SMOKE DETECTORS

Householders Ignore Fire Brigade Advice on Smoke Detectors

Thirty-two people died and 567 were injured in fires in West Yorkshire last year.

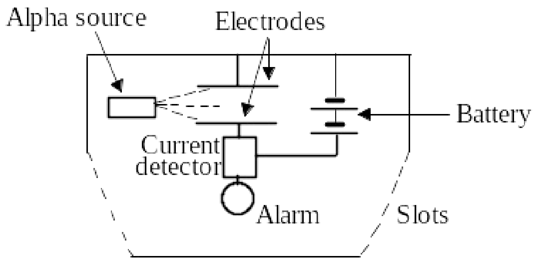
However, only 7% of householders in Yorkshire and Humberside have followed fire brigade advice to fit smoke detectors, which give an early warning of fire and allow time to escape.

A recent Government sponsored survey shows the region joint bottom of all areas in England and Wales. Said Assistant Chief Officer Peter Kneale: "Despite our efforts for the past two years, the area is still well below the national average of 10% in its provision of smoke detectors."

"We are disappointed to read the statistics when we look back at the efforts we have made to sell the message that smoke detectors save lives."

The survey also shows that pensioners are the most poorly provided for, with only 5% having a smoke detector, despite being one of the groups most at risk.

The diagram opposite shows the construction of one kind of smoke detector.



The weak radioactive source has a long half life and gives out alpha particles. (Americium-241 is often used.) The alpha particles ionise air molecules in the detector. The ions are attracted to one or other of the electrodes, so a small current flows.

If smoke enters the detector, fewer ions are produced so less current flows. This decrease in current is detected electronically and the alarm is sounded.

Americium-241 has a half life of 432 years. It is used in preference to other radioactive sources that produce mainly, beta and gamma radiation. The radiation emitted by americium has high ionizing capabilities and low penetration power. Only about one percent of the emitted radioactive ener of Americium-241 is gamma radiation.

The amount of elemental Americium-241 is small enough to be exempt from the regulations applied to larger sources. A typical smoke detector contains about 37 kBq of radioactive element Americium-241 corresponding to about 0.3 µg of the isotope. This provides sufficient ion current to detect smoke, while producing a very low level of radiation outside the device.

The americium-241 in ionizing smoke detectors poses a potential environmental hazard. Disposal regulations and recommendations for smoke detectors vary from country to country.

Questions

(a) Explain what happens to air molecules when they become 'ionised'. (2 marks)

(b) Write a likely nuclear equation for the decay of americium-241 as used in a smoke detector. (2 marks)

(c) Suggest a reason why fewer ions are produced if smoke enters the detector. (2 marks)

(d) Explain why a radioactive source that gives out **alpha** particles is used, rather than one that gives out beta or gamma radiation? (3 marks)

(e) Americium – 241 emits dangerous gamma radiation. Why is this not considered a hazard in the case of smoke detectors? (1 mark)

(f) What is meant by the 'half life' of a radioactive substance? (2 marks)

(g) Explain why the radioactive source used in the detector should have a long half life. (2 marks)

(h) Some householders might be worried about the presence of a radioactive source in the detector. What could you say to convince such a person that it is safe? (2 marks)

Answers

(a) Ionisation is the separation of an electron from an air molecule. This leaves a positively charged ion and a negatively charged electron. (2 marks)

(b) $^{241}Am_{95} \rightarrow {}^{237}Np_{93} + {}^{4}He_{2}$ (2 marks)

note: The equation could include gamma radiation as a product (γ)

(c) The smoke particles absorb the alpha particle's energy and therefore the alpha particles are less able to ionise in air. (2 marks)

(d) Smoke would not stop beta or gamma radiations yet alpha particles are stopped by smoke. Alpha particles are less penetrating and therefore safer for the user. (3 marks)

(e) There is a very small quantity (0.3 μg) of the sample of americium-241 that is capable of emitting gamma radiation and only 1% of all radiation emitted is gamma. (1 mark)

(f) The time taken for the activity of a radioactive source to halve. (2 marks)

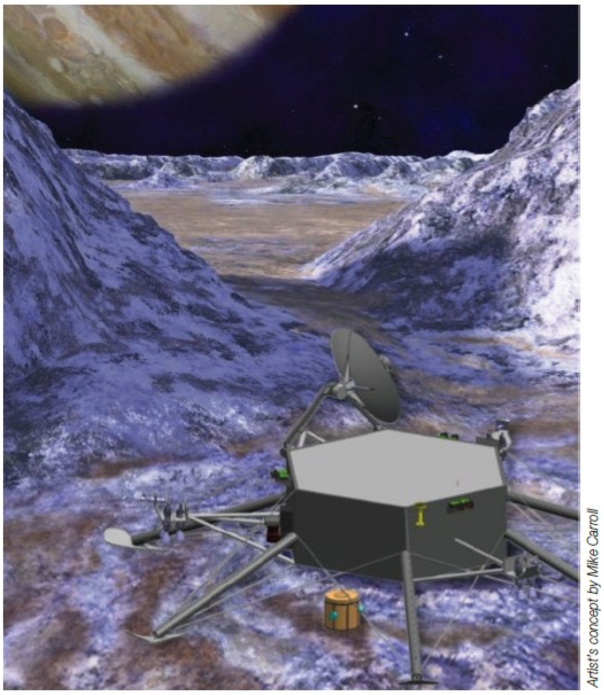
(g) So that the device can be used for a relatively long time without the radioisotope requiring replacement. (2 marks)

(h) Alpha particles are stopped by a few centimetres of air and certainly by the plastic covering so the radiation is contained within the detector. (2 marks)

Radioisotope Power Systems: Mission Need

Adapted from NASA Fact Sheet NF-2012-08-557-HQ

Radioisotope Power Systems (RPS) are long-lived sources of spacecraft electrical power and heating that are rugged, compact, highly reliable, and relatively insensitive to radiation and other effects of the space environment. This makes them an excellent option to produce power or heat for a variety of potential missions to some of the most extreme space and planetary environments in the solar system.

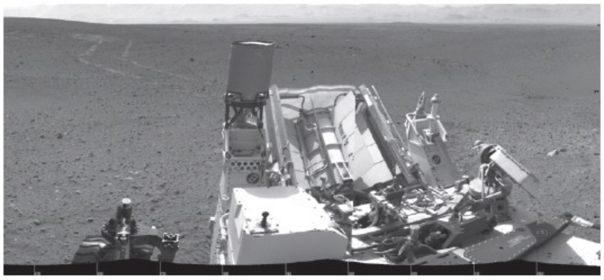


A concept for an RPS-powered mission that could softly land a science station on Jupiter's large moon Europa, which may harbor a liquid water ocean beneath its icy crust.

Many of NASA's proposed future missions aim to answer profound questions about the origin, evolution and fate of life in the solar system—does it exist beyond Earth? If so, how did it start, and how might it compare to life here? Other mission concepts would illuminate our understanding of the earliest days of the solar system, and why planets like Venus and Mars evolved so differently than Earth.

Flown on 27 U.S. space missions over the past five decades and counting, RPS are used only when they would enable or significantly enhance the capability of a mission to accomplish its scientific or technology development goals.

All RPS missions flown so far have used Radioisotope Thermoelectric Generators (RTG), such as the Multi Mission Radioisotope Thermoelectric Generator (MMRTG) launched in November 2011 aboard the Curiosity Mars rover. RTGs employ thermoelectric power conversion, where a temperature difference applied across the junction of two different metallic compounds is used to generate the electricity. Although designed for an operating lifetime of about 14 years, every RPS of this type that has flown in space has far surpassed this period of operation.



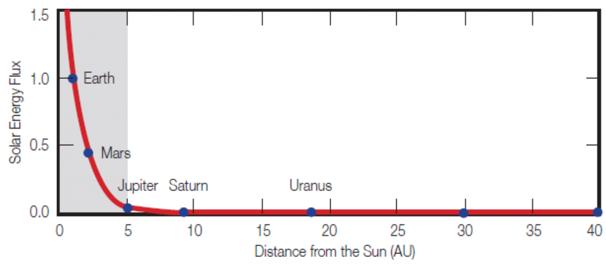
Self portrait of the Curiosity Mars rover and its RPS (the white cylinder with fins, at center) on the surface of the Red Planet in September 2012.

A new form of RPS called an Advanced Stirling Radioisotope Generator (ASRG) is currently under development. The heat from the radioisotope fuel in an ASRG is used to drive a piston that moves back and forth over 100 times per second to generate an electrical current via a generator. An ASRG can produce electricity about four times more efficiently than the more traditional RPS, meaning it can use one-quarter of the radioisotope fuel to generate a comparable amount of power.

Each of the two current types of RPS has unique strengths. The MMRTG offers a significant amount of excess heat that can be used to keep spacecraft electronics and systems warm in cold environments; the Curiosity rover uses this heat to its benefit on Mars. Conversely, the ASRG produces much less heat, which can be an advantage for missions where removing that heat would be an issue. Furthermore, the ASRG is expected to be about 25 percent lighter than the MMRTG (which equates to about 26 pounds or 12 kilograms less mass). This could make the ASRG attractive for smaller spacecraft or perhaps multiple spacecraft—such as an orbiter and lander—launched together.

Together, these two types of RPS serve to support a variety of future mission designs in their ability to function fully and reliably over a wide range of extreme conditions and destinations.

The most common past use of RPS for planetary science has been to power spacecraft on deep space missions designed to travel where sunlight drops to a tiny fraction of its intensity at Earth's orbit. Impressive progress has been made with low-temperature, low intensity solar cells on spacecraft such as the Juno mission on its way to Jupiter. But the unavoidable decline in the sun's energy as one moves outward in the solar system will always present significant limitations.



The energy of sunlight decreases rapidly as distance from the Sun increases.

Long-duration missions to the high latitudes of the surface of Mars and to the surface of the Moon (which is naturally in darkness for two weeks out of every month) are also considered extremely challenging, if not impossible, for power systems using solar arrays and batteries alone.

Sunlight may also be too weak to supply enough electrical power for a given mission when it is highly intermittent, or obscured by an opaque or especially dusty planetary atmosphere.

For example, the vast distance from the sun to Saturn means that sunlight received in the neighbourhood of the ringed planet is already 100 times less intense than the sunlight that reaches Earth orbit. The thick, hazy atmosphere of organic chemicals on Saturn's moon Titan absorbs another 60 percent of this already faint incoming energy. On Mars, the ever-present red dust has cut the amount of energy produced by the solar panels on the Mars Exploration Rover Opportunity in half, despite several serendipitous cleaning events from local winds and random "dust devils" that can help clean the panels.

When appropriately shielded, RPS are also generally impervious to the physical effects of dust and to the extremes in temperature that can affect almost every mission to space, where swings between intense heat and frigid cold can span 300 degrees, sometimes in a matter of seconds.

On the cold end of the spectrum, small components called Radioisotope Heater Units (RHUs)—each of which generates about one watt of heat—can be used to keep the electronics and other internal systems in spacecraft, rovers, and landers at proper operational temperature in deep space or in long-duration shadows. More than 300 of these pencil eraser-size components have been flown on solar system exploration missions such as the Cassini mission, orbiting Saturn for more than eight years, and the Opportunity rover, helping it survive through more than a half-dozen frigid winter seasons on the red planet.

Artist's concept by Tibor Balint/JPL-Caltech/NASA

A concept for an RPS-powered hot-air balloon that could explore the atmosphere of Saturn's moon Titan for several months, and perhaps analyze samples of its lakes.

Unlike the sensitive electronic junctions in solar panels, the power-producing elements of RPS are not greatly threatened by space radiation, which can be a severe problem in environments such as the Jupiter system. This intense radiation limits the Juno spacecraft to a one-year primary mission, even with a specially customized orbit that largely avoids the gas giant planet's damaging radiation belts.

Whether it be missions to comets and asteroids, distant planetary moons, the still-mysterious outer planets Uranus and Neptune, or the vast Kuiper Belt, scientists have identified a host of amazing destinations that ambitious RPS-powered missions could uniquely explore in the years ahead, in ways that would not be possible with other power systems alone.

(a) Briefly discuss the two ypes of RPS devices discussed in the article. (4 marks)

____

____

____

____

(b) Discuss the relevant benefits of the MMRTG and ASRG. (4 marks)

____

____

____

____

(c) Discuss the major benefit of RPS compared to solar panels as energy sources for long distance space missions. (4 marks)

____

____

____

____

(d) NASA uses Plutonium-238 as the source of heat for its RPS units. This radioisotope has a half-life of 88 years and is an alpha emitter. Explain why these two features would make it an ideal source of energy for manned space missions. (4 marks)

(e) On page 30, there is a graph showing how solar energy flux varies with the distance from the sun. Suggest a possible mathematical relationship between these two quantiites. (2 marks)

Answers

(a) Briefly discussthe two types of RPS devices discussed in the article. (4 marks)

MMRTG systems use the heat from the radioisotope to heat a thermocouple, which is a junction of two different metals. A potential difference is created across these two metals which generates electricity to power the spacecraft. ✓ ✓

ASRG systems use the heat from the radioisotope to power a reciprocating Stirling Engine that can then drive a generator to power the spacecraft ✓ ✓

(b) Discuss the relevant benefits of the MMRTG and ASRG. (4 marks)

MMRTG is quite an inefficient process, but this provides excess heat to keep instrumentation warm in cold environments. ✓ However if this excess heat needed to be removed , it could use valuable energy ✓ The ASRG system is more efficient so less excess heat needs to be removed. ✓ The ASRG system is also 25% lighter. ✓

(c) Discuss the major benefit of RPS compared to solar panels as energy sources for long distance space missions. (4 marks)

Solar systems are really only practical when missions are close to the Sun ✓ As probes reach the outer reaches of the solar system, sunlight is quite insignificant and solar systems would be ineffective ✓ Also some planets such as Mars have a lot of dust ✓ this dust can render solar panels useless as they are covered in dust that blocks sunlight. ✓

(d) NASA uses Plutonium-238 as the source of heat for its RPS units. This radioisotope has a half-life of 88 years and is an alpha emitter. Explain why these two features would make it an ideal source of energy for manned space missions. (4 marks)

88 Years is a relatively long half-life which means that even after 88 years of spaceflight, the energy systems would still be operating at 50% maximum output ✓ ✓ Also being an alpha emitter, it is relatively safe for manned spaceflight as alpha has such limited penetration ✓ ✓

(e) On page 30, there is a graph showing how solar energy flux varies with the distance from the sun. Suggest a possible mathematical relationship between these two quantiites. (2 marks)

As solar energy spreads in a radial (spherical field), the relationship is likely to be inverse-square ✓ i.e. solar energy flux $\alpha\, 1/r^2$ ✓

Question: Read the article and letter below and answer the questions that follow

In the summer of 1939, six months after the discovery of uranium fission, American newspapers and magazines openly discussed the prospect of atomic energy. However, most American physicists doubted that atomic energy or atomic bombs were realistic possibilities. No official U.S. atomic energy project existed.

Leo Szilard was profoundly disturbed by the lack of American action. If atomic bombs were possible, as he believed they were, Nazi Germany might gain an unbeatable lead in developing them. It was especially troubling that Germany had stopped the sale of uranium ore from occupied Czechoslovakia.

Unable to find official support, and unable to convince Enrico Fermi of the need to continue experiments, Szilard turned to his old friend Albert Einstein and the eventual result was the letter below. (Note: only the first page of the letter is shown, and this is a re-creation of the original letter)

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island
August 2nd, 1939

F.D. Roosevelt
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E. Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to our attention the following facts and recommendations:

In the course of the last four months it has been made probable – through the work of Joliot in France as well as Fermi and Szilard in America – that it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable – though much less certain – that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

a. Explain what Einstein meant by a “nuclear chain reaction”.

[3 marks]

b. Explain how “vast amounts of power” can be generated from the Uranium.

[3 marks]

c. How could the new Radium-like elements, that Einstein talked about, be produced?

[2 marks]

d. Consider the radioactive decay of the uranium isotope $^{238}_{92}U$. Each nucleus that decays releases 4.20 MeV of energy. Calculate the mass of $^{238}_{92}U$, in kilograms, that must decay each second to release energy at a rate of 5.00×10^2 MW.

[3 marks]

e. How might the bombs that Einstein mention be constructed?

[4 marks]

f. One of the radium-like elements produced from Uranium is Iodine-131, which is commonly used to treat thyroid cancer, probably the most successful kind of cancer treatment. It is also used to treat non-malignant thyroid disorders. Why do you think that Iodine-131 is so successful in treating thyroid cancer?

[2 marks]

g. When treating individuals with radiation, care must be taken not to confuse “Dose Equivalent” and “Absorbed Dose”. Explain the difference between these terms.

[3 marks]

Answers

a. Explain what Einstein meant by a “nuclear chain reaction”.

- **A nucleus decays as a slow neutron strikes it [1]**
- **giving off two or three neutrons [1]**
- **each of these neutrons can induce another nucleus to decay thus a chain reaction occurs. [1]**

[3 marks]

b. Explain how “vast amounts of power” can be generated from the Uranium.

- **As each nucleus decays the mass of the products is less than the mass of the reactants [1]**
- **thus some mass is converted into energy [1]**
- **The energy is calculated by $E=mc^2$ so for a very small mass a relatively large amount of energy is released. [1]**

[3 marks]

c. How could the new Radium-like elements, that Einstein talked about, be produced?

- **As the uranium undergoes fission it breaks into two daughter nuclei [1]**
- **These nuclei can be radioactive like radium. [1]**

[2 marks]

d. Consider the radioactive decay of the uranium isotope $^{238}_{92}U$. Each nucleus that decays releases 4.20 MeV of energy. Calculate the mass of $^{238}_{92}U$, in kilograms, that must decay each second to release energy at a rate of 5.00×10^2 MW.

$E_T = 5.00 \times 10^8 \text{ J s}^{-1}$

$$E_{decay} = (4.20 \times 10^6)(1.60 \times 10^{-19})$$
$$E_{decay} = 6.72 \times 10^{-13} \text{ J} \quad [1]$$

$$N_{decays} = \frac{E_T}{E_{decay}}$$
$$N_{decays} = \frac{(5.00 \times 10^8)}{(6.72 \times 10^{-13})}$$
$$N_{decays} = 7.44 \times 10^{20}\ ^{238}_{92}\text{U nuclei} \quad [1]$$

$$m = N \times m_{U-238}$$
$$m = (7.44 \times 10^{20})(3.95214 \times 10^{-25})$$
$$m = 2.94 \times 10^{-4} \text{ kg} \quad [1]$$

e. How might the bombs that Einstein mention be constructed?

- **Two subcritical masses of U-238 are positioned at the end of a tube. [1]**
- **An explosive charge pushes the two masses together [1]**
- **to create a critical mass [1]**
- **This mass of uranium will undergo an uncontrolled chain reaction which results in an explosion. [1]**

[4 marks]

f. One of the radium-like elements produced from Uranium is Iodine-131, which is commonly used to treat thyroid cancer, probably the most successful kind of cancer treatment. It is also used to treat non-malignant thyroid disorders. Why do you think that Iodine-131 is so successful in treating thyroid cancer?

- **Iodine accumulates in the thyroid [1]**
- **So its cancer killing effects are targeted in the thyroid. [1]**

[2 marks]

g. When treating individuals with radiation, care must be taken not to confuse "Dose Equivalent" and "Absorbed Dose". Explain the difference between these terms.

- **Absorbed Dose is the quantity of energy absorbed per kilogram of body mass [1]**
- **Measured in greys [$^1/_2$]**
- **Dose Equivalent is a measure of the effect of the radiation on living things [1]**
- **Measured in sieverts [$^1/_2$]**

[3 marks]

How air bags work

Air bags are designed to keep your head, neck, and chest from slamming into the dash, steering wheel or windshield in a front-end crash. They are not designed to inflate in rear-end or rollover crashes or in most side crashes. Generally, air bags are designed to deploy when the severity of a crash reaches a preset threshold value. Depending on the specific vehicle model, this threshold is normally equivalent to a vehicle crashing into a solid wall at 13-23 km/h. Air bags most often deploy when a vehicle collides with another vehicle or with a solid object like a tree. Airbags do not reduce the momentum change of the car occupants, but they do reduce the forces acting on them.

Air bags inflate when a sensor detects a front-end crash severe enough to trigger their deployment. The sensor sends an electric signal to start a chemical reaction that inflates the air bag with harmless nitrogen gas. All this happens faster than the blink of an eye. Air bags have vents, so they deflate immediately after absorbing the energy of an occupant. They cannot smother you and they don't restrict your movement. The "smoke" you may have seen in a vehicle after an air bag demonstration is the nontoxic starch or talc that is used to keep the insides of the air bag from sticking together.

Are all air bags the same?

No. Air bags differ in design and performance. There are differences in the crash speeds that trigger air bag deployment, the speed and force of deployment, the size and shape of air bags, and the manner in which they unfold and inflate. Air bag systems are very complex, computer-controlled devices which, if improperly deactivated, could deprive the vehicle occupants of the benefit of other vital safety systems. That is why you should contact your vehicle manufacturer if you want more information about the air bags in your particular car or truck.

a) Why is a threshold value needed for air bag deployment?

[3 marks]

b) Suppose you are in a car travelling at 60kmh^{-1}, when you hit a wall and come to a stop. What change in momentum do you undergo?

[3 marks]

c) How is it that airbags can reduce the force acting on a car occupant if their momentum change is not reduced?

[3 marks]

d) Why when a car hits a wall do the occupants keep moving forward?

[2 marks]

e) Why is it necessary for the airbag to inflate “faster than the blink of an eye”? Support you answer with a calculation.

[4 marks]

f) Why is it necessary for the airbag to have vents?

[3 marks]

g) Why is the inside of the airbag lined with starch or talc (powder)

[2 marks]

Answers

a) Why is a threshold value needed for air bag deployment?

[3 marks]

Airbags in themselves are quite dangerous. They need to inflate very quickly and there is thus a minimum speed at which the danger from the impending crash is greater than that posed by the airbag✓✓✓

b) Suppose you are in a car travelling at 60kmh^{-1}, when you hit a wall and come to a stop. What change in momentum do you undergo?

[3 marks]

$\Delta p = m\Delta v$ ⇨ $\Delta p = 65 \times 16.7$ ⇨ $\Delta p = 1.08 \times 10^3$ kgms^{-1} in opposite direction to original motion ✓✓

Note: Estimate mass✓

c) How is it that airbags can reduce the force acting on a car occupant if their momentum change is not reduced?

[3 marks]

Force is rate of change of momentum. Since airbags increase the time over which Δp takes place, then force is reduced. Δp stays the same with or without airbags. ✓✓✓

d) Why when a car hits a wall do the occupants keep moving forward?

[2 marks]

By First law, the occupants will continue in their current state until an external force (such as the dashboard or windscreen or road acts on them.✓✓

e) Why is it necessary for the airbag to inflate "faster than the blink of an eye" "? Support you answer with a calculation.

[4 marks]

There is only a small distance in which the airbag can act. If it does not inflate quickly, the passenger or drivers head will contact the steering wheel or windscreen prior to the airbag inflating. ✓✓If you consider a car traveling at 80 kmh-1 (22 ms-1) and the windscreen driver distance being about 50 cm, then the time for the drivers head to move this distance is only .5/22 = 0.02 seconds.✓✓

f) Why is it necessary for the airbag to have vents?

[3 marks]

Vents are necessary for the air bag to deflate when the person hits it so that time for the Δp is again increased. Hitting a solid gas filled airbag can cause substantial damage.✓✓✓

g) Why is the inside of the airbag lined with starch or talc (powder)

[2 marks]

To stop the insides of the air bag from sticking together and thus allowing it to inflate and deflate correctly ✓✓