Power Source Equipment: Safety and Environmental Assessment 5

The safety and environmental characteristics of the radioisotope thermoelectric generators (RTGs) and alternative power systems for the Burnt Mountain Seismic Observatory are of paramount importance. In their letter to the Office of Technology Assessment (OTA), Senators Stevens and Murkowski identified the following as the primary evaluation criteria of the power system:

> . . . the health and safety of the nearby population, the health and safety of Air Force Technical Applications Center (AFTAC) maintenance and transportation technicians, and the environmental impacts to the surrounding area, including anticipated or potential emission of effluents to the environment. (Areas surrounding the site are important wildlife habitat and subsistence hunting and trapping areas for local populations.)

This chapter examines the three most viable power generating systems under consideration for the Burnt Mountain Seismic Observatory: the existing RTGs, propane-fueled thermoelectric generators (TEGs), and photovoltaic (PV) power systems. The focus is on the safety and environmental impacts associated with potential accidents at the site. The risks connected with the routine deployment and operation of the candidate power systems are smaller and therefore given little attention. The accident scenarios that were examined include offsite fire, earthquake, vandalism, aircraft crash, and transportation of the RTGs out of the site or propane fuel into the site.

The risk analysis in this background paper is limited in scope. The accidents' initiating events and the associated critical pathways to environmental and safety problems are analyzed qualitatively. O TA did not attempt to calculate actual probabilities for the initiating events or the various potential pathways in the accident chain of events. Thus, this paper can only comment on possible events that could cause damage, but cannot compare actual risks.

RADIOISOTOPE THERMOELECTRIC GENERATORS

The "fuel" for RTGs, strontium-90 (Sr-90), is the main source of environmental risk associated with the RTGs. The radiation and toxicological characteristics of Sr-90 are discussed in chapter 2. It should be reiterated that Sr-90 is not an explosive material. The fuel, Sr-90, is present in the form of a ceramic material: strontium-titanate ($SrTiO_3$ or Sr_2TiO_4). This material was selected in large part for its fire resistance and low water-volubility properties. In an RTG, the fuel is encased in cladding and a capsule, and then surrounded by a radiation shield made of tungsten. The radiation shield is surrounded by thermal insulation and encased in a metal housing. RTG fuel capsules have passed stringent heat, thermal shock, impact, and projectile striking tests without developing any detectable leaks of the radioisotope material. Engineering analyses have been conducted on RTG "packages" to demonstrate their accident resistance during transportation.

~ Licenses and Emergency Plans

RTGs are covered by various federal regulations governing the use, transport, and disposal of radioactive materials, The Air Force Technical Applications Center (AFTAC) maintains the Quality Assurance Program (QAP) No. 0772, Revision O for the RTGs at Burnt Mountain. The QAP is necessary to keep (or obtain) Certificates of Compliance (COCs) from the Nuclear Regulatory Commission (NRC). COCs are necessary for transport and upgrade modifications of RTGs. In the future, AFTAC will pay approximately $1,500 per year for administration of the QAP. '

The RTGs used at Burnt Mountain were originally licensed via the NRC licensing process. In 1981, the Alaska Department of Health and Social Services confirmed its awareness of the RTGs at the station, When additional RTGs were requested in 1985, a public meeting was held in Fort Yukon.

Current use of the Burnt Mountain RTGs is covered by U.S. Air Force (USAF) Radioactive Material Permit No. 09-30272 -lAFP issued by the USAF Radioisotope Committee, whose authority is granted by NRC Master Materials License No. 42-23539 -0IAF. This permit, which was renewed for the period January 29, 1992 through October 31, 1994, covers a wide range of nuclear materials, not just the RTGs, used by AFTAC. The permit stipulates that the RTGs must be tested for radioactive leakage and/or contamination at least once every 12 months. The previous permit required that the RTGs be leak tested once every six months. This was changed because of the remoteness and difficulty of getting to the site. A threshold of 0.005 microCurie per 100 cm^2 is used to indicate a leaking source, The RTGs at Burnt Mountain have always tested at levels below 0.00005 microCurie per 100 cm^2, the detection threshold of the laboratory procedure,[2] The permittee must report each year to the USAF Radioisotope Committee on the containment (leak test) status of the RTGs and present evidence that the manufacturer's recommended operating temperature has not been exceeded.

All RTGs are designed to comply with the following standards for radiation dose rates during routine operation and transportation and for radiation containment during potential transportation accidents:

- **During operation, allowable radiation dose rates are** stipulated in Title 10 of the Code of Federal Regulations (CFR), Part 20, which is enforced by NRC. The threshold amounts of

1until recently, Teledyne Isotopes, Inc., the manufacturer of the Sentinel RTGs, maintained the OAP and held the COCs for the RTGs at Burnt Mountain. Those certificates and the associated responsibilities have been transferred to the Air Force.

2Though Sr-90 emits only beta particles, these standard assays measure alpha and g aroma levels as well as beta levels. Typical readings in 1991 were: gross alpha activity at less than 0.000002 microCurie per 100 cm^2; gross beta activity at less than 0.000001 microCurie per 100 cm^2; and gross gamma activity at less than 0.00005 microCurie per 100 cm^2. Over the years, the RTGs have on occasion tested higher than these levels, but have always **been** well below the threshold indicating leakage. In 1992, the gamma assays were discontinued.

radiation in unrestricted areas are levels which, if a member of the general public were continuously present in the area, could result in his receiving a dose in excess of: 2 millirem in any one hour, 100 millirem in any seven consecutive days, or 0,5 rem in a year.[3]

- During transportation, allowable radiation levels are prescribed in Title 49 of the CFR, Part 173, Subpart I, which is enforced by the Department of Transportation (DOT). If the RTG "package" emits radiation in excess of 200 millirem per hour at any point on its exterior and emits more than 10 millirem per hour at 3.3 feet (1 meter) from any accessible external surface, it must be shipped in a transport vehicle (except aircraft) assigned for the sole use of the consignee and must meet other restrictions.
- **For potential accidents, radioactive material containment** is covered by Title 10 of the CFR, Part 71 and Title 49 of the CFR, Part 173, Subpart I, and is enforced by NRC and DOT, respectively. These provisions set performance criteria that packages used for the transportation of radioactive material must meet for conditions of heat (fire), impact, percussion, thermal shock, pressure, and leakage resistance. Similar standards are required by the International Atomic Energy Agency (IAEA) Safety Series 33 guidelines for the safe design, construction, and use of RTGs. Under these provisions, the fuel capsule must retain its original leak tightness in the following: 1) *heat (fire) test* in which the fuel capsule is heated to 800°C (1472°F) for 30 minutes; 2) *impact test* in which the fuel capsule is dropped 9 meters (29.5 feet) onto a flat, concrete supported steel plate; 3) *percussion test* in which the fuel capsule is struck by a steel billet with an impact equivalent to 7 kg (15.4 pounds) falling a distance of 1 meter (3.3 feet); 4) *thermal shock test* in which the fuel capsule is heated to its maximum operating temperature and then plunged into O°C (32°F) water and submerged for 10 minutes; and 5) *pressure test* in which the fuel capsule is subjected to an external pressure of 14,500 psi.

An assessment of the potential environmental impact of the use of RTGs was completed in 1973 and revised in 1977 by Weiner Associates for the Naval Facilities Engineering Command.[4] The document examined normal transportation and operation of RTGs on land as well as ocean bottom and surface/near surface locations. It concluded there were no adverse environmental impacts associated with the transportation and operation of RTGs covered by the Navy's NRC license. It found that the radiation levels for the RTGs as packaged for shipment did not exceed the 200 millirem per hour at the surface and the 10 millirem per hour at 3 feet from the surface criteria, Based on tests of a Sentinel model 100F fuel capsule, the RTGs were found to comply with all IAEA Safety Series 33 tests for resistance to impact, percussion, heat, thermal shock, pressure, and leakages An extensive engineering evaluation of the resistance of RTG housings to transportation accidents was also performed (on a different model RTG, a SNAP-21). Accidents, such as a head-on collision with another truck, total burial in earth, chemical attack, truck-train collisions, and fires were evaluated. It was concluded that the impact energy from a head-on

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[3]An unrestricted area is any area that is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters.

[4]Weiner Associates, Inc., "An Environmental Assessment for the Use of Radioisotope Thermoelectric Generators, " project WAI-104, report prepared for the Department of the Navy, Naval Facilities Engineering Command, Nuclear Power Division, May 1973 and revised May 1977.

'The tests were performed by the U.S. Naval Ordnance Laboratory.

collision could rupture the RTG housing and biological shield, but that the fuel capsule would survive.

The methods of removal of the RTGs from Burnt Mountain and their disposal are uncertain. Since the RTGs contain high-level nuclear material, there is currently no permanent disposal site that will accept them. They would have to be kept at a temporary storage site such as the Hanford facility in Washington until a permanent disposal site could be located. AFTAC has the required Certificates of Compliance and the Air Force has an NRC license that allows them to "permit" the receipt, storage, use, and transportation of the RTGs under specific conditions. No additional approvals from NRC are required to move the RTGs from Burnt Mountain.

The Air Force has an emergency procedures plan in case of a suspected radiological accident at Burnt Mountain. The procedures are executed whenever there is an interruption in the data coming from the site. The first step is to check the integrity of the communications electronics, because loss of data mayor may not be caused by problems with the RTGs. If needed, a helicopter can be sent to the site or flyovers can be scheduled for quick damage assessment. The plan includes procedures for tending to any people at the site and notification of Air Force commanders, rescue teams, and radiation safety personnel.

1 Accident Scenarios

OTA has examined five accident scenarios for RTG power systems. The scenarios are identified by their initiating events: offsitc fire, vandalism, earthquake, aircraft crash onto the Burnt Mountain site, and transportation of the RTGs out of the Burnt Mountain site. The first four scenarios cover accidents possible during the continued operation of the RTGs, while the fifth scenario encompasses the risks of removing the units from Burnt Mountain. It must be noted that the units will need to be removed and disposed of at some time--at the latest when the observatory itself is taken out of service. Of course, operating RTGs at Burnt Mountain for another 20 years or so, as envisioned by the Air Force, reduces by nearly half the radioactivity of the Sr-90 that must be transported. The amount of radioactive material, however, does not decrease over this period.

Four accident scenarios--those initiated by offsite fires, earthquakes, vandalism, and the crash of an aircraft directly into a power-system enclosure at the Burnt Mountain site--have similar event pathways. However, the relative probabilities of the various events for each initiator can vary. Following the initiating event, the potential sequence of events leading to exposure of the nuclear material to humans is as follows: breach of the RTG housing, breach of the radiation shield, breach of the fuel capsule, air dispersal, water dispersal, and soil contamination. Plant uptake is highly unlikely because the strontium is bound in a ceramic with very low volubility. Unless the accident compromises the radiation shield, there is no environmental or health impact from the event. If the radiation shield is breached, but the fuel capsule remains intact, the problem is principally one of worker exposure to radiation. Environmental contamination or exposure of people (such as hunters) unaffiliated with the station to radiation could occur only if the exposed fuel capsule is not removed promptly after the radiation shield is breached, or both the radiation shield and fuel capsule are breached. Even if both of these containment layers were breached, contamination would only occur in the event of air dispersal or water dispersal. Given the stable nature of the strontium titanate and the cleared area around the sites, these events are very unlikely. More probable in the event of a containment failure is localized soil contamination. This would be a problem primarily for workers charged with cleaning up after the accident.

Fires

It is known that forest fires can impinge on the Burnt Mountain Seismic Observatory site. A fire in the summer of 1992 encroached on the site, but did little damage to the power system enclosures or any part of the power systems. A future fire could sweep across the observatory site, consuming one or more of the structures housing the RTG power generating units. In the worst case, it might be possible that an RTG unit might fall over, strike the ground, and then be exposed to fire.

RTGs have been designed to withstand both shocks (e.g., by dropping) and fires without the release of any of the radioisotope fuel. The probability of the RTG unit breaking upon a fall within the enclosure, or as a result of debris falling as the enclosure burns, is extremely small. At worst, the outer casing might crack, and the radiation shield might crack, but the probability of the fuel capsule itself being breached is smaller still. RTG fuel capsules have been tested by dropping them 9 meters onto a flat, very hard surface, without any detectable radiation leak. No conceivable impact of that magnitude could be imagined in the event of a fire.

Temperatures in the hottest of forest fires can exceed 2,000°F. This is hot enough to melt some metals, possibly including the ones in the housing of the RTG units at Burnt Mountain. This temperature would have no effect, however, on either the radiation shield or the fuel itself. Tungsten has a melting point of 6, 179°F; $SrTiO_3$ and Sr_2Tio_4. have melting points of 3,704°F and 3,380 +/- 36°F, respectively.[6] The heat of a 2,000°F forest fire would not melt or volatilize any of the radioisotope fuel contained in the RTGs at Burnt Mountain. Indeed, there is very little risk that any combination of impacts and heat exposure that could be experienced by an RTG in a worst-case forest fire would cause a release of the radioisotope fuel from the units. Even a breach of the radiation shield is extremely unlikely, and could only be the result of an impact. A breach of the radiation shield might present a risk of radiation exposure to the workers involved in the cleanup that would follow a fire, but little risk to others. Worker exposure can be minimized using standard industry practices.

Earthquakes

Earthquakes and most vandalism scenarios for accidents to the RTGs at Burnt Mountain present mainly risks of various types of impacts to the RTG energy systems. In the case of an earthquake, the risks are that the RTG units will fall over, and that the power system enclosures will collapse on them. Even in the worst case earthquake, it would appear that the chances of breaching the biological shield are extremely small, and the chances of breaching the fuel capsule are smaller still. Cleanup from an earthquake would probably be easier and safer than cleanup from the worst-case fire.

Vandalism

Vandalism of the RTGs can be divided into two categories: casual vandalism and dedicated vandalism. Casual vandalism is defined as the types of acts that might be committed by people passing through the site for other purposes, not prepared beforehand to assault the RTGs. Dedicated vandalism is defined as terrorist acts planned and carried out against the RTGs. Acts of casual vandalism might include the shooting of hunting rifles at the RTGs, and attempts to dislodge and move the RTGs from their fixcd positions in the enclosures. Acts of dedicated vandalism might include deliberate burning of the shelters and dynamiting of the RTGs.

Casual vandalism

No conceivable act of casual vandalism would cause a breach of-the fuel capsule or a leak of the radioisotope from the RTGs. Penetration of the radiation shield is also highly unlikely, and would present only slight risks for maintenance and repair workers. In fact, it is unlikely that the

[6] S .J. Rimshaw and E.E. Ketchen, *Strontium- 90 Data Sheets*, ORNL-4358 (Oak Ridge, TN: Oak Ridge National Laboratory, 1969).

shooting of a bullet into an RTG would have any impact on its operation. It is also unlikely that casual vandals would be able to dislodge the RTGs from their moorings, as the smallest of the RTG units at Burnt Mountain weighs approximately three-quarters of a ton, Even if a unit were knocked over, it is unlikely that any damage to the housing or its contents would result. Thus, casual vandalism presents virtually no radiation risk at the Burnt Mountain Observatory.

Dedicated vandalism

For RTG accidents caused by offsite fires, earthquakes, and casual vandalism, breach of both the radiation shield and the fuel capsule of an RTG and release of radioisotope material is highly improbable. However, in the case of dedicated vandalism, the situation might be different. It might be possible for a sophisticated terrorist to bring sufficiently high-powered explosives to the Burnt Mountain site to damage and breach the" radiation shield, and possibly the fuel capsule as well. In the event of a breach of the radiation shield, but not the fuel capsule, the major risk would be to cleanup workers who would recover the capsule for removal and disposal, In the event that the fuel capsule itself is breached, the radioisotope material would be exposed to the environment. It is unlikely that there would be substantial airborne dispersal, as the Sr-90 would remain bound in the form of solid strontium titanate. The titanate might break apart, but most of the particulate would be large, and thus would be likely to fall no farther away than the other debris from the explosion. The range of dispersal would depend on the power of the explosion. If the strontium titanate is released, some soil would be contaminated. However, strontium titanatc is highly insoluble, so it would not tend to migrate deep into soils, nor contaminate waterways in dissolved form. Water runoff in the event of a rainstorm following an act of vandalism could carry and disperse some of the material away from the site. Due to the biological unavailability of the titanate fuel form, plant uptake of Sr-90 and entry into the food chain would be minimal.

Aircraft and Transportiation Accidents

If a decision is made to phase out the RTGs soon, or in any case at the end of the useful life of the Burnt Mountain Seismic Observatory, it will be necessary to remove them from the site. The Air Force expects that the units will be moved by helicopter out of Burnt Mountain, with eventual storage at the Hanford site in the state of Washington. Handling accidents with the RTGs at the Burnt Mountain site should not be a problem. The major sources of risk considered are helicopter flight accidents and crashes. Both types of accidents present risks of breaching the radiation shield and the fuel capsule containing the Sr-90 fuel. The possible sequence of events following a breach of the radiation shield and/or fuel capsule are the same as those discussed above.

The two major risks to the integrity of the RTG in the event of a helicopter accident are:

- the explosive force of a major fuel explosion, either in mid-air or on impact with the ground; and
- the impact force of the entire RTG unit or the fuel capsule falling a long distance from an airborne helicopter,

The force necessary to breach the RTG housing and radiation shield would be considerably less than that needed to breach the fuel capsule itself. This is so for two reasons: first, the metal casing and tungsten radiation shield would absorb much of the energy, shielding the fuel capsule; and second, the fuel itself is encased in stainless steel and a very ductile and rupture-resistant nickel alloy, Hastelloy C. If the fuel capsule remains intact, it presents a radiation risk mainly to cleanup workers, who would recover it for proper disposal. If the capsule is breached, the radioisotope material would be exposed to the environment. In no event would there be any melting of the ceramic fuel material-strontium titanate-although some of the fuel could crumble, especially in the case of the explosion scenarios. It is unlikely that a substantial fraction of the strontium titanate would be converted into fine particulate, so in the event of a ground-level breach of the capsule, the great bulk of the material would fall out within a short distance of the accident. An explosion in the sky could cause a much wider dispersal of the material.

All of the dispersed radioisotope material will remain in the form of the ceramic material strontium titanate, which is highly resistant to dissolving into water, and relatively inert with respect to uptake by plants. Most of the contamination near a ground-based accident should be able to be recovered by a cleanup crew. The remainder of the material would present a risk mainly to animals that come into close contact with it, as the beta radiation travels no more than about 10 inches through the air. In addition to the risk of helicopter accidents during an RTG removal trip, there is also the risk of a helicopter crashing into an RTG at Burnt Mountain during a routine maintenance and inspection trip. The sequence of events following the impact of a crash would be the same as that following an RTG removal accident.

PROPANE-FUELED THERMOELECTRIC GENERATORS

Delivery, handling, and storage operations for the propane fuel for TEGs are the main source of environmental risk associated with the use of TEGs at the Burnt Mountain Observatory. Propane fuel would be stored in onsite tanks that could be either buried or installed above ground. Fuel would have to be brought to the site from Fort Yukon, some 50 miles away, by helicopter. Access by land is difficult, even via all-terrain vehicle, because there are no roads and the tundra is fragile. The tanks must be able to store more than a year's supply of fuel in order to allow refueling to be accomplished on an annual basis. Semiannual refueling operations may also be considered. A system of piping and valves delivers the propane from the fuel tank to the combustor, which is part of the generator unit. TEGs and propane storage tanks are designed to be safe from damage by dropping and fire.

Propane is a high-volatility hydrocarbon fuel that can be liquefied at ambient temperature under moderate pressure conditions. It is stored and handled in liquid form. The major environmental risks associated with propane fuel are fire and explosions. Propane is not considered to be a toxic substance, and any material spilled that is not burned will evaporate into the atmosphere. The boiling point of propane at atmospheric pressure is -44°F.

Four accident scenarios are examined for TEG power systems. The scenarios are identified by their initiating events: offsite tires, vandalism, fuel transportation and handling, and equipment and material transportation and construction. The first three of the scenarios cover accidents that could occur to the TEG energy systems during their operation and maintenance. The fourth scenario involves the environmental risks encountered during the project implementation phase of installing the TEG energy systems. Transportation and construction risks are similar to those that would be encountered with the implementation of any new energy system at Burnt Mountain.

The major source of environmental risk for the TEG energy systems is the heat source. Propane, a hydrocarbon fuel, is highly volatile and flammable, and in some conditions, explosive. It is stored under pressure in order to maintain it as a liquid, so it tends to escape quickly in the event of a leak. The only real concerns about the use of propane fuel at Burnt Mountain are in connection with fires and explosions. Fuel that escapes but does not burn will simply evaporate and dissipate in the atmosphere. The small amounts of fuel that will be stored onsite at any one time should not be a concern with regard to regional atmospheric hydrocarbon pollution,

I Accident Scenarios

Fires

In the event of a major offsite fire, it is possible that both the fuel lines and above-ground fuel tanks would fail, even though they would be designed to withstand such conditions. At the least, the onsite fuel would be consumed in the fire; at worst, there could be an explosion. Burial of the fuel tanks would help to lessen the probability of a major explosion, although it would entail increased environmental disruption at the site due to the need for digging into and disrupting the permafrost.

The presence of propane fuel at the Burnt Mountain site would increase the risk of damage to the seismic sensing facility in the event of a marginal fire encroaching on the site, including possibly a fire similar to the one that passed through the area in the summer of 1992. Should there be a breach of either a fuel line or storage tank, the presence of propane fuel at the site could spread the fire further than it would otherwise go, and/or cause explosive damage that would not otherwise occur.

Vandalism

Casual vandalism at the Burnt Mountain Observatory could cause a rupture of either the fuel lines or fuel tanks at the site, resulting in the release of propane fuel and system shut down. The leaking fuel would then present a substantial risk of tire and explosion, depending in large part on the presence of a spark or other ignition source. The ignition source could be supplied by either the vandal, the site's existing power system, or another natural source. Propane is very easily ignited, and explosive at low concentrations in the air. If the propane leaks away without ignition, it will simply evaporate and disappear, causing no toxic effects at the site, and leaving no residuals onsite,

Delivery and Handling of Propane

The propane fuel must be flown to the **Burnt** Mountain site via helicopter from the Air Force's staging area in Fort Yukon, more than 50 miles away from the seismic observatory. Each step in the fuel delivery process-handling at Fort Yukon, inflight transportation, and handling at Burnt Mountain-entails some risk of fire and explosion. Standard safety practices have been established for handling and using propane fuel-indeed propane is safely used and transported in a wide variety of everyday situations, but residual risks would remain at each step.

Two different configurations are under consideration for TEG deployment at the Burnt Mountain Observatory: 1) a centralized configuration in which the TEGs are installed near the U3 site, where the data multiplexer and transmitter are currently located, and a power distribution network must be installed in order to deliver power to each of the remote terminal (RT) sites, and 2) a distributed configuration equivalent to the current RTG power system, in which TEGs are deployed at each of the RT sites, and no electricity distribution system is required. The central-generator configuration would consume approximately 25 percent more fuel than the distributed configuration because of the need to cover electricity distribution losses, and bringing in this much additional fuel would increase the risks of fuel supply accidents by some increment. However, deployment in a distributed configuration would require fuel to be distributed on the ground to each of the RT sites from the central heliport staging area, which would present an entire set of risks that do not pertain to the central power-generating configuration.

Deployment of a TEG Power System

The deployment of a TEG energy system at Burnt Mountain entails environmental risks, All of the material needed for the deployment of the system must be flown in by helicopter, including the TEG generators and the tankage, as well as all pertinent parts and equipment. Each helicopter flight entails a level of risk, both in flying to the Burnt Mountain site and in landing at the site. The distribution of equipment and material at the site would entail risk of environmental disruption, as would installation operations, particularly the installation of the fuel tanks. The configuration used for the TEG systems would have a major influence on the types of onsite environmental impacts that are of concern. With a distributed configuration, there would be installations of generators and fuel tanks at each of the five RT sites. With a centralized configuration, there would be only one power system installation, but this configuration would also require the installation of the power distribution system.

PHOTOVOLTAICS

PV energy systems present minimal risks for safety and the environment under routine operating and maintenance conditions. During the transportation and construction phases of deploying a PV system at Burnt Mountain, the risks are similar to those of TEGs. There are also safety and environmental risks 'associated with damage to the batteries in PV systems caused by transportation accidents, fires, and bullets—shot either accidentally or with malicious intent. Breach of the batteries could release toxic fumes and lead, nickel, cadmium, or other heavy metals into the environment. These heavy metals pose a variety of environmental health hazards. If they contaminate the air, water, or soil, human exposure might occur through breathing dust, through skin contact with the soil, or through ingestion of water or contaminated plants or animals. For example, breathing cadmium can cause damage to the lungs and kidneys, while long-term exposure to cadmium through ingestion can result in harm to the kidneys and bones. Given the relatively small scale of use of batteries, the low likelihood of a significant breach and subsequent transport to the environment, and the distance from any local population, these risks are very small. Special attention to the structural integrity of the battery containment vessel could reduce, but not entirely eliminate, the risk of contaminating the surrounding soil and water sources. Additional risk arises if booster charging of the batteries is ever required. This is the risk of a helicopter accident while transporting the fuel for the charging equipment.

CONCLUSIONS

The three power systems (RTGs, TEGs, and PVs) examined in this background paper all incorporate human safety and environmental quality as important design criteria. During routine operation and maintenance, the three systems present little risk to the Burnt Mountain environment and to the safety of maintenance personnel and nearby populations. The safety and environmental risks are also very low in most accident and vandalism situations.

The risk associated with RTGs is the possible exposure of radioactive material (Sr-90) to humans, plants, animals, and the environment. The radiation exposure received from physical proximity to an operating RTG is very low. The RTGs are designed such that radiation levels are less than 10 millirem per hour at a distance of 1 meter from the RTG surface. At the maximum rate of 10 millirem per hour, exposure for 4 1/2 hours would yield a dose equivalent to a typical chest x-ray. Of greater concern is the possible exposure caused by breach of the inner shields of the RTG units and release of Sr-90 into the environment. Natural disasters and most accidents associated with human activities present little risk of such release of radioisotope material to the environment. Dedicated vandalism presents greater risk in this regard, but measures can be taken to lower the risk somewhat. In the event that radioisotope material is released, there will probably be minimal long-range dispersal, so cleanup activities should be able to recover most if not all of the radioisotope. Residual Sr-90 material in the environment will remain in a fairly inert form (strontium titanate ceramic), with minimal uptake by plants and incorporation into the food chain.

The risks associated with TEGs are the possible fires and/or explosions connected with propane, Propane is highly volatile and flammable, and is explosive under some conditions. Propane accidents can happen in delivering the fuel to the Burnt Mountain site, and while distributing fuel on the ground at the site. Propane accidents during unattended operation of the observatory can be caused either by natural events, like fires and earthquakes, or by vandalism. The construction phase of installing a TEG system could also cause environmental impacts at Burnt Mountain, but these could be minimized with proper design.

PV systems, while benign in most respects, are not without safety and environmental risks. With them, the risk is the possible release of toxic fumes and heavy metals from the batteries. Such releases could result from damage to the batteries caused by bullets, fires, or transportation accidents. There are also risks of helicopter accidents in deploying and maintaining a PV system, as there are with other systems.