Choosing nuclear garbage bins

There is a debate on whether to recycle or bury nuclear waste, says s ananthanarayanan

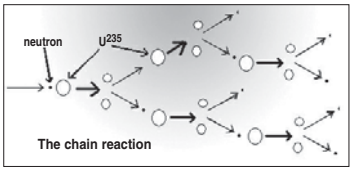
PLUTONIUM is a radioactive element that is a byproduct of the nuclear reactor, a byproduct that can also be used as nuclear fuel and to build an atom bomb. But when it is used as nuclear fuel, it can be made to create more plutonium, which could make the process self-sustaining. If it is not so used, it is still radioactive and needs to be sequestered and stored. And if it is used as fuel, the further byproducts are radioactive and need to be sequestered and stored. Frank von Hippel, Rodney Ewing, Richard Garwin and Allison Macfarlane — scientists and policy experts in the USA — have analysed the options in a paper carried in the journal, *Nature*.

Atoms consist mainly of a number of particles packed in the central nucleus of the atom. About half the particles are electrically charged and the rest, the neutrons, are not. The force that holds the particles together does some work in keeping them that way, and the energy for this work comes from the total energy of the nucleus. When a nucleus gets very large, the force holding the particles together begins to weaken and the nucleus may split into two, with or without some of the particles, like neutrons or groups of particles that do not find a place in the "daughter" nuclei, getting left out. But the main change is that the daughter nuclei are collectively more efficiently packed than the parent, and there is "saved" binding energy to spare. This energy is expressed in a violent separation of the daughters or the expulsion of the additional particles that are released. The appearance of these particles is what is usually called radioactivity.

The splitting of nuclei of some atoms in this way can be induced by the impact of a stray neutron. The atom of uranium 235, denoted U^{235}, is one such. The number "235" denotes the number of particles in the nucleus. The same element can also exist with a few more, or less, neutrons — because neutrons only affect the mass of the nucleus, not its electric charge. As the charge stays unchanged, the atoms with nuclei differing only in the number of neutrons behave as the same element. Now, when U^{235} is struck by a neutron, it splits into a pair of daughters plus either two or three free neutrons. These neutrons can then set off more nuclear fissions, which would release more free neutrons. As neutrons move fast and the distances are small, a mass of U^{235} could undergo very rapid fission, releasing huge energy. This is the energy that is used to boil water and generate power in the nuclear reactor.

Now, this useful kind of uranium, which is U^{235}, is only a small part of natural uranium. The large part is U^{238}, which has three more neutrons and cannot take part in the chain reaction. But U^{238} is also affected by the neutrons zipping about and it gets changed, on being struck, into radioactive form, which promptly breaks down into another radioactive element, plutonium. The interesting thing is that plutonium decay also generates neutrons, which can set off more decay and there can be a chain reaction, just like with U^{235}. If left over, U^{238} is packed in a plutonium reactor and then more plutonium gets generated, which promises economy of fuel materials!

Frank von Hippel, Rodney Ewing, Richard Garwin and Allison Macfarlane.



The chain reaction

Dangerous remnants

Many daughter elements and byproducts of nuclear reactions are also radioactive. Over years of operating nuclear reactors, there can be a build-up of such radioactive waste and this represents great danger. In commercial reactors, which use uranium ores, there are advantages if processed ore, which concentrates the content of U^{235}, is used.

But it is easier and quicker to use ordinary uranium, which is rich in U^{238}. Now, this U^{238} content, which does not take part in the chain reaction, still absorbs neutrons and the product decays into plutonium. Plutonium is radioactive and is the important hazardous byproduct of reactors that use natural uranium. As plutonium also undergoes fission in chain reaction, like U^{235}, it can also be used, not necessarily in reactors but to make atom bombs. Simple facilities to generate power using natural uranium would, thus, provide a ready source of material for military use.

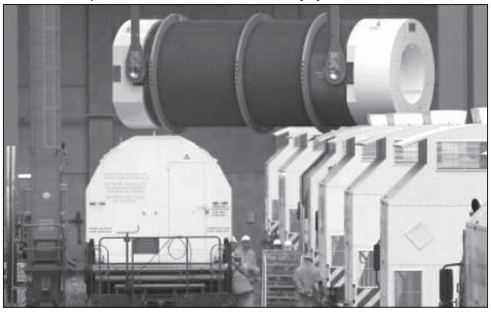
Apart from the danger of military application, even the build-up of plutonium alone needs to be stored, with arrangements to contain its radioactive emissions. The large number of natural uranium reactors the world over is said to have generated 500 tonnes of plutonium, enough for 100,000 nuclear weapons and a dangerous treasure, in any case. This stockpile of plutonium is largely the result of the separation of plutonium from spent fuel, for use in plutonium reactors that could then "breed" more fuel.

This fuel cycle is the grand plan of India's nuclear programme, supplemented by the generation of U^{233}, another chain-reaction-worthy form of uranium, by exposing thorium, of which India has good resources, to neutrons in plutonium reactors.

But these proposals, of "breeder" reactors, have not taken off and stockpiles of plutonium have been built up. Separating plutonium from spent uranium fuel and then fabricating pellets of plutonium mixed with depleted uranium is expensive business.

While France continues to separate plutonium and has become the world expert in constructing separation plants, the cost of separation is yet to be recouped. Japan also followed the reprocessing route, in part to sidestep finding a place to sequester nuclear waste. But their reprocessing plant did not get off the ground and now Japan's whole nuclear power programme has been reviewed.

The experience of Britain and the USA has been that reprocessing has proven to be costlier than the value that could be recouped by using the plutonium fuel.



Nuclear waste disposal.

Burying waste

The alternative is to "immobilise" separated plutonium or to directly bury it. The USA and Russia had each committed to dispose of 34 tonnes of plutonium stocks. Russia objected to "immobilisation" as this could be reversed and the fuel recovered. The USA also considered converting plutonium into fuel pellets, rather than immobilising, to be economical, but the economy did not materialise. The UK will soon have over 100 tonnes of separated plutonium and has plans to convert this into fresh "mixed" fuel.

The UK tried this route earlier and did not succeed. The article in *Nature* thinks the UK should abandon trying to make fresh fuel and opt instead for disposing of the plutonium by "immobilisation", which is to encase the waste in ceramic and bury it 500 metres deep in a geological repository. This can be done without the precise machining of pellets and if the plutonium is mixed with the waste that comes from the reprocessing plant, it would be so radioactive for a century that it would be safe from thieves or terrorists. The other method is to directly bury the waste out of reach, in boreholes that are 5,000 metres deep.

Tailpiece

This discussion is about disposal of the plutonium stocks that have piled up, thanks to the weapons programme and also the pursuit of the plutonium reactor and the breeder reactor. But even if these programmes had succeeded, with the plutonium getting consumed the spent "mixed" fuel would have needed to be disposed of along with other spent fuel.

There is no getting away from the need to dispose of nuclear waste. An evaluation of the geographical areas that would get blocked for habitation or other use, over years of generating nuclear energy and burying waste, would place a limit on the power that is finally possible through this route.

It may be more workable to find ways of reducing power consumption — by reducing power consumers, ie, population.

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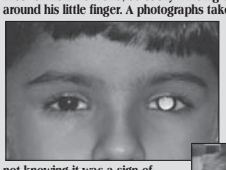
Tell-tale sign

Retinoblastoma is a life-threatening eye cancer in very young children and early detection can make a world of difference

THREE-YEAR-OLD Ashu Varma (name changed) loves colouring books and picture books with animals and vegetables. Every three weeks, she travels with her mother by train from a remote town in Rajasthan to Hyderabad for treatment of retinoblastoma, an eye cancer that occurs in children under three years of age. She is one of 250 beneficiaries of a donation made by Bharat Petroleum Corporation Limited to provide books, colour pencils and wax crayons to children receiving chemotherapy at the LV Prasad Eye Institute, Hyderabad. Her mother says, "Ashu can now tell A is for 'Aeroplane' and A is also for 'Apple'!"

Little Abdullah travelled from Saudi Arabia to Hyderabad as the doctor in Riyadh found he had a white shining glow inside his eye — the first symptom that something was seriously wrong. "The child was on chemotherapy and had to undergo laser treatment to control the cancer in his eye," his mother said.

Abhiram recently underwent major surgery to remove an eye because it had an advanced stage of retinoblastoma. He now does a great job making the most of his little world, so easily winding everyone around his little finger. A photographs taken on his first birthday clearly showed there was a white glow in his eye and his parents are distraught at how they lost three months not knowing it was a sign of retinoblastoma. "Living here in Hyderabad and having the best access to care, and yet not having the basic information on this killer disease was the biggest problem," said Abhiram's father.



Dr Santosh G Honavar

Dr Santosh G Honavar established and now heads the Ocular Oncology Service at the LV Prasad Eye Institute, the first such facility in the country. The comprehensive multi-specialty Children's Eye Cancer Centre he has established in collaboration with SightSavers International has done pioneering work and is now recognised as one of the best in the world.

Retinoblastoma is a life-threatening eye cancer in very young children, the tell-tale sign being a white shiny reflex. Crossed eyes or *bhengaapan*, a swelling of the eye, and continuous watering are other symptoms. Vision is lost rapidly and the child might frequently bump into objects and get hurt.

Each year, more than 1,500 new cases are diagnosed in India. Seventy-five per cent of the children have retinoblastoma in one eye. If a child is examined early by a specialist and referred for treatment, then the cancer can be controlled and the child's life saved. Treatment ensures 95 per cent are saved from death, 85 per cent have their eyeballs intact and 75 per cent have their vision protected. The rate of tumour control using plaque brachytherapy is 80-90 per cent.

Take a flash photograph of your child…Look carefully into his/her eyes. If there is a white shining spot inside, click a few photographs using a flash and a still camera to capture the glint. If the photograph shows there is a white reflex in the eye, it confirms the tell-tale sign of retinoblastoma.

For more information on the LV Prasad Eye Institute, call: 040-30612345.

Dosage compensation

There is, says tapan kumar maitra, a correlation between X chromosome inactivation and somatic differentiation

OUR contention that chromosomes behave as functional units is strengthened by our knowledge and understanding of the phenomenon of dosage compensation. It is generally observed that the amount of gene product bears a rather precise relationship to the number of *autosomal* genes responsible for the product. If one gene makes x amount of product, two genes or *alleles* will make twice the amount, and so on. This, however, is not true for X chromosome-linked genes. Here the two-X female produces the same amount of gene product as does the one-X male, rather than twice as much. Loci on the X chromosome that behave in this fashion are said to compensate.

That this is a chromosomal rather than a gene function, however, is indicated by the fact that the genes compensated appear to have no direct responsibility for sex determination or differentiation, and may involve a variety of different phenotypic expressions ranging from enzyme structure to eye colour and bristle form.

First discovered in Drosophila, dosage compensation has also been clearly established in a number of mammals, including man, but it seems clear that it operates differently in different species. In mammals, the phenomenon appears to be by way of the "Lyon," or, perhaps more correctly, the "single active X" mechanism. In a woman, inactivation of one of the X chromosomes occurs in somatic cells at about the 16th day after fertilisation of the egg. Prior to this, both X chromosomes are active and are necessary for normal sexual differentiation. Inactivation does not occur in germinal tissue.

When more than two X chromosomes are present, all but one is inactivated. The result is genetic inactivity — "heterochromatinisation" — of all but one of the X chromosomes in a somatic cell. Thus, the XX female has but one functioning X chromosome in each of her somatic cells, whereas the single X of the male functions in all cells. Whether the Y chromosome remains operative in a transcriptional sense is not known, although its effect on sex determination is established.

There is, therefore, a correlation between X chromosome inactivation and somatic differentiation. At the onset of differentiation, one of the two X chromosomes, selected at random unless one of the X chromosomes is abnormal, becomes genetically inactive in the sense that it apparently ceases to transcribe at the same time that its ability to replicate remains unimpaired. If one of the X chromosomes is abnormal — is deleted or is a ring — it is selectively inactivated and only the "normal" X functions. Replication of the inactivated X is delayed in relation to the remainder of the chromosomes in the complement, and it is usually the last member to complete its DNA synthesis. During interphase, the inactive X may be observed as the heteropyknotic "Barr body", or sex chromatin, in somatic cells of women.

Elegant genetic experiments by Barton Childs and his colleagues on the cells of women heterozygous for two kinds of glucose-6-phosphate dehydrogenase have established the randomness of the inactivation process to produce the single active X chromosome. In humans, inactivation of the X chromosome appears to be an all-or-none phenomenon. Variations of this are known, however, in other organisms. In the mouse, a number of X chromosome genes show compensation and others do not, suggesting only partial inactivation. In the bandicoot, an Australian marsupial, one X chromosome is rendered inoperative by its elimination from all somatic cells, thereby obviating the need for continued replication of an inactive element. A somewhat different system characterises the creeping vole, *Microtus oregoni*. The male germ line is OY, the male soma XY, the female soma XO, and the oocyte XX. Males develop from XY fertilised eggs, with the X being subsequently eliminated from the germ line.

Females arise from XO fertilised eggs, and no elimination occurs, so that male and female somatic tissues possess a comparable X chromosome composition. The oocyte, prior to meiosis, is presumed to have acquired its XX state through selective non-disjunction of the single X chromosome in the germ line. It would appear, therefore, that inactivation of chromosomes in part or whole, elimination of chromosomes, and late replication are but varied expressions of the same phenomenon of dosage compensation.

Many X-chromosome loci in *D. melanogaster* demonstrate dosage compensation whereas those in autosomes do not. Here, however, differential inactivation of one of the X chromosomes does not occur and the equality of phenotypes in males and females must be accounted for in other ways.

Two general hypotheses have been advanced, each having some experimental support. Hermann Joseph Muller proposed a system of modifying genes on the X chromosome which, through enhancement or repression, altered the expression of those genes which he studied. Richard Goldschmidt, on the other hand, denied the existence of special modifying loci and, instead, advanced the notion that compensation was a consequence of the different development systems characteristic of the male and female cellular milieu. Unequivocal experiments to distinguish between these hypotheses, or to test their validity, have not been done.

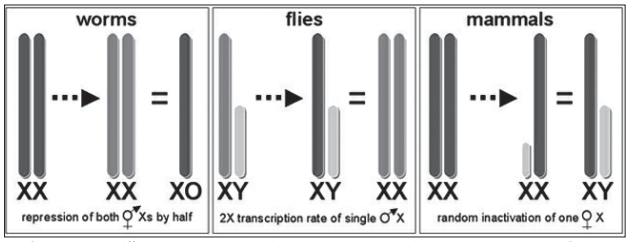
Whether the synthetic rate of the single X chromosome in *Drosophila* males is twice that of the comparable haploid X chromosome in the female, or whether each of the female X chromosomes is synthesising its gene product at half-normal capacity, is not known. The former case would involve enhancement, the latter repression. It is known, however, that the single X chromosome in the salivary gland cells of the male is nearly as wide as are the two paired X chromosomes in the female, even though the amount of DNA per chromosome remains constant.

The increase in size in the male must be due, therefore, to some kind of a generalised puffing that extends throughout the length of the chromosome. Furthermore, it has been recently shown that the single X chromosome in the male produces nearly as much RNA, as measured by the uptake of tritiated uridine, as do the two X chromosomes in the female. The difference, consequently, is expressed quantitatively at both morphological and biochemical levels. No qualitative differences in compensation have yet been discovered.

When compensation is examined at a genetic rather than a chromosomal level, it is clear that both the alleles are operative in a female *Drosophila*. Selective inactivation of alleles cannot, therefore, be the cause of compensation in *Drosophila* as it is in mammals, and some as yet undiscovered mechanism must be responsible.

As in the cases of the X autosome translocations and of the *D. hydei* Y chromosome, discussed earlier, these observations suggest that the X chromosome is unique in its control of the formation of gene products. The control in all instances appears to be via transcription rather than through control of translation or some more remotely removed step in synthesis.

Why an equivalence of gene products in the two sexes is a necessary feature of development is not immediately evident, because most enzymatic systems seem to possess a fair margin of safety. It may well be that dosage compensation is a reflection of selective forces associated with the retention of sex-determining mechanisms which have become preserved intact in the X chromosome.



Organisms use different strategies to equalise X-linked gene expression between males (XY or XO) and females (or hermaphrodites; XX). Female mammals randomly inactivate one X chromosome. Male fruit flies double the transcription rate of their single X chromosome. Hermaphrodite worms halve the expression of both X chromosomes.

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