XA8007194

International
Nuclear
Fuel
Cycle
Evaluation

INFCE

INFCE/DEP/WG.5/29

ECONOMIC EVALUATION OF FAST BREEDERS

INFCE - Working Group 5A 1979-03-28
Sweden / DOC 3
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ECONOMIC EVALUATION OF FAST BREEDERS

1. BACKGROUND

The discussions at the last meeting of Sub-Group 5A on 19-20 February in Brussels revealed severe doubts concerning the validity of the economic evaluations presented in Fig. 4 (A.2) of the second draft report of Sub-Group 5A [1]. These doubts concerned mainly the US-data used in Fig. 4 (A.2) due to:

- inconsistencies between the data in various contributions from the USA [2,3];
- significant discrepancies between US-results and other work [4,5,6] concerning the influence of the uranium price on the competitivity of FBRs with LWRs.

In order to clarify this situation in the short time available for the production of the final WG-5A report, an independent evaluation has been performed of the permitted FBR-capital cost premium for power generation cost break-even with "once-through" LWRs. Comments to a first draft of this economic evaluation [16,17,18] have been considered in this final version as agreed at the last WG-5A meeting. However, no comments were received from the US-delegation.

2. MAIN ASSUMPTIONS

The main assumptions are summarized in Table 1 and discussed below.

2.1 CASES CONSIDERED

In order to reflect the possible range of uncertainty and differences of judgement, bounding cases were selected based on assumptions typical for the current views in USA and Europe.

The US-case is entirely based on US-contributions to WG-5 and WG-8 including performance data for:

- A "standard" and "15%-improved" PWR-design [7] at 0.2% enrichment tails;
- The US-reference oxide LMFBR-design [8], which also has been selected as a reference design for system analysis in WG-5. This design is characterixed by an excellent breeding performance coupled however with a low thermal efficiency and a low average discharge burn-up similar to values for the initial Super-Phenix core.

The European case is based on performance data for:

- A "standard" PWR-design submitted by F.R.G. to WG-8 [9] at 0.2% enrichment tails;
- The Super-Phenix nominal design submitted by France to WG-5 [10].

The average capacity factors were assumed to be 0.70 for the US-case and 0.75 for the European case in order to represent the range considered in different INFCE-working groups.

2.2 FINANCIAL ASSUMPTIONS

The economic evaluation is performed "deflated" i.e. in constant currency value (1978 US $) with assumptions indicated in the US-contributions to WG-5 [2,3]:

- A discount rate of 4.5%, which is somewhat higher than "deflated" discount rates used in some European countries;
- A total annual capital charge rate of 9%, which includes a conservative margin of 1.3-2.2% for taxes and insurance assuming 20-25 years of economic plant life. As an example, for similar evaluations in Sweden a total annual capital charge of about 7% is used.

2.3 UNIT FUEL SERVICE COST ESTIMATES

It would be desirable to assess these unit fuel service costs assuming:

- a mature fuel cycle industry with a sufficiently large scale of production;
- "deflated" financial conditions as assumed above for this study.

However, due to the lack of experience in most of the involved fuel cycle processes, the associated cost estimates have to be considered as fairly speculative.

For the US-case the unit cost data given in the US-contributions to WG-5A [2,3] were used without modifications.

For the European case the selected data represent average judgements based on a review of data submitted to different INFCE-working groups [11,12,13].

From this survey deviations in the order of ±20 to 30% from the selected mean value were observed. Comparing the US- and European fuel service cost estimates it should be noted that:

- the back-end costs for once-through LWRs used in US-contributions to WG-5A [2,3] are only 50-60% of the corresponding US-figures
  - stated in other INFCE working groups [11,18];
  - envisaged by DOE for the recently proposed AFR spent fuel storage plan [19].
- for FBR-core fuel the total of fabrication and reprocessing costs is estimated to be the same in both cases.

3. METHODOLOGY

For the same power generation costs (excluding R&D) at the same capacity factor for the FBR and LWR, the plant capital cost premium P of the FBR can be generally expressed as:

$$P = \frac{A_f}{A_p} \cdot \Delta CF_o + \frac{A_d}{A_p} \cdot \Delta CD_o + \frac{1}{A_p} (\Delta CF_a + \Delta CO_a) \qquad (1)$$

where:

A_p	total annual capital charge of the plant, here assumed 0.09.
A_f, A_d	capital charge on present worth of initial and final fuel and decommissioning, here assumed to 0.077 (no taxes).
ΔC	cost difference LWR-FBR for:
ΔCF_o	- pres. worth of the initial and final fuel;
ΔCD_o	- pres. worth of decommissioning typically $-0.03 \cdot P$ [14];
ΔCF_a	- annual fuel costs;
ΔCO_a	- annual operation costs, typically $-0.002 \cdot P$ [2,3].

For the assumed conditions, the FBR-capital cost premium becomes according to equation (1):

$$P^{\$/kW_e} = 0.80 \cdot \Delta CF_o^{\$/kW_e} + 10.50 \cdot \Delta CF_a^{\$/kW_e y} \qquad (2)$$

For the computation of the annual fuel costs and the present worth of the initial fuel the following "payment"-periods are considered:

- uranium 1.8 year before fuel loading
- enrichment 1.0 " " " "
- fabrication 0.4 " " " "
- backend 0.4 " after fuel discharge

The initial core is assumed to be loaded 0.5 year before the commissioning of the plant.

With these assumptions and a 0-Pu-value for the comparison of FBRs with once-through-LWRs, the influence of the natural uranium price U on the premium becomes according to equation (2):

$$\frac{\Delta P^{\$/kW_e}}{\Delta U^{\$/kg}} = 0.88 \cdot RU_o^{kg/kW_e} + 11.23\ RU_a^{kg/kW_e y} \qquad (3)$$

where: RU_o natural uranium requirement for the initial core.

RU_a annual requirements for natural uranium.

For the US-standard PWR at 0.7 capacity-factor and 0.2% enrichment tails $\Delta P/\Delta U$ becomes accordingly 1.85, which is 87% greater than the corresponding value given in the US-contribution to the economic evaluation in WG-5A [2] for appearently the same input data.

4. DISCUSSION OF RESULTS

In Table 2 the main results are summarized for the economic evaluation of FBRs relative once-through LWRs using typical US- and European assumptions concerning the fuel cycle performance.

Fig. 1 shows a comparison of the influence of the uranium price on the FBR-capital cost premium (for break-even with LWRs) from this study and the following other sources:

- US contributions to Working Group 5A [2,3] for the once-through LWRs;
- UK contribution to Working Group 5A [15], which refers to the "fuel cycle cost advan-

tage of FBRs over thermal reactors" under not clearly specified conditions;

- The "Economic evaluation of reprocessing" by the Technical Secretariat of Working Group 4 [11]. These values have been normalized to the same FBR-premium at present uranium prices as in the "European" case of this study.

From this comparison it becomes evident that the results of the US-economic evaluation of FBRs [2,3] are inconsistent and differ significantly from corresponding other results (e.g. by a factor of about 2 concerning the influence of the uranium price) for similar input data. Therefore the original US-economic evaluation of FBRs according to contributions to WG-5A [2,3] should be disregarded in the further work of WG-5A.

Consequently Fig. 4 (A.2) in the second draft report of WG-5A should be modified e.g. according to the proposal shown in Fig. 2 with the following bounding cases for the FBR-capital cost premium:

- "USA-LOW" as the (hardly realistic) lowest FBR-premium according to this study based on current US-assumptions [2,3,8], which are most pessimistic for FBRs mainly due to:
    - practically no further improvement of the FBR fuel burn-up compared with the present state-of-the-art;
    - a 50%-improvement of the fuel burn-up for LWRs compared with present values;
    - 40-50% too low back-end costs for once-through LWRs compared with other current US- and European estimates [11,13,18,19].
- "Europe" as a typical estimate of the possible FBR-premium according to this study and the evaluations in Working Group 4, based on current European expectations for the near term performance. This case might be preferable to the UK-data used originally in the second draft report of WG-5A

as upper bound since it is more clearly defined.

Additional scales on Fig. 2 indicate:

- the typical ratio of FBR/LWR-capital costs corresponding to the FBR-premium;
- the typical increase of power generation costs with rising uranium prices.

According to comments received on the first draft of this evaluation, the following points should be clearly brought out in the final report of WG-5A in context with Fig. 4 (A.2) (i.e. Fig. 2 here):

- The permitted FBR-premium can be expected to be closer to the more realistic case "Europe" than the case "USA-LOW" which is considered too pessimistic regarding FBRs [16,17];
- The uranium price is to be understood as the life-time average value, which can be expected more than 20 years after the decision for a project and therefore would be appreciably higher than at the start of the project. Also it should be noted, that without the large scale introduction of FBRs the uranium price escalation would be considerably faster than with a significant global FBR system [18].

Taking these points into account it might be concluded that even FBRs with a conservative capital cost premium of up to 50% could be expected to compete with LWRs at life-average uranium prices of 2-3 times the present market price. Since it is not unreasonable to expect such U-price levels by 2000-2010, this would indicate that FBR-projects started about 20 years earlier could become competitive. The corresponding increase of power generation costs compared to present LWR-values would be less than 20%.

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TABLE 1. MAIN ASSUMPTIONS FOR THE ECONOMIC EVALUATION OF FBRs RELATIVE LWRs WITH ONCE-THROUGH FUEL CYCLES

CASE		USA			EUROPE	
PARAMETER / REACTOR DESIGN		Standard PWR (WG-8)	Improved PWR (WG-8)	Reference oxide LMFBR (WG-5)	Standard FRG-PWR (WG-8)	Nominal Super-Phenix (WG-5)
1. GENERAL						
- average discharge burn-up	MWd/kg	30	50	50	33	70***
- thermal net efficiency		.334	.334	.365	.326	.40
- average capacity factor		.70	.70	.70	.75	.75
- enrichment tails	%	.20	.20	-	0.20	-
- discount rate	%	4.5	4.5	4.5	4.5	4.5
2. PERFORMANCE						
2.1 Initial core						
- heavy metal • core	kg/kW_e	.0781	.0781	.0266	.0843	.0287
• rad. blank.	"	-	-	.0450	-	.0420
- natural uranium required	"	.314	.314	-	.366	-
- separative work required	SWU/kW_e	.212	.222	-	.256	-
2.2 Annual equilibrium reload						
- heavy metal • core	kg/kW_ey	.0252	.0152	.0124	.0255	.0083
• rad. blank.	"	-	-	.0084	-	.0093
- natural uranium required	"	.140	.119	-	.150	-
- separative work required	SWU/kW_ey	.111	.105	-	.119	-
3. FUEL SERVICE COST ASSUMPTIONS ****						
- conversion	$/kgU	3	3	-	3	-
- separative work	$/SWU	100	100	-	100	-
- fabrication • core *	$/kgHMC	115	115	1500	140	1000
• rad. blank.	$/kgHM	-	-	115	-	140
- backend ** • core *	$/kgHMC	150	150	1000	300	1500
• rad. blank.	$/kgHM	-	-	560	-	560

* incl. axial blanket but per kg heavy metal in the core

** incl. spent fuel transport, reprocessing (in FBR-cases) and waste management and disposal.

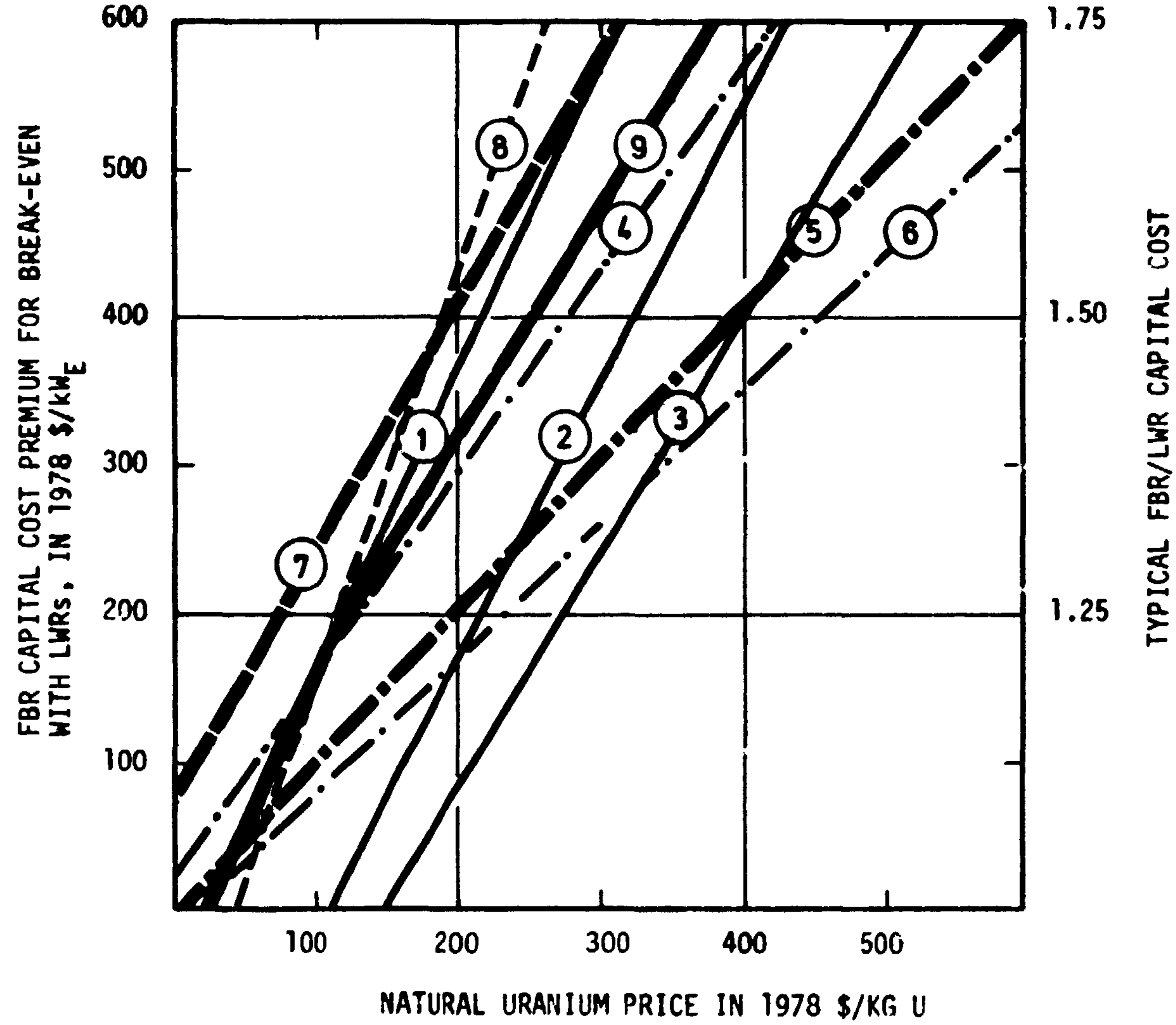
*** the average burn-up at beginning will be 45 MWd/kg.

**** the author's own assumptions for the case "EUROPE".

TABLE 2. ECONOMIC EVALUATION OF FBRs RELATIVE LWRs WITH ONCE-THROUGH FUEL CYCLES

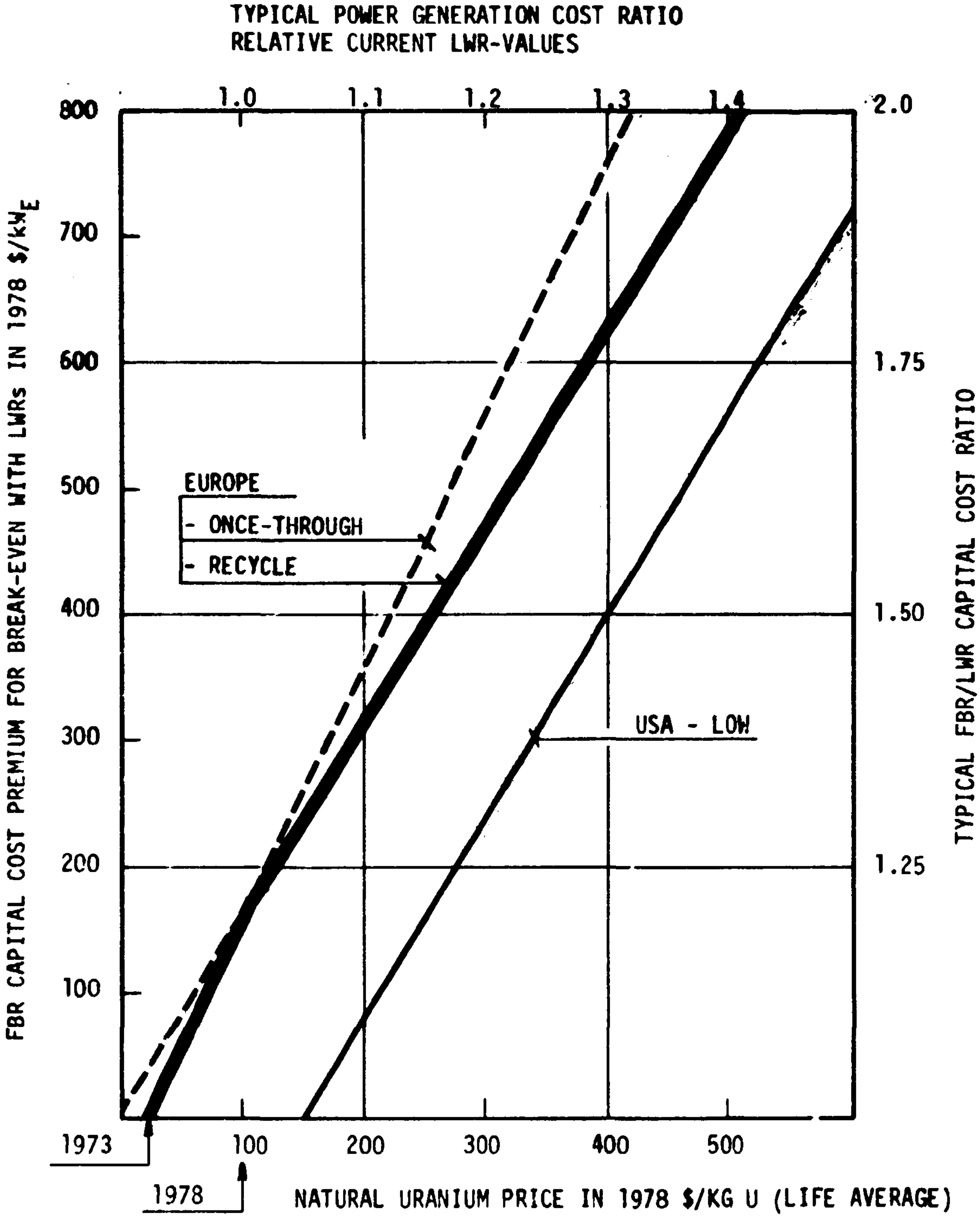
CASE		USA			EUROPE	
COSTS \ REACTOR DESIGN		Standard PWR (WG-8)	Improved PWR (WG-8)	Reference oxide LMFBR (WG-5)	Standard FRG-PWR (WG-8)	Nominal Super-Phenix (WG-5)
1. FUEL SERVICE COST (0-FISSILE VALUE)						
- present worth initial core	$/kW_e$	33.9	34.9	46.8	41.5	36.0
- annual reload	$/kW_e y$	18.9	15.5	36.7	24.4	27.3
- present worth last core	$/kW_e$	4.7	4.7	20.7	10.1	26.6
2. FISSILE MATERIAL COSTS AT 200 $/kgU						
- present worth initial core	$/kW_e$	69.1	69.1	0	80.5	0
- annual reload	$/kW_e y$	30.	25.5	0	32.1	0
3. FBR-CAPITAL COST PREMIUM FOR BREAK-EVEN WITH LWR AT 9% TOTAL ANNUAL CAPITAL CHARGE		Reference		Low		
- at U-price = 0	$/kW_e$	- 210		- 245	- 39	
- at U-price = 200 $/kg	"	+ 160		+ 78	+ 362	

Note: The values for the case "EUROPE" are based on the author's own assumptions regarding unit fuel service costs.



CURVE	SOURCE	LWR-DESIGN	COMMENT.
1	THIS STUDY "EUROPE"	STANDARD-O-T	PROPOSED UPPER BOUND FOR FIG. 4 (A.2)-SG-5A
2	" "US"	"	CORRESPONDS TO CURVES 4 & 5
3	" "US"	IMPROVED-O-T	PROPOSED LOWER BOUND FOR FIG. 4 (A.2)
4	US-REF. PAPER	STANDARD-O-T	SHOULD BE SAME AS CURVE 5, SIMILAR TO 2
5	US-CONTRIB.	"	LOWER BOUND IN FIG. 4 (A.2) 2. DRAFT
6	"	IMPROVED-O-T	CORRESPONDS TO CURVE 3
7	UK-CONTRIB.	RECYCLE	UPPER BOUND IN FIG. 4. (A.2) 2. DRAFT
8	WG-4	STANDARD-O-T	CORRESPONDS TO CURVE 1
9	WG-4	RECYCLE	PROPOSED UPPER BOUND FOR FIG. 4 (A.2)

FIG. 1 COMPARISON OF THE FBR-CAPITAL COST PREMIUM VS URANIUM PRICES ACCORDING TO DIFFERENT SOURCES



ASSUMPTIONS:
- TAIL ENRICHMENT 0.2 %
- NO R & D - COSTS INCLUDED
- CASE

CASE	FBR	LWR	CAPACITY FACTOR
EUROPE	SUPER-PHENIX NOMINAL	STANDARD PWR	0.75
USA - LOW	US-OXIDE REFERENCE LMFBR	IMPROVED PWR-O-T	0.70

FIG. 2 INFLUENCE OF THE NATURAL URANIUM PRICE ON THE PERMITTED FBR CAPITAL COST PREMIUM FOR POWER GENERATION COST BREAK-EVEN WITH LWRs (PROPOSED MODIFICATION OF FIG. 4 (A.2) IN WG-5A REPORT)