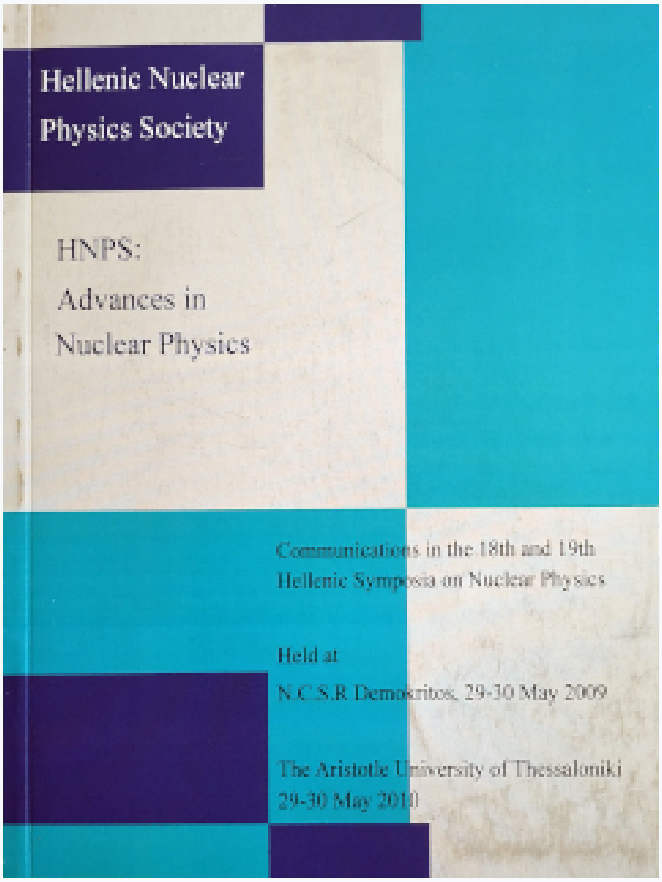
HNPS Advances in Nuclear Physics

Vol 18 (2010)

HNPS2010



Theoretically and under very special applied conditions a nuclear fission reactor may explode as nuclear bomb

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doi: 10.12681/hnps.2558

Theoretically and under very special applied conditions a nuclear fission reactor may explode as nuclear bomb

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Abstract

This article/presentation describes a theoretical and applied research in nuclear fission reactor systems. It concerns with theoretical approaches and in very special applied cases consideration where a common nuclear fission reactor system may be considered to explode as nuclear bomb. This research gives critical impacts to the design, operation, management and philosophy of nuclear fission reactors systems. It also includes a sensitivity analysis of a particular applied problem concerning the core melting of a nuclear reactor and its deposit to the bottom of reactor vessel. Specifically, in a typical nuclear fission power reactor system of about 1000 MWe, the nuclear core material (corium) in certain cases can be melted and it may deposited in the bottom of nuclear reactor vessel. So, the nuclear criticality conditions are evaluated for a particular example case(s). Assuming an example composition of melted corium of 98 tones of U238 , 1 tone of U235 , 1 tone Pu239 and 25 tones Fe56 (supporting material) in a 5 m diameter of a finite cylindrical nuclear reactor vessel it is found that it may result in nuclear criticality above the unit. This condition corresponds to Supercritical Fast Nuclear Fission Reactor case, which may under certain very special applied conditions to nuclear explode as nuclear bomb.

Key words: Nuclear reactor, fission, core meltdown, nuclear accident, human factor, nuclear safety, nuclear bomb, nuclear engineering, corium

1. Introduction

The Nuclear Safety is a vital theme of paramount value for the Humanity and Ecosystems. The Deaths from the Chernobyl Nuclear Accident, USSR ,1986 , until 2009 was estimated from IAEA/WHO to about 4000 [1] and from according to literature [2] to about 1.000.000. Also have been reported from the Associated Press,USA,on Thursday 21-April-2011,that the cost of worst case(Not for our extreme severe case of nuclear explosion as nuclear bomb which is much more worst case) of a severe Nuclear Accident for example in Germany, has estimated to result in a total cost as much as 7.6 Trillions Euro!

The Nuclear Safety has three critical components: a) the nuclear human factor (management, workers, designers, others effecting the Nuclear Safety) [3], [5], [12], [13], [16] and b) the nuclear technological factor [4], [6], [13]and c) the theoretical critical factor [7]. The nuclear human factor has been proven in practice from the nuclear accidents to be the most critical factor [3].

The author goal in this research is to warn the nuclear society for the possibility of extreme severe nuclear accidents in order together with future studies to contribute to minimization or perhaps zero of probabilities for extreme worst nuclear fission accidents to happens in particular nuclear system.

Until now, qualitative simple arguments have propagated the belief that nuclear fission reactor accidents cannot lead to nuclear explosions as nuclear bomb(examples of articles can be found by Internet search). The present scientific research offers the first quantitative research in the question if a nuclear fission reactor (or/and with perhaps similar thinking approach for a nuclear waste storage) can explode as nuclear bomb, and therefore may contribute to open a new direction in research in the nuclear safety of severe nuclear fission accidents (considering the very critical case of extreme worst nuclear fission accidents).

A nuclear fission system can explode with conventional (chemical) explosions from f.e. the ignition of an explosive mixture of hydrogen,etc, or from nuclear explosions of low yield(early dispersion of nuclear fissioning material,common cases in nuclear accidents) or with high power nuclear yield (explosion as a nuclear bomb).

The study of the real cases of Nuclear Fission Reactors System (theoretically, applied or in simulators) demands a system of equations which contains the integral differential NON-linear system of equations of the neutrons flow (considering the system of neutrons transport equation(s)) with nuclear reactivities feedbacks and time-depended transients states (in the dynamic of nuclear fission reactors) with at least 6 to 13 energies groups of delayed neutrons (>6 if we consider and the photo-neutrons f.e. in CANDU nuclear fission reactor types). The study must be made in three spatial dimensions (because of the Non-homogenous flow of neutrons in the core of the nuclear energy reactor) and considering the influences («poisoning», feedbacks, oscillations,etc) of the products of nuclear fissions, the generations of transuranic elements, the burn up considerations, and possible «external» neutron sources. The above must be considered for a finite nuclear reactor system model, in real spatial-time (geometry) dimensions and material (space,time) composition calculations ,and in this nuclear system the description of its nuclear energy states(in a multi energy groups approach model) to be coupled with the system of equations of dynamic thermohydraulic of two phases flow (considering also the possibilities of cases of nucleate boiling,etc) for a compressible and viscous fluid (which can also possible to include turbulence flow cases) ,and also to be coupled with the rest of sybsystems of the Nuclear Plant (f.e turbine(s) behaviours, electrical load behaviour, accidents,etc) . All the above considerations must also be coupled with the Human(s) cognitive intelligence & education & Management knowledge of the nuclear system & its behaviour in (space,time,case) ,and with the plant ergonomics & information fields & Human psychologies of workers ,test cases considerations, etc, which may effect directly or/and indirectly the nuclear plant…

With the considerations in the mathematical models of the mathematical existence of solution(s) and its uniqueness studies with the problems in analytical solutions and numerical algorithms approximations, in convergence and stability of solution(s) thinking, and in simulator sensitivities research and optimization studies considerations.We also recommend the studies of relevant ILL-posed problems that may arise in research and in modelling,etc.

In order to evaluate the possibility of the explosion of a nuclear reactor as a nuclear bomb the following principles are considered:

the physical processes in nuclear reactor meltdown accidents [8] and in the reactor safety study [9], the cases of Uranium and Pu239 nuclear energy reactor core meltdown, the human factor and the conventional explosions that can occur. Considering the literature [10] an initial evaluation has been made using our original model of the above processes. There are uncertainties in applied cases because most of experiments concerning specific system of engineering nature are considered uncertain to be generalize to other systems. It is possible ([10],etc) a «closet» configuration to be formed inside the nuclear reactor vessel, which is similar, in principles, with the first Uranium nuclear bomb configuration (f.e. [17])[at least theoretically a nuclear supercritical fissioning system which can be maintained together for adequate nuclear fission generations can nuclear explode as nuclear bomb...]

This could be a steel «closet» with steel on top, steel on sides and in the bottom, and inside to contain Nuclear Fissioning Mass [NFM] (mostly melted Uranium and Plutonium). So the configurations (geometry, composition, etc) in combination with the expected nuclear and transport phenomena can create supercritical NFM. Any kind of maintaining in the enclosed space «closet» for adequate time the supercritical NFM will create nuclear explosion. The reactor vessel is made from very strong steel (in most common nuclear reactor types) which form the very strong construction of the "closet" of the reactor vessel and thus can increase considerably the probability of a nuclear explosion as nuclear bomb, since it will keep in restricted space a supercritical fissioning mass for long time(many nuclear fission generations in supercriticality).

In Additional to the above mentioned consideration, there may be the worst case where conventional explosions of explosive melt plus water (or more general , two or three phases solid ,liquid and air (usually in the form of bubbles) in a nuclear reactor melted core to interact with cold material in which spontaneous explosions may occur (as melt is falling through water the melt surface temperature fall below the minimum film boiling temperature, causing the vapour film to become unstable and collapse, triggered explosions may occur (when water is forced in contact with melt due to some external event). Thinking on the accidental cases of Spontaneous, Triggered Explosions and the case of the enclosed NFM in «closet», this may be similar in certain specific cases to the case of Plutonium nuclear bomb, since strong implosive compressions may occur.

2. Material and Methods

In this work the evaluation of the criticality of melted corium in f.e. pressurized light water nuclear fission reactors or boiling water fission reactors or other types is studied when all the corium is deposited in the bottom of the nuclear reactor vessel. The following scenario will be examined:

A. The Scenario of Nuclear Fission Reactor Severe Accident, where all the nuclear core material (corium) is melted and go as corium to be deposited in the bottom of the nuclear reactor vessel, and the corium can form a nuclear super critical mass configuration in a steel "closet" situation which may lead to nuclear explosion.

B. Assumptions in our the applied simplified model:

a. Assuming that the nuclear reactor vessel has finite cylindrical shape with internal diameter five (5) meters, into which all the melted corium is deposited in its bottom.

b. Assuming the approximately validity of neutrons diffuse equation and considering one energy group (fast neutrons group).

c. Assuming instantaneous steady-state for the evaluated position of corium inside the bottom of the nuclear reactor vessel.

d. The extrapolated distance, d, from the boundaries of the corium and the nuclear reactor vessel is taken into account.

e. Assuming finite cylindrical shape of the nuclear reactor vessel; therefore the critical Buckling and fluxes are used for a reflected finite cylinder fast nuclear fission reactor.

f. Assuming that the corium to be composed, in first approximation, from homogenous mixture of melted 98 tones U238, 1 tone of U235 , 1 tone Pu239 and 25 tones Fe56.

g. Assuming that the nuclear reactor vessel , initially, holds for certain time the melted corium (which it is separated from the water above it).

h. Assuming in the calculation a fast neutrons nuclear fission reactor case study , to consist the layer of melted corium, in the closet.

g. Assuming neutrons reflection in the fissioning mass' "closet" walls and we approximately calculate its impact to the multiplication factor.

3. The Results

I. Simple Approximation calculation of the problem (the CGS system of units is used in calculations)

The Criticality Coefficient (or the Fissions Multiplication factor) is defined as

$$\mathrm{k} = \frac{\text{Number of fissions in one generation (in nuclear fission(s) chain reaction)}}{\text{Number of fissions in the preceding generation}}$$

and the Critical state of the nuclear chain reaction system is present when k=1, subcritical state when k<1 (reducing nuclear fission power) and Supercritical state when k>1 (increasing nuclear fission power). The calculations were made according to the literature [11]. Considering the relevant assumptions and the approximation is derived in similar way as the equation for k for a homogenous mixture of materials, considering that now in our case the term for the neutron sources, in the approximation of one-energy group (the fast energy neutrons group) neutron diffusion equation for nuclear fission reactor will be:

$$S(sources\,of\;neutron) = \left[\sum_{i=1}^{3} \nu_i \cdot \left[\left(\frac{V_i}{V_{tot}}\right) \cdot N_i \sigma_{f,i}\right]\right] \cdot \Phi\left(vector(\vec{r},t)\right)$$

where Φ(vector[r],t) is the neutrons flux in the melted corium nuclear reactor system.

Therefore we can write:

$$k = \frac{\nu_{fast(Pu239)} \cdot \sum_{f,fast}(Pu239) + \nu_{fast(U235)} \cdot \sum_{f,fast}(U235) + \nu_{fast(U238)} \cdot \sum_{f,fast}(U238)}{D \cdot B^2 + \Sigma\alpha}$$

Where νfast is the average number of fast neutrons (both prompt and delayed) released per fission event in a fissioning isotope. This number take the values : νfastPu239 , νfastU235 , νfastU238 for the isotopes of Pu239,U235,U238 respectively , for the fast neutrons energy group.

Σf is the macroscopic cross section for fission ,here induced by fast neutrons, Σα the macroscopic cross section of absorption of neutrons, D the diffusion coefficient (which is considered constant) for the diffusion of neutrons approximation of nuclear fission reactor, B^2 the Geometrical Buckling.

Now we consider the very simple approximation of a HOMOGENOUS mixture of nuclear “fuel” consisting from [Pu239 , U235 , U238] for fast neutrons nuclear fission reactor model. In a homogenous mixture the following approximation is used:

$$\Sigma\alpha = \sum_{j=1}^{4} \frac{V_i}{V_{tot}} \cdot N_j \cdot \sigma(a)_j$$

where Vi denote the volume occupied in the corium from the i constituent of corium (i=1,…,4 , for Pu239,U235,U238,Fe56) and Vtot the total volume of corium

Also from equations (5.10) & (5.11) & (5.12) of reference [11] we obtain:

$$D = \frac{1}{3 \cdot \Sigma transport}$$

and by denoting N the Nuclei(or atomic) density in nuclei/cm^3 we can write(for one type of material system) Σχ = N. σχ , for the x-type of nuclear interaction. In order to calculate the Σtranport(Mixture of Materials) the following equation is used (and similar for the calculations of others Σχ macroscopic cross sections, in the homogenous mixture of isotopes in
our system) :

$$\Sigma trasport(mixture) = \sum_{i=1}^{4} \left(\frac{V_i}{V_{tot}} \right) \cdot N_i \cdot \sigma_{i,tr}$$

where σi,tr the microscopic transport cross section , Ni the nuclei density ,of element i, per cm^3

Also by considering the case of a FINITE cylindrical geometry Nuclear Fissioning Masss (a Nuclear Fission Reactor type, representing the melted corium) the Geometrical Buckling (from table 6.2 of the book [11]) is given as follows (and considering the extrapolation distance d due to correction from the neutrons transport theory and the reflector saving δ due to neutrons reflections in the thick walls of steel “closed” which is formed from the thick walls of nuclear reactor vessel on the sides and in the bottom and in the upper side the reflection from steel plate reflection.):

$$B^2 = \left[\frac{2.405}{R + d + \delta} \right]^2 + \left[\frac{\pi}{H + 2d + 2\delta} \right]^2$$

where R is the radius in cm and H the height in cm of the Finite cylinder nuclear reactor. Now we do the relevant for the problem numerical calculations using the above system of equations

a. relevant nuclear data

N(Pu) = 0.04938 . 10^{24} (nuclei{atoms] densities per cm^3)
N(U) = 0.04833 . 10^{24}
N(Fe) = 0.08487 . 10^{24}

ρ(Pu239) = 19.816 (mass density in gr/cm^3)
ρ(U238) about equal to ρ(U335) = 19.1
ρ(Fe56) = 7.87

ν-fast (Pu239) = 2.98 (ν for fast(energetic) neutrons)
ν-fast (U235) = 2.6
ν-fast (U238) = 2.6

microscopic cross sections of relevant nuclear interactions (to be multiplied by 10^{-24})

σ[α]fast (Pu239)=2.11 σ[transport]fast(Pu239)=6.8 σ[fission]fast(Pu239) =1.85
σ[α]fast(U235) = 1.65 σ[transport]fast(U235) = 6.8 σ[fission]fast(U235)= 1.40
σ[α]fast(U238) =0.255 σ[transport]fast(U238) = 6.9 σ[fission]fast(U238)=0.095
σ[α]fast(Fe56) =0.006 σ[transport]fast(Fe56) = 2,7 σ[fission]fast(Fe56)= 0

b. We assume a homogenous mixture of melted Corium as fluid , forming a FAST nuclear fission reactor of Finite cylindrical geometry , as following:

0.008 %w Pu239 → 1000 Kgr =106 gr VOL(Pu239)=50464.27 cm^3
0.008 %w U235 → 1000 Kgr=106 gr VOL(U235)=52356.20 cm^3
0.784%w U238 → 98000 Kgr=98 x106 gr VOL(U238)=5 130 000 cm^3
0.20 %w Fe56 → 25000 Kgr=25 x106 gr VOL(Fe56)= 3 176 620 cm^3
TOTAL VOLume= 8 409 440 cm^3

c. Geometry of the Finite Cylinder Nuclear Reactor

Radius =250 cm Height=TotalVolume/BottomSurface=42.90 cm

BottomSurface= π , R^2 = 19.6 x104 cm^2

And using the following equations:

$$d = 2.13 \cdot D_c$$

$$\delta = \frac{D_c}{D_R} \cdot L_R , \quad L_R = \sqrt{\frac{D_R}{\Sigma_{\alpha,R}}}$$

$$D_R = \frac{1}{3 \cdot \Sigma_{tr,R}}$$

Where d is the extrapolation distance , δ the reflection saving (simple approximate calculation), D_C, D_R, the diffusion constants for the core and the reflector areas respectively , and $\Sigma\chi$,R the macroscopic cross section for χ nuclear interaction type in the reflector areas.

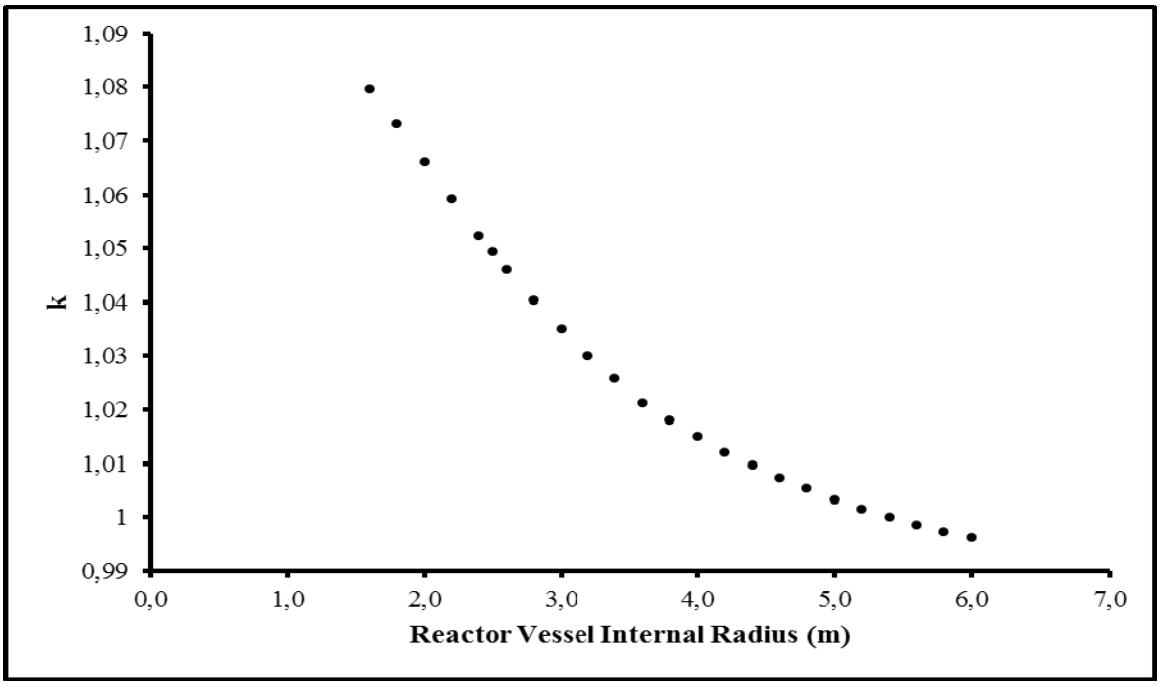
d. Using the above mentioned system of equations, the relevant numerical calculations result to the following value of fissions multiplication factor k, (for 2.5 m internal nuclear reactor vessel radius):

$$k= 1.0492 > 1$$

This result may interpreted that the operation of the nuclear fast reactor (fissioning corium) becomes supercritical and thus it may nuclear explode and under certain special conditions(strong tamper effects, very strong steel "closet" formation, etc) may even explode as Nuclear Bomb.

II. Sensitivity Analysis of the main problem

In order to improve the Nuclear Energy Safety, a Sensitivity study is performed on the simplified model used, by considering a nuclear energy reactor with hypothetical from 1.6 m to 6.0 m internal radius of the nuclear reactor vessel and by increasing the vessel radius in steps of 0.2 m we calculated the fissions multiplication factors k , and the results are presented in the graph-1 which is following:



Graph-1. Sensitivity analysis of the nuclear criticality (k factor) as a function of the reactor vessel internal radius.

From the Graph-1 we notice that from internal reactor vessel radius 1.6 m to about 5.5 m , there may be, theoretically, a possibility of nuclear explosion , because in these radius values, the k can be greater to one. These results must motivate further research and to be considered in the designs and operations of nuclear fission reactors.

4. Conclusions

According to this simplified model, it is shown that in a nuclear fission reactor severe accident , it is probable in a nuclear core meltdown to be formed a nuclear configuration of Supercritical mass layer (in form of a closet) in the bottom of the nuclear reactor vessel. Further scientific research is required in order to understand more precisely the phenomena and preventions in nuclear fission reactors severe accidents. This study recommend the following aspects:

a. Further research and studies are required by using more precise models calculations of fission multiplication factor k (nuclear criticality studies) for different (space,time,case) configurations.

b. The development of high advanced scientific nuclear fission reactor types simulators is proposed with spatial and time transients' consideration and sensitivity analyses in many views of hyper-nodes network model[13] and considering our discussion in the introduction of this article which refer to the study of the real cases of Nuclear Fission Reactor Systems….
c. A Mathematical hint, for studying ill posed ,initial and boundary value problems relating to the uniqueness, stability, continuous data dependence and instability of solutions for both linear and non-linear partial integral/differential equations[14] , and also studying stochastic neutron transport cases[15].
d. The multi-factors sensitivity analysis of solutions in the simplified or more advanced model, where the case of Supercriticality of nuclear corium configuration is obtained, recommends new designs of nuclear fission reactors considering the size of cylindrical nuclear reactor vessel of larger diameters, and under the nuclear fission reactor the cavityies to be in such way constructed so to be more "manageable" the possible processes that they may lead to the creation of Super critical configuration of nuclear fissioning mass(NFM).

Here we must stress that , considering the official report by Henry De Wolf Smyth ,1945 and the double importance of the Tamper (neutrons back reflection , delay of the expansion of supercritical mass) and the fact that U238 is an excellent tamper in the design of nuclear bombs,
And that in this article we have Not taken in precise account the tamper effects, which are very serious because of about 98 tones of U238 in the corium , we conclude that the probability of a nuclear fission reactor in a case of meltdown severe nuclear accident to nuclear explode as nuclear bomb may be higher than what we initially thought.Therefore further scientific research in our theme is considered Mandatory and Must be Supported in order to be prepared and to find Preventive ways to increase significantly the Nuclear Safety in Extreme Severe Nuclear Accidents cases…

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