NUCLEAR "GARBAGE" AS A SOURCE OF ENERGY

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ABSTRACT

The object of this paper is to make a quali-quantitative evaluation of the advantages that the implementation of a strategy making use of the synergy the system LWR-HWR would bring about. The hypothesis is that a nuclear growth moratorium would be established as from the year 2000 until 2030.

During that period all LWRs that cease working would be replaced by HWRs, tending to arrive to the year 2030 with HWRs only.

The analysis is based on a Utopian hypothesis. The objective is to show quali-quantitatively the advantages of synergism in the system LWR-HWR. By synergism, we understand the use of spent fuel from LWRs as input fuel for HWRs. Both data on costs and the conclusions are merely guidelines to evaluate the magnitude of the problem being discussed, and they are not to be considered as scientific-economic proof.

This is a prospective analysis based on the hypothesis that, as from the year 2000, a global nuclear moratorium will be declared by which all countries would commit themselves -during 30 years- to maintain a level of electronuclear production equal or smaller to that of 2000 (approximately the equivalent of 400 GWe). This hypothesis would be based on the need, expressed by public opinion, to wait for other technologies (e.g. fusion) to mature so as to guarantee more safety in the operation of present day nuclear power stations and in the management of radioactive waste.

Within this framework, the idea is that as from the year 2000 all LWR nuclear power stations that cease working due to obsolescence would be replaced by HWR plants. Fuel for the stations to be installed after 2000 would be U + Pu (MOX), resulting from stored Spent Fuel Elements (SFE) discharged from LWR stations.

Using the following premises:

- to use a "once through" cycle in the HWRs to be installed as from the year 2000;
- to treat SFE LWRs with >10-30 cooling years, to produce fuel elements for HWRs;
- LWRs effective life should not exceed 30 years;

the following can be proved:

- the same capacity installed in the year 2000 will be mantained until 2030, when all of the nuclear system will be composed of HWRs.
- all HWRs installed as from 2000 will have their fuel guaranteed further than the year 2030, resulting from LWRs' SFE.

Basis of Estimates and Calculations

Graph 1 is built considering the values in Table 1 (1), and assuming that all reactors are LWR type (from the year 2000 onwards, when LWRs cease working they will be replaced by HWRs, keeping nucleoelectrical power constant).

It is estimated that by the year 2000 the amount of fuel discharged by the plants will be 200,000 t. and that all that fuel, either reprocessed or not, will be available for the HWRs that will be installed after the year 2000.

In graph 1, integration of curves gives the following results:

Power supplied by LWRs from the year 2000 until 2030:
5160 GWey.

Power supplied by HWRs from the year 2000 until 2030:
6840 GWey.

Calculation of the amount of fuel needed to feed HWRs. Accumulated fuel until the year 2000:
200,000 t

Fuel discharged from LWRs until 2030: 5160 GWey x 25 t/GWey = 129,000 t

Fuel discharged from the core of LWRs that cease operating:
400 GWe x 78 t/GWe = 31,200 t

Total fuel accumulated: 200,000 t + 129,000 t + 31,200 t = 360,200 t

It is assumed that HWRs will burn LWRs' decontaminated fuel up to 25,000 MWd/t (Canflex type fuel), as from an average initial enrichment (U+Pu) of 1.5% fissile.

3570 MWth/GWe x 6840 GWey=285,000 t
25,000 MWth d/t
365 d/y 0.8(uf)

Amount of fuel needed for the first loading of HWRs:
400 GWe x 143 t/GWe=57,200 t

Total fuel demanded by HWRs: 285,000 t + 57,200 t = 342,200 t

Unused LWR fuel until 2030: 360,200 - 342,200 = 18,000 t

Determination of minimum cooling time of fuel to be treated. Power supplied between 2020-2030 by LWRs (integration last section, curve 2, graph 1):

$$\left[(70 - 20)\frac{5}{2} + 20 \times 5 + \frac{20 \times 5}{2}\right] \text{GWey} = 257 \text{ GWey}$$

Power supplied between 2000 and 2020: 5160 GWey - 257 GWey = 4885 GWey

Exhausted fuel: 4885 Gwey x 25 t/Gwey = 122,125 t

Fuel discharged from stations that cease operating:
(400 - 70) Gwe x 78 t/Gwe = 27,740 t

Fuel accumulated until the year 2000: 200,000 t

Total fuel exhausted until the year 2020:
122,125 t + 27,740 t + 200,000 t = 349,865 t

The total amount of fuel to feed HWRs is 342,000 t. But, by the year 2020, 349,865 t would have accumulated, so that fuel will always be reprocessed with a decay time of over 10 years.

Consumption of natural uranium. Only the uranium that is necessary to feed the remnant LWR installations between the years 2000 and 2030 will be used.

$$\frac{3100 \text{ MWth/GWe} \times \frac{(3.3 - 0.3)}{(0.72 - 0.3)} \text{ t Unat/t}}{\frac{35{,}000 \text{ MWthd/t}}{365 \text{ d/y}.0.8(\text{uf})}} = 190 \text{ t Unat/GWey}$$

190 t Unat/GWey x 5160 GWey = 980,400 t Unat
Production of high level activity waste. As HWRs' SFE: 285,000 t.

As LWRs' untreated SFE : 18,000 t (considered as fuel)

Reprocessing wastes:

$$\frac{3.4\ 10^{5} \text{ t U} \times 0.032 \text{ t FP/t U}}{0.2 \text{ t FP/t HLW vitr.}} = 5.4\ 10^{4} \text{ t HLW vitr.}$$

$3.4\ 10^{5}$ t U x 0.24 t hulls/t U = $8.2\ 10^{4}$ t hulls

Total high level activity waste:

285,000 t + 54,000 t + 82,000 t = 420,000 t HLW

Required SWU.
4609 SWU/Kg U (3,3%) x 26,000 Kg U/GWey = 1.2 10^5 SWU/GWey

1.2 10^5 SWU/GWey x 5160 GWey = 6.2 10^8 SWU

Pu Contents in HLW.
285,000 t x 6.9 Kg Pu/t + 18,000 x 9.1 Kg Pu/t = 990 t Pu

Initial D2O Use. 625 t D2O/GWe x 400 GWe = 250,000 t

Operative use of D2O is not considered.

Comparison with an "LWR only" Strategy.

Consumption of natural uranium, 2000-2030.
190 t Unat/GWey x 400 GWe x 30 y = 2,280,000 t U nat

Accumulated HLW. Discharged from the reactors 2000-2030:
400 GWe x 30 y x 25 t U/GWey = 300,000 t

Accumulated until the year 2000: 200,000 t

From decommissioning of 400 GWe: 400 GWe x 78 t/GWe = 31,200 t

Total uranium accumulated until the year 2030 (HLW):
200,000 t + 300,000 t + 31,200 t = 531,200 t HLW

Required SWU. 1.2 10^5 SWU/GWey x 1.2 10^4 GWea = 1.4 10^9 SWU

Pu contents in HLW. 531,200 t x 9.1 Kg Pu/t = 4832 t Pu

Table 2 summarizes the calculations.

Table 3 compares the costs of both strategies. These values have been calculated ignoring the time factor in investment and payments.

If we analyze the values obtained in Table 3, the cost of both strategies, after a simplified calculation, does not reflect a marked advantage of one over the other.

Conclusions

According to the analysis with present day data, the advantage of a strategy that makes use of synergy between HWR and LWR systems, is fundamentally centered in the management of waste (either produced at the front-end or at the back-end of the fuel cycle). The saving of uranium must also be emphasized, since it is a non renewable resource.

At the front-end, thousands of Rn curies would not be released into the environment and billions of m^3 of deads and contaminating liquid effluents would not be produced. Also, the production of large volumes of tails in the enrichment plants would be avoided.

At the back-end a smaller volume of HLW would be produced, with a much smaller specific contents of plutonium. This waste is potentially less dangerous than the HLWs produced by LWRs (2).

Although the above mentioned advantages are not easily quantified, they will surely influence future decisions on nucleoelectrical planning.

Another advantage, even more difficult to quantify, but that opens vast possibilities for the use of this power, is the partition and transmutation of minor actinides and long-lived fission products. Irradiated LWR fuels treated through wet way enable the development of this possibility.

Last, when analyzing the table of costs, we may infer that the factors that will influence future decisions on the choice of a LWR-HWR strategy will be the following:

- the cost of natural uranium;

- the cost of reprocessing;

- the cost of D_2O;

- the cost of enrichment.

At present, it is difficult to foresee the development of the cost of natural uranium; it may be expected to increase, and this would favor the use of HWRs.

Regarding the cost of reprocessing, it can be estimated that, if a type of process like the coprocessing-Impurex is used, and with long decay time fuel, prices should tend to decrease (3).

Regarding the cost of D_2O, at present it should be lower than the one used for these calculations ($ 275/Kg) due to the apparently over installed capacity. Also, new types of HWRs, specially designed to work with MOX fuels, should be considered because they should operate with a smaller D_2O inventory.

New enrichment processes, cheaper than present day ones, will influence negatively a LWR-HWR strategy.

Scale economy in the new fuel cycle plants and international commercial agreements in the nuclear area will certainly have strong repercussions over nucleoelectrical planning.

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Table 1. INSTALLED NUCLEAR POWER IN THE WORLD

Year	Year	GWe	Qty. of Reactors
1955	0	0.005	1
1960	5	1.21	17
1965	10	5.4	53
1970	15	16.5	80
1975	20	71.7	176
1980	25	135	253
1985	30	251	375
1990	35	330	420
1995	40	380	475
2000	45	400	500

Graph 1. ELECTRIC POWER GENERATED BY BOTH ALTERNATIVES

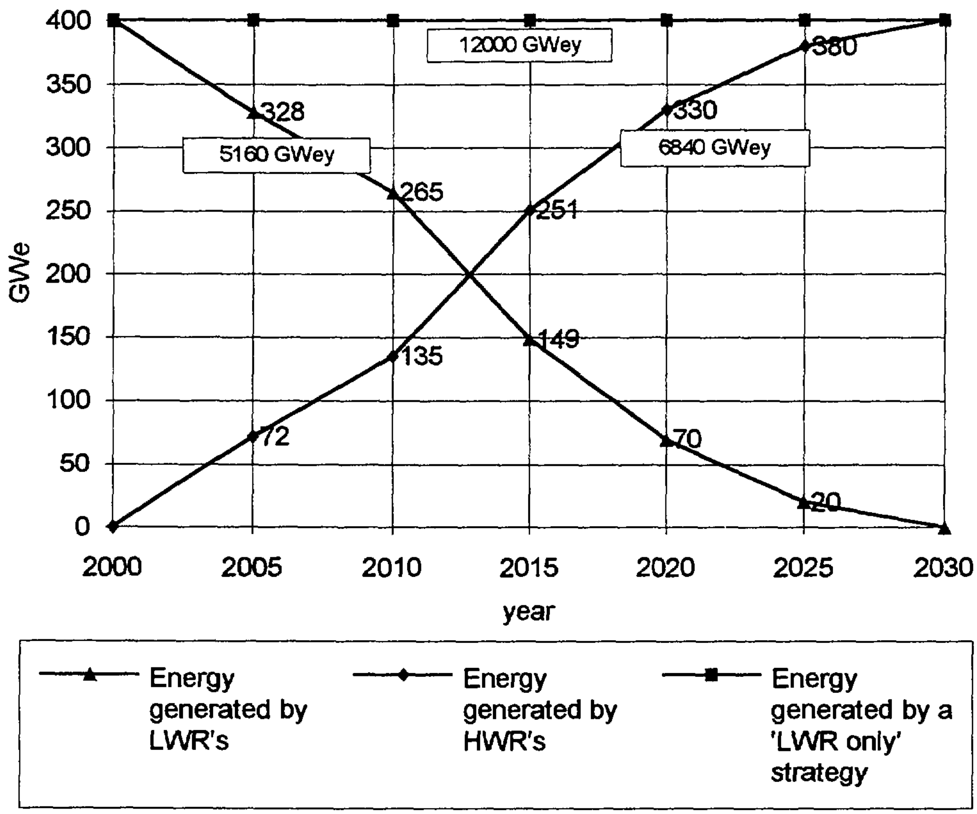

Table 2. HWR STRATEGY VS. LWR STRATEGY

	HWR Strategy	LWR Strategy	% Savings (or Pu content) with HWR Strategy
Natural U Consumption (t)	9.8×10^{5}	2.3×10^{6}	**135**
HLW Intermediate (*) and Final Storage Capacity (SFE + Vitrified HLW + Hulls) (t)	4.2×10^{5}	5.3×10^{5}	**26**
Required SWU	6.2×10^{8}	1.4×10^{9}	**126**
Pu Content in HLW (t)	9.9×10^{2}	4.8×10^{3}	**-385**

(*) The saving in the Intermediate Storage Capacity could be higher than 26%

Table 3. COSTS HWR AND LWR STRATEGIES

U$S (billions)	HWR Strategy	LWR Strategy
Cost of natural U		
9.8 10^5 x **60** 10^3	59	
2.3.10^6 x **60** 10^3		140
Cost of conversion of UF_6		
9.8.10^5 x **9** 10^3	9	
2.3.10^6 x **9** 10^3		21
Cost of manufacturing FE		
type PWR: 1.3.10^5 x **180** 10^3=2.3 10^{10} type Canflex MOX: 3.5 10^5 x **210** 10^3=7.4 10^{10} Total: 9.7 10^{10}	97	
type PWR 3.4.10^5 x **180** 10^3		61
Cost of SWU		
6.2.10^8 x **100**	62	
1.4.10^9 x **100**		140
Cost of Intermediate Storage		
Pool Storage (10 years) + Dry Storage 2.9.10^5 x **(80+10)** 10^3=2.6 10^{10} 1.8 10^4 x **(80+10)** 10^3=1.6 10^9 2.8 10^{10}	28	
5.3 10^5 x **(80+10)** 10^3		48
Cost of Reprocessing		
3.5 10^5 x **650** 10^3	230	
Cost of transport		
from reactor pool to reprocessing plant 3.4 10^5 x **40** 10^3=1.40 10^{10} to final storage (SFE) 2.9 10^5 x **40** 10^3=1.20 10^{10} (HLW vitr.+hulls) 1.4 10^5 x **10** 10^3=0.14 10^{10} 2.74 10^{10}	27	
from reactor pool to storage away from reactor 5.3 10^5 x **40** 10^3= 2.1 10^{10} to final storage 5.3 10^5 x **40** 10^3= 2.1 10^{10} 4.2 10^{10}		42
Cost of Final Storage		
4.2 10^5 x **350** 10^3	150	
5.3 10^5 x **350** 10^3		190
Cost of Nuclear Power Plant		
400 x **1360** 10^6 (CANDU 600E)	520	
400 x **1411** 10^6 (AP 600)		560
Cost of D_2O		
2.5 10^5 x **275** 10^3	69	----
Approximate Total Cost of Investments and Main Supplies (2000-2030)	**1250**	**1202**