Importance of Closing the Nuclear Fuel Cycle

a report by

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Human development correlates strongly with *per capita* electricity consumption. That is why the current surge in global electricity demands is being led by the continuous growth in energy needs of China, India and other emerging economies. Although most of the power sector expansion till now has come from fossil fuel-based thermal plants and the latter will continue to play an important role in the near future, there is strain on the limited fuel stock available. Fossil fuels are likely to run out sooner or later and the world has begun to think of conserving fossil fuel sources for carbon-based industries of the more distant future. Hydroelectric systems use a renewable resource and, in addition to electricity, provide water for irrigation but inevitably they displace people and have also been criticised for disturbance of ecology. Solar, wind, biomass and other renewable sources are important, but, at the present time, are not generally competitive, except in remote areas, with hydroelectric, fossil fuel-based thermal or nuclear being the main sources of primary energy needed for large-sized power plants.

Optimum utilisation of all the available sources of energy should, therefore, be planned to achieve sustainability of resources and sustainability of ecology and environment. It is in this context that one must see the increasingly important role that nuclear energy is likely to play in satisfying the future energy needs of the world. In some countries, which have no significant indigenous fossil fuel sources, nuclear power is seen as providing energy security. The trend in the developed countries, where nuclear power growth has come to a standstill in the recent past, is also reversing due to global climate change concerns and the recognition of nuclear energy as a clean environment-friendly source. Sustainable development, therefore, requires nuclear energy and in securing a sustainable and secure energy source for the future, the nuclear fuel cycle has a key role to play.

While much work has been undertaken towards development of nuclear reactor systems, less focus has historically been given to have an optimised approach to the whole fuel cycle. This can be mainly attributed to currently plentiful availability of cheap uranium supplies, in the absence of a steady growth in nuclear energy generation in the world. With an envisaged growth of nuclear power in the coming decades, mainly in the developing countries with strong economic development, there is a growing need to recognise fuel cycle as an integral component of the nuclear energy system for any holistic assessment in the areas of sustainability, economics, safety, environment and waste management. It is with this realisation that the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) methodology for assessment of innovative nuclear energy systems targets the evaluation of the integrated system of reactors and associated fuel cycles.

Currently, about 20–25% of spent fuel unloaded from the current operating nuclear reactors is reprocessed. Commercial scale reprocessing is being carried out in France, India, Japan, UK and Russia. In most other countries, the decision on the fuel cycle option has been deferred. The spent fuel, not taken up for reprocessing, is being kept in interim storage facilities where it can be monitored continuously and can be retrieved back.

The choice of closed or open fuel cycle, while being governed by the national policy and the preferred reactor systems, has a strong bearing on sustainability, waste management and associated long-term environmental issues. It is increasingly becoming clear that sustainability and issues concerning environmental impact favour a closed fuel cycle which permits recycle to the maximum possible extent. A short-term perspective on nuclear energy has inhibited some countries from going ahead with reprocessing of spent fuel and development of fast breeder reactors.

Worldwide resources of uranium are limited and at present the world's production volume of natural uranium covers only half of the actual demand. The gap is being filled by transfers from the stored stocks and by using military uranium. These secondary supplies will not last long. The spot price of uranium over the past few years has been showing an increasing trend. These facts provide a reflection of the uncertainty about the future supplies. The use of uranium in the once-through mode will enable us to use only about 1% of the available uranium resource and with this option alone, the life span for availability of uranium will be almost the same as that of oil and natural gas. Fast reactors are, therefore, emerging as important candidates for next generation reactors and these in the closed fuel cycle mode provide the option for the full exploitation of the natural resources. It may be worth mentioning that four of the six reactor systems selected for further development by the Generation IV International Forum are fast reactors.

The industrial-scale recycle of plutonium and reprocessed uranium has been carried out in thermal reactors. This has demonstrated the commercial feasibility of the closed fuel cycle.

The other naturally occurring nuclear resource of interest is thorium. Unlike natural uranium, which contains fissile isotope ^{235}U, thorium does not contain any fissile isotope. Its utilisation requires the aid of fissile material from the uranium cycle. Thorium is three to four times more abundant worldwide than uranium and can therefore be an abundant sustainable resource. The large-scale utilisation of thorium requires the adoption of closed fuel cycle and the (Th-^{233}U) fuel cycle is similar in most aspects to that of (U-Pu) fuel cycle.

The net cost of reprocessing and recycle in a closed fuel cycle is almost the same as the cost of long-term storage of spent nuclear fuel in the current open fuel cycle. The difference in cost is negligible as the fuel cycle costs are only a small fraction of the total cost of electricity produced by nuclear energy. The increasing resource prices and the lower storage cost of waste associated with the closed fuel cycle makes it all the more attractive.

Spent fuel contains about 96% valuable materials (95% uranium, 1% plutonium) and 4% wastes (3–4% fission products and 0.1% minor actinides). The closed fuel cycle, in comparison to the once-through cycle, reduces the volumes of waste requiring treatment and disposal. The benefit of managing a smaller waste volume assumes great significance due to the limited availability of waste disposal sites. This can be seen from the fact that Yucca Mountain, a direct disposal site for spent fuel in the US, was approved formally by the government after a long political dispute, although the dispute in court still continues. The US, if it continues with its policy of once-through fuel cycle and at its current nuclear power generation level, will need to construct almost every 30 years a disposal site having the same scale as that of Yucca Mountain with storage capacity of 63,000 tons.

Unlike chemically toxic substances like mercury and arsenic, which maintain their toxicity eternally, a radioactive element reduces its toxicity due to its natural decay. The closing of the nuclear fuel cycle significantly reduces the radiotoxicity of waste by the removal of plutonium which is the primary contributor to long-term radiotoxicity. The separation of minor actinides and fission products further reduces the radiotoxicity during storage by orders of magnitude.

Advanced partitioning processes and transmutation in advanced reactors could make it possible to recover and recycle all the actinides (uranium, plutonium, americium, curium, neptunium) and reduce the ultimate waste to only the fission products, the radiotoxicity of which drastically decreases in a few hundred years. The closed fuel cycle greatly reduces the geological repository requirements.

The other environmental aspect to be considered is the radiation dose to the public. The collective public dose per unit energy per year in the entire nuclear cycle is a small fraction of the prescribed regulatory limits. Within this small fraction, the contribution from mining exceeds that from reprocessing. The closed fuel cycle, therefore, also provides advantages in terms of public radiation exposure.

Nuclear power requires the closed fuel cycle for sustainability. The open fuel cycle economics lay major emphasis only on reactor performance, whereas the closed fuel cycle economics is based on an integrated model and focuses on all the three facets of fuel cycle – the reactor, the front-end and the back-end.

The plutonium recycling in thermal reactors has demonstrated the feasibility of commercial reprocessing. This should be followed by development of fast breeder reactors, advanced partitioning and transmutation techniques, recycling of minor actinides, remote fabrication technologies etc., to exploit the full benefits of closed fuel cycle. The spent fuel dry storage technology is well proven and provides the time to develop and commercially exploit these technologies.

Generally, the fuel burn-ups in fast reactors are much higher than those in thermal reactors. This results in reduced quantity of materials being handled in the fuel cycle facilities, improving the economics and environmental benefits.

The closed fuel cycle provides the benefit of reduction of the quantity and toxicity of the wastes requiring geological disposal. ■

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