Plutonium in Perspective

This note in the SONE series of briefings seeks to set out the facts about the element called plutonium that has somewhat imaginatively been described by anti-nuclear campaigners as "the deadliest substance known to man". This was put in perspective during the Queen's visit to Harwell in the 1950s when she was handed a lump of plutonium in a bag and invited to feel how warm it was.

Plutonium is nonetheless a hazardous, toxic substance. But it is valuable as a generator of electricity, as well as for weaponry, and so is a sword, in the form of dismantled nuclear weapons, which can be converted into a ploughshare. That conversion is increasingly relevant in a world seeking to combat nuclear proliferation and global warming since nuclear power emits next to no greenhouse gases.

Source

Plutonium is a man-made element and in its pure form a very heavy, silver-coloured radioactive metal twice as dense as lead. It acquires a yellow tarnish when oxidised. It is the product of the use of uranium in nuclear reactors over the last 60 years. It is scarcely found in nature, though very small quantities were created about two billion years ago in Gabon, Africa, by a sustained underground nuclear reaction in a concentration of uranium.

Traces of plutonium244 remain from the birth of the solar system since it has a half-life (the time taken to lose half its radioactivity) of 80m years. If, say, 1bn tonnes were originally incorporated in the Earth's formation, all bar about one-hundredth of a gram would by now have decayed. Most plutonium in the environment is the result of nuclear weapons testing during the Cold War up to 1980.
This released about 10 metric tonnes into the atmosphere.

How Plutonium is formed

Plutonium is formed when the nucleus of a uranium atom's structure is transformed by capturing one or more neutrons. This reaction produces a number of plutonium isotopes – or forms of plutonium - of which the most important are numbered 239, 240 and 241. Virtually pure plutonium239 is necessary for nuclear weapons but all the isotopes can be used in nuclear power reactors.

Plutonium's production was predicted in 1940 soon after the outbreak of World War II by research scientists working separately at Berkeley in the University of California and at Cambridge University's Cavendish Laboratory. They independently gave it the same name – plutonium – after the solar system's planet order since it was discovered immediately after neptunium.

It was first produced and isolated in 1941 by a team led by Dr Glenn Seaborg at Berkeley, California, by deuteron bombardment of uranium, but news of the development was suppressed because of the war. Seaborg and his colleagues considered calling it ultinium or extremium because they wrongly thought they had found the last possible element in the periodic table.

Properties

All isotopes of plutonium are radioactive but most emit relatively weak alpha radiation that can be blocked by a sheet of paper. That is why Harwell was able to invite the Queen to feel the heat generated by a lump of plutonium. Plutonium241 is the exception in that it emits beta particles but their radioactive energy is very low.

The heat given off by alpha emissions makes plutonium warm to the touch, as the Queen discovered, and in larger quantities it can boil water. Plutonium238 emits a large amount of heat as it decays and much more energy can

Continued over

be released by fission. Plutonium239 and 241 are fissile and will split when bombarded by neutrons to release heat. By this means plutonium created from the uranium fuel in nuclear power reactors helps to raise steam to generate electricity.

In fact, about one third of the electricity generated in most nuclear power plants comes from the plutonium that is actually produced in situ as a by-product and about half of it is "burned" in the process. This makes the recyclable residue a highly valuable commodity.

In the environment – that is, largely resulting from weapons testing - plutonium exists most commonly as an oxide. It is very insoluble, sticks tightly to soil particles or sediments and tends to remain in the upper layers of soil or sand. There is no evidence that it is biologically concentrated in aquatic or land food chains.

Application

The continuing hostility to plutonium arises from its first use in nuclear weapons. During World War II the Americans built a reactor to produce plutonium in Tennessee and it was used in the "Fat Man" bomb dropped on Nagasaki in August 1945. Britain constructed a similar plant at Sellafield, now being decommissioned, to manufacture plutonium for weapons. Overall, during the Cold War it is estimated that the USA acquired about 110 tonnes of plutonium and the Soviet Union 170 tonnes, producing a world-wide inventory at its peak of some 300 tonnes.

Increasing attention is now being paid to converting this plutonium for use in civil nuclear reactors generating electricity and about 130 tonnes of plutonium, recovered from "spent" civil nuclear reactor fuel or weapons grade material, has already been employed to produce power.

Because of the heat it generates as it decays plutonium238 has been used in navigation beacons and space satellites and radioisotope thermoelectric generators to power cardiac pacemakers to reduce the risks of repeated surgery. Plutonium has powered 24 US space vehicles and enabled the Voyager spacecraft to send back pictures from distant planets. The Cassini spacecraft has three generators on board providing power as it orbits round Saturn.

Hazards

Health

Plutonium is a health hazard only if it enters and lodges in the body since its alpha radiation does not penetrate the skin. It is therefore relatively easy to shield people from its radiation. As we have seen, plutonium241 emits very weak beta radiation. Leaving aside open wounds, there are only two routes into the body – the nose and mouth, that is, by inhalation and ingestion.

Ingestion: Chemically, plutonium is roughly as poisonous as lead and other heavy metals. Arsenic and cyanide are much more immediately toxic and remain so whereas plutonium's radioactive toxicity slowly decays. It is nonetheless important to protect people from ingesting plutonium, even though little plutonium is absorbed from the gastro-intestinal tract and the risk from it is much lower than from inhalation.

Inhalation: As with any other dust particles, when plutonium is inhaled the larger particles are trapped in the upper airways and rapidly eliminated with natural mucus. The very small ones get into the lung and are again eliminated by way of the body's natural defence mechanism. But neither of these mechanisms is effective with an even smaller range of particles measured in microns, one micro being one-thousandth of a millimetre.

These particles can pass into the blood stream and so around the body. About half end up in the skeleton and a third in the liver. This is where the cancer hazard from radioactivity arises, though it is small. It has been estimated in the USA that breathing in 5,000 respirable plutonium particles, each of 3microns, raises an individual's risk of a fatal cancer by no more than one per cent above that arising from the average "background" rate from all causes.

No fatalities have been attributed to the contamination of 26 workers at a USA weapons facility in the 1940s. Indeed, 50 years on only seven had died compared with the 13 deaths expected on the basis of the mortality rates for comparable men. In the UK no adverse effects have been seen among the volunteers who had either been injected with plutonium or had inhaled it. So much for the anti-nukes' claim that "a speck can kill". It is without foundation.

Criticality

Care has to be taken in handling plutonium to avoid accumulation of amounts that approach critical mass, permitting a self-sustaining fission chain reaction. The geometry – i.e. shape - and nature of storage are important since compact shapes such as spheres and storage in water are more likely to cause criticality. However, there is no danger of accidental explosion in storage of nuclear reactor fuel since any initial release of energy disperses the material into a sub-critical state before explosive conditions are reached.

It is also necessary to combat a fire hazard from metallic plutonium since, if it is finely divided, it can react chemically with oxygen and water to ignite at room temperature. Consequently, plutonium is stored in small separated amounts in a dry, inert atmosphere.

Weapons

Weapons-grade plutonium is produced in small, purpose-built reactors burning natural uranium with frequent changes of fuel. It is a different process from the generation of electricity and, coupled with international safeguards, generally rules out the use of commercial power reactors for the production of weapons material.

Power stations not bombs

Some nuclear opponents imply that nuclear power stations are atomic bombs waiting to go off. This is entirely mischievous and impossible. For one thing, the fissile content of the fuel is too low. Secondly, the plutonium is far too impure. And third, given there is enough of it in pure form, it then has to be held long enough in a particular shape and in a critical state for enough atoms to be affected to make it explosive. To achieve this in bombs a chemical explosive is used around the plutonium. But the spherical shape of both plutonium and explosive – and the timing of the explosion – it must be simultaneous all the way round the sphere – are absolutely crucial. The idea that anything approaching the required conditions could arise in a nuclear power reactor by accident or malpractice is incredible.

Chernobyl

The disaster at Chernobyl nuclear power station in the Ukraine 1986 was not a nuclear explosion. It was of superheated steam and possibly of hydrogen released by chemical reaction with molten fuel cladding. What is more, it occurred in a type of reactor that could never have been licensed in the West and which was also being dangerously mishandled as part of a test. Chernobyl was bad enough but it was nothing like a nuclear explosion.

The future

In the post-Cold War world, the main issue arising from disarmament is what to do with the stockpiled plutonium, as well as that arising from the reprocessing of “spent” fuel. Britain now has some 100 tonnes in store and it could, if turned into a ploughshare to fuel nuclear power stations, contribute substantially to electricity generation over the next half century. Combined with recovered or depleted uranium, it could provide about 100 reactor-years of operation in a standard PWR without further recycling. With recycling in fast reactors (see below), the number of reactor years would be more like 6,000, almost dispensing with the need for fresh uranium. Its potential value is thus in the region of £10bn, depending on the cost of uranium and displaced fossil fuels.

Because of the build-up of stocks of plutonium, mainly at Sellafield, the Royal Society has reported on the health, environmental and security risks associated with the stockpile. Among other things, it recommended that weapons-grade plutonium should be blended down to limit its usefulness to terrorists – i.e. to make disarmament irreversible, as required by treaty commitments.

Over and above that, the major question for the Government is whether to treat the stockpile as waste and eventually dispose of it by vitrification in glass inside stainless steel containers or whether to capitalise on its immense value as a fuel. It has just opened up the possibility of burning up much of the stockpile as fuel in Britain by clearing the way in a statement in January 2008 for the development of nuclear power in Britain.

Any new nuclear power stations likely to be built in Britain will have the capacity to use plutonium, mixed with uranium, in mixed oxide fuel pellets not surprisingly called MOX. This fabrication has the virtue of building in further protection against misuse.

Options

MOX

Britain's ageing Magnox and AGR nuclear power stations cannot burn MOX, though they produce plutonium in the process of raising heat for steam. Only the pressurised water reactor, Sizewell B, is capable of doing that but it is not so far licensed to do so. Nonetheless, Britain has considerable experience of manufacturing MOX fuel at Sellafield for export. Russia is strongly committed to using plutonium in mixed oxide fuel, the USA and Japan are moving in that direction, Canada promotes its CANDU reactor as suitable for disposing of weapons plutonium and Europe has a well-developed MOX capacity.

This suggests that the stockpile of weapons-grade and recovered plutonium from "spent" nuclear fuel could be usefully disposed of fairly quickly. It is estimated that across the world 15 tonnes of warhead plutonium could be disposed of every year - the equivalent of 3,000 warheads – to produce 110TWh of greenhouse gas-free electricity - enough to supply the UK a third of the year, underlining the value of plutonium as a fuel.

Fast reactor

In the 1960s Britain originally envisaged recovering plutonium from "spent" fuel in our first generation of nuclear reactors – Magnox – to help fuel fast reactors, with the prototype reactor at Dounreay in the North of Scotland. Fast reactors have the potential of getting 60 times more power out of their fuel than conventional reactors and, apart from this major boost to their economics, it would have been a significant development in a world then erroneously thought to have rather limited resources of uranium.

Subsequently, it was decided not to use plutonium recovered from second generation AGR reactors but to store it for future use in fast reactors.

Changing economics – and plentiful supplies of uranium - saw the demise of the prototype fast reactor at Dounreay but not the accumulation of plutonium in store. It now represents an economic resource worth around £10bn – and rising – and there is renewed international interest in fast reactors for the longer term.

In short, there is no shortage of options, subject to economics, for disposing of plutonium:

1. disposing of it as waste – which would, as we have shown, be a monumental waste; this would make the plutonium less accessible but it would not eliminate it;
2. selling it as fuel, under licence, to countries that decide to use it as fuel;
3. using it in MOX fuel for the present PWR and new generations of nuclear reactors;
4. using it as MOX fuel and recovering recyclable plutonium (along with recyclable uranium) from "spent" nuclear fuel for use in future fast reactors, thereby making maximum use of a valuable element in current and foreseeable circumstances.

CONCLUSION

As the Organisation for Economic Co-operation and Development (OECD) put it in 1989: "Plutonium is far from being the uniquely hazardous material of popular imagination. Rather it is one among many toxic materials that have to be handled with due caution to minimise the associated but well understood risks".

Britain is now to develop its nuclear industry.
This creates an opportunity medium term to use up both the defence and civil nuclear plutonium stockpile to the economic benefit of the nation. Its deployment in this way would help to increase Britain's energy security and pursue our international obligations in minimising the use of fossil fuels and combating global warming.

Longer term it could provide the fuel for vastly more efficient fast reactors which would further serve our objectives of energy security, less reliance on ever more costly and scarce fossil fuels and a low carbon society.

The "plutonium society" disparaged by Greens can thus been seen to be highly desirable as an economic user – and disposer - of a controversial but immensely valuable element.

Supporters of Nuclear Energy (SONE) is a small but high powered organisation of individuals who have been campaigning for more than 10 years for the development of nuclear power.

They believe that, on the basis of its 50-year record of operation in the United Kingdom, it is eminently safe, a reliable generator of electricity, highly competitive and a clean form of power. It emits next to no carbon dioxide emissions. Without it, we run grave risks over the continuity of power supplies and meeting our international obligations on climate change.

Over recent years SONE has sought to develop an informed debate about the UK's energy situation in the context of global realities and obligations. In doing so, it has drawn attention to the merits of nuclear power as a means of bringing greater security of supply to UK power supplies, improving the competitiveness of British business, minimising the use of fossil fuels and actively combating global warming.

As well as this briefing on plutonium, it has published the following briefing notes:

The Looming Energy Crisis

Briefing Note
(a factual document about nuclear power in the context of the energy scene)

Uranium Availability

Renewable and alternative sources of electricity

The Hydrogen Economy

Micro-generation Briefing Note

The Management of Nuclear Waste

All these briefings can be obtained free from the Secretary, SONE, c/o BNES, 7 Great George Street, London SW1P 2ZS or e-mail sec@sone.org.uk

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