Plugging the leaks

Ceramic containers for radioactive waste have been found to get leaky, says S.Ananthanarayanan.

The journal, ***Nature*** reports this week the work of Ian Farnan and colleagues at Cambridge, UK, who found that zircon crystals, a candidate material, may be less durable that was thought.

Nuclear waste

With fossil fuels (coal and oil) getting depleted, the only way to meet the growing energy needs we face may be through a worldwide network of nuclear power plants. But the trouble is the mammoth nuclear waste that this would generate.

Nuclear power taps the energy stored in the structure of some very heavy atomic nuclei. These complex nuclei are not packed in the most efficient way and they sometimes readjust to a closer, lower energy, state, usually with the ejection of energy and part of their constituents. This energy that is released can be converted to electricity. But the extra nuclear particles ejected show up as ***radiation*** – and radiation is harmful to plant and animal life!

For controlled nuclear reactions, the original material is barely radioactive by itself. But individual nuclei are 'pushed over the ledge' by chance radiation from their neighbours. But the trouble is that the end products, the ***daughter*** nuclei are generally radioactive, on their own, without the need for a stimulus, and often very much so. And these radioactive nuclei are generated by nuclear reactors in good quantity.

Half life

There is no fixed time after which a nucleus decays – it is a matter of chance and the average time differs from substance to substance. The average actually depends on the energy difference between the ***parent*** and the *daughter* state and also the height of the ***barrier*** that separates them. By the rules that govern nuclear particles, there is always a probability that systems spontaneously scale an energy barrier and so different materials decay at different rates.

Now, the total radioactivity, or the number of decays, depends on the number of nuclei present in the sample. As the nuclei decay, less of them are left and the number of decays also reduces. The time it takes for the number of active nuclei to fall to ***half*** is then an indicator of how readily the nuclei decay and is known as the ***half life*** of the substance.

Some substances have half lives in seconds or even less. The substances then show intense activity, but the activity falls and almost disappears in a very short time. Some substances have half lives in years and some in thousands of years. These are the deadly ones, which need to carefully quarantined, because they do not become harmless for a very long time.

Nuclear Waste

The usual fuel in reactors in reactors is $Uranium^{235}$. Spent ***nuclear fuel rods*** contain the direct fission products, which are emitters of beta radiation (electrons) or Gamma radiation (like X Rays, only many times more powerful). The fuel rods also contain other forms of uranium itself, or related nuclei., and radioactive nickel or iodine is generated in the of the reactor vessel. These are emitters of alpha particles, which are massive projectiles, thousands of times as heavy as an electron.

Many of these materials have long half lives indeed, running into hundreds of thousands of years. Leakage into ground water, soil or the atmosphere could take place over a very long time and could build up to dangerous levels. These long lived waste products are the greatest challenge in a major nuclear power programme.

Zircon and ceramics

An attractive containment material is concrete. It locks in the radiation and is also hard wearing and can last for a long time. But for the really long time-scales involved in radioactivity, much hope has been pinned on zircon, or zirconium orthosilicate, a naturally occurring ceramic.

The quality of zircon is that it extremely hard and has a very stable crystalline structure. Zircon, in fact, is considered to be the longest lived material in the earth – there are samples that are 4.4 billion years old – which have survived since the beginning of the earth! A substance as hardy as this could be perfect for storing long lived radioactive waste.

The trouble is that the alpha radiation in nuclear waste may batter and destroy the crystal structure of zircon. It would then lose its stability and begins to crack, like glass, or decompose and dissolve in water. Computer simulations of this process had suggested that zircon may still last to serve the purpose. But the work of the Cambridge scientists, using direct measurements, rather than simulations, have shown that the breakdown of zircon is five times faster than estimated. It may then survive for only 1,400 years, while a life of 240,000 years is desired!