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Identification of regional requirements for small reactors without on-site refueling and neutronics calculations of FBNR'

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Abstract

Economy of Vietnam is fast developing and energy demand, especially in form under electricity, is growing drastically. In the last five years, the GDP average annual growth rate is 7.2% at the base scenario, and estimated to be 7.1% by 2020. In this case, the electricity demand will also increase fourfold by 2020. The deficiency of domestic resources and the security of energy supply need favorable consideration of nuclear power. Small reactors in general, and small reactors without on-site refueling in particular, become attractive for developing countries like Vietnam because of their special features.

A. Comprehensive study of present energy supply and demand as well as the potential role of nuclear power based on population growth, economic development and other challenges for a developing country like Vietnam

I. current situation on electricity production and consumption of vietnam

1.1 Electricity production

By 2004, the total installed capacity of Vietnam's electricity generating system was 8,910 MW and the available capacity was 8,650 MW, among them the hydroelectricity occupies 48%, from coal and oil-fired plants – 20%, from gas-turbine plants – 28%, and from diesel – 4%. By 2000, 2001 and 2002 the electricity production growths were 12.2%, 15.0% and 17.0%, respectively. The electricity production situation during the period 1990 – 2002 is presented in table 1.1.

Table 1.1: Electricity production situation during the period 1990 – 2002

Year	90	91	92	93	94	95	96	97	98	99	00	01	02
Electricity production, *billion kWh*	8.68	9.15	9.65	10.7	12.3	14.6	17.0	19.2	21.7	23.7	26.6	30.6	35.8

Growth, %		5.4	5.5	10.9	15.0	18.7	16.4	12.9	13.0	9.2	12.2	15.0	17.0
Aver. elect. prod. per capita, *kWh*	131	135	139	150	169	198	225	250	285	309	341	390	450

Source: Institute of Energy/Electricity of Vietnam

1.2 Electricity consumption

In the period 1990 - 2002, commercial electricity consumption has been increased at an average rate of 14.2% higher than the rate of electricity production. Even by 1997 and 1998, the commercial electricity demand had been increased to 14.2% and 15.7%, respectively, although during these years there was the regional financial crisis. The commercial electricity consumption had been grown up to 14.3%, 15.6% and 16.6% by 2000, 2001 and 2002, respectively. The evolution of the commercial electricity consumption during the period 1990 - 2002 is shown in table 1.2.

Table 1.2: The evolution of the national commercial electricity consumption
during the period 1990 - 2002

Year	90	91	92	93	94	95	96	97	98	99	00	01	02
Commercial elect. consumption, *billion kWh*	6.2	6.6	6.9	7.8	9.3	11.2	13.4	15.3	17.7	19.6	22.4	25.9	30.2
Growth, %		6.45	4.55	13.0	19.2	20.4	19.4	14.2	15.7	10.7	14.3	15.6	16.6
Aver. elec. consumption per capita, *kWh*	93	97	100	110	128	151	177	200	233	255	295	338	382

Source: Institute of Energy/Electricity of Vietnam

II. Potentiality of energy resources and their exploitation capability

2.1 Potentiality of coal resource and forecast of its exploitation capability

According to the coal sector development scheme during the period 2001 - 2020, the total discovered coal reserve that had been remained to January 1, 2002 was 3,808.52 million tons. The reserve that was divided into different coal levels is shown in table 2.1.

Table 2.1: Reserve divided into coal levels

Rank	Geologic reserve at levels, *million tons*			
	Total	A (*) + B (*)	C_1 (*)	C_2 (*)
Anthracite coal	3,238.19	395.31	1,595.91	1,246.98
Brown coal	215.23	42.84	149.56	22.83
Fat coal	6.91	0.58	6.18	0.15
Mud coal	348.19	0.0	228.83	119.36
Total	***3,808.52***	***438.73***	***1,980.48***	***1,389.32***

Source: Institute of Energy/Electricity of Vietnam & Institute for Mining Science and Technology

During the period 2002 – 2020, the clean coal production was anticipated to be increased from 13.8 million tons by 2002 to 29.9 million tons by 2020. Among them the proportion of surface coal production will be decreased from 60% by 2002 to 26% by 2020, but the proportion of pit coal production will be increased from 39% to 74%, respectively. The total coal production was anticipated to be 35.61 million tons by 2020. An expectation of the coal production during the period 2002 – 2020 is presented in table 2.2.

Table 2.2: Expectation of coal production exploited during the period 2002 – 2020.

Year	2002	2005	2010	2015	2020
Coal production, *million tons*	16.32	21.06	27.28	32.52	35.61

Source: Institute of Energy/Electricity of Vietnam

(*) See appendix 1.

2.2 Potentiality of oil and gas resource and forecast of its exploitation capacity

According to a recent assessment, until 2002 the total oil and gas reserve possible collected was estimated to be about 3.75 billion Cubic Meters of Oil Equivalence (m^3 OE), mainly concentrated at Vietnam's mainland veranda floor, among them the reserve confirmed was 1.25 billion m^3 OE with a gas share of over 50%. The oil and gas reserve is shown in table 2.3.

Table 2.3: The oil and gas reserve

List	Total, *million m^3 OE*

Total oil-gas reserve and potentiality:	**3,750**
• Reserve discovered and possibly collected	1,251
• Reserve non-discovered, among them:	2,499
- Supposed	1,535
- Forecasted	964
Exploitation production	141.4
Reserve remained and possibly exploited	1,109.6

Source: Institute of Energy/Electricity of Vietnam

According to a development strategy of the oil and gas sector until 2010, an average production of crude oil exploited will be about 16 – 20 million tons per year in domestic and 2 – 4 million tons per year from abroad. After 2010, domestic exploitation will gradually decreased, while oversea exploitation will be increased. A probability of crude oil production that will be exploited is shown in table 2.4.

Table 2.4: A forecast on probability of crude oil production until to 2020

Year	2000	2005	2010	2015	2020
Base scenario, *million tons:*	**16.5**	**17.2**	**20.6**	**16.1**	**10.7**
- Domestic production, *million tons*	16.5	17.0	17.6	12.3	4.7
- Oversea production, *million tons*	0	0.2	3.0	3.8	6.0
High scenario, *million tons:*	**16.5**	**17.8**	**21.6**	**21.8**	**18.0**
- Domestic production, *million tons*	16.5	17.0	17.6	15.5	10.2
- Oversea production, *million tons*	0	0.8	04.0	6.3	7.8

Source: Institute of Energy/Electricity of Vietnam

The total gas reserve discovered and possibly exploited of Vietnam is estimated to be about 680 billion m^3, among them there is about 590 billion m^3 of non-associated gas. An average production of gas will possibly attain 6 – 14 billion m^3 per year in the period 2006 – 2010 and 14 – 18 billion m^3 per year in the period 2011 – 2020. A possibility of gas production is shown in table 2.5.

Table 2.5: A possibility of gas production

Year	2000	2005	2010	2015	2020
Base scenario, *billion m³*	1.6	6.7	12	13	14
High scenario, *billion m³*	1.6	6.7	14	17	18

Source: Institute of Energy/Electricity of Vietnam

An exploitable possibility will be about 20 million tons of crude oil per year and 18 – 20 billion cubic meters of gas per year, forecasted for the period after 2020.

2.3 Potentiality of hydroelectricity and forecast of its exploitation capability

The total hydroelectric reserve of the Vietnam's 10 main river valleys has been estimated to be at over 17,660 MW, occupying 85,9% of all the hydroelectric economic-technique reserve of the country, equivalent to an electricity generation of 72 TWh; of which the 38.8 TWh (54%), 21.8 TWh (30%), and 11.6 TWh (16%) are from the North, Middle and South of Vietnam, respectively. At the present time, the hydroelectric capacity of 2,850 MW generating 10.6 TWh has already been developed and 720 MW expected to generate 3.64 TWh is under construction. According to the recent study, an exploitation capability of hydroelectricity may only attain 12,000 – 14,000 MW, equivalent to 60 – 65 TWh by 2020, taking account of emigrant and environment problems.

For the Vietnam's hydroelectric potentiality, hydropower plants at mean and small capacities (~ 10 MW) that may be built at no big rivers, have also to be counted. In accordance with the Electricity of Vietnam's estimation, a total capacity of such hydropower plants is about 1,000 MW, equivalent to 4.2 TWh. However, it is very difficult to build the plants because the sites expected for them are very far from electric consumption centers and their construction may only be carried out concurrently with social - economic development of the site regions.

2.4 Potentiality of new energy resources and forecast of its exploitation capability

a. Geothermal resource

According to a study of the geology sector, in Vietnam there are about 300 hot mineral water resources with their surface temperature of 30 – 105°C, which concentrate on the North - West and the North - Middle of Vietnam. On the basis of this geothermal resource, some electric plants at a total capacity of 400 MW will be constructed.

b. Solar energy resource

Vietnam has average 2,000 – 2,500 sunny hours per year, equivalent to 100 – 175 kcal/(cm^2.year). However, equipment for the solar energy is at very high price and its maintenance cost is also high. Therefore, it is difficult for Vietnam to construct this kind of the plants in the future.

c. Wind energy resource

A potentiality of wind energy is estimated to be about 800 – 1400 kWh/(m^2.year) at the islands of Vietnam and 500 – 1,000 kWh/(m^2.year) at the other regions. There had been about 1,000 wind power stations with capacities of 150 - 200 W installed and operated by 1999. There are now 5 projects for wind power plant development with a total capacity of 37.25 MW. In general, it is difficult to develop wind power plants in Vietnam because of the complicated topography and the seasonal climate, which make wind flows various. According to a study of Electricity of Vietnam, the total capacity generated by wind energy resource is estimated to be 100 – 150 MW by 2020.

d. Biomass energy resource

A potentiality of biomass energy resource, including firewood, rubbish, and agriculture by-product..., has been estimated to be 43 – 46 million Tons OE (TOE) per year. However, its exploitation capability may be at a level of 17 – 18 million TOE/year. A forecast on electric plant development from this resource may only attain 250 – 300 MW by 2020.

2.5 Potentiality of a uranium resource and its exploitation capability

According to information of geologic experts, a potentiality of an uranium resource was estimated to be about 218,167 tons of U_3O_8 by 2003, including 113 tons at the C_1 level, 16,563 tons at the C_2 level, 15,153 tons at the P_1 level, and 186,338 tons at the (P_2 plus P_3) level. This uranium resource has only been detected, but not exploited at the present time.

2.6 Capability of electric importation

In accordance with estimation of Electricity of Vietnam, Vietnam may import about 2,000 MWe from Laos, 1,000 MWe from Cambodia, and 500 – 1,000 MWe from the South of China in the period 2010 – 2020. An electric importation from foreign countries may be increased to 6,000 MWe by 2030.

III. Situation of social-economical development In the period 1990 – 2001 and its outlook until 2020

3.1 Situation of social-economical development in period 1990 – 2001

(a) GDP growth rate

In the period 1990 –2001, the Gross Domestic Production (GDP) growth rate of Vietnam was higher in comparison with ones of the other ASEAN countries. One of the noticeable events was a regional economy crisis happened in the period 1998 – 1999, and at which the GDP growth rate of Vietnam had been decreased to the lowest level (5.8% - 4.8%) during the 10 years. After that time, of course, Vietnam had already escaped from the crisis rapidly (See the GDP growth during the period 1991 – 2002 in table 3.1).

Table 3.1: GDP growth in the period 1990 – 2001

Year	90	91	92	93	94	95	96	97	98	99	00	01
GDP, *10^6USD* (price by 95)	13.614	14.425	15.673	16.938	18.435	20.194	22.08	23.88	25.265	26.478	28.30	30.247
GDP/person, *USD*	113.7	118.48	144	183.4	219.2	289.2	335.6	360.6	357.7	385.6	329.3	405.1
GDP growth rate, %	5.1	6.0	8.6	8.1	8.8	9.54	9.34	8.15	5.8	4.8	6.88	6.88

Source: Institute for development strategy

(b) Economy structure

The movement of the Vietnam's economy structure in the period 1990 – 2002 was as the following:

- A share of agriculture in GDP had been decreased from 38.74% by 1990 to 22.99% by 2002,
- A share of industry in GDP had been increased from 22.7% by 1990 to 38.5% by 2002,
- A share of service in GDP had been decreased from 38.6% by 1990 to 38.46% by 2002,
- The economy structure, including two essential components such as state-managed and collective ones, has been changed into a multi-component economy (market economy), of which the state economy plays an important role.

The GDP growth rate of the economic sectors in the period 1990 – 2001 is shown in table 3.2.

(c) Inflationary situation

During the recent years, the Vietnam's inflation has been decreased remarkably. The inflation rate was decreased from 67% by 1990 to 0.8% by 2001.

(d) Export

There has been a high increase in exportation; the average growth rate of annual exportation was 20% in the period 1991 - 1995, 22.7% by 1997, and 20% in the period 1996 - 2000. During the 10 years, the average growth rate of exportation had been 3 times as high as the increase in GDP.

Table 3.2: GDP growth rate of the economic sectors in the period 1990 - 2001

Year	GDP growth rate, %				Share of different sectors, %			
	Totality	Agriculture	Industry	Service	Totality	Agriculture	Industry	Service
1990	5.1	1.0	2.27	10.19	100	38.74	22.67	38.59
1991	6.0	2.18	7.71	7.38	100	40.49	23.79	35.72
1992	8.6	6.88	12.79	7.58	100	33.94	27.26	38.8
1993	8.1	3.28	12.62	8.64	100	29.87	28.9	41.23
1994	8.8	3.37	13.39	9.56	100	27.43	28.87	43.7
1995	9.54	4.8	13.6	9.83	100	27.18	28.76	44.06
1996	9.34	4.4	14.46	8.8	100	27.76	29.73	42.51
1997	8.15	4.33	12.62	7.14	100	25.77	32.08	42.15
1998	5.80	3.53	8.33	5.08	100	25.78	32.49	41.73
1999	4.80	5.23	7.68	2.25	100	25.43	34.49	40.08
2000	6.88	4.63	10.07	5.32	100	24.53	36.73	38.74
2001	6.88	2.98	10.39	6.1	100	23.25	38.12	38.63

Source: Statistical office of Vietnam

(e) Social development

In general, Vietnam has attained a remarkably progress in reduction of population growth per year. The average population growth rate by 2001 was 1.35% instead of one of 1.7% before.

The living standard of the Vietnamese people in the whole country has been gradually improved. The average income in GDP per capita has been increased and the proportion of population under poverty line in accordance with the international standard based on food safety criteria has been reduced. At the present time, the poor families occupy 39% of the total number of families in the country.

3.2 Forecast of social-economical development until 2020

According to a study of Institute of Development Strategy of Ministry of Planning and Investment, a forecast of social-economical development in accordance with 3 different scenarios (high scenario, base scenario, and low scenario) is presented in table 3.3, 3.4, and 3.5.

Table 3.3: GDP annual average growth rate

Unit: **%**

	2000 - 2005	2006 - 2010	2011 - 2020	2021 - 2025	2026 - 2030
1. High scenario					
GDP growth	8.0	8.0	7.5	7.0	6.2
Agriculture	3.2	3.2	3.5	3.2	3.5
Industry	10.3	10.8	8.9	7.6	6.5

Services	8.9	8.5	7.1	7.0	6.5
2. Base scenario					
GDP growth	7.2	7.2	7.1	6.9	6.1
Agriculture	3.2	3.0	3.6	2.9	3.5
Industry	9.2	8.8	8.5	8.0	6.8
Services	7.2	7.6	6.7	6.7	5.6
3. Low scenario					
GDP growth	6.5	6.5	6.3	6.5	5.5
Agriculture	3.6	3.2	3.5	3.2	3.5
Industry	8.4	7.1	7.3	6.9	5.5
Services	5.7	6.5	6.3	7.1	6.2

Source: Institute of Development Strategy

Table 3.4: Structure of economic development by scenarios

Unit: %

	2000 - 2005	2006 - 2010	2011 - 2020	2021 - 2025	2026 - 2030
1. High scenario					
GDP	100	100	100	100	100
- Agriculture	23.0	21.1	11.1	9.3	8.2
- Industry	38.5	39.0	44.1	44.8	40.6
- Services	38.5	39.9	44.8	45.9	51.2
2. Base scenario					
GDP	100	100	100	100	100
- Agriculture	23.0	21.1	11.7	9.9	7.7
- Industry	38.5	39.0	43.9	44.7	40.5
- Services	38.5	39.9	44.4	45.4	51.8
3. Low scenario					
GDP	100	100	100	100	100
- Agriculture	23.0	21.1	13.3	11.3	10.2
- Industry	38.5	39.0	39.7	40.4	36.7

- Services	38.5	39.9	47.0	48.3	53.1

Source: Institute of Development Strategy

Table 3.5: Forecast of population growth and urbanization until 2030

Year	Population		Urbanization	
	(**A**) *Million persons*	Growth rate, *%/year* (during 5 years)	Urban person (**B**), *million*	Rate = B/A, *%*
2000	77.64	-	18.81	24.2
2005	82.58	1.27	22.67	27.5
2010	87.77	1.26	28.24	32.2
2015	93.01	1.19	33.57	36.1
2020	97.85	1.04	39.10	40.0
2025	101.94	0.84	45.51	44.6
2030	105.41	0.68	51.93	49.2

Source: Institute of Development Strategy

IV. Forecast of energy and electricity demand until 2030

A forecast of energy demand has been calculated in accordance with the high, base, and low scenarios mentioned above. One of the important factors that make affection on the forecast of energy demand is a change of economy structure. In addition, while energy resources are gradually exhausted, an increase of energy demand will lose a balance between energy supply and the demand. Vietnam has been now in starting period of economy development, its economy sectors have not been developed, and its energy consumption has also been at a low level in comparison with other countries in the same region. Therefore, in the period 2004 - 2020, at the forecast, an energy demand growth rate will be equivalent to the GDP one, and then its growth rate will be lower and equal to about 5% in the period 2020 - 2030.

4.1 Forecast of final energy demand

According to a study of Electricity of Vietnam, a forecast of final energy demand until 2030 is shown in table 4.1. The final energy demand growths for the base and high scenarios have been also forecasted to be 8.1% and 8.7%, respectively, in the period 2000 – 2020, and 4.9% and 5.4% in the period from 2021 to 2030.

Table 4.1: Forecast of final energy demand until 2030

Unit: *MTOE*

Year	2000	2005	2010	2015	2020	2025	2030
High scenario	12.2	21.1	33.0	47.1	65.4	85.0	110.5
Base scenario	12.2	20.2	31.0	43.2	58.7	74.7	95.0

Low scenario	12.2	18.4	27.2	36.1	47.8	60.0	75.2

Source: Institute of Energy/Electricity of Vietnam

From the forecast of the energy demand and the population growth mentioned above, the commercial energy consumption per capita at the high scenario has been calculated and shown in table 4.2.

Table 4.2: Commercial energy consumption per capita

Year	1995	2000	2010	2020	2030
Commercial energy consumption per capita on average, *kgOE/(person.year)*	107	155	372	670	1,048

Source: Institute of Energy/Electricity of Vietnam

4.2 Forecast of electricity demand until 2030

To meet requirements of the national social-economic development and people's life, an electricity consumption demand for the period from 2000 to 2030 has been analyzed.

From 2000 to 2005, the forecast of electricity demand has been carried out by a direct method such as checking and supplementing a list of present loads, new-made loads and foreseen loads, specially, big loads for industrial centers, factories, and residential areas, and regulating forecasted values on electricity consumption of each province, etc. For the periods after 2005, the forecast of electricity demand has been carried out by an indirect method such as simulation of scenarios similar to the forecast of energy demand mentioned above. Based on the high, base, and low scenarios of the country's economic growth, the result of the electricity demand forecast is shown in table 4.3.

Table 4.3: Forecast of electricity demand until 2030

Unit: *billion kWh*

Year	2000	2005	2010	2015	2020	2025	2030
High scenario	26.6	55.0	99.0	157.8	230.0	310.8	395.5
Base scenario	26.6	53.0	93.0	142.8	201.3	263.9	326.3
Low scenario	26.6	48.5	88.7	131.4	176.9	221.3	362.0

Source: Institute of Energy/Electricity of Vietnam

From the forecast of the electricity demand and the population growth mentioned above, a commercial electricity demand per capita at the scenarios has been calculated and shown in table 4.4.

Table 4.4: Forecast of commercial electricity demand per capita until 2030

Unit: *kWh/capita*

Year	2000	2005	2010	2015	2020	2025	2030
High scenario	343	666	1,128	1,697	2,350	3,049	3,752
Base scenario	343	642	1,060	1,536	2,058	2,589	3,096
Low scenario	343	587	1,011	1,413	1,808	2,171	2,486

Source: Institute of Energy/Electricity of Vietnam

4.3 Energy balance between demand and supply

A balance of the energy demand-supply for the country's middle and long term planning is based on provisions as follows:

- Estimation of potentiality and capability to exploit domestic primary energy resources.
- Results of a total energy demand forecast in the period 2003 – 2030.
- Forecasted costs of fuel and energy kinds to be changed towards international and regional integrated trends.
- Capability to exchange energy and electricity with some neighbouring and Asian-Pacific countries.

According to an energy forecast for the base scenario, the primary energy demand calculated by 2010, 2015, 2020, and 2030 from the final energy demand will be 44.4, 62.8, 88.2, and 135 million TOE, respectively. The balance between the primary energy demand and its exploitation capability at the base scenario is presented in table 4.5.

Table 4.5: Balance between the primary energy demand and its exploitation capability at the base scenario

Energy kind	2010	2015	2020	2030
Primary energy demand, *million TOE*	**44.360**	**62.804**	**88.228**	**134.971**
Domestic primary energy supply, *million TOE:*	**50.085**	**60.130**	**63.324**	**72.149**
	12.772	15.337	16.846	22.400
- Coal	21.989	22.192	18.324	18.324
- Crude oil	7.939	12.301	16.200	16.200

- Gas - Hydroelectricity & new energy	7.385	10.300	11.954	15.225
Energy excess, *million TOE*	**5.725**	0.0	0.0	0.0
Energy lack, *million TOE*	0.0	**2.674**	**24.904**	**62.822**

Source: Institute of Energy/Electricity of Vietnam

From the table it can be seen that, the exploitable capability of domestic primary energy resources will exceed the energy demand until 2010. It means that at that time, the Vietnam's energy balance will tilt toward exportation trend. From 2012 for the high scenario, 2014 for the base scenario, and 2017 for the low scenario, if the exploitable capability of domestic primary energy resources does not have any big change suddenly, the energy supply will be impossible to meet its demand, and then an energy importation will be unavoidable. Data from table 4.5 shows that an energy lack at the base scenario will be 2.67 million TOE by 2015, 24.9 million TOE by 2020, and 62.8 million TOE by 2030. If there are not new energy sources supplemented, a share of energy import will be 28.2% and 32.3% by 2020, and 46.5% and 54.8% by 2030 at the base and high scenarios, respectively.

V. Balance measures of energy supply-demand

5.1 Viewpoint of electricity development

There are some viewpoints of electricity development as follows:

- Electricity supplies at reasonable costs to guarantee a social-economical development.
- Enhancements of safe, continuous, and stable electricity supplies.
- Diversification of energy production to enhance a security in energy supply and not to depend on one or two fuel kinds.
- A maximum use of hydroelectric potentiality and reasonable development of hydroelectric plants to meet requirements of water supply assurance and transport on rivers, and resistance to floods.
- A priority for development of coal-fired plants in the North, gas-fired thermal plants in the South and Middle of Vietnam.
- Application of advanced technologies in the world for electricity production, transmission and distribution.
- Power plant development synchronous to transmission and distribution.
- Diversification for investment and participation in activities for electricity development in order to reduce national budget

charges and effectively enhance economical competitions in the electric sector.

5.2 Expectation of electricity generating sources in the future

To meet an electric demand growth during the 30 coming years, electricity generating measures will still be plants using fossil fuel (coal-fired, gas-fired and oil), hydroelectricity plants and some other plants using renewable energy such as geothermal, and biomass energy resources.

In term of an energy balance, the energy sources discovered will not be enough for the domestic energy demand, therefore, the measures exchanging energy (gas import as lacked and gas export as redundant) with some countries in the Asian-Pacific area have to be considered soon. In addition, to meet requirements of stable energy development, environmental protection, and scientific-potential enhancement, ***introduction of nuclear power into Vietnam has to be considered.***

5.3 Measures of energy supply and the role of nuclear power

a. Up to 2020

At the estimation of Electricity of Vietnam, a fuel balance for electricity production in accordance with the different scenarios is presented in table 5.1.

The table 5.1 shows that Vietnam will lack fuel for electricity production of about 36 billion kWh for the base scenario and 65 billion kWh for the high scenario by 2020, although a capability of resource exploitation has been assumed to be at a high level. To meet electricity demand there are some solutions considered as follows:

(1) Import: A capability for electricity import has been estimated to be about 3,700 – 4,000 MW, equivalent to a electricity generation of 16.0 – 17.0 billion kWh, and then a foreign currency demand necessary will be about 1.6 – 2.9 billion USD (at electricity price of 4.5 US cents per kilowatt), which will make increase in a super-import charge. In addition, the share of electricity demand dependent of foreign countries will be 16 – 28% of the total national requirement of electricity demand, which will have influence on the country’s energy supply security.

(2) Gas import through ASEAN conjugate gas pipes: A gas quantity necessary for production of 36 – 65 billion kWh has been estimated to be 7 – 13 billion m^3. However, according to forecasts, a majority of the ASEAN countries will not have a lot of gas resources by 2020 and then their gas quantities will not be enough for trade demand. In addition, the gas quantity imported at that time will also be possible to only compensate for one exploited from the Vietnam’s gas mines coming to the end of their projects.

(3) *Gas-liquefied import:* Gas-liquefied has been now bought and sold widely as other fuels in the world, but at a cost higher than one of gas-fired through conjugate pipes (2.8 USD/10^3BTU). That thing makes the cost of electricity generated from the gas-liquefied 15 - 20% higher than one generated from the gas-fired. Therefore, a foreign currency quantity necessary to buy the gas-liquefied has been estimated to be 1.3 – 2.4 billion USD.

Table 5.1: The fuel balance for electricity production in accordance with the different scenarios

Potentiality	2015				2020			
	Exploitation	Elec. production /*billion kWh*/, for scenarios:			Exploitation	Elec. production, /*billion kWh*/, for scenarios:		
		Low	Base	High		Low	Base	High
Coal production, *million tons*:	**27.4**				**30.0**			
- For electricity	14.2		31.6		16.2		36	
- For other sectors	13.2				13.8			
Domestic gas production, *billion m³*	**16.0**				**18.0**			
- For electricity	13.7		67		14.3		69	
- For other sectors	2.3				3.7			
Hydroelectricity	**13,000 *MW***		49		**15,100*MW***		58	
New energy	**5,000 *MW***		1.5		**700*MW***		2	
Total domestic electricity production, *billion K Wh*			**149**				**165**	
Total electricity demand, *billion KWh*		**131**	**142**	**158**		**176**	**201**	**230**
Excess of electricity, *billion KWh*		**18**	**7**	**0**		**0**	**0**	**0**
Lack of electricity, *billion KWh*		**0**	**0**	**9**		**11**	**36**	**65**

Source: Institute of Energy/Electricity of Vietnam

(4) *Electricity generated from new energy resources:* An according to the estimation of Electricity of Vietnam, a capability of new energy exploited by 2020 will be 700 MW,

equivalent to 2 billion kWh, so that it has a very small role in the balance of energy supply - demand.

(5) *Coal import:* A coal market will be available in the Asian - Pacific area in 20 coming years. At estimation, a coal quantity of 16 - 29 million tons will have to be imported and coal-fired power plants will have to be built with a total capacity of 7,000 - 13,000 MW by 2020 to meet the energy demand. However, it is difficult to entirely estimate expenditures for environmental pollution.

(6) *Combinative solution:* Combination of all the solutions mentioned above has to be considered, concretely: electricity imported and exploited from new energy resources will meet about 18.0 billion kWh; and then to have 18 - 47 billion kWh left (equivalent to a coal quantity of 7.6 - 21 million tons) for the balance of electricity supply - demand, shares of importing coal and gas, exploiting new sources, and introducing nuclear power into the country have been considered.

b. Up to 2030

A forecast of electricity production at the low, base, and high scenarios is 263.0; 327.0; and 369.0 billion kWh, respectively. According to calculation, a capability mobilizing the domestic energy sources will maximally meet an electric demand of 208 billion kWh, and then there will be an electric lack of 55, 119, and 189 billion kWh for the 3 different scenarios. It is estimated that, a capability of importing electricity by 2030 will reach 22 - 34 billion kWh (about 5,000 - 7,000 MW), of which 3,000 MW will be from Laos and Cambodia, and 2,000 - 4,000 MW from the South of China. Therefore, *an electric quantity of 85 - 154 billion kWh will still be lacked at the base, and high scenarios, respectively*.

The analysis mentioned above shows that the electric demand will be gradually increased (about 4.9 - 5.6 %/year) in the period 2021 - 2030, it has been necessary to consider a capability for introduction of nuclear power in the country after 2017 together with the solutions of fuel and electricity imports, because the domestic energy sources then will be exhausted. In spite of initial difficulties that have to be overcome by the Government such as shortage of financing issues, weakness of manpower for nuclear technology, and national industrial possibility limited, the nuclear power development will meet the electricity demand, intensify the energy security, reduce the environmental pollution, and create potentiality for development of science and technology of the country.

VI. Government policy on electricity development

6.1 Government policy

The potentiality of primary energy sources has been though diversified, but no profuse. At that time, to meet an economy development rate at a relatively high level (about 7 – 8%/year) so that Vietnam may become a industrialized country by 2020, requirements on development of energy source diversification, safe and steady energy supply, and protection of resources and environment have been extremely important in the country’s energy policy.

The Vietnam Government has allowed carrying out some research projects as follows in order to identify a possibility for introduction of nuclear power into the country:

- The balance between energy demand and energy supply resources;
- The economical availability;
- The environmental impacts (including nuclear safety and radioactive wastes management); and
- The sustainable energy development of Vietnam.

Based on the result report of the studies above, on May 29th, 2001, in text No 40/TB-VPCP sent to the Ministry of Industry, the Primary Minister proposed the Ministry of Industry to carry out pre-feasibility studies for introduction of nuclear power into Vietnam for the fundamental purpose as follows:

- To study necessities of nuclear power for the country;
- To define a moment at which the nuclear power will be in Vietnam;
- To select the site for the first nuclear power plant in Vietnam;
- To choose a type of the first nuclear power plant;
- To study technical solutions, radiation protection, and nuclear safety;
- To assess environmental impacts from nuclear power plants;
- To search public acceptance for nuclear power; and
- To assess finance and economic ability for the nuclear power plant...

The result of the pre-feasibility studies for introduction of nuclear power into Vietnam was carried out by Institute of Energy/Ministry of Industry and Vietnam Atomic Energy Commission/Ministry of Science and Technology, and submitted to the Vietnamese Government. The result shows that based on the national energy demand and supply sources, and development potentiality of the country’s economy – technology, the first nuclear power plant in Vietnam will start operating after 2017. In the present time, competent organizations, which are responsible to advise the government, are examining the result report of the pre-feasibility studies before it will be submitted to the National Assembly.

In the development strategy of the Vietnam atomic energy sector, it is also written, “...The development strategy aims at building and carrying out a nuclear power development program safely, economically, and reliably in political, economical, financial, and technical aspects protected by the Government. The nuclear power development program aims at a target in order to build a national nuclear industry that assures electricity production effectively and reasonably in investment capital, meets requirements of national manpower development, radioactive and nuclear safety, and environmental protection, and gradually comes to self-control in nuclear power technologies...”

6.2 A general program for electricity development in the period 2003 – 2020

A general program for electricity development in point of economical and diversification views, of which there will be construction of the first nuclear power plant, has been considered, based on effective uses of the domestic energy sources to generate electricity as follows:

- Hydroelectricity production being 60 - 65 billion kWh/year;
- Natural gas production being 15 – 16 billion m^3/year (its total production - 18 billion m^3/year);
- Coal production being 15 – 16 million tons/year (its total production being 28 - 30 million tons/year);
- Electricity import being about 17 billion kWh/year; and
- Nuclear power and coal-thermal power imported being in competition at costs dependent of their load factor in the national electric system.

Calculated results of electricity development by 2020 in accordance with the base and high scenarios are shown in tables 6.1 and 6.2, respectively.

For the base scenario, all the energy sources mentioned above would assure a maximal capacity demand of 32,500 MW, of which reserve margins of 22% and 14.7% are to be for rainy and flooding seasons, respectively. At this base scenario, the calculation also shows that the first nuclear power plant with a capacity of 2,000 MW will operate by 2019.

Table 6.1: Electricity development program by 2020 at the base scenario

Electricity generating plants	Total capacity, *MW*	Production, *billion kWh*
Hydroelectricity & Pump storage plants	16,100 (40.6%)	58.4 (29.0%)
Gas-fired thermal plants	12,300 (31.0%)	78.0 (38.8%)
Coal-fired thermal plants	5,600 (14.1%)	33.9 (16.8%)
Electricity import	3,700 (9.3%)	17.1 (8.5%)
Nuclear power plants	2,000 (5.0%)	13.9 (6.9%)

Total	39,700 (100%)	201.3 (100%)

Source: Institute of Energy/Electricity of Vietnam

At the high scenario, a maximal capacity demand of the all electricity sources is 37,260 MW by 2020 with reserve margins of 20% and 13.8% for rainy and flooding seasons, respectively. At estimation, for the high scenario the first nuclear power plant with a capacity of 4,000 MW will operate by 2017.

Table 6.2: Electricity development program by 2020 at the high scenario

Electricity generating plants	Total capacity, *MW*	Production, *billion kWh*
Hydroelectricity & Pump storage plants	17,200 (38.4%)	62.7 (27.3%)
Gas-fired thermal plants	12,300 (27.5%)	76.4 (33.2%)
Coal-fired thermal plants	6,600 (14.7%)	39.4 (17.1%)
Electricity import	4,700 (10.5%)	23.3 (10.1%)
Nuclear power plants	4,000 (8.9%)	28.1 (12.2%)
Total	44,800 (100%)	230.0 (100%)

Source: Institute of Energy/Electricity of Vietnam

B. Identification of the features of small reactors that could enable them to meet specific challenges for developing countries

In recent years, many IAEA Member States have interested in the development and deployment of small and medium sized reactors. Small and medium sized reactors have been defined by IAEA in accordance with their net electrical power rating, or equivalent thermal power rating. Small reactors are defined as having rated electrical generation capacity of less than 300 MWe or thermal output of less than 1,000 MWth, while medium reactors are from 300 to 700 MWe. The question is that identification of the main features of small reactors, which could enable them to meet specific challenges for developing countries in general. Vietnam, a developing country, has to take into account of following features of small reactors for the first period of its nuclear power development program.

I. Capital cost lower and construction period shorter for small reactors than for large ones could be suitable in the situation of shortage of financial sources

1.1 Financial solutions for nuclear power plants

A financial estimation for nuclear power plants will not be an easy task for following reasons:

a. An investment capital of some billions United States Dollars for a nuclear power plant is equal to two times of one for a coal-fired electricity plant and three times of one for a mixed gas turbine electricity plant at the same capacity.
b. An average construction time interval for a nuclear power plant is 7 - 8 years, much longer than for electricity generating plant of any other type.
c. Some questions on safety in operation of nuclear power plants and treatment of radioactive wastes raised by public opinions must be noticed.
d. A project for construction of a nuclear power plant, especially the first plant, has a high risk such as its construction time lengthened and its investment capital altered in comparison with the given expectation.

In general, developing countries have usually mobilized financial sources for their big projects according to traditional financial approaches in order to attract every national and international capital source.

1.1.1 National financial sources:

a. Financial sources from investors: This financial sources include share capitals and capitals from Electricity Utilities;
b. Borrowing capitals: These capitals may be mobilized through bonds, domestic credit banks, and public benefits and credits from public organizations and trade companies.

1.1.2 International financial investment sources: International financial investment sources include exportable credits, multilateral developing organizations and international markets.

Generally, a capability of borrowing capitals from exportable credits or international bank organizations mainly depends on high trust in acquittance from borrowing countries. The traditional financial approaches mentioned above sometimes do not meet the big finance for projects of nuclear power plants. Therefore, there are no-traditional financial approaches as follows used:

- Rent of plants;
- Personalization of plants in investment and operation
- Export of commodities and import of energy
- Building – Operation – Transfer (BOT), and
- Building – Own – Operation (BOO)

1.2 Project on finance for nuclear power plants in Vietnam

a. About 13 - 17% of all the investment capital with favor may be mobilized from international financial organizations (World Bank, Asian Development Bank...) and industrialized countries under the Official Development Assistance (ODA) form and so on...

b. Vietnam shall mobilize national finances from the electricity sector and other investments. A share of 20 – 30% of all the investment capital may consist of share capitals, capitals from the electricity sector, capitals borrowed from the national budget, capitals given from domestic bond selling, and capitals mobilized from national trade companies.

c. The left share of 50 – 60% of all the investment capital may be mobilized under forms as follows:
   - Directly exportable credits;
   - Borrowing capitals from international capital markets with acceptable interest rates;
   - Selling of bonds and share certificates at international stock markets under sponsoring of international financial organizations;

1.3 Capital cost lower and construction period shorter for small reactors could be suitable to shortage of financial sources

While electricity demand will increase more and more, and because of the limited capacity of the national financial sources, Vietnam has to investigate financial solutions as follows for nuclear power plants:

- Application of the BOT or BOO forms for development of nuclear power plants, in general;
- Investigation of a national project for introduction of small or medium-sized nuclear reactors into the country instead of one for introduction of large-sized nuclear units. Definitely, investment costs acceptable for investors are less difficult to address for small nuclear reactors than for large-sized nuclear units because their total investment costs are lower through their simplified design and their construction time periods are expected to be shorter. The investors may wish to invest in technologies that can be implemented in smaller increments of capacity within shorter time intervals, and that have total smaller investment costs. For this reason, small and modular reactors may become rather attractive for developing countries. Small reactors may be factory-fabricated, and the production of multiples of a single design at a factory site offers some cost advantages. It may be possible to better match the supply growth to the demand growth, and avoid the construction of power plants with an excessive capacity in expectation of future demand growth.

II. Low capacity of small reactors will be suitable to weakness of electricity network

2.1 Situation of Vietnam's electricity supply

During over the last ten years, the commercial electricity has been increased from 6.2 billion kWh by 1990 to 34.84 billion kWh by 2003, its average increasing rate is 14.2%/year; the average electricity per person has been increased from 93 kWh/(person.year) by 1990 to 432 kWh/(person.year) by 2003. The maximum capacity of the Vietnam electricity system has been increased from 1660 MW by 1990 to 7366 MW by 2003. In the commercial electricity structure by 2003, the two components that had consumed the most electricity were the Construction-Industry sector, occupied 43.6% of the total commercial electricity, and household lighting, occupied 45.9%. The electricity demand has been concentrated at the two big load regions such as the Red river delta in the North of Vietnam, occupied 33% of the country demand, and the Cuu-long river delta in the South of Vietnam, occupied 38%.

2.2 Situation of Vietnam's electricity network

The electricity distribution and transmission network has been interested and invested for its development. During over the ten recent years, the total length of the electricity network had been increased from 46,550 km by 1990 to 173,600 km by 2002, while the total capacity of transformer stations had increased from 13,600 MVA to 45,100 MVA. A united north-south national electricity grid has been created from different electricity networks in the North, Middle, and South of Vietnam. Therefore, the effect of electricity generating plants' operation has been increased; the electricity loss rate had been decreased from 28.7% by 1990 to 12.7% by 2003.

The national electricity grid system has been enlarged and developed to rural areas. By 2003, the national electricity grid had been conducted to 509 districts, attained to 97.7% of the all Vietnam's districts. About 10.7 million rural households, occupied 83.3% of the total rural households, have used electricity.

The super-high voltage of 500 KV has been used to transmit the big capacity at long distances and to unify the regional electricity networks. The electricity grid system of 500 KV has played an important role in the Vietnam electricity system in point of economical and technical view.

The electricity grid system of 220 KV has also played an important role to transmit electricity from large power plants to load centers, however, its development rate has still been slow and affected transmitting and distributing electricity to economical regions, and exploiting electricity sources safely and economically. Some transformer stations with modern equipment have recently started operating in order to enhance electricity transmission and distribution.

For many years, the electricity grid system of 110 kV has been developed slowly and affected electricity supply. In the recent time, many transformer stations of 110 KV have been overloaded.

Electricity distribution grid systems have been taken attention in its development, but does not meet a rapidly load growth. Consequently, the electricity distribution grids have been overloaded in many regional areas because they have been very old and not improved. Moreover, the electricity grid systems have many transformer stations at different voltage levels, and thus, they have brought about difficulties for operation management. In the present time, the electricity loss is still in continuation and sometimes there are accidents of power cut off.

In general, since the investment for the national electricity grid system has been at a low level compared to the demand, its improvement was achieved only for about 70% and was mostly carried out at plains and areas with favorable traffic. Therefore, overload situation for electricity grids has been happening.

To meet electricity using demand and overcome weakness of the electricity grid systems, Electricity of Vietnam has a plan until 2010 to construct non-nuclear power plants with electricity generation capacity of some hundreds megawatts as follows:

- A hydro-electricity plant with installed capacity of 70 MW in the Quang-tri province,
- The Sesan hydroelectricity plant with installed capacity of 260 MW in the Gia-lai province,
- The Nahang hydroelectricity plant with installed capacity of 300 MW in the Tuyen-quang province,
- The Uongbi coal-fired thermal plant with installed capacity of 300 MW in Quang-ninh province,
- The Langbang coal-fired thermal plant with installed capacity of 300 MW in Quang-ninh province, and so on

2.3 **Low capacity of small reactors will be suitable to weakness of Vietnam' electricity grid systems**

According to the results of the National Project on "General survey studies for introduction of nuclear power into Vietnam" that Ministry of Industry presided over in co-ordination with Ministry of Science and Technology, the first nuclear power plant will start its operation after 2017. The current nuclear power plants (PWR, BWR, PHWR...) have been developed for use in large electricity grid systems of high quality and likely to face problems when introduced into small and weak grid systems. The major causes of poor grid voltage and frequency instability include insufficient generation and interconnection, inadequate control equipment and load dispatching, unreliability of protective systems, non-optimal grid operation management, lack of co-ordination between different electricity generating stations. Therefore, limited amount of generating capacity and fragmented transmission grids are one of the most important factors limiting and delaying the possible introduction of nuclear power into the country. Of course, this situation could be improved if small reactors are available in the market. In the Vietnam's areas where populations are sparser or electricity grid systems are not well developed, there may be very considerable demand for small nuclear power plants.

III. Small reactors will be suitable for Vietnam to desalinate seawateR

In general, water and energy consumption depends on an extent of population growth and urbanization, and an amount of islands or remote areas. The population of Vietnam now is 82.58 million and will amount to 98 million by 2020. In addition, the population movement from rural to urban areas and changing life style will have an impact on fresh water and energy demand. It is forecasted that urban population will constitute 40% of the total population by 2020 compared to 22.7% by 2005, and therefore, the need for fresh water and energy, in particular in the form of electricity, is higher and higher.

In real life, most of the people in Vietnam have been using natural resources, especially underground water. Therefore, the underground water now is gradually exhausted and even in some regions there is much pollution because of its non-sensible exploitation. In the last year, the Vietnamese government had to promulgate a policy on use and exploitation of underground water. Accordingly, one of the most promising measures for securing abundant fresh water is seawater desalination. Seawater is inexhaustibly available, and desalination technologies are well developed in the world.

From the environmental requirements such as reducing global warming and air pollution, the nuclear reactors is one of alternatives for providing a reliable energy source. Moreover, for islands or remote areas, where the cost of transportation of fossil fuel is very high, nuclear reactors represent a favorable solution. In developing countries with weak infrastructure and limited financial capabilities, small reactors become attractive choice. They not only meet electricity demand but also are used to desalinate seawater in order to supply fresh water.

IV. Simplified operation and maintenance for small reactors will be correspondent to weakness of manpower for nuclear power plant development

3.1 Present manpower situation of the regulatory body for radiation and nuclear safety

In Vietnam, the atomic energy law that is not only to control but also to urge every activity in the nuclear energy field has been not promulgated yet. The highest legal system at the present time is a state law on radiation protection and control, promulgated by the Executive Commission of the National Assembly by 1996. Based on the state law, a state management organization on radiation and nuclear safety is Ministry of Science and Technology. The Department of Nuclear and Radiation Protection and Control (DNRPC), which belongs to Ministry of Science and Technology, is directly responsible to state management on radiation and nuclear safety. The function of the DNRPC is such heavy, but it has not enough officers and equipment in order to carry out its responsibility. This department needs usually assistance from different organizations, Vietnam Atomic Energy Commission (VAEC) in particular, so that it may achieve its work. Therefore, independence according to responsibilities between the DNRPC and VAEC (R&D organization) has not been carried out.

3.2 Present situation of R&D manpower

Vietnam has had researchers and scientists in nuclear physics speciality; most of them were educated in the former Soviet Union and the East-European countries. They have played an important role in application of nuclear techniques for economical and social fields, in safely operation and effectively exploitation of the Dalat nuclear research reactor, and in pre-feasible studies for introduction of nuclear power into Vietnam. In the present time, there are over 600 staffs with specialities related to the nuclear field, including nuclear and reactor physics, nuclear electronics, non-destructive testing, radioactive chemistry and biology, radiation protection, and so on. They are working in different organs and organizations. The VAEC that is the vanguard to carry out the national project for introduction of nuclear power into the country has about 500 staffs, including 300 university graduates and 70 Ph. D’s and doctors of science. However, the quantity of such our researchers and scientists has gradually been decreased because some of them has retired, moved to work in other organizations or abroad while it is not been timely supplemented by young researchers because Vietnam has not had the best policy in order to attract them for the nuclear energy sector. On the other hand, students do not like to study fundamental science because they may not have big salaries after graduation. Therefore, the people that are working in the VAEC now are at high ages, 47 years old on average, and do not meet requirements on quantity, quality, and learning standard for a nuclear energy development program.

3.3 Small reactors will be suitable to starting construction of the first nuclear power plant in Vietnam

To develop the first nuclear power plant after 2017, Vietnam needs full staffs of not only the nuclear energy sector but also other professional ones with different learning standards (workers, technicians, engineers, and experts). Therefore, it needs now a education and training program according to different styles such as regular education, in-service training, retraining, and so on. Moreover, Vietnam has to investigate small reactors with features of simplified operation and convenient maintenance... if they are available in the market. Development of small reactors into Vietnam, a developing country, shall be the most reasonable way because it may meet not only the weakness of manpower for nuclear power plant development but also the electricity demand, mentioned above.

C. Definition of major requirements to small reactors without on-site refueling that could enable their successful deployment in developing countries

I. safety features (inherent safety, passive cooling, and minimized production of waste...)

1.1 Thermal-hydraulic characteristics and operational mechanism of coolant water

Small reactors without on-site refueling in general, and the Fixed Bed Nuclear Reactor (FBNR, in the future) or HTR-10 reactor (from China) in particular, have a spherical shape fuel with a diameter of about 15 mm or 60 mm, made of compacted micro-fuel-elements, cladded by silicon carbide that creates resistance against corrosion at high temperature under normal operating and accidental conditions. Therefore, one of the important safety features for this kind of reactor fuel is the high ration surface to volume ratio for spherical fuel elements creates a good heat transfer that results in a very low level of an average fuel temperature.

In case of the Fixed Bed Nuclear Reactor, the spherical fuel elements form a suspended core by the flow of coolant water, and any accident will signal cutting off of the power to the coolant pump, thus causing a stop in the flow. Therefore, the fuel elements fall out of the reactor core by the force of gravity and become stored in passively cooled fuel chamber through national convection of coolant water and under highly sub-critical condition.

1.2 Waste minimization

The FBNR’s fuel elements are composed of small fuel spheres and each one is very small (about 0.2%) in comparison with cylindrical fuel elements of any conventional large reactor type (PWR, BWR, PHWR...). Definitely, radioactive release from such a fuel element will cause an insignificant consequence. From the inherent safety and passive cooling mentioned above, it is very difficult for melting of the FBNR core to occur.

A site selection for radioactive waste disposal in the future is very interested by developing countries because the countries usually have a dense population. For example, Vietnam is a developing country with a population of 81 million persons (by 2002) and a land area of 330,000 km^2. The country's urbanization rapidly enlarges from 18.8 million urban persons by 2000 to 22.67 million urban persons by 2005 and 39.1 million urban persons (estimated) by 2020. Since 1986, the Vietnamese government has committed itself to a policy of renovation. This policy has been the liberalization of the economy with a strategic policy towards all economic sectors (State-owned business entities as well as non State business entities). In order to implement this policy, Vietnam has opened its door to overseas investors and successfully achieved significant development, thus there have been many industrial centers constructed everywhere. It is difficult to find a large site that is far from population areas, city areas, industrial centers, and factories, and so on, and has features on terrain, geology, and weather... which meet the site standard for radioactive waste disposal.

Therefore, the inherent and passive safety characteristics, and minimized production of radioactive waste of small reactors make it a possible option in competitiveness with large nuclear power plants, and attractive for developing countries in general, and Vietnam in particular.

1.3 Treatment and management of radioactive wastes from nuclear power plants

Even in the pre-feasibility study project for introduction of nuclear power into the country, Vietnam has established a policy on the treatment and management of radioactive wastes collected from nuclear power plants or research reactors as follows:

- To construct a treatment and management system of radioactive wastes at low and medium activities, based on suitable technologies;
- To use nuclear fuel elements only one time; it means that the spent fuel is not used to reprocess, and
- To construct storage with an enough volume to safely keep all the radioactive wastes and spent fuel collected from reactors.

II. simple and modular design convenient for effective safeguard measures

2.1 Simple and modular structure features

Small reactors have structures made of modules, the basic module of which is the reactor core. Each core module is fuelled in a factory and carefully sealed, and then is transported to the reactor site to be used and from the site after the spent fuel. Therefore, there is not refueling for the reactor on the site and this thing is suitable to **weakness** of manpower in the nuclear power field.

2.2 FBNR convenient for effective safeguard measures

Small reactors in general and the small reactor without on-site refueling in particular offer some advantages as compared with large nuclear power plants because they play a role as decentralized sources of electricity generation that are able to provide energy services to rural areas, remote areas, and islands. In general, they are suitable and attractive for developing countries. However, the construction and operation of a large number of such small reactors on multiple sites may raise social concerns from view of safeguard measure point. At the present time, in spite of the demonstrated effectiveness of the international safeguard regime, the risk of proliferation of nuclear weapons remains a social concern deserving to be addressed by the nuclear industry. Therefore, gaining social acceptance will require specific efforts of designers to enhance proliferation resistance features of small reactors in general.

In case of the Fixed Bed Nuclear Reactor (FBNR), during the long fuel cycle time, the FBNR is not refueled on the site, but in the factory. The FBNR module is fuelled and sealed in the factory under the supervision of the IAEA safeguard measures. The module is taken to the site to be installed for operation. After the fuel spent, the module is again sealed under the supervision and returned to the factory. Therefore, the FBNR that has the simple and modular design is convenient not only for safely operation but also for effective safeguard measures against any nuclear weapon development. On the other hand, the irradiated coated particle fuel discharged from the FBNR is very resistant against heat and nitric acid; thus it is difficult to reprocess. Reprocessing technology now has not been developed for such micro-spherical fuel elements.

III. on-site non-refueling and a long refueling cycle

During the operational process of any reactor, fission fragments are continuously generated. Some of the fission products have very large absorption cross-sections for thermal neutrons such as Xe^{135}, Sm^{149}... Their presence affect criticality coefficients or reactivity of reactors and such phenomenon is called “burnable poison”.

In case of the FBNR, it is to not use any burnable poison for long-term control in order to have a long core lifetime. The core level limiter allows enough spherical fuel elements to enter the core to make it critical. The fine control rod at the core center is to make the fine control adjustments. The fuel elements that are in the reserve chamber, which is made of a high neutron absorber, normally do not contribute to the reactivity of the core, and are outside the reactor core. When the level limiter is raised, the fresh spherical fuel elements that are in the reserve chamber enter the core and contribute to its reactivity. This thing eliminates the need for burnable poison, cause better neutron economy, and can increase the core lifetime.

Small reactor without on-site refueling means that they are not refueled on the site, but in the factory. In case of the FBNR, as mentioned above the core module is fuelled and sealed in the factory, and then, is taken to and from the site. Therefore, the FBNR is one of the small reactors with a long fuel cycle and without on-site refueling offers advantages over large nuclear reactors that require frequent shipments of fuel, and then, the FBNR is able to operate with limited technical staff. This thing is very suitable for a developing country like Vietnam, where there is the weakness of manpower for nuclear power plant development but the electricity demand is large.

Conclusions

The introduction of nuclear power into the country would keep up with the general world tendency in energy development demand. Moreover, The diversification requirement for energy resources that is becoming one of the important lines in the energy policy of each country. The introduction of nuclear power in the country is a difficult task requiring great manpower, good infrastructure, large financial resource and great national effort. Therefore, developing countries like Vietnam have to consider the role and special benefits of small reactors in general and ones without on-site refueling in particular.

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Appendix 1

Different levels of the coal geology reserve

1. **The coal geology reserve that is given in the A level has to have conditions as follows:**

- Coal quality and its technological feature have to be studied so that they may be used to explain relations and distributions of different coal ranks in natural characteristics, mark, ash degree, sulfur content, weather-beaten degree, and so on. Based on these elements, a decision may or not be promulgated by the Vietnamese government to exploit and use each coal rank.
- National elements such as hydrogeology, engineering geology, and so on having an important role in decision for coal exploitation have to be studied in detail and have enough reliable data for exploitation design.

2. **The coal geology reserve that is given in the B level has to have conditions as follows:**

- The coal quality and its technological feature have been studied so that they may be used to guarantee definition of sensible measures for exploitation industry. General distribution law of coal ranks with natural features and different marks must be shown, but it is not requested to define a space site and a borderline of each coal rank.

- The natural elements that have an important role in decision for mining exploitation have to be studied at the same level as level A.

3. **The coal geology reserve that is given in the C_1 level has to have conditions as follows:**

- The coal geology reserve that belongs to level C_1 is in coal seams, of which data such as the thickness, structure, and stabilization as well as the seam context having an industrial value must be studied more exactly. The coal quality and measures that are used for coal exploitation industry have been studied at a primary level.
- The natural elements that have an important role in decision for mining exploitation have to be studied only at a primary level.

4. **The coal geology reserve that is given in the C_2 level has to have conditions as follows:**

The coal geology reserve that belongs to level C_2 is in coal seams, of which data such as site in stratigraphic columns, thickness, structure, coal quality... have been investigated, but only based on general data on geology and geography or deduced from the data of the neighbouring mining regions that had been studied.