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Diego MOLINA ORERO has a degree in Physical Science from the University of Granada (1979). He began his professional career in the Technological Institute for Postgraduates (ITP), where he participated in several projects within the field of Reactor Physics and Energy Planning. Since 1983, he has worked in Hidroeléctrica Española in the Engineering and Nuclear Analysis Department in jobs related to Nuclear Design and Fuel Management of the Cofrentes Nuclear Power Plant. He has been a member of the Spanish Nuclear Society since 1981.

NUCLEAR FUEL MANAGEMENT TRENDS

M. BIELZA - J. GOMEZ - D. MOLINA

INTRODUCTION-PRESENTATION OF OPEN

OPEN (Organisation des Producteurs d'Energie Nucléaire) comprises most of the Electricity Producers from seven European countries with nuclear production capability: Belgium, France, Germany, Italy, Spain, Sweden and Switzerland. Its activities encompass the study of all the technical, economic, legal and media problems arising from electricity generation utilising nuclear energy.

In order to provide a figure on the representativity of OPEN, it must be considered that the electrical utility members of OPEN purchase about one-third of the uranium consumed in the western world and operate, in terms of power, about the same fraction of existing nuclear power plants, most of which are of the Light Water Reactor (LWR) type.

Through its working Groups, OPEN has been concerned for the past few years with the analysis of fuel cycle management in the reactors operated by its Electrical utility members. One of these working Groups, "Planning and studies", to which the authors of this paper belong, has recently finished a study about the mutual influences of nuclear fuel cycle management and reactor operation. This paper is to report on the principal lines of thought and some conclusions drawn by this OPEN working Group in the previously mentioned study.

NEW CAPABILITIES IN NUCLEAR FUEL MANAGEMENT

The occurrence in the industry of new fuel types, generally called "advanced" fuels, as a response by nuclear fuel designers and manufacturers to the electrical utilities demand for higher energy production in each cycle and/or greater operational flexibility, has increased each electrical utility's capacity to optimize its own fuel cycle management and thus overall reactor operation.

One of the most important items that these new fuel types are able to achieve is an increased degree of burning. Now the main question is how to best use this higher burning capability so as to minimize production costs without reducing plant safety and reliability.

Basically, there are two choices: either maintain the cycle length while reducing the reload fraction, or maintain the reload fraction while increasing cycle length.

Obviously, in both cases, a higher initial U-235 enrichment is required in comparison with the original base case.

Table I shows the values used for the fuel cycle economic analysis. In orden to obtain results as generic as possible, only equilibrium situations have been considered, without specifically taking into account either appreciation of materials in stock or transition situations between different reloading strategies or management modes for the recycling of reprocessed materials.

The results have been established for a typical PWR-900 MW reactor in which the Plutonium and reprocessed Uranium are reprocessed and recycled.

Figure I shows fuel cost per KWh variations with the increase of discharge burnup in three basic reload strategies: 1/3rd, 1/4th and 1/5th of the total core reload. Moreover, figure I shows the cost trends of the between which utilities have to choose when they intend to start using higher burnups: maintenance of the cycle length with a decrease in the reload fraction and maintenance of the two options reload fraction associated with an increase in the cycle length.

In all reload strategies, it is quite clear that an increase in burnup results in a decrease in the fuel cost.

However, assuming that it would be possible, the expected benefit from this increase becomes less substantial beyond 50-60 GWd/t than in the 33 to 45-55 GWd/t range. In practice, it therefore seems advisable to strive for maximum burnup in the 55-60 GWd/t range.

Many other assumptions have been posed by OPEN's "Planning and Studies" Group in order to analyze the sensitivity of these results to major parameters such as other possibilities on the back-end side (for example: direct disposal) or natural Uranium, SWU, etc. price trends. In all cases, the overall results obtained remain the same, particularly as regards the relative position and slope of the KWh cost curves in terms of burnup.

Figure II shows that the principal economical advantage created by an increased burnup is due to the reduction of the number fuel assemblies needed to produce the same amount of electricity. Thus of the benefits stem from savings in fuel fabrication and back-end costs.

TECHNICAL INTERACTION OF NEW FUEL MANAGEMENT PLANS WITH PRODUCTION TARGETS

The use of advanced fuels that achieve a higher burnup, allows the design of more aggressive fuel management strategies, which in some cases may reduce the reactor operating margins.

This is an additional aspect (and in this case negative) to be considered among the economic in order to select a specific reloading strategy, because it might have an impact on the operational flexibility required in those reactors that are not producing in base conditions (i.e. load following).

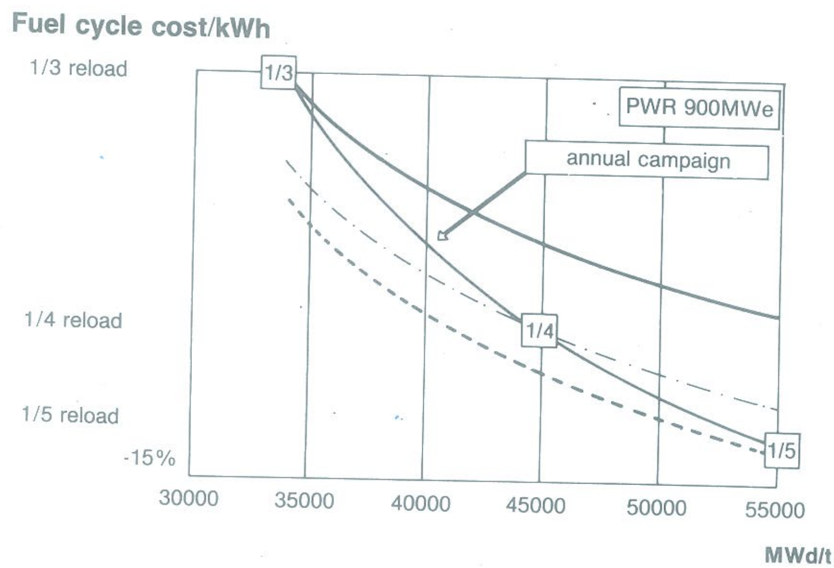
However, current reactor operating margins and sizing of the fuel cycle plants are sufficient to allow all of OPEN's electrical utility members to increase burnup of the fuel assemblies without any technical constraints. On the other hand, as mentioned previously, it does not seem that burnup will be increased indefinitely and that a value of around 60 GWd/t appears to be a technical-economic optimum.

The choice of a management scheme depends not only on the fuel cycle cost, but also on the cost of the energy that replaces the nuclear energy during reactor shutdown for reloading. In this sense, significant differences have been encountered between the production installations of the different OPEN members, and within a given strategy seasonal variations may occur.

T I

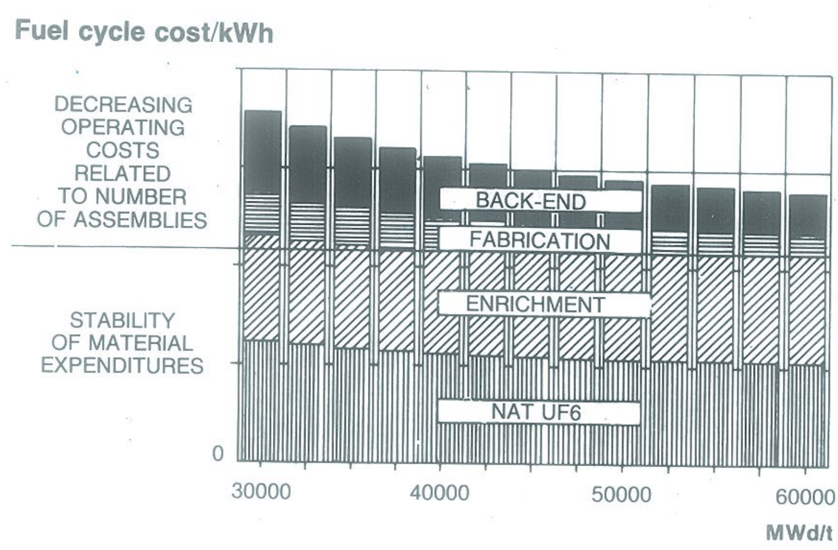
ECONOMICAL ASSUMPTIONS

Price of uranium concentrates ($/1b U_3O_8)	30
UF6 conversion of concentrates ($/kg U)	6
Enrichment (NW = 0.25%) ($/SWU)	120
Fabrication of PWR assemblies ($/kg EU)	200
Reprocessing and waste packaging ($/kg EU)	900
Discount rate in constant currency (%/year)	5



F I *Evolution of fuel cycle cost versus burnup increases*

F II *Fuel cycle cost versus burnup increases*

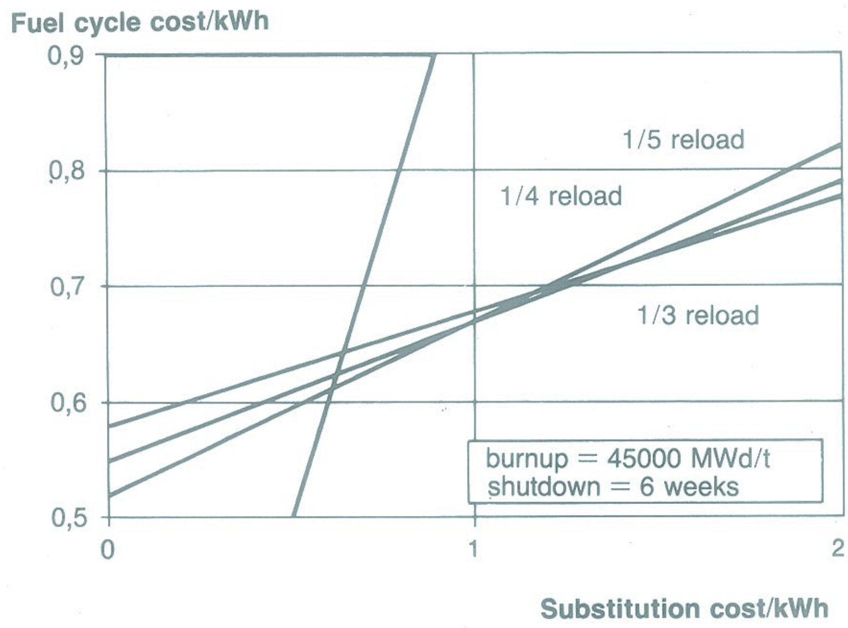


From a general point of view, if the substitution energy cost stays constant throughout the year and has a value two times higher than the cost of nuclear reactor fuel, the utility would be wise to opt for longer cycles (i.e. 18 months) while keeping the same fraction of reloaded core in each shutdown. This would increase the availability of its nuclear reactors and save on fossil fuels.

On the other hand, if the substitution energy cost is higher in winter and lower in summer, the economic optimum would be to keep shutdowns to an annual frequency and reduce the core fraction reloaded at each shutdown.
To illustrate these points regarding the effect of substitution energy cost, some simple cases of nuclear generation cost evolution have been analyzed and are shown in figure III.

CONCLUSIONS

A burnup increase produces notable savings in electricity generation costs. It also allows adaptation of fuel loading strategies to the desirable cycle length, which leads to improved management of the production installation.
These new reload modes can have a certain impact on natural Uranium consumption and enrichment, but above all, they directly affect all fuel cycle parameters related to the number of fuel assemblies to be reloaded (fabrication, reprocessing, etc.).
In the OPEN utilities, a general tendency to increase burnups can be observed, up to values around 50 GWd/t for PWR's and 45 GWd/t for BWR's. As for cycle length, two tendencies are apparent, either 12 or 18 months, depending basically on the substitution energy cost and the particular conditions of each generation installation.



F III *Fuel cycle cost versus substitution cost*

AUTHORS NOTE: Our acknowledgement to Mr. Jauregui for his extensive contributions and participation in the OPEN working Group.

SPANISH NUCLEAR POWER PLANTS

ALMARAZ

Almaraz I

		1989	Total
Gross electrical production	MWh	6.827.550	44.581.970
Net electrical production	MWh	6.562.180	42.624.369
Hours on line	h	7.641	56.014
Capacity factor	%	83,81	63,07
Unit availability factor	%	87,23	73,69
Automatic scrams while critical		2	57
Programmed outage		3	20
Forced outage		1	12

Almaraz II

		1989	Total
Gross electrical production	MWh	6.800.380	40.158.890
Net electrical production	MWh	6.545.674	38.545.359
Hours on line	h	7.638,25	46.042,75
Capacity factor	%	83,47	79,02
Unit availability factor	%	87,19	84,25
Automatic scrams while critical		3	43
Programmed outage		1	12
Forced outage		3	11

ASCO

Ascó I

		1989	Total
Gross electrical production	MWh	7.008.701	35.285
Net electrical production	MWh	6.750.803	33.782,4
Hours on line	h	7.771,92	41.562,5
Capacity factor	%	86,03	67,76
Unit availability factor	%	88,72	74,23
Automatic scrams while critical		5	59
Programmed outage		1	9
Forced outage		1	11

Ascó II

		1989	Total
Gross electrical production	MWh	6.981.676	26.252.794
Net electrical production	MWh	6.732.188	25.183.555
Hours on line	h	7.729,35	30.269,63
Capacity factor	%	85,70	76,83
Unit availability factor	%	88,23	82,38
Automatic scrams while critical		2	25
Programmed outage		1	60
Forced outage		0	3

COFRENTES

		1989	Total
Gross electrical production	MWh	7.318.290	35.621.950
Net electrical production	MWh	7.052.190	34.259.110
Hours on line	h	7.650	39.098
Capacity factor	%	84,3	81,4
Unit availability factor	%	87,3	83,6
Automatic scrams while critical		7	58
Programmed outage		1	17
Forced outage		5	11

JOSE CABRERA

		1989	Total
Gross electrical production	MWh	1.188,58	20.341,08
Net electrical production	MWh	1.132.921	19.384.959
Hours on line	h	7.766,29	143.629,45
Capacity factor	%	84,42	68,20
Unit availability factor	%	88,66	77,41
Automatic scrams while critical		—	—
Programmed outage		—	—
Forced outage		—	—

STA. M.ª DE GAROÑA

		1989	Total
Gross electrical production	MWh	3.689.310	49.006.520
Net electrical production	MWh	3.515.791,2	46.339.412,2
Hours on line	h	8.324,29	116.586,54
Capacity factor	%	91,22	64,44
Unit availability factor	%	95,03	71,34
Automatic scrams while critical		8	111
Programmed outage		1	27
Forced outage		1	47

TRILLO I

		1989	Total
Gross electrical production	MWh	7.642.990	10.770,140
Net electrical production	MWh	7.147.794	10.044.028
Hours on line	h	7.665	11.337
Capacity factor	%	83,7	78,8
Unit availability factor	%	87,5	82,8
Automatic scrams while critical		2	6
Programmed outage		1	3
Forced outage		2	5

VANDELLOS I

		1989	Total
Gross electrical production	MWh	2.537.234	55.646.957
Net electrical production	MWh	2.454.372	53.729.721
Hours on line	h	6.349	136.382
Capacity factor	%	70	73
Unit availability factor	%	87	89
Automatic scrams while critical		4	225
Programmed outage		1	21
Forced outage		—	—

VANDELLOS II

		1989	Total
Gross electrical production	MWh	6.131.127	10.889.110
Net electrical production	MWh	5.868.788	10.424.220
Hours on line	h	6.357,73	11.398,67
Capacity factor	%	71,03	69,44
Unit availability factor	%	72,58	71,52
Automatic scrams while critical		6	17
Programmed outage		1	2
Forced outage		0	2