LONG-TERM ISSUES ASSOCIATED WITH SPENT NUCLEAR POWER FUEL MANAGEMENT OPTIONS

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Abstract

Spent fuel management is perceived as one of the crucial issues to be resolved for sustainable utilisation of nuclear power. In the last decades, spent fuel management policies have shown diverging tendencies among the nuclear power production countries – a group has adhered to reprocessing/ recycle and another has turned to direct disposal, while the rest of the countries have not taken decision yet, often with "wait and see" position. Both the closed and open fuel cycle options for spent fuel management have been subject to a number of debates with pros and cons on various issues such as proliferation risk, environmental impact, etc. The anticipation for better technical solutions that would mitigate those issues has given rise to the renewal of interest in partitioning and transmutation of harmful nuclides to be disposed of, and in a broader context, the recent initiatives for development of innovative nuclear systems. The current trend toward globalisation of market economy, which has already brought important impacts on nuclear industry, might have a stimulating effect on regional/international co-operations for cost-effective efforts to mitigate some of those long-term issues associated with spent fuel management.

Introduction

The past production of nuclear power in the world has resulted in a total discharge of 230 000 tHM of spent fuel as of the end of last century. In the current projection of global nuclear power, the total discharge will reach to 339 000 tHM by 2010 and to 445 000 tHM by 2020. Roughly one-third of this amount has been reprocessed until now, but the pace of reprocessing has recently been slowed down mainly due to limited use of separated plutonium as mixed oxide fuel (MOX). The bulk of the global inventory of spent fuel is in storage, either in AR or AFR facilities of which capacities have to continue to be expanded in order to accommodate incremental arising of current annual average of 11 000 tHM, unless the global inventories are abated by shipping to further destinations like reprocessing or geological repository for disposal.

Regarding the forecast on spent fuel arising, there are currently two global trends which would affect the medium term future. The continuing search for better economics of nuclear power production will be a strong driver toward higher burn-up with a result to reduced spent fuel arising which would be, however, off set by the current trend towards lifetime extension of existing nuclear power plants which would contribute to additional arising of spent fuel. Longer term projections to 2050 or 2100 are subject to larger uncertainty, however, due to various unpredictability on the fate of nuclear energy in that time frame. As spent fuel represents the major source of fissile materials and high radioactivity, how to manage the large amount of spent fuel to be accumulated around the world is obviously a challenging question.

In the classical strategy for fuel cycle backend, closed fuel cycle by reprocessing of spent fuel with fast breeder reactors in mind had been regarded as a standard strategy which was culminated by the oil shock in the seventies, some repercussions of which are still lingering in some countries devoid of natural resources for energy production. The classical scenario was based on an exponential growth in nuclear energy and uranium demand which turned out later to be much more sluggish than the expectations, thus requiring a squeezing down of the earlier plans. The condition was further aggravated with other adverse circumstances, in particular the widespread socio-political perceptions that have become unfavourable to nuclear. Due to these and other new realities, an increasing number of countries have abandoned closed cycle, either turning to once-through cycle adopting direct disposal of spent fuel or by deferring decision to a future time, with a "wait and see position". Evidently the latter group of countries are storing spent fuel pending future developments and decisions regarding the use of nuclear power, in particular energy economics and security, and resolution of environmental, safety, proliferation and nuclear security concerns.

In view of the expected role of nuclear energy as a carbon-free source of electricity supply to the growing demand in the future, calls for development of innovative nuclear systems has been amplified in recent years in search of solutions to the issues of existing nuclear power systems. An exemplary case is the R&D on partitioning and transmutation (P&T) which are being conducted with a view to reduce the radiotoxicity of some nuclides which is meant to be disposed of. The P&T system should be an integral part of future innovative nuclear systems that would have to be optimised in compromise with other challenging criteria. Several nuclear companies, topic laboratories and also some international organisations are working on design of new rector concepts, various aspects of innovative fuel cycles and development of partitioning and transmutation techniques and procedures.

Interim storage

The bulk of spent fuel in world inventories has been sitting in storage, either in at-reactor (AR) storage pools or in away-from-reactor (AFR) facilities of wet or dry type, where the spent fuels have to be kept in safety as long as they are not removed to further destinations. As the temporary AR pools of older reactors have encountered the problem of storage capacity, utilities have taken measures to expand capacity mostly by re-racking which could accommodate significantly larger amount of spent fuel arisings, and in some cases enough for life-time operation. However, those cheaper methods have almost been used up and new builds of AFR type at higher costs are required in many cases, especially when there is no further destinations available within the time frame. In fact, interim storage is an essential component for any spent fuel management option, pending further endpoint solutions.

Given such current status, the most imminent service required for the spent fuel management worldwide is to provide sufficient and prolonged storage capacity for the future spent fuel inventory arising either from the continued operation of nuclear power plants or from the removal of fuel in preparation for plant decommissioning purpose. As for the prolonged storage, there is a confidence in coping with the long-term storage requirements without major technical issues. Such a confidence has been built on the extensive industrial experience gained in spent fuel storage, and especially on the development of dry storage systems which are considered cost-effective and particularly suitable for interim storage as long as up to one hundred years or even beyond. The dry storage systems are also capable to cope with the needs for storage of high burn-up and MOX type of spent fuel that result from a better plant and fuel utilisation. Further optimisation of storage systems will also be possible in the future by relying on the use of burn-up credit. Capability in long-term storage is an important base for future flexibility in the approach to various strategies for spent fuel management options.

A question on the possible duration and location of interim storage appears to have begun to be seriously discussed in recent years, in an increasing number of countries, in confrontation with the requirements for extended storage and the interface thereto the possible endpoint options. The possibility of interim storage of spent fuel for a long period of time can be an important merit for buying time in search for better solutions. Providing proper liability management by reliable storage is economically a defendable solution to allow in the mean time for further developments addressing not only technical but also societal and infrastructural issues and concerns about the endpoint.

A key issue associated with interim storage is to ensure by design, operation and institutional arrangements the retrievability of spent fuel at the end of the storage period. Maintenance of physical integrity throughout the duration of storage is considered to be the key technical requirement. An institutional consideration evidently requires appropriate record keeping of all the necessary information required for further actions and assuring information is transferred to future generations.

Direct disposal

An increasing number of countries have turned their policies to disposal of spent fuel, from the original direction of reprocessing of spent fuel for recycle. Some of these countries have committed schedules for implementation of the plan for providing repository, but with quite different results up to now. The political moves forward to siting of a repository, as have recently been witnessed in Finland and USA, are notable in the sense that they might provide a instigating event to other countries' programmes in stalemate. However, the prospects for decrease of the growing inventory of spent fuel in storage by actually disposing spent fuel in repositories is still decades away. Currently there are only a few programmes endorsed by government for developing spent fuel disposal facilities and even these programmes are based on a stepwise approach, wherein an interim geologic storage or/and a retrievability stage is foreseen.

The concept of the spent fuel disposal in deep geological disposal has long been endorsed by international groups of experts on various grounds including the ethical one that the waste burdens should not be passed over to future generations. More recently, however, a counter argument against permanent disposal appears to gain a new ground wit the contention that the possibility of better options for the future generations should not be precluded. The context of this latter argument is in line with the retrievability provision, especially in the case of spent fuel because of the enormous fuel value contained therein. There is another concern in support of retrievability for fear of something that might go wrong unexpectedly along the long reaches of time. The provision of retrievability blurs the physical distinction between interim storage and disposal and a new concept of interim disposal seems be emerging.

Another issue associated with direct disposal of spent fuel is related with safeguards of nuclear materials in the spent fuel of which radioactivity decays out with time and become "plutonium mine" which would be more easily accessible to potential intruders in the distant future. The IAEA considers safeguards cannot be terminated for spent fuel in a disposal facility, even after it is sealed, and thus a surveillance programme will have to be maintained indefinitely, which raises another concern for some Member States.

Reprocessing/Recycle

Early development of reprocessing based on PUREX technology has evolved in the past decades to a matured industry. There are currently six countries adhering to the classical option of reprocessing/recycle, although only two reprocessing facilities are predominant in the commercial market. A little more than one third of the global total amount of spent fuel accumulation, equivalent to 85 000 tHM of spent fuel of various types has been reprocessed by the end of last century. This figure may show a bit of increasing trend in the future when the facilities in construction come on line some later years, but the portion it occupies in the global amount of spent fuel arising is likely to be steady, as far as there is no drastic change due to some currently unknown reasons.

The drift to direct disposal policy for spent fuel management began in the seventies spurred by concerns on proliferation and then further socio-economical aspects associated with reprocessing/recycle of spent fuel. As will be shown hereafter this reprocessing option does not mean an absolutely total elimination of problems related to long term management of nuclear and radioactive materials resulting from the irradiated fuel. There have been equally many debates on such issues as non-proliferation, safety, economics, environmental impacts, etc. One critical issue of reprocessing has been the diversion risk of separated uranium and plutonium that might be misused to non-peaceful ends. As for the only reprocessing technology that has matured to commercial industry is PUREX which enables quantitative separation of plutonium, a discussion on proliferation controversy was culminated in late seventies by the extensive debates during the INFCE (International Nuclear Fuel Cycle Evaluation) which examined various fuel cycle concepts that might would mitigate the proliferation concern. Over the years, proliferation issue has become one of the key considerations in R&D efforts on new fuel cycle concepts. An example of such exercise is the DUPIC (Direct Use of Spent PWR fuel in CANDU reactors) concept which is being developed with a view to enhance some fuel cycle features, including proliferation resistance. The proliferation concern is also a high priority criterion in such international projects as Gen IV (USA) and INPRO (IAEA) being initiated with a view to develop sustainable nuclear technologies.

As the high-level waste arising from reprocessing has to be solidified (e.g. by vitrification) and, after an interim storage, disposed of in a deep geological repository, the reprocessing option is not relieved of the disposal burden neither. The before mentioned concerns and their resolution are extremely important for the future spent fuel management options. The long-term radiotoxicity and level of activity of spent fuel or high level waste resulting from it is a safety and environmental concern for some countries studying the economics and feasibility of partitioning and transmutation of minor actinides and long lived fission products, for instance in special burner reactors or in accelerators.

P&T (Partitioning and transmutation)

Partitioning, as an additional step in standard reprocessing procedures, can provide for separation of long-lived actinides as well as some other long lived radionuclides and contribute this way to reduction of radiotoxicity and level of activity of the bulk volume of high level waste for disposal. A radioactive waste of lower level of activity and shorter lived, obtained by partitioning and transmutation and its disposal would give rise to less concerns. The relatively smaller amount of separated actinides could be stored until their transmutation or disposal in a significantly smaller repository. Evidently the concerns of the storage of these materials need to be assessed and compared against the entire picture of waste streams and the various storage and disposal scenarios.

Transmutation of long lived actinides together with utilisation of plutonium in power reactors represents the another prospective step in advanced fuel cycle and waste management concepts. However, if partitioning can be conceptually implemented in a few years to come, the status of R&D works on transmutation does not allow yet to fully assess its industrial full scale application in all terms and the forthcoming one to two decades will be need to get the references for such assessment. IAEA is preparing document on implications of partitioning and transmutation on waste management and waste management strategies as a useful guideline for decision makers and policy making people.

One of the key issues surrounding P&T may be the cost/benefit which is not so easily accountable now, in view of the difficulty above all in converting the price of mitigating the burdens to the environment. Considering significant investments required for further development of P&T, it should also be mentioned, that its full deployment goes in pair with an increasing role of nuclear energy in the future global energy policy.

Regional/International co-operation

There have been a number of past initiatives on regional or international co-operation for spent fuel management looking for potential benefits that can be accrues for the co-operative partners. The benefits are especially attractive to the countries (or utilities) of small nuclear programmes for which suitable site to build facilities is not available or not justified on the ground of economy of scale. No-proliferation has also been an important rationale in favour of regional or international management of spent fuel or plutonium as extensively discussed at the time of INFCE. Most of those initiatives have not been successful for various reasons. As the spent fuel management is based on national politics, it would have not been easy to tune up the relevant interest of the stakeholders in different countries. Among others, the deteriorating public perception on spent fuel management facilities has made it very difficult to expect a host for the site. With the widespread problems in public acceptance, those countries preoccupied with their national programmes show sensitive reactions to regional or international initiative for fear of marring national programmes by the public concern for bringing foreign spent fuel. In a similar token, public opposition has been extending even to the case of commercial services in reprocessing businesses in Western and Eastern Europe.

Very recently, however, there has emerged a sign of development for "from cradle to grave" service, meant to commercial services for comprehensive fuel cycle requirements. This is a service concept based on lease rather than purchase of fuel by the utilities which will return after use thus avoiding the liability of spent fuel management. This concept seems to match well with the regional or international management of spent fuel, something that might be viable in the longer term, in view of the recent tendency toward liberalisation and globalisation of nuclear energy sector.

Conclusion

The current situation in three different groups of countries in terms of spent fuel management option is likely to persist in the immediate foreseeable future, unless a reorientation in energy and environmental strategies would call for reconsideration of the options or firmer commitments concerning the endpoint of the disposition of spent fuel are taken.

The bulk of spent fuel inventories in the world are in storage with majority in water pools, but showing conspicuous tendency toward dry types which is considered suitable for long term interim storage. The interim storage can provide a flexible time span for further research and development in search of better solutions to the issues identified with the conventional fuel cycle options, an example being with the P&T technology which addresses reduction of radiotoxicity of radionuclides to be disposed of. These various concerns and issues in spent fuel management and radioactive waste management, particularly from the prospective view for future nuclear reactor and fuel cycle systems are being addressed in national and international initiatives such as INPRO and Gen IV.

Globalisation of market economy which have brought profound impacts to nuclear industry is might creating new businesses concept for fuel cycle services which might provide a new condition for regional/international co-operation to the resolving of some issues associated with long term management of spent fuel.