AN ENERGY AMPLIFIER FOR CLEANER AND INEXHAUSTIBLE NUCLEAR ENERGY PRODUCTION DRIVEN BY A PARTICLE BEAM ACCELERATOR

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AN ENERGY AMPLIFIER FOR CLEANER AND INEXHAUSTIBLE NUCLEAR ENERGY PRODUCTION DRIVEN BY A PARTICLE BEAM ACCELERATOR

COMPLEMENT ON COST ANALYSIS

C. Gelès, G. Lindecker, P. Mandrillon, C. Roche, C. Rubbia, J.A. Rubio.

1. Introduction

Two notes (enclosures 1 and 2) have been written on the Cost Analysis of an Energy Amplifier for Cleaner and Inexhaustible Nuclear Energy Production driven by a Particle Beam Accelerator (CERN/AT/ET/INTERNAL NOTE 94-002, dated 26 January 1994 and CERN/AT/ET/INTERNAL NOTE 94-002/ADD, dated 22 February 1994).

These notes have been extensively discussed with experts in energy economics, in particular from the IEPE (Institut d'Economic et de Politique de l'Energie-CNRS, Grenoble). In addition, further information has been received from specialized institutions such as the US Department of Energy.

In the present note we summarize the findings and analysis made in the various papers on the basis of these discussions and information. The calculations have been coordinated by C. Roche and made in collaboration with C. Gelès, G. Lindecker, P. Mandrillon, C. Rubbia and J.A. Rubio.

In addition we have calculated a set of figures giving a "low" and a "high" limit in costs to be compared with the previous values which we still consider as the "best" estimate.

2. Calculations

Remarks have been made on the hypotheses used in the previous notes. In addition we have been provided with further and very detailed information, from the Department of Energy of the United States, on the models they used to calculate the cost of conventional facilities*.

The remarks and further information were related to:

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1 Technical Reference Book for The Energy Economic Data Base Program EEDB Phase IX (1988) and An Analysis of Nuclear Plant Operating Costs (1991).

a) The largest uncertainty about the cost of the “Tank” of the Amplifier. Therefore we doubled this cost for the high limit. However we reduced the cost of the prototype of the Amplifier system down by 40 M$ in the low limit.

b) The conversion factor from thermal to electric power of 0.43 applies to high temperatures and Helium-cooling. Therefore we considered an option with a factor of 0.35 (but with a lower temperature and water-cooling) for the high limit. We normalized all calculations to obtain the same output in electrical power with corresponding adaptations of the cost of both the Amplifier and the Conventional systems.

c) The estimated life-time of 35 years. This figure is based on our experience of the potential life-time of accelerators (more than 40 years). However 30 years is the figure commonly used for classical nuclear plants. Therefore we took a life-time of 30 years for the high limit and of 40 years in the low limit.

d) The number of staff involved in the operation. It is higher in the classical nuclear plants than in our estimates but its cost per man-year is significantly lower. Therefore we considered a higher number of staff, leading to a cost 50% higher, for the high limit and a lower man-year cost, 50 k$ instead of 80 k$, for the low limit.

e) The cost of conventional facilities appears to be lower by about 15% in the examples given by the DOE when compared to our previous calculations. Therefore we did not change them for the high limit but assumed a reduction of 15% for the low limit.

f) According to some of the experts consulted, the cost of fuel and maintenance may have been overestimated. Therefore we considered a cost lower by a third for the low limit but we did not change them for the high limit.

3. Results

We indicate, as a reminder in Annexes 1 and 2, the calculations, used for the best estimate, of the cost of the Amplifier (prototype and series production) and of the operation for the “basic” unit of 130 MWe and extrapolations for units of 130,260,650 and 1300 MWe.

In Annex 3, Tables 1,2,3 and 4 give the total costs of construction and the yearly financial and operating costs as well as the cost per kilowatt hour produced by plants based on the Energy Amplifier and generating 130,260, 650 and 1300 MWe for each approach considered above: best estimate, low limit, high limit.

The graph in Annex 4 shows a comparison of the cost of the kWhe for our different options with other sources of electricity (gas-fired, coal, nuclear plants). This is a development of the graph given in the first note which contained error bars for the cost of a kWhe: these error bars have been now replaced by our estimated low and high limits.

4. Conclusions

We consider that the estimates given in the previous notes are confirmed. These estimates correspond to our present knowledge. Any further analysis of the direct costs of the Energy Amplifier beyond cross-checking our present calculations and makes sense only after a detailed design study is completed. Such a cross-checking is planned and should be undertaken in collaboration with the IEPE.

We should now concentrate our efforts on the analysis of the External Costs and the Impact on Society of the Energy Amplifier. We can mention the protection of the environment, the waste management (in particular Plutonium), the employment, the subsidies and taxes related to the production of energy. A comparison of the efficiency of the Energy Amplifier with other sources of energy, on a long-term basis integrating the potential world needs, should be undertaken. In particular a detailed frame should be defined to take into account the more relevant socio-economic concerns mentioned above and related parameters to measure efficiency should be more precisely defined. We plan to establish a collaboration with specialized institutions (again such as the IEPE) to achieve this essential chapter of the economic study of the Energy Amplifier.

Amex 1:	- Table 1: Cost of Prototype - Table 2 Cost of series production
Amex 2:	- Operating Costs
Annex 3:	- Table 1: Cost of Energy Amplifiers, Best Estimate - Table 2: Cost of Energy Amplifiers, Low Limit - Table 3: Cost of Energy Amplifiers, High Limit - Table 4: Cost of Energy Amplifiers, Summary of Approaches
Annex 4:	- Graph: Cost / kWhe for options of Energy transformation

ANNEX l

TABLE 1: COST OF PROTOTYPE (130 MWe for 300 MWt) (Best Estimate)	MUS$
Booster Ring	60
Intermediate Injector	25
Ion Source Injector	10
Beam Transport	5
Control Room, equipment for measurements	5
Installation	20
Total Accelerate]	**125**
Amplifier Tank (hardware)	**50**
Installation	**15**
Waste Transformation	**20**
Connections between Systems	**20**
Total Tanl	**105**
Personnel (560 man-years for 4 years	**45**
Contingency (20%	**55**
GRAND TOTAL ENERGY AMPLIFIER (EA	**330**

The costs of the prototype do not include land and premises. It is assumed that the region hosting the project (or another partner) **will** provide for them. **It** could be envisaged to build the prototype close to an existing plant **in order to study how to connect the amplifier to the "conventional" part of an existing plant.**

TABLE **2:** COST OF **OPTIONS** **IF SERIES PRODUCTION (at least** 10 **units)**	**MUSS**
Industrialization of one unit of 130 MWe: 45% of Prototype	150
Stack of 2 **units:** -5% reduction of unit cost	290
Stack of 5 **units:** -7.5% reduction of unit cost	700
Stack of 10 **units:** -15% reduction of unit cost	1270

ANNEX 2

OPERATING COSTS (Best Estimate)

1, Yearly Operating Costs for a 130 MWe Plant are estimated as follows:

Staff to operate the accelerator:	15 persons (2 persons on shift)
Staff to operate the "tank":	15 persons (2 persons on shift)
Staff to operate **the conventional part:**	**35 persons (5 persons on shift)**
Management and administration	**10 persons**

Costs of 75 persons:	**6 M$**
Fuel (including reprocessing):	**3 M$**
Other Consumables:	**3 M$**
Other Maintenance costs:	**4 M$**
Total Operating **Costs:**	16 **M$**

2. Yearly **Operating Costs for the other options are estimated** as follows:

Our model is that costs of fuel and other consumables are proportional to the energy, that personnel costs evolve from one value to the other as the square root of the energy and that other maintenance costs evolve as power **0.8** of the energy.

Option (MWe)	130	260	650	1300
Personnel	6	9	13.5	19
Fuel & Consumables	**6**	**12**	**30**	**60**
Other Maintenance	**4**	7	14.5	25
TOTAL COSTS (MS)	16	**28**	**58**	**104**

ANNEX 3: COSTS OF ENERGY AMPLIFIERS IN MUSS OF 1993

Table 1: Best Estimate

M We	130	260	650	1300
Land and preparation, Buildings, Safety, radiation protection, etc.	70	120	260	'450
Mechanical systems (Turbines, cooling, heat exchange, etc.)	70	130	280	490
Electrical systems (cabling, transformers, etc.)	50	80	160	250
General expenses	40	70	1.50	240
Total Conventional systems	230	400	850	1430
Total Amplifier (Prototype at 330 MS)	150	290	700	1270
GRAND TOTAL	380	690	1550	2700
Annual Financial costs (35 years life-time, 6% interest rate)	26	48	107	187
Annual Operating costs (including fuel) -(80 k$/my)	16	28	58	104
Contingency+Possible unforeseen Recurrent costs	4	8	17	29
TOTAL ANNUAL COSTS	46	84	182	320
GWh/year (conversion 0.43, 80% operation)	911	1822	4555	9110
US$ ct/KWh	5.0	4.6	4.0	3.5

Table 2 Low Limit

M We	230	260	650	1300
and and preparation, Buildings, Safety, radiation protection, etc.	60	100	220	380
Mechanical systems (Turbines, cooling, heat exchange, etc.)	60	110	240	420
Electrical systems (cabling, transformers, etc.)	45	70	135	210
General expenses	3s	60	125	200
Total Conventional systems (Best Estimate minus 15%)	200	340	720	1210
Total Amplifier (prototype at 290 MS)	130	250	600	1110
GRAND TOTAL	330	590	1320	2320
Annual Financial costs (40 years life-time, 6% interest rate)	22	40	8a	155
Annual Operating costs (incl. fuel) -(50 k$/my, M&O lower by 1 /3)-	13	24	47	85
Contingency+Possible unforeseen Recurrent costs	4	7	14	24
TOTAL ANNUAL COSTS	39	71	149	264
GWh/year (conversion 0.43, 80% operation)	911	1822	45s5	9110
US$ ct/KWh	4.3	3.9	3.3	2.9

Table 3: High Limit

MWe	130	260	650	1300
and and preparation, Buildings, Safety, radiation protection, etc.	80	140	310	530
Mechanical systems (Turbines, cooling, heat exchange, etc.)"	60	120	270	480
Electrical systems (cabling, transformers, etc.)	60	90	190	290
General expenses	40	70	150	240
Total Conventional systems (Lower Temp., water, 23% more MWth)	240	420	920	1540
Total Amplifier (Prototype at 450 MS)	200	380	930	1700
GRAND TOTAL	440	800	1850	3240
Annual Financial costs (30 years life-time, 6'% interest rate)	32	58	135	236
Annual Operating costs (including fuel) -Staff cost 50% higher-	19	32	65	113
Contingency+Possible unforeseen Recurrent costs	5	9	20	35
TOTAL ANNUAL COSTS	56	99	220	384
GWh/year (conversion 0.35 but for 23% more MWth, 80% operation)	911	1822	4555	9110
USS ct/KWh	6.1	5.4	4.8	.s.2

• Although they correspond to the overall High Limit, the figures in this specific line are lower than the best estimate because we consider water-cooing at a lower temperature. This reduces significantly the cost of the turbines and associated equipment.

Table 4: Summary, Low Limit, High Limit, Best Estimate

MWe	130			260			650			1300		
	Low	Best	High	Low	Best	High	Low	Best	High	Low	Best	High
Total Conventional systems	200	230	240	340	400	420	720	850	920	1210	1430	1540
Total Amplifier	130	150	200	250	290	380	600	700	930	1110	1270	1700
GRAND TOTAL	330	380	440	590	690	800	1320	1550	1850	2320	2700	3240
Annual Financial costs	22	26	32	40	48	58	88	107	135	155	187	236
Annual Operating costs	13	16	19	24	28	32	47	58	65	85	104	113
Contingency	4	4	5	7	8	9	14	17	20	24	29	35
TOTAL ANNUAL COSTS	39	46	56	71	84	99	149	182	220	264	320	384
GWh/year	911	911	911	1822	1822	1822	4555	4555	4555	9110	9110	9110
USS ct/KWh	4.3	5.0	6.1	3.9	4.6	5.4	3.3	4.0	4.8	2.9	3.5	4.2

ANNEX 4: COST OF ELECTRICAL KWH
FOR DIFFERENT OPTIONS OF ENERGY TRANSFORMATION
(Best Calculated, Optimistic and Pessimistic Options for the Amplifier Plant)