MANAGEMENT OF RADIOACTIVE WASTE FROM OPERATION OF NUCLEAR POWER PLANT -PERSPECTIVE FOR INDONESIAN PROGRAM-

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ABSTRACT

MANAGEMENT OF RADIOACTIVE WASTE FROM OPERATION OF NUCLEAR POWER PLANT -PERSPECTIVE FOR INDONESIAN PROGRAM-. *Nuclear power is the only energy industry which takes full responsibility for all its wastes, and costs this into the product. Nuclear power is characterized by the very large amount of energy available from a very small amount of fuel. The amount of waste is also relatively small. It is predicted in the near future of Indonesia NPP program, about approximately 200m*^{3} *of low and intermediate level waste and 6,76m*^{3} *of spent fuel is taken each year from the core of a l000 MWe Nuclear Power Plant. There is a new option for the spent fuel management i.e. repatriation of the spent fuel to the supplier country through Global Energy Partnership (GNEP) or Developing Global Nuclear Infrastructure (DGNI) programs. Disposal methods for radioactive wastes vary in many countries. The two main options currently employed or planned by countries are, near surface disposal facilities (for short lived and low level waste); and geologic repositories (for long lived and high level waste).*

Keywords: *radioactive waste, management, nuclear power plant, prediction, disposal*

ABSTRAK

PENGELOLAAN LIMBAH RADIOAKTIF DARI OPERASI PEMBANGKIT LISTRIK TENAGA NUKLIR -PERSPEKTIF UNTUK PROGRAM INDONESIA-. *Tenaga nuklir merupakan satu-satunya industri energi yang bertanggungjawab penuh seluruh limbah yang dihasilkannya., termasuk memperhitungkan biaya limbah dalam produksi listrik. Tenaga nuklir dicirikan dengan energi yang sangat besar berasal dari kuantitas bahan bakar yang sangat kecil. Limbah yang dihasilkannya kuantitasnya juga kecil. Diprediksikan dari operasi tiap 1000MWe PLTN di Indonesia yang akan dibangun dalam waktu dekat, akan dihasilkan 200m*^{3} *limbah aktivitas rendah dan sedang serta 6,76m*^{3} *bahan bakar bekas. Ada opsi lain untuk pengelolaan bahan bakar bekas, yaitu repatriasi ke negara asal melalui program Global Energy Partnership (GNEP) atau Developing Global Nuclear Infrastructure (DGNI). Pembuangan limbah radioaktif bervariasi di berbagai negara. Dua opsi utama adalah pembuangan limbah dekat permukaan (aktivitas rendah dan sedang), dan pembuangan di lapisan geologi (limbah umur panjang dan aktivitas tinggi).*

Kata kunci: *limbah radioaktif, pengelolaan, pembangkit listrik tenaga nuklir, prediksi, disposal*

1. INTRODUCTION

The history of radioactive waste management program in Indonesia is as old as the nuclear application in this country, and it was also importantly considered when the nuclear power plant (NPP) initiative was introduced in Indonesia for the first time[1]. From the beginning of the nuclear energy program, radioactive waste management from NPP operation is considered as an important point. From the early years, Nuclear Energy Agency of Indonesia (BATAN) perform research and development on the radioactive waste management, and in 1988 the Radioactive Waste Management Center was established to conduct research, and also manage the waste coming from hospitals, industries and laboratories.

On the other side, regulation for the radioactive waste management is already stated in Act No. 10/1997 on nuclear energy[2], and some important points in this Act are:

- The radioactive waste management shall be performed by the Executing Body (BATAN).
- The Executing Body (BATAN) shall provide the final repository for high level radioactive waste (HLW). The siting of final repository above shall be stipulated by the government after getting an agreement from the House of Representatives of the Republic of Indonesia.
- The radioactive wastes storage shall be subjected for fee.

This paper shows the development of strategy to manage the Indonesian future waste coming from the operation of nuclear power plant and also by considering the front end and back end of nuclear fuel cycle by using both reference sources and a computer program called Nuclear Fuel Cycle Simulation System (NFCSS)[3]. The scope of the radioactive waste management starting from mining-milling of uranium until decommissioning of the nuclear power plant and the disposal of the waste. The options for the recent fuel assurance with the consequence of repatriation of its spent fuel also briefly described. While funding system is also evaluated to support future fate of the radioactive waste.

2. METHODOLOGY

The content of this paper is a combination between calculation to predict the spent fuel generated (back-end) from the operations of NPP, and also calculation for the waste produced in the front-end of the nuclear fuel cycle. While the rest is reference study (including the generation of low and intermediate level waste during NPP operations, decommissioning, disposal and funding system).

However all aspects are based on the assumption below.

2.1. Scenario Assumption for NPP Program in Indonesia

According to the plan by Indonesian Government, it is stated that the time for the operations of first four NPPs in Indonesia are as follow[4].

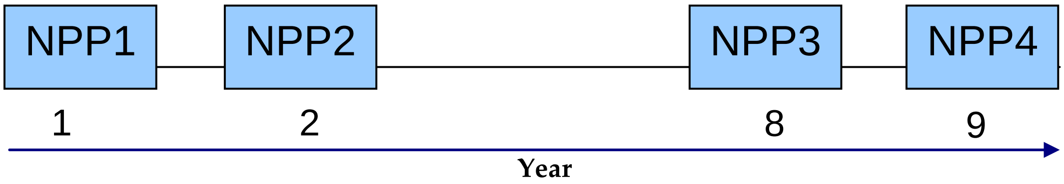

Figure 1. Operating Schedule for the First 4 NPPs in Indonesia.

So in the long term of waste management the starting time of operation of these NPPs are assumed relatively the same since in less than 10 years there will be 4 NPPs operate.

To calculate and predict the waste generated from the nuclear fuel cycle using NFCSS, characteristics of the reactors and fuel are determined as in Table 1. The values in the table may be different with the PWR present condition, but this study use the future load factor, enrichment and burnup according to the reference[3].

Table 1. Assumption of Characteristic of the Future Indonesian Reactors and Its Fuel

Type or reactor	PWR
Power (1000 MWe)	1000
Thermal Efficiency (%)	35
Load Factor (%)	86
Enrichment (%)	4,5
Burnup (Gwd/ton)	53

Up to now the Indonesian Government policy on fuel cycle is open nuclear fuel cycle or once through, and it means there will be no reprocessing for the spent fuel. This spent fuel will be stored and disposed as the high level waste.

2.2. The Nuclear Fuel Cycle Simulation System (NFCSS)

The Nuclear Fuel Cycle Simulation System (NFCSS), formerly known as VISTA, is a scenario-based computer model for the estimation of fuel cycle material, service requirements and actinide arising. The NFCSS is a computer simulation system which uses simplified approaches to calculate the fuel cycle requirements. These simplified approaches enable the code to estimate the long-term fuel cycle requirements for both open and closed fuel cycle strategies. The NFCSS is used as a tool to calculate the spent fuel arising from the operation of NPP, and help identifying the waste generated during the operation of fuel cycle [3].

3. RESULTS AND DISCUSSION

3.1. Generation of Wastes from the nuclear fuel cycle

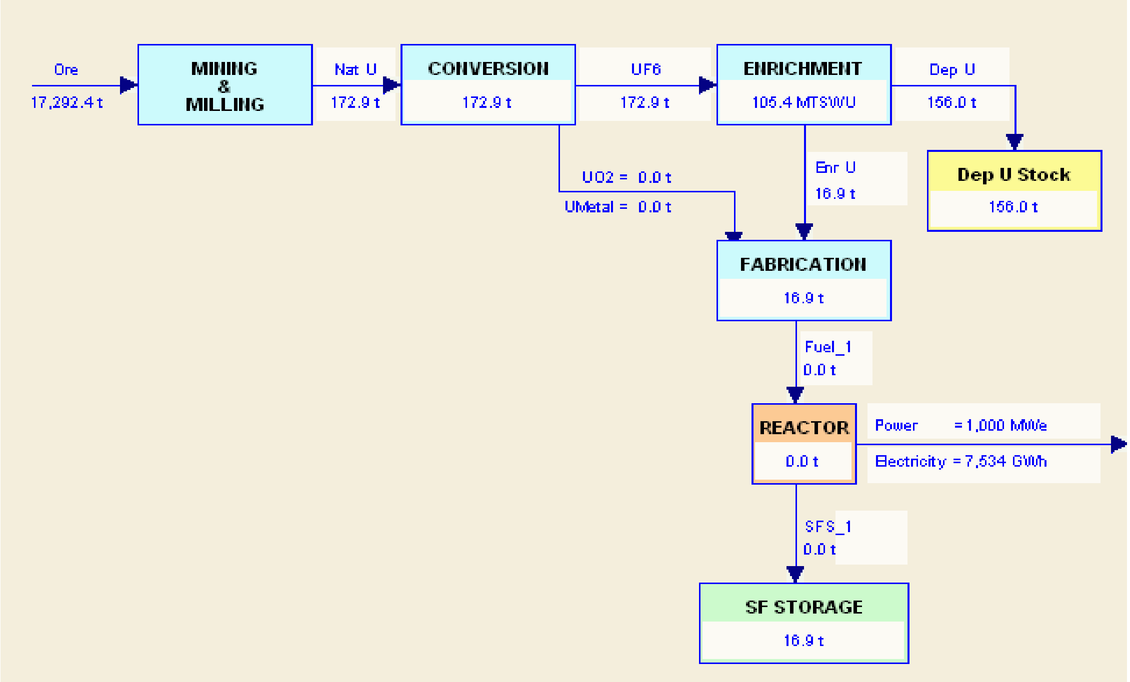

Figure 2. Result of NFCSS Calculation for 1000 MWe PWR

The nuclear fuel cycle is often split into two parts: the "**front end**" (from mining through to the use of uranium in the reactor); and the "**back end**" which covers the removal of spent fuel from the reactor and its subsequent treatment and disposal. Figure 2 shows result of calculation using NFCSS for the uranium requirements and spent fuel generated of 1 NPP using the data in Table 1.

3.1.2. Waste from the "front-end"

According to the NFCSS result, the annual fuel requirement for l000 MWe light water reactor (LWR) is 16.9 tonnes of enriched uranium oxide. This requires the mining and milling of more than 17,000 tonnes of ore to provide 172.9 tonnes of uranium oxide concentrate (U_3O_8) from the mine. This calculation shows that to support 1000 MWe LWR generates around 17,000 tonnes mill tailings. Taking an average tailings density (tonnes/m^3) of 1.5[5] gives an estimated volume of tailings of about 11,000m^3/year of mill tailing. By taking into account the Indonesian scenario for 4 NPP then there will be 44,000m^3/ year mill tailing, and that if each NPP operates for 50 years, so total mill tailings will be about 2.3 million m^3.

Radioactive waste generated by mining and milling of uranium ore contains long lived radionuclides with relatively low concentrations. Waste considered being radioactive but containing only naturally occurring radioactive material (NORM) is defined as NORM waste. This waste is discharged into tailings dams designed to retain the remaining solids and prevent any seepage of the liquid. Eventually the tailings may be put back into the mine or they may be covered with rock and clay, and then revegetated. With in situ leach (ISL) mining, dissolved materials other than uranium are simply returned underground from where they came[6].

Uranium oxide (U_3O_8) produced from the mining and milling of uranium ore is only mildly radioactive. Processing uranium oxide concentrate into a usable fuel through conversion, enrichment and fabrication has no effect on levels of radioactivity and does not produce significant waste.

For the first Indonesian NPPs, the waste from the “front end” will not be the real problem for Indonesia for several decades, since due to the economic factors there is high possibility that Indonesia tend to purchase uranium from abroad rather exploring the mine in the country. However, in the long term, dependency on the uranium supply from abroad will face challenges from the public, so it is expected that the exploration of uranium in Indonesia territory will extensively be conducted after the first success of NPP in Indonesia. Then, the front end waste will be generated and must be managed properly.

3.1.2. Low and Intermediate Level Waste (LILW) from the "back-end"

Several reports[7-9] present typical LILW amounts generated by Light Water Reactor (LWR). For PWR, reported annual waste production per GWe is 177 – 338 m^3 (with activity ranged 27-112 TBq); which indicates the large uncertainty in these estimates. The Nuclear Energy Institute reports that since 1980, annual amounts of low level waste disposed of have decreased sharply in the United States. In 1999 the amount was reduced by more than 93% even though the number of power plants had increased by more than 50%[10].

In spite of this variance, for the purpose of producing approximate Indonesian future inventory for LILW accumulations, one of the above sets of values was used. An average value was chosen as the source of data regarding the waste production of the PWR. Consequently the assumed annual generation of LILW for PWRs is 200 m^3 with 100 TBq. Then for Indonesia's case, 4 NPPs may generate 800 m^3/year of LILW, and the total estimation of waste for the operation of 50 years is 40,000 m^3. In this case for two decades the waste can be stored in the interim storage with total capacity of 20,000 m^3 near the reactor while waiting for one ultimate disposal facility. In a worst case, when there is resistance from the public on the disposal facility, then that 40,000 m^3 waste can be store in a long term storage that will last for 100 years before disposal.

3.1.3. Spent Fuel Generations

As shown in Figure 2 the spent fuel generated from 1000 MWe PWR is 16,9 tonnes. The American integrated data base report [7], shows the ratio of spent fuel mass [MTHM] to volume (m^3) to be 2.5 for LWR, so, annual volume of spent fuel for 1000 MWe PWR is 6.76 m^3 (27.04 m^3/year for 4 NPPs), and for 50 years these NPPs will generate only 1352 m^3 spent fuel. This result is far different with the current operating Light Water Reactor (with the burnup and fuel enrichment are below estimation value of this study), where the same 1 GWe LWR annually generate 30 – 50 metric tons of heavy metal spent fuel (volume: 12 – 20 m^3).

Table 2. Calculation Result by NFCSS for Composition of Radionuclides Inside Spent fuel Generated Annually from 1000 MWe PWR.

Isotope	Fresh Fuel (tonnes)	Stored Fuel (tonnes)
U235	0.761482	0.101060
U236	0.000000	0.101639
U238	16.160350	15.595021
Np237	0.000000	0.014591
Pu238	0.000000	0.005857
Pu239	0.000000	0.085980
Pu240	0.000000	0.045828
Pu241	0.000000	0.027251
Pu242	0.000000	0.013714
Am241	0.000000	0.000963
Am242m	0.000000	0.000022
Am243	0.000000	0.003525
Cm242	0.000000	0.000381
Cm244	0.000000	0.001366
Total Heavy Metal	16.921833	15.997200
Total Fission Product	-	0.924633
Grand Total	16.921833	16.921833

According to Table 2, spent fuel from 1000 MWe PWR contains approximately:

- 93.36% uranium (0.56% of which is U-235),
- 5.46% fission products,
- 1.06% plutonium (about two thirds fissile Pu-239 & Pu-241),
- 0.12% minor actinides (americium, curium, neptunium).

For Indonesia that use the once through fuel cycle policy, spent fuel can be regarded entirely as waste. The spent fuel is first stored for several years under water in large cooling ponds at the reactor site, and after that moved at a central site for several decades (the radioactivity of spent fuel reduces significantly after 30 years). The other type of storage is dry casks or vaults with air circulation and the fuel is surrounded by concrete.

As shown in Table 2, spent fuel still contain all the highly radioactive isotopes, and then the entire fuel assembly is treated as HLW for direct disposal. It too generates a lot of heat and requires cooling. However, since after 40-50 years the heat and radioactivity have fallen to one thousandth of the level at removal. So it is not necessary the spent fuel goes directly for disposal. The 50 years storage provides a technical incentive to delay further action with HLW until the radioactivity has reduced to about 0.1% of its original level.

For Indonesia, it is recommended to build disposal facility evolving concepts lean towards making it recoverable if future generations see it as a resource. This means allowing for a period of management and oversight before a repository is closed.

Meanwhile, recently there is an option not to dispose the spent fuel in the user country but sending back to the origin country by fuel assurance program. There are two proposed nuclear fuel assurance program from United States (through Global Nuclear Energy Partnership/GNEP)[11], and from Russia (through Developing Global Nuclear Infrastructure/ DGNI)[12], that allow the user country to send back the spent fuel to the supplier country. However these new initiatives depends on non technical parameters including socio-political situation in each country, since spent fuel still largely contain valuable materials, such as uranium and plutonium. Recent news show that even the GNEP is not a priority under the new Government of United States[13]. There are problems for Indonesia on about this option; (a) dependency to the supplier countries that related with the political dependency, and (b) there will be no option to develop the sensitive technology such as enrichment and reprocessing.

3.2. Decommissioning waste

At the end of their useful lives nuclear facilities need to be decommissioned. At present the number of facilities that have been decommissioned is relatively small, but the experience that has been accumulated to date allows some simple deductions to be made[14].

Recognizing that the amounts of decommissioning waste may vary depending on a variety of factors, including, for example, the clearance levels applied for release from regulatory control of the material generated in decommissioning, it is reported that decommissioning a LWR with an installed capacity of about 1 GWe can be expected to generate a quantity of short lived LILW between 5000 and 6000 metric tons (MT)[15]. The production of long lived LILW and HLW is significantly lower, generally less than 1000 MT.

For Indonesia, when accepting 6000 MT per GWe as a representative average production of decommissioning waste, the future 4 NPPs will eventually cause a total generation of about 24,000 MT of decommissioning waste. Depending on the assumed average density of the waste and on conditioning and packaging procedures, decommissioning of that NPPs may eventually cause the production of a volume of decommissioning waste (excluding the spent fuel)about 10,000 – 20,000 m^3 . As far as the reactors operate normally than the waste can be moved to the interim storage before disposal. The worst case is when the abnormal operations occur than the location of the NPP to become disposal facility (entombment method). That is the main reason that the future NPP location in Indonesia will have also meet the safety requirements as the radioactive waste repository. However in a normal situation, the spent fuel and the other waste have to be moved to the long term storage and/or disposal facility. So by adding the waste coming from the operation of NPP and from the decommissioning, the total capacity of the future LILW disposal/repository is at least 60,000 m^3, and much smaller for the spent fuel (about 1400 m^3).

3.3. Waste disposal

Disposal methods for radioactive wastes vary in many countries. The two main options currently employed or planned by countries are: near surface disposal facilities (for short lived and low-intermediate level waste); and geologic repositories (for long lived and high level waste). For the first option, about 40 near surface disposal facilities have been safely operating during the past 35 years, and an additional 30 facilities are expected to be in operation over the coming 15 years[16]. Both options use "multi barrier" disposal concept i.e. two or more natural or engineered barriers used to isolate radioactive waste in, and prevent radionuclide migration from, a repository[17], to ensure that no significant environmental releases occur over period long time after disposal,.

For the near surface disposal, the isolation period is usually up to 300 years, after this time the radioactivity of the wastes has decayed to such extent that no control is required any longer[18].

The ultimate disposal of high level waste requires their isolation from the environment for ten thousands years. The most favored method is burial in dry, stable geological formations some 500 meters deep. There is no facilities in operation except, one example of geological repository for long-lived nuclear waste is in operation in New Mexico USA (for defense wastes)[19]. After being buried for about 1,000 years most of the radioactivity will have decayed. The amount of radioactivity then remaining would be similar to that of the naturally-occurring uranium ore from which the fuel originated, though it would be more concentrated.

Indonesia conducts the disposal study for near surface and deep geological facilities since 1989. Site investigation has been done, and two universities were involved in the preliminary study. The locations for this activity include some uninhabited islands with the characteristic of basaltic rock, andesitic rock[20-22] that suitable for the high level waste, and in Java with the characteristic of volcanic host rock, clay host rock[23]. Some locations have been considered as the suitable media for isolating the waste; however some more studies, especially on demography change, socio-economical impact, and also political trend must be reviewed.

3.4. Funding System

Since many of the activities associated with long term management of radioactive waste will take place several decades (more) into the future (possibly after the generators of the waste have gone out of business), it is prudent to collect the financial resources that will be needed for future operations while the waste generators are still in operation. There are various financial systems in the world to ensure the long term availability of financial resources for their disposal programs. Funds and reserves are the two most common financing systems. In the former, the financial resources are usually maintained by organizations independent from the waste generators. In the Russian Federation, financing is obtained from the national budget.

The annual fees that are widely used to obtain the resources kept in the funds are generally calculated and determined based on the amount of electricity or waste generated in a certain year (i.e. on the basis of the future liability associated with the waste generated in that year).

The costs of dealing with the radioactive waste are built into electricity tariffs. For instance, in the USA, consumers pay 0.1 cents per kilowatt-hour, which utilities pay into a special fund[24]. The waste management fees of some countries are listed in Table 3.

Table 3. Waste management fees[24]

Country	Fee per Kwh	Remarks
• USA	• US $0.001	• HLW/Spent Fuel disposal
• Japan	• ¥0.13	• HLW/Spent Fuel disposal
• Finland	• €0.0023	• Spent Fuel storage and disposal
• Spain	• 0.8% of the retail price of electricity generated by all power stations	• Including decommissioning, storage and disposal spent fuel and other wastes.

For Indonesia case the establishment for the radioactive waste funding system is necessary after the government agree to build the NPP. The independent organization rather than government is suitable to maintain the financial for future waste management, and it is recommended that all of waste (not only spent fuel and LILW, but also including generation from decommissioning activities) is under this funding system. This fund organization must establish the fee based on the amount of electricity or waste generated in a certain period.

4. CONCLUSION

In nuclear industry, safe management practices are implemented or planned for all categories of radioactive waste. Low level waste (LLW) and most intermediate level waste (ILW), which make up most of the volume of waste produced (97%), are being managed and disposed of securely in near-surface repositories in many countries so as to cause no harm or risk in the long-term. This practice has been carried out for many years in many countries as a matter of routine.

By considering the assumption of the 4 reactors will be built in a row as the first NPPs in Indonesia, then annual generation of waste can be deducted as follow: the front- end of fuel cycle will generate 11,000 m^3 of tailing wastes; and the back-end cycle will generate 200 m^3 0f LILW and 6.76 m^3 of spent fuel.

For decommissioning waste, this study accepted that 6000 MT of radioactive waste are generated per GWe , then the future Indonesian 4 NPPs will eventually cause a total production of about 24,000 MT of LILW with volume about 10,000 – 20,000 m^3 .

Recently, there is a new option for the spent fuel management i.e. repatriation of the spent fuel to the supplier country through GNEP (proposed by USA) or DGNI programs (proposes by Russia). So user country does not need to manage the HLW/used fuel, but socio-political case must be considered, before using this option.

Disposal facilities are operated in several countries for the final step for the management of LILW, and currently being developed for HLW that are safe, environmentally sound and publicly acceptable. Indonesia has conducted R&D for radioactive waste disposal, including site investigation in some uninhabited islands and in Java, and laboratory activities to meet the safety requirements for the disposal facilities.

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