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THE NEED FOR HIGH PERFORMANCE BREEDER REACTORS

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1. THE NEED FOR BREEDING

It is reasonable to forecast that coal and nuclear will be the two most reliable sources of energy for the industrialized countries at the end of this century.
Oil and gas will be limited (or very expensive) ; hydroelectric power will be saturated ; tides, wind, geothermal and solar are not likely to supply over 10 % at the maximum of the needs ; fusion has still a very long way to go before reaching a commercialisation phase. Even coal may have production limits related to environment, pollution, transportation and cost.

Therefore, in spite of the problems related to its safety, the nuclear energy appears to be the one on which the society will rely most for its economy and prosperity, as the tendency will be towards the limitation in oil consumption.

The nuclear energy will only play its role, however, if the breeding is introduced rather soon, otherwise, there is likely to be a serious crisis in the supply of uranium.

It is now clear that, of the 2000 and 4000 million tons existing in the earth crust and sea water respectively, only an extremely small part is recoverable at acceptable cost. Figures ranging from 3 to 10 million tons have been put foreward.

The real problem however is not related to the available quantities but more to the annual discovery, extraction and processing rate, since the known deposits of uranium will only be sufficient for a few more years. Hitherto, the best annual discovery rate up to now was not more that 60,000 tons, with an average of 40,000. But annual outputs of 150,000 to 200,000 tons would be necessary at the end of the century to cope with the demand if thermal reactors only would be in service. This would require an immense effort in terms of prospection, mining and financing.

It is therefore easy to forecast that, in any case, the price of natural uranium will strongly increase if the breeding economy is not introduced soon.

Europe is at particular disadvantage here, in term of nuclear resources, and would be the first to suffer the crisis if nothing is done to limit the natural uranium requirements.

Figs 1 and 2 illustrate, as an example, the trends in the respectively cumulative and yearly requirements of uranium for the European Economic Community. It can be seen, for instance that, in 2015, assuming a no-breeding strategy based on LWR's, the EEC would have to import 66,000 tons. This represents an actual production cost of $ 10 billions. It is not inconceivable that in time of crisis, i.e. if there is no breeding, the price might rise 5 to 10 times this cost : $ 50 to 100 billions in that year, an amount equal to EEC's 1975 oil bill. If the breeding is introduced, the uranium consumption would be reduced to about 21,000 tons in 2015 or a total cost for the EEC of about $ 17 billions. In this case, the prices are likely to be only 1.5 to 1.9 the cost and the total EEC bill could, under those circumstances be reduced to $ 2.2 to 2.5 billions in that year.

2. BREEDER PERFORMANCE

The simple conclusion that breeding must be introduced soon is not in itself sufficient for proceeding with the construction of any type of fast breeder.

The rate of installation of breeder reactors, quite apart from the development problems will depend upon several things :

- the amount of Pu available from thermal reactors
- the incentive and possibility to start with U_{235}
- the quantities required for the first cores of the breeders
- the Pu produced by the fast reactors, i.e. breeding gain
- the Pu held up or lost to residues in the fuel reprocessing cycle.

Given an adequate supply of Pu in the first instance, from the thermal reactor programme, the expansion of fast breeder capacity depends on two parameters, the reactor's specific plutonium inventory and its net plutonium production. These are interconnected insofar as the doubling time of a fast reactor is directly proportional to ist plutonium inventory (in-pile plus out-of-pile) and inversely proportional to its net plutonium production. In-pile inventory depends particularly on fuel rating and burn-up, while out-of-pile inventory varies with burn-up and process hold-up time. Net plutonium production varies with process losses and breeding gain which, in turn, derives from fuel parameters such as rating, burn-up, fuel density and core geometry. Features which lead to increases in breeding gain (and so decrease doubling time) sometimes tend also to increase total inventory (and so increase doubling time). The best reactor parameters result from a choice of fuel length, diameter, density, rating and burn-up and fuel material to promote breeding gain, but they can be overshadowed by the importance of plutonium process hold-up times and losses.

It is now worthwhile to see what nuclear growth might be achievable and to discuss how it could be affected by changes in the three performance parameters : breeding gain, plutonium hold-up time and plutonium "losses" to residues. A diagram is presented in Fig. 3 showing the effect on the total nuclear capacity in operation in the year 2015 of fast reactor breeding gain and fast reactor fuel cycle plant performance quantified as the amount of plutonium lost to residues and the time plutonium is held up out-of-pile. The diagram represents the total nuclear capacity achievable and hence the difference between any point on the diagram and the thermal capacity line is the total fast reactor capacity in operation.

Prototype mixed uranium-plutonium oxide-fuelled sodium-cooled fast reactors (LMFBR) are at present in operation in several countries of the world. Plans exist for commercial sized (i.e. 1000-1500 MWe) follow-up plants based on the same fuel technology. These, and subsequent commercial reactors, will have a breeding gain in the range 0.2 to 0.3 and present development work on reprocessing will demonstrate plutonium turn-round times of 12-18 months. Losses of plutonium from the fuel cycle will lie between 5 % and 3 % with the intention of reducing these figures during subsequent recovery operations on waste residues.

Examination of the lower part of the diagram in Fig. 3 indicates that the fast reactor capacity cannot be significantly increased by improvement in breeding gain or by reductions in recycling losses as long as the out-of-pile plutonium delay times exceed 18 months and total inventory is, therefore, large. In the early stages of a fast reactor programme, the number of stations commissioned from the stock-piled thermal reactor plutonium is (if no U_{235} is used for start-up) roughly inversely proportional to the total plutonium inventory, and low doubling time due to better breeding gain and reduced recycling losses cannot materially affect the situation until an appreciable fraction of a doubling time has passed. Plutonium inventory affects doubling time as well as determining the number of early reactors, and so is important at all times. As time elapses, the proportion of plutonium production arising from the thermal reactors falls and those factors which reduce doubling time, such as lower process losses and increased breeding gain, become increasingly important. The influence of breeding gain would for instance be in 2025 about twice that in 2015. In Fig. 3 the heavy lines indicate the reasonably achievable capacity assuming that reactors with higher breeding gain can be introduced around the turn of the century to support continued growth in excess of 2 % per annum.

3. THE GAS COOLED BREEDER REACTOR

Due to its harder neutron spectrum, the Gas cooled Breeder Reactor [GBR] is a high performance breeder. It is mainly characterized by the use of pressurized helium coolant at 90 bar and vented - pressure equalized pin fuel.

The GBR plant is similar to that of any other modern thermal gas cooled reactor [AGR or HTR]. It has a multicavity [or podded] pre-stressed concrete vessel and integrated boilers and circulator sets.

The fuel assembly is also designed in the same way as that of an LMFBR : the fuel bundle held together by spacer grids is located inside a wrapper tube. The difference consists of using roughened claddings and venting the fission gases.
The latter, when they are generated, migrate through a manifold grid and delay traps and are finally swept away to a purification plant where they are absorbed.

The large background of experience in Europe on Gas cooled Reactor plant technology and fast fuel irradiation, gives therefore confidence that all aspects of R & D are adequately specified and indicates the best experimental techniques to adopt. The development effort prior to construction of a 600 Mwe demonstration plant would call for less than 10 % of the rate of expenditure currently being committed on the LMFBR in Europe.

The launching cost [i.e. to be supported by governments] of such a concept would be of about $ 475 millions over 10 to 12 years ; it includes the construction of the 600 Mwe GBR demonstration plant.

As far as performances are concerned, the GBR has roughly twice the breeding gain of that of a comparable LMFBR. It does not require the use of complicated solutions as the heterogeneous core or carbide fuel to reach breeding gains of at least 0.4. It must be acknowledged that the GBR Pu inventory is by about 20 to 25 % higher than that of an LMFBR and therefore the gain in doubling time is reduced. But in the longer term, the influence of a high breeding gain reactor is going to increase, as said above.

Because GBR engineering is so like that of AGR or HTR, the capital cost can be predicted with confidence ; current assessments indicate that power generating cost will be competitive with those of LWR's as soon as the GBR is ready for commercial introduction.

The GBR is therefore perceived as having the potential for both superior economic and technical performance than that of the LMFBR. It is concluded that the present GBR development effort in the world should be pursued and increased as a back-up to the LMFBR programme with the possibility of becoming the main option if difficulties arise with the LMFBR.

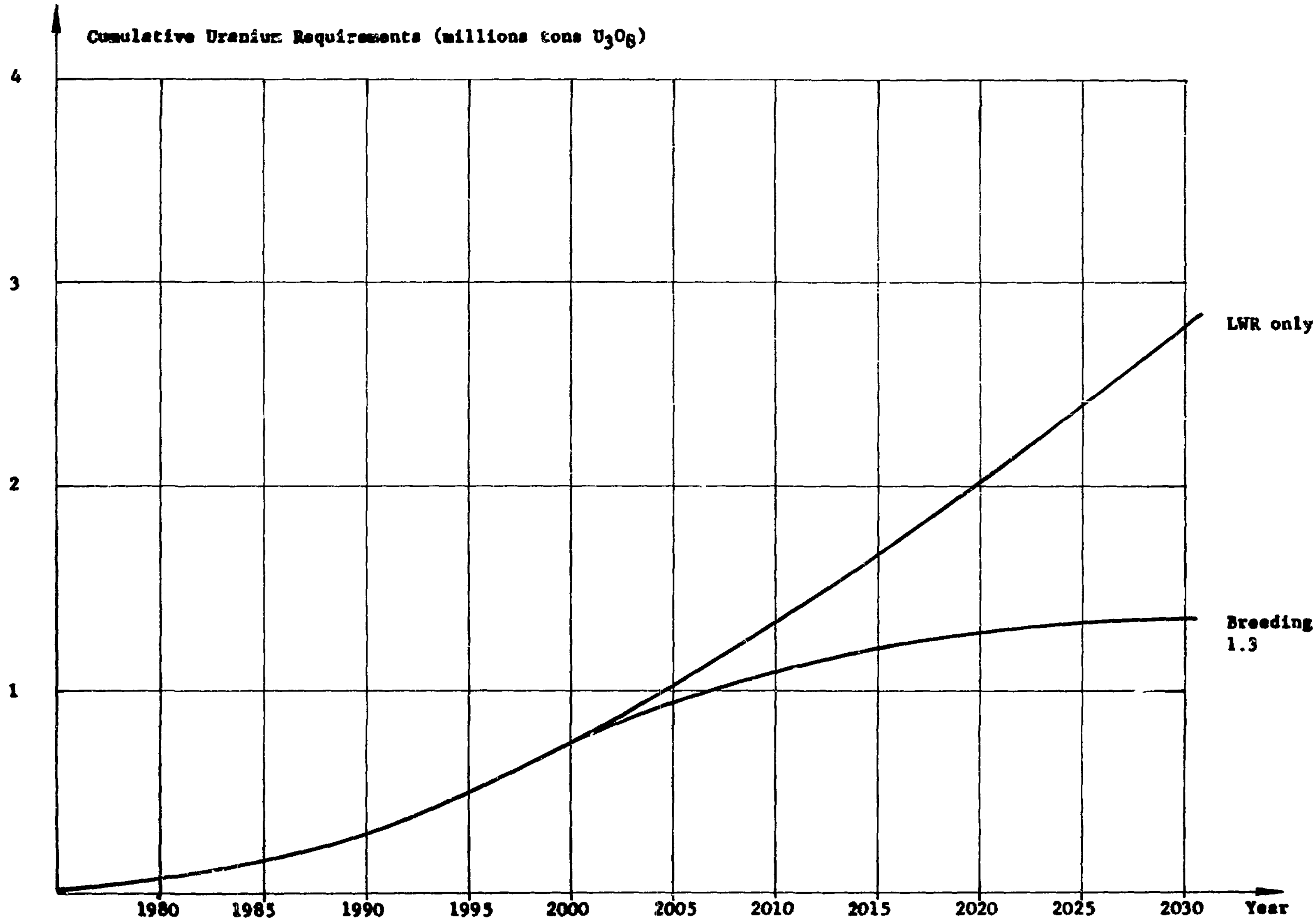

Fig. 1. - CUMULATIVE NATURAL URANIUM REQUIREMENTS FOR THE EUROPEAN ECONOMIC COMMUNITY

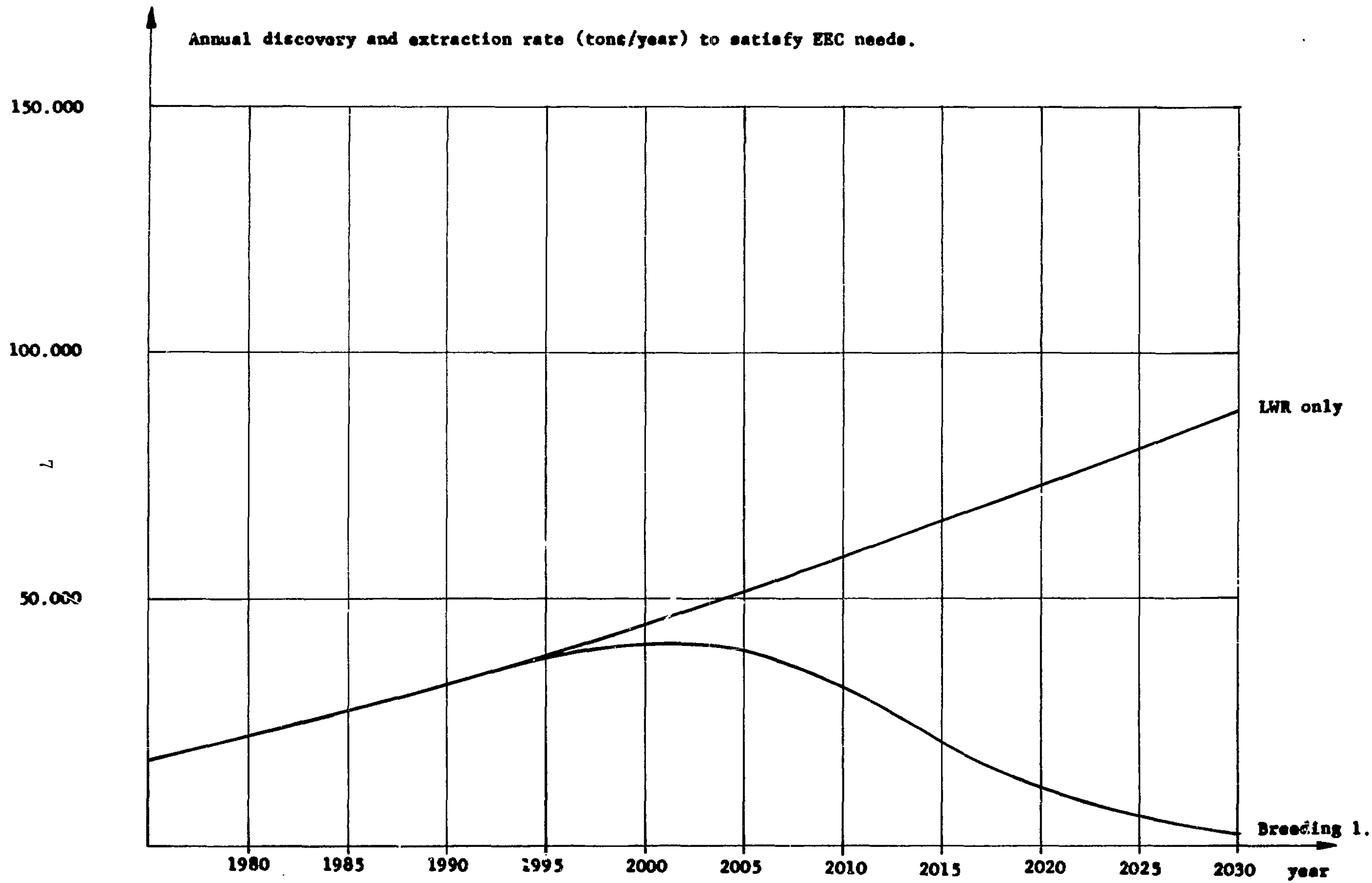

Fig. 2. YEARLY REQUIREMENTS OF NATURAL URANIUM OF THE EEC.

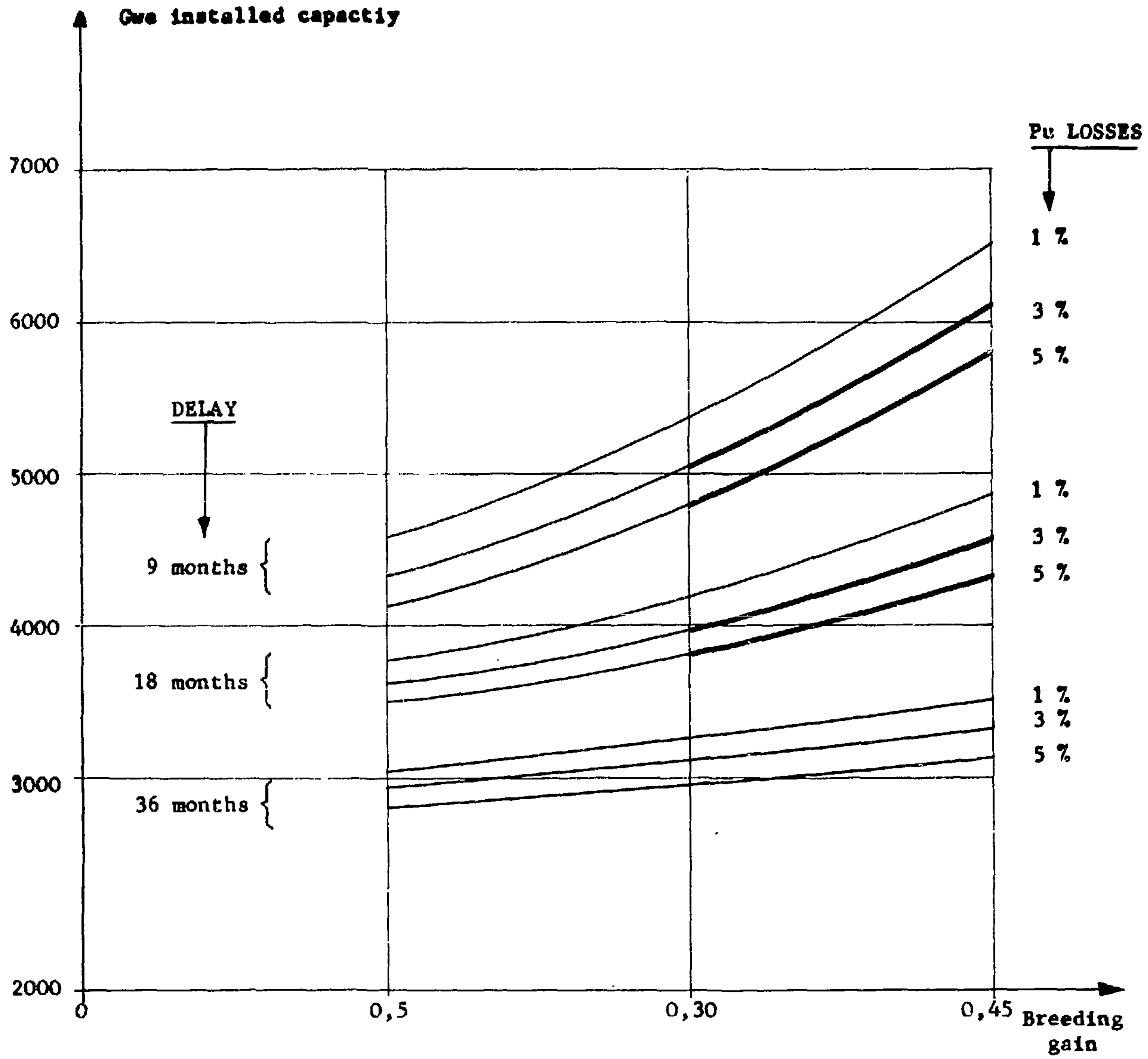

Fig. 3 POSSIBLE NUCLEAR CAPACITY WESTERN WORLD, 2015