Saturn and the Voyager Grand Tour of the outer planets.

RTGs will be used again on the Galileo spacecraft when it is launched to Jupiter to study the planet, its moons and giant magnetic field. Galileo's two RTGs each contain 24 pounds of non-weapons grade plutonium-238 dioxide. The RTGs are constructed in such a manner as to preclude any possibility of a chain reaction.

Thus, in an accident, RTGs could never explode like a bomb.

00:00

RTG Safety Tests

This videotape is intended to illustrate the extensive safety testing program that the RTGs have undergone.

00:06

Galileo at Jupiter

The first video clip shows what Galileo will look like when it arrives at Jupiter in 1995. The spacecraft must use RTGs because it travels too far from the Sun to use solar panels and the mission lasts too long to use batteries.

00:38

Galileo's Trajectory to Jupiter

The second video clip shows how Galileo will get to Jupiter. A VEEGA trajectory will take Galileo first to Venus and then back around the Earth twice where it will pick up a gravity assist from each planet to boost the spacecraft on to Jupiter.

01:28

RTGs have been used for 25 years

The third clip illustrates some of the missions RTGs were used on in the past. RTGs were used in the Apollo lunar landing experiments, the Viking mission to Mars, the Pioneer missions to Jupiter and Saturn and the Voyager missions to Jupiter, Saturn, Uranus and Neptune.

02:27

Cutaway View of an RTG

The fourth clip is a cutaway view of an RTG. An RTG is about 44 inches long and 16 inches across at the fin tips. The plutonium fuel capsules are surrounded by multiple layers of protection built to withstand heat, explosion and impact. As the plutonium decays, it gives off heat which is converted by small thermocouples into electricity that powers the computers and scientific instruments on the spacecraft.

02:54

Heat Source Modules

The fifth clip shows the heat source modules that are locked together inside the thermoelectric converter. Each module consists of multiple layers of protection designed to ensure the survival of the fuel capsules over a broad range of possible accidents. The outer block-like structure is made of a sturdy carbon-carbon composite material that helps to protect the fuel capsules against the stresses and heating of atmospheric reentry from Earth orbit. Beneath this material, a special graphite thermal insulator sleeve serves to further protect against the heat of reentry. And, below this sleeve, yet another layer of carbon-carbon composite material exists to provide additional protection against impacts.

03:18

Plutonium-238 Fuel Capsules

The sixth video clip shows the fuel capsules. The plutonium-238 fuel is formed into ceramic, marshmallow-sized pellets and clad with an iridium alloy metal that serves as the primary means of containment in the event of an accident. Iridium is used because of its excellent mechanical properties (strength) at high temperatures and because it resists oxidation and other chemical effects.

RTGs are designed to protect their plutonium-238 fuel during all mission phases -- including assembly, testing, transportation, launch, and, in the event of an accident, explosion, fire, or reentry during the payload deployment phase of the launch. More than nine years of engineering and safety tests have subjected RTGs to conditions that would occur if the shuttle exploded or if the spacecraft were to reenter Earth's atmosphere.

Specifically, engineers tested the RTGs to see how they would respond to the following accident environments:

- o Blast overpressures and small projectile fragments. These hazards are typical of the environments that could result from a liquid propellant spill, an external tank leak, or a main engine failure.
- o Large, plate-like fragments and high-speed impacts. These hazards could result from an SRB case failure or a range destruct action.
- o Module or fuel capsule impact. This hazard could result from reentry due to on-orbit guidance or propulsion failures.
- o Fire. Like the blast overpressures and small projectile fragments, this hazard could result from a liquid propellant spill, an external tank leak, or a main engine failure.

04:16

Explosion Blast Overpressure Test

The seventh video clip shows a simulated blast overpressure test that simulates a blast overpressure worse than if the shuttle exploded.

Twelve of these test were conducted. The tests showed that the fuel capsules do not break open when subject to overpressures in excess of a shuttle launch vehicle explosion.

05:02

#### Projectile Impact Bullet Test

The eighth video clip shows the results of bullet tests. .50-Caliber aluminum bullets and .30-Caliber titanium bullets -- designed to simulate nuts, bolts and other small, heavy fragments -- were fired into heat source modules and fuel capsules.

A series of these tests showed the RTG heat source modules could withstand small pieces of shrapnel traveling up to 900 miles per hour with no release of fuel. This velocity is 42% greater than the fastest piece of shrapnel anticipated in an accident.

06:22

#### Rocket Sled Tests

The ninth video clip shows three different rocket sled tests from different angles. These tests simulate the impact of large pieces of solid rocket booster (SRB) casings that could pass through the orbiter walls and strike the RTGs if a shuttle solid rocket booster were to rupture during launch or ascent.

06:38

#### Face-on Fragment Collision

For this test a solid rocket booster fragment, made of  $\frac{1}{2}$  inch tool steel, was mounted on a rocket-sled and driven face-on into a mock-up of an RTG that contained fuel capsules filled with simulated fuel.

High-speed footage of this test was shot at the Sandia Laboratory Test Site in New Mexico. The RTG can be seen hanging in front of a sheet metal tube that catches the various RTG components after the collision.

Two versions of the test were conducted. In the first, the SRB fragment is traveling at 260 miles per hour -- the average velocity of fragments generated in an SRB explosion. The film is

followed by a shot of what the fuel capsules look like after the test.

In the second version, the SRB fragment is traveling at 470 miles per hour -- the highest velocity anticipated for fragments generated in an SRB explosion. Again, the film is followed by a post-test shot of the fuel capsules.

Two of the fuel capsules developed small cracks, allowing a total fuel release of six one hundredths of an ounce. In examining the circumstances surrounding this release, Sandia researchers concluded that the release occurred as a result of secondary collisions that occurred after the initial SRB fragment impact and not as a result of the fragment impact itself.

In interpolating from the results of these two tests and allowing for differences between the tests' simulated fuel and the real plutonium fuel, it was concluded that the plutonium fuel is completely contained in initial face-on fragment collisions at velocities up to 360 miles per hour. Fragment velocities in this range do not occur unless a shuttle solid rocket booster ruptures at a very high altitude -- an unlikely event.

08:04

#### Edge-on Fragment Collision

For this test another solid rocket booster fragment was mounted on a rocket-sled and driven edge-on into a mock-up of an RTG that contained simulated fuel capsules.

The RTG can be seen hanging in front of a sawdust and earthen mound designed to catch the various RTG components after the collision.

In the test the solid rocket booster fragment is propelled at a velocity of 210 miles per hour. Although the film shows the RTG structure being severely damaged by the edge-on fragment, the individual fuel capsules proved resistant to these improbable accident conditions. As shown in the shot of the fuel capsules after the test, only two of the RTG's leading fuel capsules experienced partial fuel releases. These releases totaled 2 ounces. The trailing capsules remained entirely intact.

While a small fraction of fuel may be released during an edge-on fragment collision, the probability of any edge-on fragment reaching the RTGs is low in any given accident.

09:07

### Impact Tests

The tenth clip illustrates the impact tests that were done using a special gas gun at the Los Alamos National Laboratory. These tests simulate what would happen to RTG components impacting on concrete, steel, and sand.

These test results showed that the plutonium fuel is completely contained by unbroken capsules impacting on sand. To the extent that water is less rigid than sand, complete fuel containment can also be expected for impacts on water -- sand and water being the most probable impact surfaces. While capsules impacting on steel or concrete may release very small amounts of fuel if their velocities exceed 112 miles per hour, the probabilities of such impacts are quite low after the first 13 seconds into launch. In an accidental reentry resulting from an upper stage failure the probability of impacting a hard surface is less than 2%.

10:21

### Fire Test

The eleventh clip shows a test that simulates solid propellant fires caused by a shuttle explosion on or near the launch pad. In this test a bare fuel capsule and two capsules in an impact shell were placed next to solid propellant. The propellant was ignited producing a violent flame zone about 15 feet long. The temperatures in this zone exceeded 3700 degrees Fahrenheit. These conditions could occur in a massive failure of a shuttle solid rocket booster shortly after lift-off -- an unlikely event that could directly expose the RTGs to burning propellant.

The results show that the fuel is completely contained even when unbroken fuel capsules are in intimate contact with the solid propellant fires. Liquid propellant fires would be less severe and pose no threat to fuel containment, either.

10:56

Conclusions

This extensive series of tests was performed to provide a better understanding of how RTGs would respond in an accident. The results of these tests were used in the RTG safety analyses for Galileo. These analyses found that the probability of any credible accident (an accident with a probability of occurrence greater than 1 in a million) resulting in a release of plutonium is very low and that the projected release for these low probability events would also be very small.