ECONOMIC IMPACT OF PCI REMEDIES

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ABSTRACT

The paper first outlines the data base on which the economic evaluation is performed. It includes :

- *modifications of the design of the fuel,*
- *preconditioning of the fuel,*
- *ramping limitations,*
- *in-core fuel management modifications.*

The economic assumptions on which the study is performed are also outlined. They are representative of a PWR situation.

For what fuel design modifications are concerned, some have a minor cost impact (e.g. pellet density, pellet length to diameter ratio, gap size, etc ...), while some others may have a quite large impact on the fissile material cost (e.g. duplex pellet), the fabrication cost (e.g. coating of the cladding ID) or the reprocessing cost (e.g. interlayer between pellet and cladding).

The preconditioning of the fuel may require to run the reactor in a mode unrelated to the energy demand. This aspect can be minimized by a proper adjustment of in-core fuel management.

The ramping limitation is the most usually adopted approach. Different cases are investigated and the impact on generating cost is discussed.

The in-core fuel management can also contribute to a better ramping performance of the fuel. Exemplative cases show that this leads to a minimum cost penalty.

1. *INTRODUCTION.*

It is generally agreed that PCI is the most limiting phenomenon in the behaviour of fuel under power ramping and under power cycling conditions.This is however not the only limiting factor ; e.g. licensing requirements may lead to more stringent constrains than what would be required to avoid PCI. This was namely the case for the PWR fuel, in which the reduction of diameter of the rods (to meet LOCA criteria) and prepressurization (to cope with the regulation concerning densification) has almost reduced PCI failures by a factor 10. Although safety analyses do not address PCI per se, at present, the fuel must meet the Specified Acceptable Fuel Design Limits, taking into account that it experiences PCMI.

This paper limits itself in assessing only a few PCI remedies ; it is not a comprehensive insight into the cost-benefit analysis of possible remedies or improvements to the fuel. Such an analysis would be difficult : new remedies or remedies applicable in a given context are necessarily overlooked and, on the other hand, each economic context is different from any standard one that can be adopted for such an analysis. **30**

2. *DATA BASE.*

Most of BELGONUCLEAIRE's experimental data arise from the operation of the BR 3 or from irradiations performed in BR 2 either on fresh fuel or on fuel pre-irradiated in BR 3 [1, 2]. Till now the experiments have essentially been focused on the load following behaviour. In the Belgian context, indeed, one quarter of the electricity is generated in nuclear plants and this proportion will raise to 50 % in 1984. Experience should include the effect of a load following mode of operation on fuel ramping behaviour. Such a programme can never be comprehensive enough to cover all fuel parameters and operating conditions to be assessed. We have therefore developed and benchmarked a computer code (COMETHE) able to model in great detail the behaviour of fuel under irradiation. A previous presentation to this Symposium [3] gives an example of the approach used.

Furthermore, the present paper will be guided by the results of foreign programmes, e.g. the data utilized for benchmarking probabilistic or best fit codes [4].

Finally, remedies proposed by various organizations will also be considered [5, 6, 7, 8]. On these bases, the parameters outlined in Table I will be analyzed hereafter.

3. *ECONOMIC ASSUMPTIONS.*

The impact of fuel behaviour must be considered by each Utility in its own context which is not only limited by straight economic considerations, but also by constrains which have an economic impact, e.g. licensing implications, the social context, etc ...

We shall consider a typical 1000MWe PWR,the economic parameters of which are given in Table II. The cost of fuel failures was evaluated with the CHEPA computer programme outputs [9]. The case taken as basis case is very close to the PWR example case given in [9], except that all failures were supposed to occur at or near the beginning of cycle and to be limited to one rod per assembly, and that the resulting loss of power generation is 15 000 MWd/t on the average for a prematurely discharged assembly. This situation is deemed to be representative of most cases of PCI occurrences involving a limited number of failures. The data are given in Table III. The replacement cost is assumed to be 600 k$/d GWe.

We will consider that the present failure level attributable to PCI is 0.01%, i.e. the most likely world-average for the PWR's. All costs will be given in k$ per year operation for the notional 1 000 MWe PWR plant, i.e. k$/yr.

4. PELLETS.

4.1. FGR inhibitors.

Fission gas release (and therefore I release) can be reduced by promoting closed porosity and large grains. Both characteristics can be achieved by blending an additive with the powder.

The use of a pore former is already applied industrially. Its economic impact is to increase only slightly the fabrication cost (13 k$/yr) ; for the selected economic and failure assumptions, it is therefore cost effective if it reduces the failure rate by 5 % relative. In this perspective, the incentive to utilize a pore former is sufficient to warrant its application. While the concept has been demonstrated for the present power reactor conditions, it remains to be demonstrated that the large closed pores are efficient in accommodating the fuel swelling occurring in low rated fuel irradiated to the extended burnup range presently envisaged (40 GWd/t assembly average and 60 GWd/t peak pellet).

A fuel with a large grain size can be obtained by blending a sintering dopant with the UO_2 powder. In addition to the slight increase in fabrication cost, some grain growth dopants induce a reactivity penalty ; e.g. for the concentrations usually considered, the reactive lifetime is reduced by 0.2 % for Al_2O_3, 0.9 % for Nb_2O_5 and 2 % for MgO, TiO_2 and Cr_2O_3 additions. If compensated by adjusting the enrichment, the additional cost penalty is between 40 and 400 k$/yr. It is only half if an (eventual) stretchout operating mode is acceptable at EOC, which is unlikely, contractual penalties being usually linked to reactivity lifetime. To be cost effective, doping fuel with Al_2O_3, Nb_2O_5, MgO, TiO_2 or Cr_2O_3 should reduce the failure rate respectively by 20, 70 or 100 % relative. This is a field that justifies a R&D programme : it should indeed be ascertained that the increased tendency of grain growth under irradiation, observed in some tests, does not produce increased FGR due to the grain boundary sweeping effect.

Another likely side-effect of doping the fuel with some grain coarsener is to increase its pasticity ; this should reduce the stresses in the cladding and therefore be beneficial. If utilized in conjunction with a pore former, it most likely helps making the closed spherical porosities available to accommodate fuel swelling in the most adverse irradiation histories. Almost no additional fabrication cost is to be foreseen when two additives (i.e. a pore former and a grain growth dopant) are incorporated instead of only one ; the profitability threshold is therefore the same. Doping the fuel with a grain coarsener should then be an incentive to adopt also a pore former.

4.2. Density.

A stochastic analysis of an irradiation data base [4] seems to indicate that the failure probability drops by a factor 2 when the fuel density is decreased from 95 % TD to 93 % TD. The phenomenon is most likely assignable to the usually higher creep rates of lower density fuel. It is however probably not the case for a low density pellet resulting from the utilization of a pore former, already discussed (§ 4.1.). Beside a potential

increase in pellet manufacturing costs to meet the standard specifications (density tolerance, resintering test stability, H content, etc ...), the main economic impact results from the adaptation of the enrichment. The increase in enrichment is less than proportional to the density decrease, since an improved fuel utilization results from the higher water-to-fuel ratio. The net result is a marginal cost increase (9 k$/yr). Even if the effect were only to reduce the failure level by 3 % relative, the trend to lower average densities should be pursued, inasmuch it is in line with the modifications requested to increase the discharge burnup.

The same effect can be achieved by adopting an annular pellet design. Most specification aspects mentioned hereabove are as easy to meet as for plain pellets. Pellet defects are however more difficult to keep within specified limits, resulting in a higher control cost and reject rate. The central hole can practically be as large as 1/3 of the pellet OD ; the water-to-fuel ratio increases by over 10 % and the fuel utilization by 3 to 4 %. Even taking into account the fabrication penalty and additional engineering duties (design, safety analysis, etc ...) a benefit of 600 k$/yr is foreseeable. Since a reduction of fuel failures is almost certainly to be foreseen (reduction of FGR ; reduction of PCMI for most power histories), the global benefit is certainly over 600 k$/yr. Demonstration programmes have however to be (and are being) conducted to demonstrate, at a statistically significant level, that the concept is licensable, without undue limitations. For instance, if the admissible local peak LHGR were to be decreased to account for a potential filling of the central hole by fuel fragments and if, for a given plant, the peak pellet rating were continuously at the licensing limit (an unlikely hypothesis), such plant would have to be derated to almost 94 % of its capacity, resulting in a loss of 11000 k$/yr (i.e.17 times the benefit expected from the annular pellet concept).

4.3. Structure.

Some structure related remedies have already been discussed sub § 4.1.

Developments and experiments have been reported on an original approach resulting in an open structure of high density agglomerates, know as the DCI process [10]. Being applicable to the manufacture of low density fuel, it should take advantage of the benefits mentioned sub § 4.2. The structure should result in a high FGR (which adversely affects PCI resistance of the fuel), a high thermal conductivity (which is beneficial) and a high mechanical resistance. Some evidence indicates that such fuel should present a negligible amount of radial cracks [10] ; this will most likely result in an increased PCI resistance. The economic impact is limited to the pellet manufacturing step, which adds probably some 80 k$/yr to the fabrication cost. It is therefore attractive if it results in 30 % reduction of the failure rate. This might be achieved if the properties of the structure are maintained throughout life and if the porosity is accommodating fuel swelling at high burnups under low rating conditions, without stressing the cladding.

4.4. Geometry.

A proper design of the end features of the pellets (dish, shoulder, chamfer, admissible defects) influences PCMI at or near the pellet/pellet interfaces, where most PCI failures are observed. Improving this design is therefore worth the money and time most concerned organizations have or are spending on this subject. Discounted over the reactors in which the design improvements have been implemented, it does probably not represent more than 7 k$/yr. The control of specifications concerning the end features represents some additional 8 k$/yr. This total effort of 15 k$/yr, for the exemplative 1 000 MWe PWR, has certainly played an important role in reducing the 0.1 % failure rate observed a few years ago to the present level of 0.01 % and has therefore paid off (see Table III).

The L/D ratio is also recognized to influence the PCMI. Depending on the equipment of the fuel fabrication plant, a reduction of the L/D ratio may increase the fabrication cost to a very variable extent (from a negligible amount up to 260 k$/yr). Since the benefit to be expected, as reduction of the cost of fuel failures, from adopting a small L/D ratio is most likely a minor proportion of the failure cost adopted as best estimate in the present paper (271 k$/yr), it is normal to see small L/D ratios only adopted by the manufacturers able to cope with it at a reasonable cost.

Various organizations have promoted fuel concepts in which the enrichment at the fuel periphery is higher than in the central part : e.g. the "heterogeneous" fuel approaches developed by BN-SCK/CEN from 1959 through 1969, the duplex pellet being developed by UKAEA-BNFL [11], the LOWI fuel promoted by Risø [12], etc ... The main advantages result from a lower central temperature, with consequently a lower FGR and a smaller number of cracks at the pellet periphery. The fabrication costs were reported to be increased by 10 % [12]. The effect of the concept on fuel utilization is complex (reduced conversion resulting from the shielding of part of the U 238 ; improvement resulting from the higher "effective" water-to-fuel ratio) ; it would require a complete design exercise, far beyond the scope of this survey, and is therefore neglected. Assuming depleted U is adopted for the central part, only the enrichment cost is then increased ; this is the major item of cost increase. This increase totals over 1 000 k$/yr. The concept can therefore only be taken into account for reactors presenting high failure rates or for fuels in which the enrichment is obtained by blending (e.g. Pu recycle fuel).

4.5. Vipac.

Our experience with vipac fuel is that FGR is larger than in pelleted fuels but the propensity to PCI failures is lower under normal operating conditions. This is probably assignable to a more uniform distribution of the corrosive species and of the stresses at the cladding ID. It must however be mentioned that the statistical significance of the results can be questioned and that a PCMI leak has developed during an abnormal operation experiment. This concept would therefore require additional testing to confirm its likely advantages. If the technology were implemented at a same commercial level as the pellet route, the fabrication costs would be reduced by some 300 $/yr ; with the additional effect of the lower density, the total benefit would be 600 $/yr. However, during the first 10 years the vipac process would have to compete with the pellet route applied in large manufacturing plants, the cost of vipac fuel would be very high and a total penalty of some 400 $/yr is to be foreseen. It is therefore unbelievable that the vipac process could be marketed on purely economic groundrules; it would necessarily require to be launched by long-term policy considerations. The break-in cost of such alternative process is of course smaller for non-standard fuel, like mixed oxides.

5. CLADDING.

5.1. Structure and texture.

Although the opinion is controversed, most indications are that a CW-SR structure presents a better PCI resistance than an annealed structure.

Indications also point to the advantage of a 0° texture at the tubing ID, rather than the 30° texture typical of commercial tubing.

Specifications relating to such characteristics should, most likely, have no other cost effect than a possible increase of control level to assure that the requested characteristics are met. This would add no more than 70 k$/yr to the base case and would most likely be cost effective, as mentioned in a paper by a Utility [13].

5.2. Thickness.

The thickness-to-OD ratio ranges between 5.9 and 7.1 % amongst the various fuel vendors. Most tubing manufacturers have set up to meet this range of demands. In such conditions, the economic balance is only affected by the quantity of Zry, the number of pellets (for an identical L/D ratio) and the water-to-fuel ratio. The net balance from increasing the thickness-to-OD ratio from 5.9 to 6.7 % is to decrease the generating cost by 80 k$/yr. It is therefore worth being considered, irrelevant of any effect on the failure rate.

The rationality of the better behaviour of thicker claddings has already been presented earlier [1,2,14]. It is confirmed by the statistics based on the ramping experiments analyzed in [4], which present a minimum failure probability for a thickness-to-OD ratio of 6.7 %.

5.3. ID surface.

The smoothness of the inner surface of the tubing and an absence of inclusions at or near this surface improve the resistance to SCC. Most of the cost related to a more stringent specification in this respect is assignable to additional controls and rejects. It is probably not more than 70 k$/yr and is paid-off by a 30 % decrease in the failure rate, for the selected base case.

An efficient solution to improve the inner surface morphology and mechanical properties of the cladding is a Zr liner. It has probably the same cost-benefit implications as mentioned in the previous §.

A Cu barrier plated to the ID of the tubing has also been proposed as a remedy. Beside the drawbacks resulting from defects in this barrier on its *efficiency, the acceptability by the reprocessor and by the plant operators* (effect on the primary circuit in case of gross failure rates) is questionable. The additional costs are associated not only with tube manufacturing but also with the reduction in reactivity lifetime ; they are evaluated at 100 k$/yr and therefore cost effective, if it reduced the failure level by 40 % relative.

Graphite (and alternatively siloxane) coatings have proven to be efficient in HWR fuels. This efficiency could be lower in a LWR ; indeed, in a HWR, the cladding collapses against the pellet early in life and the lifetime is quite short ; in a LWR, the coating might well flake-off locally. Except the effect on reactivity lifetime, the other arguments presented in the previous § should also be considered [5]. The increase of costs is evaluated at 30 k$/yr.

6. *ROD.*

6.1. Gap size.

The importance of gap size has also been reported in earlier presentations [e.g.14]. It is confirmed by an analysis of experimental data [e.g. 4]. Most of the tolerances on the gap size result from the tolerance on tubing ID. A reduction of this tolerance would likely cost some 70 k$/yr and thus be cost effective if the failure level were reduced by 30 %, which is questionable.

6.2. Prepressurization.

Experience indicates that prepressurized rods behave better than unpressurized fuel. The catastrophic FGR phenomenon resulting from the so-called "triggering" effect, first observed in the MAINE YANKEE fuel and explained by the COMETHE code, is greatly attenuated in a prepressurized rod. An other paper presented at this meeting [3] indicates however that the various effects are complex and that the pressure level should be adapted to the foreseen fuel duty cycle. Even accounting for the additional design and manufacturing steps, the related cost should not be higher than 9 k$/yr. Since prepressurization is applied by most fuel vendors, it is not an additional cost to present practice.

6.3. Fuel loading.

Spatial variation of the enrichment has been proposed to improve fuel utilization. Incorporating axial blankets of natural or lower enriched fuel, will most likely adversely affect the propensity of the fuel to fail (higher rating and burnup of the central proportion of the fuel, axial power and temperature discontinuity at the blanket edge). The foreseeable U saving is most likely worth 300 k$/yr and is economically justified if it does not increase the failure level by a factor 2 or more.

7. *IRRADIATION CONDITIONS.*

7.1. Power ramps.

Recommendations to raise the power at a reduced rate at BOC and after operating for an extended time at reduced power level, often referred to as PCIOMR's, have proven effective in reducing the fuel failures by an appreciable factor.

A companion paper [3] presents 4 startup histories :

1. corresponding to no loss in generating capacity,
2. (full power reached after half-a-day) corresponding to a 0.08 % loss of capacity, i.e. a cost of 200k$/yr,
3. (full power reached after 3 days) corresponding to a 0.2 % loss of capacity, i.e. a cost of 400 k$/yr,
4. (full power reached after 6 days) corresponding to a 0.5 % loss of capacity, i.e. a cost of 900 k$/yr.

Since 2 was shown not to be more efficient than 1 in providing a margin against PCI failure and 4 not more efficient than 3, the cost-benefit of PCIOMR's is very difficult to assess. It also indicates that any money spent on calculating or experimenting power ramp restrictions, to minimize the cost of lost capacity for a selected safety margin against failures, is paying off.

On the average, a plant is twice a year in a situation where the PCIOMR must be applied. Given the cost levels indicated hereabove, a plant with a failure level of 0.01 % (nl. the plant taken as base case in the present study) has no economic incentive to apply the recommendations. It must however be recognized that the ALARA guideline will increasingly be applied to fuel failures and overrule any other consideration (except power maneuver requirements, e.g. to avoid the plant being disconnected from the grid). The PCIOMR's will therefore be applied in most circumstances.

It adds in fact the cost of lost capacity to the failure costs given in Table II. While losses of capacities up to 6 % have been mentioned [6], the real figure is more likely around 0.4 % representing some 800 k$/yr, for the plants with a low failure level. In some older plants with a higher propensity to fuel failures, more restrictive PCIOMR's might well cost up to 4 - 7 M$/yr.

7.2. Power.

The power level at which the fuel operates plays also an important role in fission product release. Experience shows that a reduction of the maximum LHGR has reduced the PCI failure occurrences.

The main effect has been through the reduction of the fuel rod diameter (adopted to cope with LOCA related SAFDL's). The cost increment of a 17 x 17 over a 15 x 15 design is mainly linked to an increase in fabrication costs and amounts to some 800 k$/yr. It would therefore not economically be justifiable on fuel failure reduction grounds, for the base case considered.

7.3. Power history.

Another contribution to this meeting [3] has outlined the importance of the power history on the margins to PCI failure. Preconditioning the fuel by running at high LHGR's at or near BOL is beneficial. Fuel management schemes (e.g. the in-out scheme) providing a reduction of LHGR at each successive refuelling should be adopted whenever SAFDL's can be met in such management scheme ; this is unfortunately not the case in most plants. Beside the benefit of reducing PCI related failures, at no additional cost, such management schemes improve the fuel utilization to an extent that can reach 300 k$/yr.

EOC stretchout has been proposed as another means of improving the fuel utilization. Its benefit (some 200 k$/yr) has to be balanced against the lost power (up to 1 000 k$/yr) and the risk of having to impose a more restrictive PCIOMR at the next BOC. Given the costs of PCIOMR's (cf. § 7.1), the adoption of stretchout as a routine mode of plant operation should thoroughly be assessed before being adopted.

8. CONCLUSIONS.

Some fuel improvements are justified economically, irrespective of their beneficial effect on fuel performance and maneuverability. In this category are :

- annular pellets,
- vipac fuel,
- falling rating fuel management schemes : in-out, ...

In a power plant operating at a low fuel failure level (0.01 %), the implementation of the other PCI remedies can hardly be justified on cost-benefit bases, grounded only on a further reduction of this already low failure level. The maneuverability restrictions (PCIOMR's) applied to maintain this low failure level are however quite costly (800 to 4 000 k$/yr). Many improvements to the fuel or to its management are justified, if the PCIOMR's can be thereby relaxed (which needs to be demonstrated). This is likely the case, to a variable extent, for :

- the utilization of a pore former,
- low density fuel,
- the DCI fabrication process,
- a proper design of the pellet end features,
- thick claddings,
- more restrictive cladding specifications : structure, ID surface, ID tolerance, ...
- a Zr liner on the cladding ID,
- a graphite or siloxane coating (if it does not penalize the fuel cycle back-end),
- prepressurization.

The other PCI remedies are only economically justified if they are a solution for plants still experiencing high failure rates. Amongst those remedies are :

- the grain size dopants,
- a small L/D,
- duplex or LOWI pellets,
- a Cu barrier on the cladding ID,
- PCIOMR's,
- small diameter fuel rods.

Some improvements do not seem justified in the restricted domain investigated in this paper, the reason being either that they are likely to have an adverse effect on PCI failure propensity or that the associated cost increase does not justify them being adopted ; amongst them :

- axial variation of the fuel enrichment,
- EOC stretchout.

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NOMENCLATURE :

ALARA	:	*as low as reasonably achievable.*
BN	:	*BELGONUCLEAIRE*
BOC	:	*beginning of the reactor cycle.*
BOL	:	*beginning of life (= fuel irradiation).*
CW-SR	:	*cold-worked, stress-relieved.*
DCI	:	*"double cycle inverse" ; powder preparation process characterized by the utilization of a granulation pressure higher than the pelletizing pressure.*
EOC	:	*end of the reactor cycle.*
FGR	:	*fission gas release*
ID	:	*innder diameter of the cladding.*
k$/yr	:	*yearly influence of the considered item on the 1 000 MWe PWR power plant (k$/GWe yr).*
L/D	:	*pellet length-to-diameter ratio*
LHGR	:	*linear heat generation rate (W/cm).*
LOCA	:	*loss-of-coolant accident.*
LOWI	:	*low-interaction pellet concept, characterized by 2 concentric pellets, the inner one having a lower enrichment than the annular one.*
O & M	:	*operation and maintenance of the power plant.*
OD	:	*outer diameter of the cladding.*
PCI	:	*pellet/cladding interaction (mechanical and chemical aspects).*
PCMI	:	*pellet/cladding mechanical interaction.*
PCIOMR	:	*Preconditioning Interim Operating Management Recommendation.*
SAFDL	:	*Specified Acceptable Fuel Design Limit (10 CFR 50 App. A).*
Zry	:	*Zircaloy.*

TABLE I - ITEMS ANALYZED IN THE PRESENT PAPER.

1. *DESIGN MODIFICATIONS.*

1.1. *Pellets :*

- large grains : doping with Nb_2O_5, ...
- density,
- structure : closed porosity, DCI, ...
- shape : dish, chamfer, L/D, annular, ...
- enrichment distribution : duplex, LOWI, ...
- vipac.

1.2. *Cladding :*

- heat treatment : CW-SR versus annealed,
- texture : 0° (versus 30° typical of commercial tubing),
- thickness,
- ID surface : smoothness, Zr liner, Cu barrier, graphite or siloxane coatings, ...

1.3. *Rod :*

- gap size,
- prepressurization,
- spatial variation of enrichment.

2. *IRRADIATION CONDITIONS.*

- power ramps : PCIOMR, ...
- power : fuel rod diameter, ...
- power history : preconditioning, core management schemes, EOC stretch-out, ...

TABLE II - PWR ECONOMIC PARAMETERS - BASE CASE.

Cost component		%
Generating cost :	- amortization	50.8
	- fuel cycle cost	30.1
	- operating cost	19.1
Fuel cycle cost :	- U ore	51
	- conversion to UF_6	2.3
	- enrichment services	34.7
	- fissile material	88
	- fuel fabrication	12
	- fuel cycle back-end	pm
Fabrication cost :	- UF_6 withdrawal and conversion	5
	- rod hardware	19
	- pellet and rod fabrication	26.5
	- assembly hardware	15
	- assembling operation	5
	- shipments	3
	- engineering	19
	- contingencies (U losses, etc ...)	7.5

TABLE III - COST OF FUEL FAILURES (k$/GWe yr - Aug. 1978)

EOC failure level %	0.001	0.01	0.1	0.5
Lost power :				
- derating	-	-	-	13 040
- shutdown	-	-	-	-
Fuel cycle cost :				
- sipping	-	-	1 772	3 070
- inspection	-	-	195	975
- hot cell examinations	-	-	180	180
- reconstitution	-	-	390	1 950
- shipment	6	62	624	3 120
- lost burnup	-	-	8 140	40 540
- non-optimum load	-	-	827	4 135
- new reload calculation	-	-	60	60
- storage	-	10	98	488
- reprocessing penalty	6	59	585	2 925
O & M cost :				
- plant O & M	-	40	400	2 000
- radwaste treatment	7	70	700	3 500
- radiation exposure	3	30	300	1 500
Total w/o maneuver restrictions	22	271	14 240	77 480

PCI ANALYSIS OF A STAINLESS-STEEL CLADDING FUEL ROD FOR A SMALL-SIZED PWR UNDER POWER RAMPING CONDITIONS

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SUMMARY

In order to evaluate the behaviours of a fuel rod for a small sized PWR, PCI analysis has been carried out, with special emphasis on the performances for a rapid power ramping that is important for this type of reactor.

The analytical procedures used were divided into two phases. First, the whole-rod-wise calculation was performed by using a general fuel performance code, and the fundamental behaviours of rod were obtained for an averaged operational history over the life of rod. Then, these results were transfered to the second phase analysis, in which very localized PCI behaviours were calculated by using a finite element program. One radial slice was taken out of the axial position of rod where the severest PCI was expected to occur, and it was analyzed in detail for a rapid power ramping condition, taking special consideration for the pellet relocation effect. On the choice of the other calculational conditions, the worst combination of parameters was assumed.

It was found, from the results of analysis, that in spite of the conservative calculational conditions, the stresses in clad were well below the clad strength criteria, and excellent performance for power ramping is expected.