# THE FORTRAN NALAP CODE ADAPTED TO A MICROCOMPUTER COMPILER

**Paulo David de Castro Lobo, plobo.a@uol.com.br**
**Eduardo Madeira Borges, eduardo@ieav.cta.br**
**Francisco Antonio Braz Filho, fbraz@ieav.cta.br**
**Lamartine Nogueira Frutuoso Guimarães, guimarae@ieav.cta.br**
*Instituto de Estudos Avançados – IEAv/CTA – Rod. dos Tamoios, km 5.5, Putim, 12228-001, São José dos Campos, SP, Brasil*

***Abstract.*** *The Nuclear Energy Division (ENU) of the Institute for Advanced Studies (IEAv) is conducting the TERRA project (TEcnologia de Reatores Rápidos Avançados), Technology for Advanced Fast Reactors project, aimed at a space reactor application. In this work, to attend the TERRA project, the NALAP code adapted to a microcomputer compiler called Compaq Visual Fortran (Version 6.6) is presented. This code, adapted from the light water reactor transient code RELAP 3B, simulates thermal-hydraulic responses for sodium cooled fast reactors. The strategy to run the code in a PC was divided in some steps mainly to remove unnecessary routines, to eliminate old statements, to introduce new ones and also to include extension precision mode. The source program was able to solve three sample cases under conditions of protected transients suggested in literature: 1) the normal reactor shutdown, with a delay of 200 ms to start the control rod movement and a delay of 500 ms to stop the pumps; 2) reactor scram after transient of loss of flow; and 3) transients protected from overpower. Comparisons were made with results from the time when the NALAP code was acquired by the IEAv, back in the 80`s. All the responses for these three simulations reproduced the calculations performed with the CDC compiler in 1985. Further modifications will include the usage of gas as coolant for the nuclear reactor to allow a Closed Brayton Cycle Loop – CBCL – to be used as a heat/electric converter.*

***Keywords****: NALAP, Nuclear Energy, Nuclear Space*

## 1. INTRODUCTION

The Nuclear Energy Division (ENU) of the Institute for Advanced Studies (IEAv) is conducting the TERRA project, Technology for Advanced Fast Reactors project. The main objectives of this project are: 1) the establishment of the concept for a Closed Brayton Cycle Loop (CBCL), for building a demonstrative simulator and 2) the study of a nuclear reactor design to be the heat source for the thermal cycle (Guimarães *et al.,* 2008). New developments on thermal cycle's research were presented by Camillo and Guimarães (2008), where they discussed the CBCL and a redesign of the NOELLE 60290 in order to operate in a closed cycle. Also, they gave an overview of the full cycle design.

At this moment, there is no available computer program to simulate and solve thermal hydraulic transients of fast nuclear reactors to be used as a heat source with applications to the CBCL. To attend the TERRA project, this work presents the NALAP code adapted to a microcomputer compiler called Compaq Visual Fortran (Version 6.6). For further applications the intention is to modify the NALAP to use gas as coolant, allowing a CBCL to work as converter. To do this, some routines must be modified or replaced.

The source program was able to solve some sample cases using sodium as coolant, and comparisons were made with results from the time when the NALAP code was acquired by the IEAv, back in the 80`s (Luz *et al.,* 1985).

## 2. CODE ADAPTATION

The NALAP code, written in FORTRAN-IV computer language is a Liquid Metal Fast Breeder Reactor (LMFBR) system transient code and was developed by the Brookhaven National Laboratory in 1975 (Martin *et al.,* 1975). This code, adapted from the light water reactor transient code RELAP 3B, simulates thermal-hydraulic responses for sodium cooled fast reactors and is provided with the potential for modeling the entire plant.

To save computer memory and execution time, the original code was divided in six sub-programs (called by subroutines OVERLAY), where it was possible only two of them (the main program and one of the remaining subprograms) to work simultaneously in the memory. These subprograms are: TWOLAP - the main program that controls the other ones; INMAIN – controls the beginning of the problem for reading and printing data; PRINTR – saves data during the execution for further using; RESTRT – controls the restart of the problem ; TRAN – used for transient analysis; and STMPR – used only when coolant properties tables are available.

With the micro processor evolution, the FORTRAN language from the 70`s was modified in such a way that some statements are not used anymore, being eliminated or substituted by others, and new statements were introduced.

To have the NALAP able to run sample cases in a PC, it was decided to use the Compaq Visual Fortran compiler, already used at IEAv. At the initial runs, as expected, the results showed many error messages and a lot of warnings, during compilation and execution of sample cases.

The strategy used in this work was divided in six steps as follows (Lobo *et al.,* 2010).

### 2.1. Removing unnecessary routines

The subprograms used only for saving computer memory and execution time were removed, as well as almost all routines related to them. The exceptions were only two routines: one that reads and calculates data from tables and another one that calculates coolant properties.

Besides, all routines and functions that were not inside these subprograms but related to save intermediated results to be read in a further problem restart were also removed.

### 2.2. Including the extended precision mode for execution

In the main program and in all subroutines and functions, the statement defining real variables in extended precision mode had to be included, because runs of some cases in single precision caused execution errors.

To do this, all the original intrinsic functions were substituted by the correspondent ones in the new mode, taking a long time to search and find them in the entire program.

### 2.3. Correcting compilation and execution errors and warnings

The OVERLAY statements were substituted by SUBROUTINE statements, keeping the same title of the program associated to the overlay, and the PROGRAM statements, specifying files used, were omitted.

All the variables of CHARACTER type had to be identified at the beginning of the main program and at the subroutines, specifying the size of each one (number of characters). This kind of problem was solved as soon the error was advised by the compiler. In consequence, new errors messages were caused because those variables were not in a proper order inside the COMMON and DIMENSION statements. The solution was either to separate the character variables in different statements or to arrange them in a proper order by type (real, character, integer).

The comments from the majority of warnings were not directly related to the specific error, so the exact location had to be found out to get the reason of the error message and correct it properly.

### 2.4. Removing reading and printing errors

The input and output files were identified by the statements OPEN and CLOSE.

The statements ENCODE and DECODE (used only for preparing output page headings) had to be removed because they were not accepted by the compiler.

The PRINT statement was kept only to follow the related output on the monitor.

The outputs from the statement WRITE were sent to files for further analysis.

### 2.5. Executing sample cases

The NALAP code manual contains a detailed description of input cards and the output of two test cases. The already corrected source program, using the microcomputer compiler, could reproduce the results of the transient calculations in both examples.

### 2.6. Reproducing old runs

With this new NALAP version, the outputs available at the IEAv for old runs, were reproduced. Details on this can be find next.

## 3. CODE VALIDATION

To validate the new version of NALAP code, the thermal hydraulic behavior of the primary circuit of a 5 $MW_{th}$, pool type experimental fast reactor was simulated under the conditions of protected transients suggested in literature. All the components of the primary circuit, including the core and the intermediate heat exchanger (IHX), are inside a tank containing the pool of sodium. The tank is shown in Fig. 1.

The space between the top of the tank and the sodium surface is filled with an inert gas (argon) to allow thermal expansion. The argon is maintained at an over atmospheric pressure (about 2 atm) to ensure that any leaks are out of the system rather than in. The primary tank is surrounded by a leak jacket, so that, in the event of a leak, the sodium level would not fall so far to expose the core.

Sodium is drawn into the pump and then forced upwards past the fuel pins in the core, which is surrounded by a breeder region. The hot sodium from the core then flows down through tubes in the intermediate heat exchanges, and transfers heat to a secondary sodium flow on the shell side of the heat exchanger. The secondary sodium then goes to the steam generator. The complete separation of the primary and steam circuits by means of this intermediate sodium circuit is done partly to avoid having radioactive sodium in the boiler and partly to prevent any possibility of steam or water leaking into the primary tank.

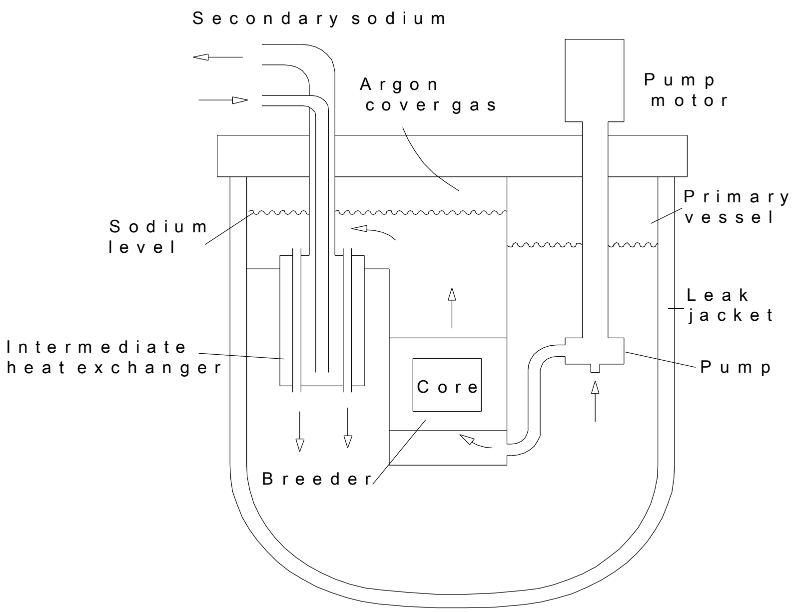


Figure 1. Primary Coolant Circuit in a Fast Breeder Reactor

Three situations were simulated in this work:

1) normal reactor shutdown, with a delay of 200 ms to start the control rod movement and a delay of 500 ms to stop the pumps;

2) reactor scram after transient of loss of flow; and

3) transient protected from overpower.

In all cases, the results show that the used configuration is extremely safe, and all the responses for these three simulations reproduced the calculations performed with the CDC compiler in 1985.

Figure 2 presents the thermal hydraulic response for the first case.

It is observed that, while the power needs 0.8 s to decreases 80%, the flow, due to inertia of the pumping system, needs 5 s to drop to 50%.

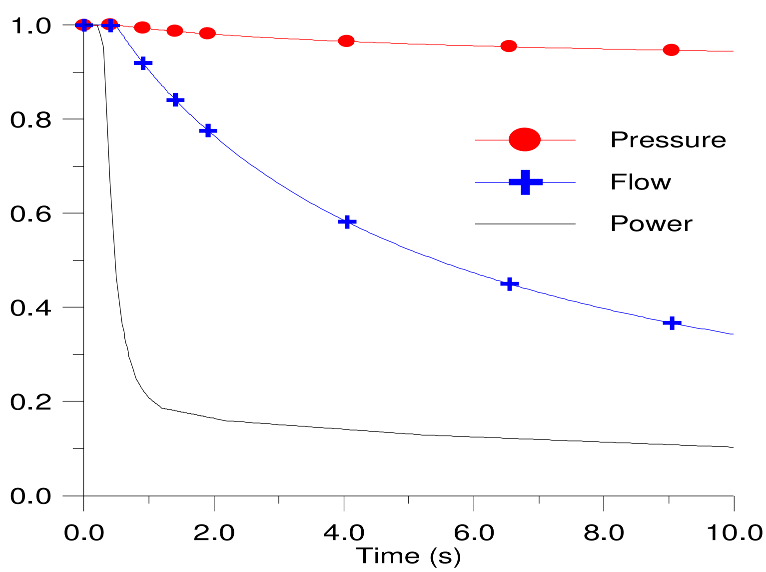


Figure 2. Normalized Curves (Normal Reactor Shutdown)

Also, it is noted that the reducing of sodium pressure is very smooth.

Figure 3 shows the temperature responses for a single rod inside the core for the first case, after the reactor shutdown, which shows decreasing profiles.

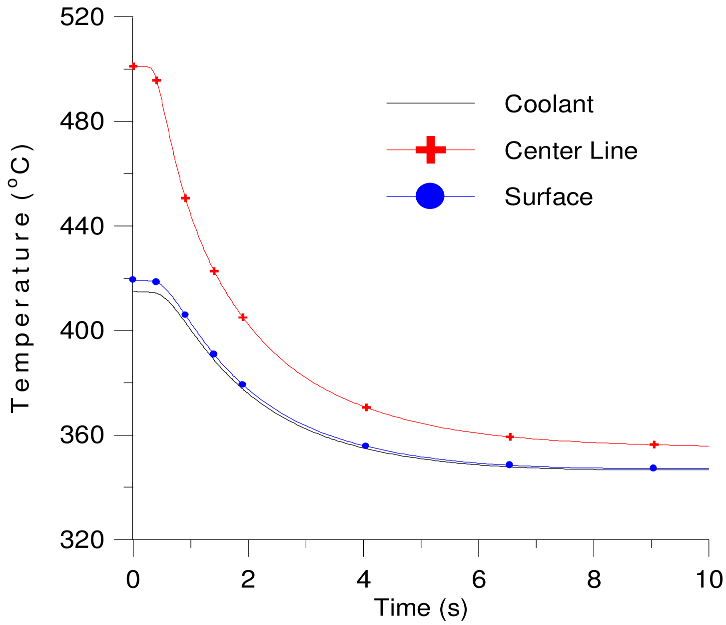


Figure 3. Temperature responses for one rod (Normal Reactor Shutdown)

For the second case, a normal behavior of the Power Protection System (PPS) was studied. To do this, a pump stopping was allowed after 0.2 seconds, leading to loss of flow, and followed by a scram at 0.9 seconds, due to the PPS responses delays, as we can see in Fig. 4 and Fig. 5. It was not observed big differences compared to the first case transient.

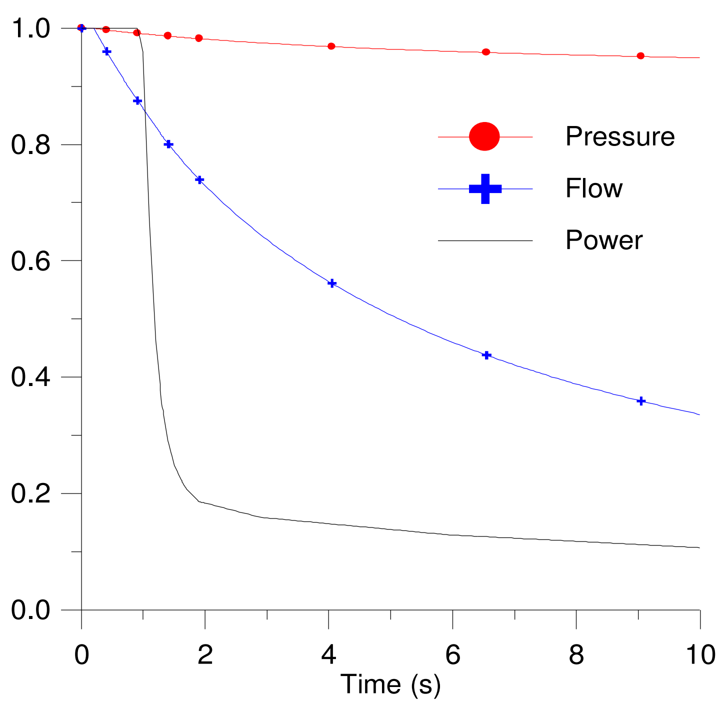


Figure 4. Normalized Curves (Loss of Flow Transient)

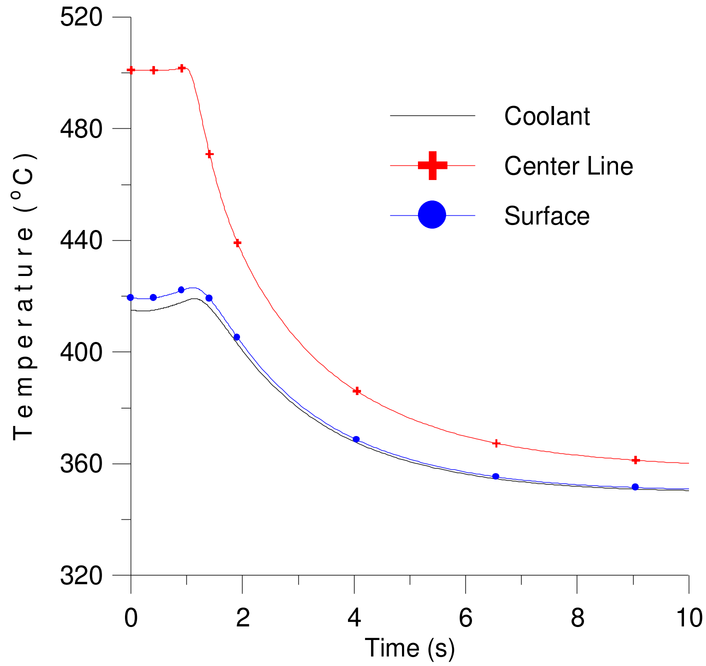


Figure 5. Temperature responses for one rod (Loss of Flow Transient)

To simulate the case of transient protected from overpower, a reactivity of 0.1 $/s was inserted, leading to a value of pressure twice the initial value. After this, the pressure was reduced by the action of the control rods, as we can see in Fig. 6. The temperatures responses at the coolant, at the center line and at the surface of a rod are showed in Fig. 7. Due to the small fuel thermal inertia, the thermal response from the reactor was very fast.

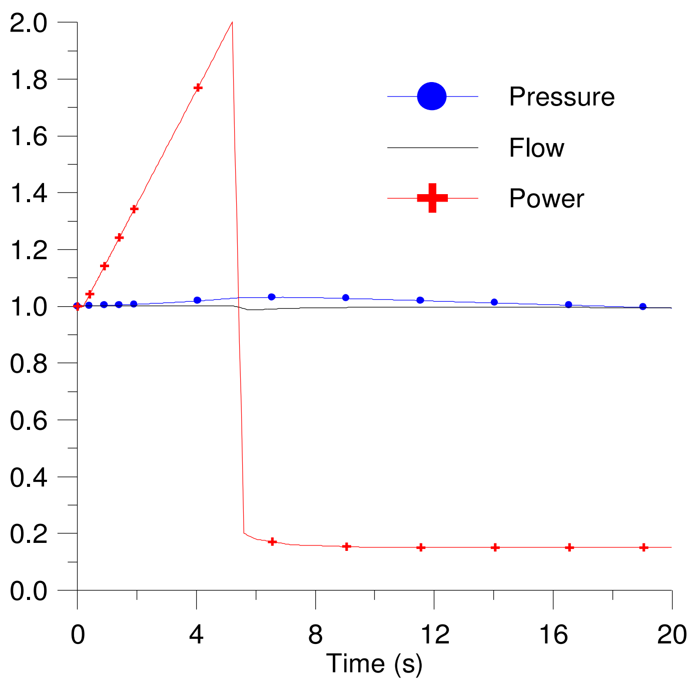


Figure 6. Normalized Curves (Transient Protected from Overpower)

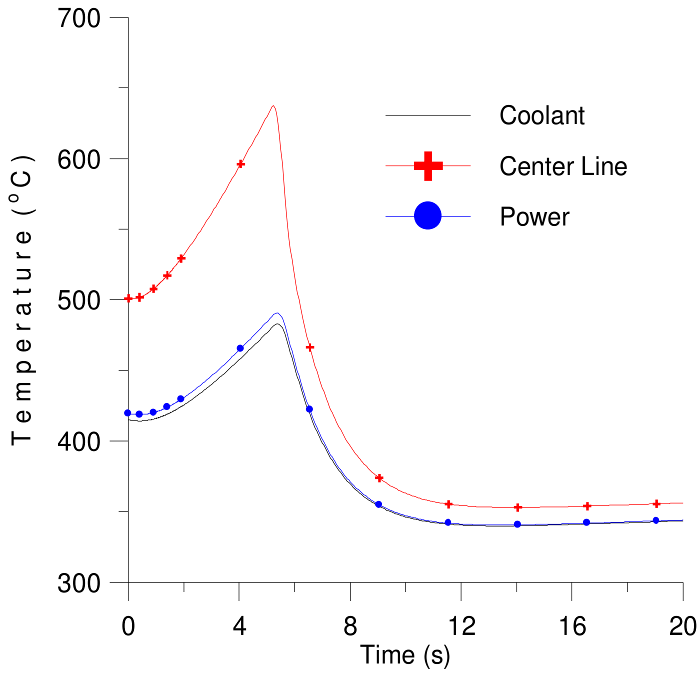


Figure 7. Temperature responses for one rod (Transient Protected from Overpower)

## 4. CONCLUSIONS

Using this PC version of the NALAP code, transient conditions in sodium cooled fast reactors are simulated. All the responses for these three simulations reproduced the calculations performed with the CDC compiler in 1985. Further modifications will include the usage of gas as coolant for the nuclear reactor. This will allow the use of a Closed Brayton Cycle Loop – CBCL – as a heat/electric converter.

## 5. ACKNOWLEDGEMENTS

The authors are sincerely thankful for the assistantship provided by "Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq" given to first author of this contribution, under the contract number 150712/2009-0.

## 6. REFERENCES

Camillo, G. P. and Guimarães, L. N. F., 2008, " A Preliminary Design for a Simplified Closed Brayton Cycle Modeling for a Space Reactor Application", Proceedings of the 12th Brazilian Congress of Thermal and Sciences, Belo Horizonte, MG, Brazil.

Guimarães, L. N. F., Nascimento, J. A., Borges, E. M., Caldeira, A. D., and A. F. Dias, A. F., 2008, "TEcnologia de Reatores Rápidos Avançados TERRA: reatores para aplicações espaciais e estratégicas", 8th Workshop Anual de Pesquisa e Desenvolvimento do Instituto de Estudos Avançados. S. J. dos Campos, SP, Brazil, Vol. 1, pp. 115.

Lobo, P. D.; Borges, E. M. and Guimarães, L. N. F., 2010, "Adaptação do Código NALAP ao Sistema 'Compaq Visual Fortran', Versão 6.6", Publicação Interna IEAv-ENU-B/002/2010.

Luz, M. S., Borges, E. M. and Braz Filho, F. A., 1985, "Análise de Transitórios num Reator Rápido Experimental com o Uso do Código NALAP", Relatório Interno IEAv – 09/85.

Martin, B. A., Agrawal, A. K., Albright, D. C., Epel, L. G. and Maise, G., 1975, "NALAP an LMFBR System Transient Code" BNL 50457, Brookhaven National Laboratory.

## 7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.