PHYSOR 2004 -The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments
Chicago, Illinois, April 25-29, 2004, on CD-ROM, American Nuclear Society, Lagrange Park, IL. (2004)

Performance Comparison of Different Absorbent Materials in BWR Control Rods

José L. Montes*[1], Juan J. Ortiz[1], Raul Perusquía[1] and Robert T. Perry[2]
[1]*Instituto Nacional de Investigaciones Nucleares, Carr. México-Toluca Km. 36.5., Ocoyoacac Edo. De México, México.*
[2]*Los Alamos National Laboratory, PO Box 1663, Los Alamos, NM 87545, USA*

Nowadays there is a trend of increasing the cycle length of commercial operation in nuclear reactors. This demands to control a greater quantity of reactivity excess in this type of cycles.

In this work, a comparative study of the use of various absorbent materials in the control rods of a BWR is presented. The behavior of the different absorbent material used is accomplished only from the neutron point of view. The capability of each different material to control the reactor is analyzed by studying the required control rod density and the complexity to design the target control rod patterns (CRP).

The system GACRP was used to generate the target control rods patterns for an 18 months equilibrium cycle. This system is based on genetic algorithms computational technique. The found results show that the behavior of the dysprosium is acceptable and very similar to the boron one. In average, both require around 4.3% of control rod density, while in Hf cases 5.1% is needed. Although the greatest impact of including different absorbent material is noted in cold condition, GACRP could obtain a CRP in any of the considered cases.

KEYWORDS: Control Rod Patterns, Genetic Algorithms, Neutron Absorbent

1. Introduction

Recently, the convenience of increasing the cycle length in LWR reactors has been seen [1]. To extend the reactor operation it is required to load fuel bundles with high enrichment. This reactivity excess must be controlled with adequate neutron absorbers. An ideal neutron absorber has an absorption cross section similar to U-235. Cochran et al [2] consider that Dysprosium (Dy) is a good candidate. Figure 1 shows the absorption microscopic cross section (σ_{abs}) for different materials compared with U-235. In that figure atomic percent abundance for isotopes is included.

In Figure 1, in green color it is shown the U-235 σ_{abs} behavior, in blue color σ_{abs} for Hafnium (Hf) isotopes, in purple color σ_{abs} for Dy isotopes and finally, in red color σ_{abs} for Borum-10 isotope (the material most commonly used in control rods). All these isotopes have σ_{abs} greater than σ_{abs} for U-235.

---

* Corresponding author, Tel. 53 2 9 72 00 Ext. 2464, FAX 53 29 73 68, E-mail: jlmt@nuclear.inin.mx

Hf-176 and Hf-177 have the property that, when they absorb one neutron, they become into new hafnium absorbent isotopes. As we can see, total absorption cross section of isotope Dy-164 has a very similar behavior to that of B-10 in a relatively great energy range [3].

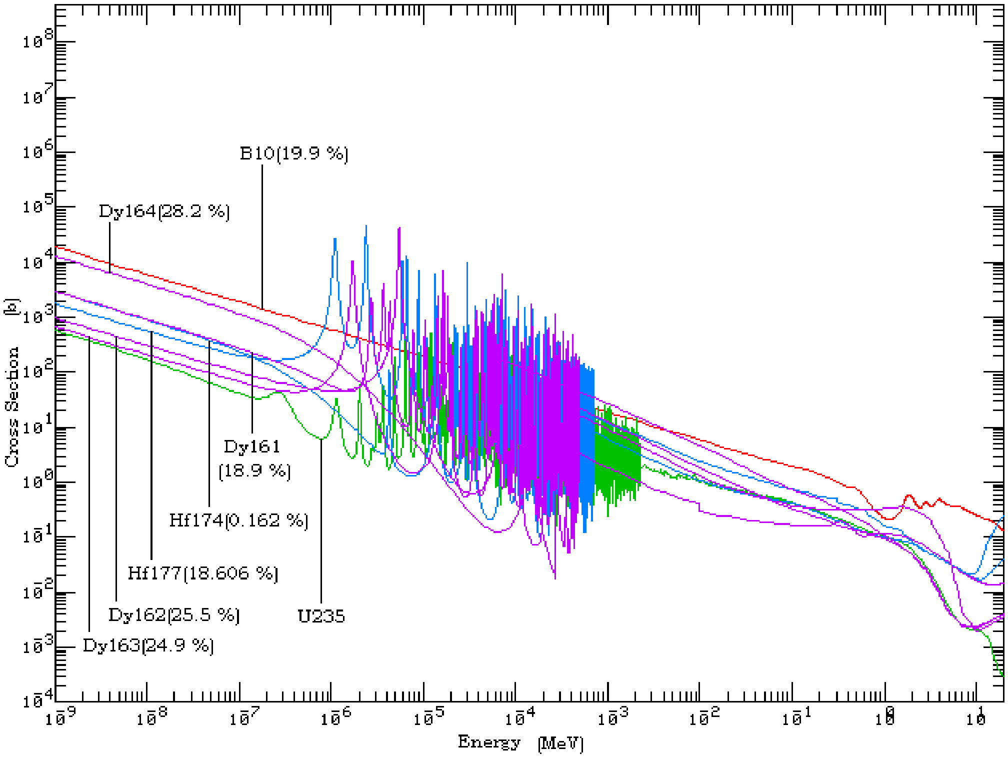


Fig.1 Comparison of absorption microscopic cross sections of the Boron, Hafnium, Dysprosium isotopes and U-235.

In this work we show a performance comparison of different absorbent materials in control rods of a BWR. We simulated an 18 months equilibrium cycle [4] with Control Cell Core (CCC) fuel load strategy. The loaded new fuel bundles have a 10X10 lattice fuel assembly design. The reactor operation was based on the Spectral Shift technique. We changed the absorbent material in control rods, keeping their geometrical structure in all cases. The comparison was made analyzing the required control rod density and the complexity to design the target control rod patterns. CRP were generated by GACRP system [5].

2. Description

2.1 Absorber Materials

We consider three different absorbent materials. The first one, which corresponds to the original design of Laguna Verde Nuclear Power Plant (LVNPP) reactors control rods, is Boron Carbide (B_4C). The second and third absorber materials are Hafnium (Hf) and Dysprosium (Dy), respectively. These control rods are geometrically identical to those used in LVNPP. In the case of Hf, two cases are analyzed: one where a density of 13.3 g/cm3 (Hf case), and the other (a more realistic case) where the theoretical density is reduced in a 37.2%

(Hfm case).

2.2 Target Control Rod Patterns Design

As it was mentioned, CRP for each absorbent material were designed, with help of the GACRP system. This system is based in a Genetic Algorithm (AG) to search the best CRP, taking into account the following restrictions:

1. The k-effective value must be in the range of ± 100 pcm around a target k-effective value, in each exposure point of cycle.
2. Minimum Critical Power Ratio (MCPR) and Maximum Linear Heat Generation Rate (MLHGR) thermal limits must be satisfied.
3. The axial power profile must adjust to the target power shape.

This system has proven its efficiency previously in different studies with BWRs [5,6].

3. Results

The study starts with a 2D lattice physics calculation of the new fuel bundles, using HELIOS-1.5 program [7].

k-infinity behavior as a function of the fuel burnup considering control rod presence of the different control rod types for a typical lattice is shown in Figure 2. k-infinity for CZP cold 0% and HFP 40% voids conditions are shown. It can be observed a similar behavior between the B_4C control rods and those with Dy, as opposed to the control rods with Hf, which show a lower neutrons absorbency.

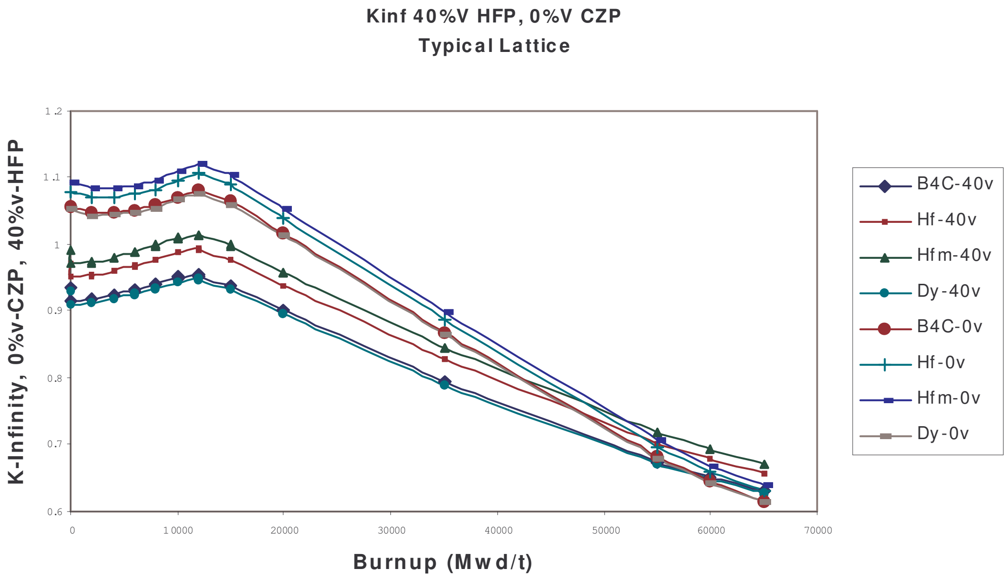


Fig.2 k-Infinity as a function of fuel burn up (Mwd/t) for CZP 0%V, and HFP 40%V conditions.

The behavior of k-effective as a function of cycle exposure, considering the presence of the different types of control rods, is shown in Figure 3. In the shown case, CRP was always the same and corresponds to CRP using the B_4C control rod type.

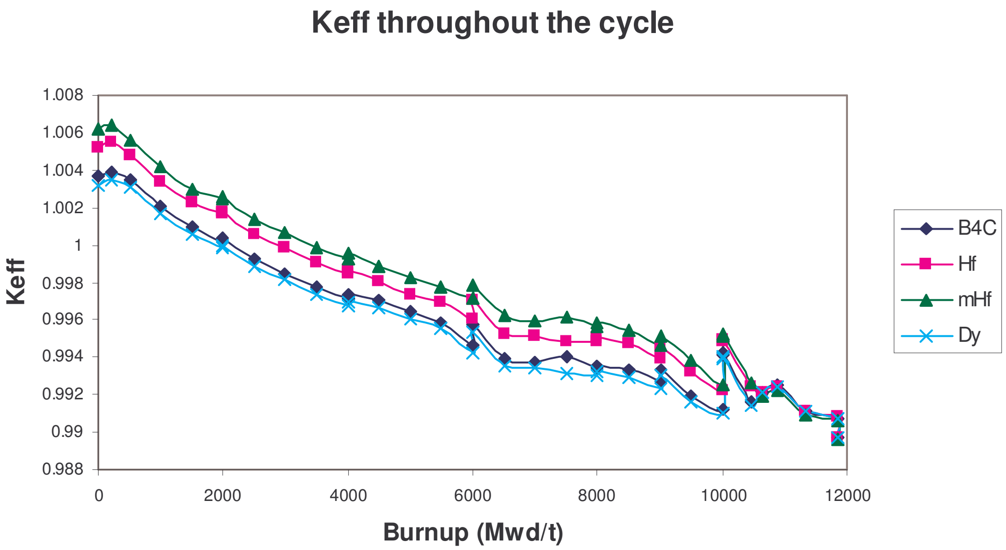


Fig.3 Equilibrium cycle k-effective as a function of fuel burnup (Mwd/t) with different control rod types presence, Hot Condition.

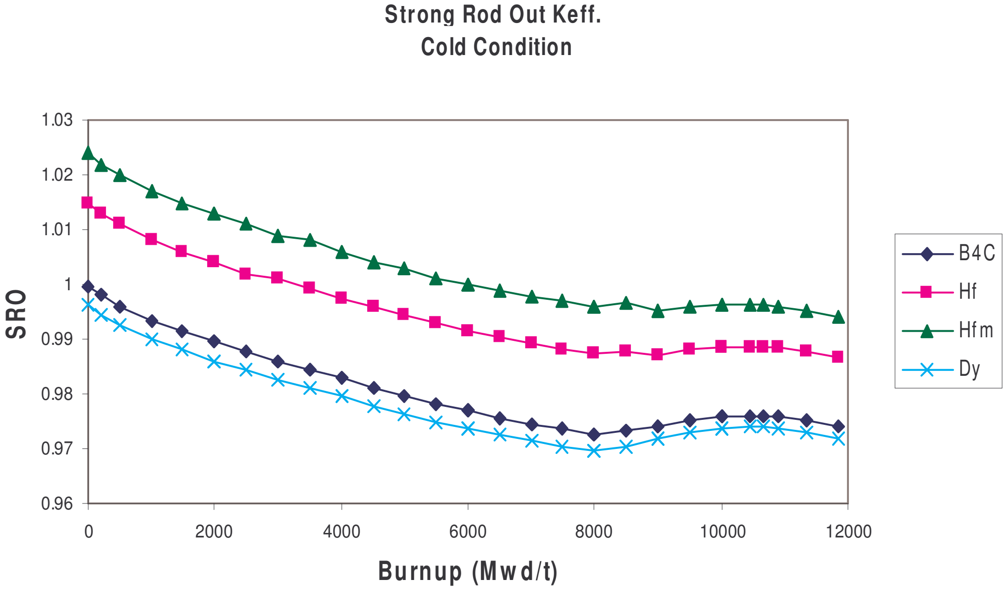


Fig. 4 Equilibrium cycle K-Effective as a function of fuel burnup (Mwd/t) with different control rod types presence, Cold Condition SRO.

With respect to cold condition results, we can see in Figure 4 the core reactor keff with the strong rod out (SRO). Both dysprosium and boron present better behavior than the other two analyzed cases.

GACRP and CM-PRESTO reactor simulator [8] were used to propose CRP using different absorbent materials.

Table 1 presents the GA generations average number and the average control rod density required to control the reactor, for the different absorbent materials. These are obtained in five times of GACRP searching. Finally, the average value of k-effective at the end of cycle condition (EOC) is presented.

Table 1 Results Comparison of Different Absorbent Materials.

Parameter	B_4C	Dy	Hfm	Hf
GA Gen. Avg. Nr	15.78	15.2	18.54	16.58
Avg. CR Density	4.363	4.230	5.199	5.081
Avg. EOC keff	0.9897	0.9895	0.9911	0.9912

B_4C and Dy results are similar, both require around 4.3% of control rod density, while in Hf cases 5.1% is needed. The maximum LHGR and minimum CPR through the cycle are shown in figures 5 and 6 respectively. GA generation average number for Hf cases is greater than B_4C and Dy cases. GACRP needs more trials to design CRP with Hf control rods.

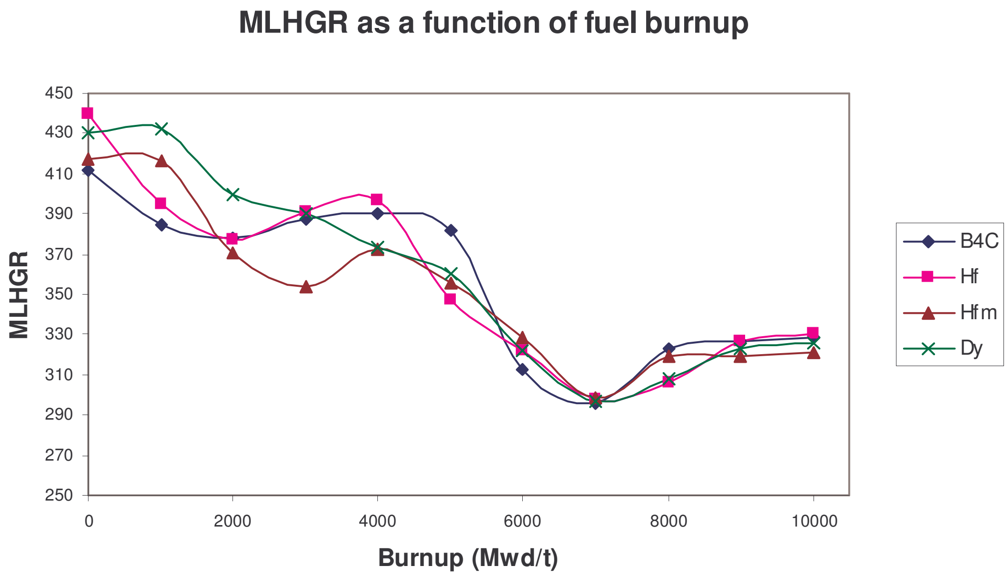


Fig.5 MLHGR as function of fuel burnup for the different absorbent materials.

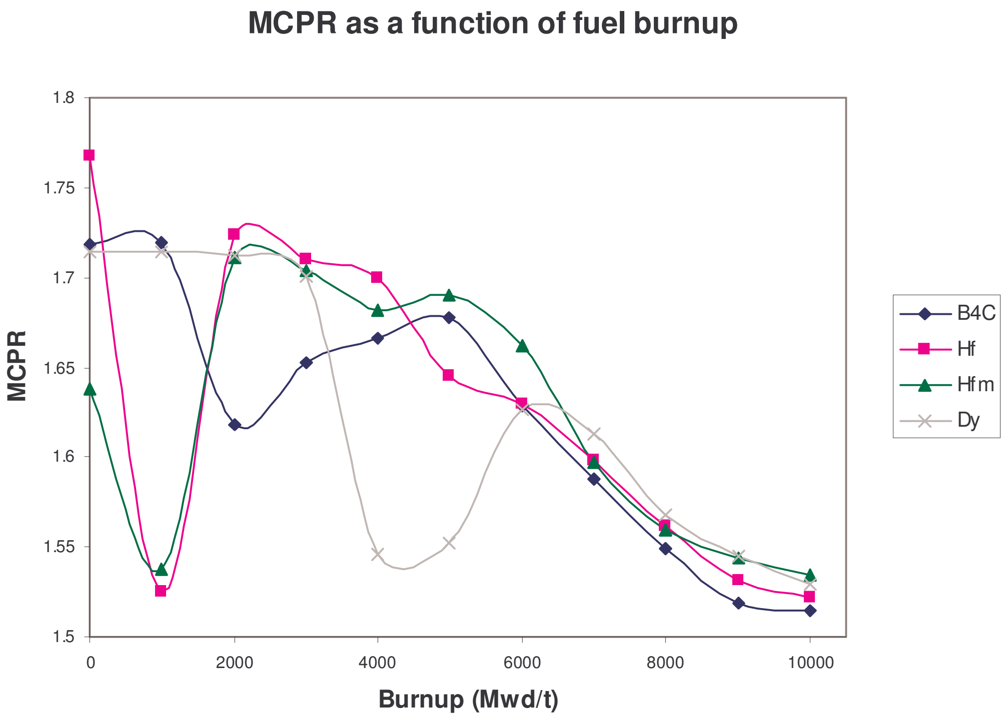
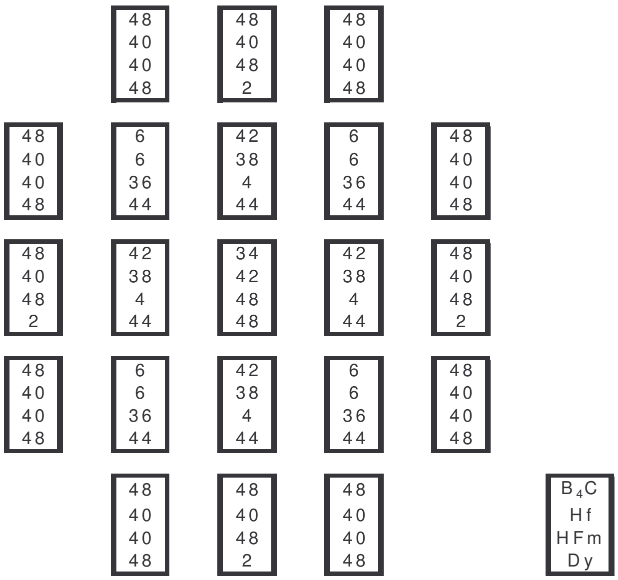


Fig.6 MCPR as function of fuel burnup for the four absorbent materials.

Rod positions using different absorbent materials are shown in Figure 7 for 5000 Mwd/t. For each cycle step a scheme like this was obtained. Figure 3 only shows control rod positions of A2 control rod sequence.



	48 40 40 48	48 40 48 2	48 40 40 48		
48 40 40 48	6 6 36 44	42 38 4 44	6 6 36 44	48 40 40 48	
48 40 48 2	42 38 4 44	34 42 48 48	42 38 4 44	48 40 48 2	
48 40 40 48	6 6 36 44	42 38 4 44	6 6 36 44	48 40 40 48	
	48 40 40 48	48 40 48 2	48 40 40 48		B_4C Hf HFm Dy

Fig. 7 Rod positions using different absorbent materials for 5000 Mwd/t.

Central control rod movement history throughout the cycle is shown in Figure 8. In this Figure it can be seen the behavior shown in the maps like it is shown in Figure 7.

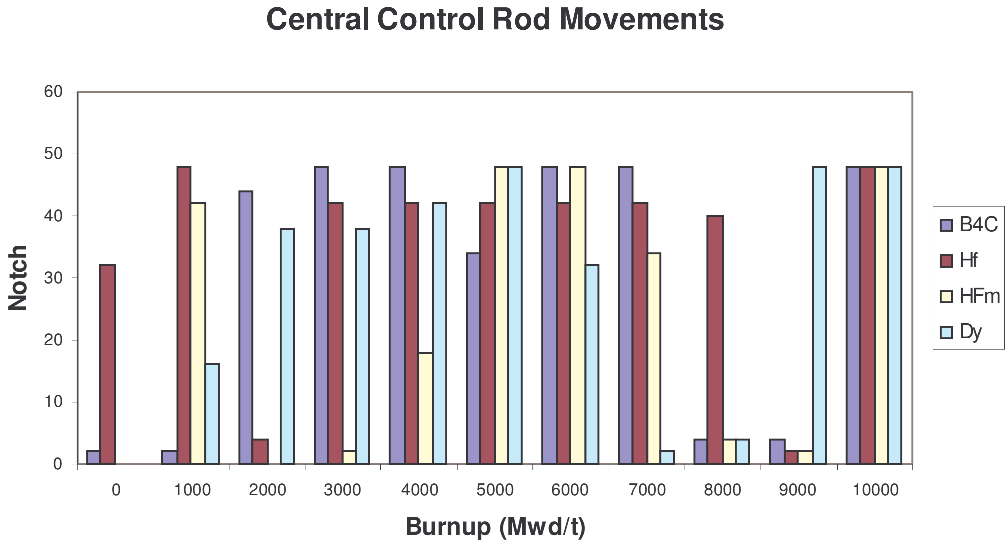


Fig.8 Central control rod movements throughout the cycle.

4. Conclusion

According to the conditions used in the study, it can be observed that the Dy and B_4C behavior is similar. Hafnium cases show notable differences with respect to other absorbent materials. In all the cases the system GACRP fulfills the imposed requirements. However, the influence of the different absorbent materials in safety parameters can be observed. Cases that require smaller control rod presence occur when B_4C and Dy are used as absorbent material. In fact, it must be said that dysprosium theoretical density puts in better position with respect to the other materials. However if we consider a more realistic density value t, we can see that boron is a little better than dysprosium.

Although it is possible to find CRP that fulfill the requirements in HFP condition, SRO CZP calculations show that only Dy, Hf cases have an acceptable behavior throughout the cycle.

Acknowledgements

The authors wish to thank Guillermo Duque for helpful comments for preparation of this paper.

References

1) Garcia-Delgado L.; Driscoll M.J.; Meyer J.E.; Todreas N.E. “An economically optimum PWR reload core for a 36-month cycle”. Annals of Nuclear Energy, vol. 26, no. 8, pp. 659-677-19. (1999).
2) R.G. Cochran, N. Tsoulfanidis, “The Nuclear Fuel Cycle: Analysis and Management”. pp 83 American Nuclear Society, La Grange Park, Illinois USA (1999).
3) Korea Atomic Energy Research Institute, homepage http://www2.bnl.gov/ton/
4) J. L. Montes, R. Perusquía, J. L. Hernández, “Estudio del Ciclo de Equilibrio de 18 Meses para la CLV con Combustible 10x10 Usando el Simulador 3D CM-PRESTO”. Proc. XII Annual Meeting of Mexican Nuclear Society, Zacatecas, México. October, 2001 (2001).
5) J. J. Ortiz, J. L. Montes, I. Requena, “Una Metodología para Obtener los Patrones de Barras de Control en un BWR Usando Algoritmos Genéticos”. Proc. XIV Annual Meeting of Mexican Nuclear Society, Guadalajara, México. September,2003 (2003).
6) R. Perusquía, J. J. Ortiz, J. L. Montes, “Mejora del Patrón de Barras de Control del Ciclo de Equilibrio de 18 Meses para la CLV Empleando Algoritmos Bio-Inspirados”. Proc. XIV Annual Meeting of Mexican Nuclear Society, Guadalajara, México. September,2003 (2003).
7) HELIOS Documentation, the ScandPower Fuel Management System (FMS), 05Jul96.
8) User Manual CM-PRESTO 91 Input Rev.6; Scandpower, July 1993.