LETTERS TO THE EDITOR

REMARKS ON THE PLUTONIUM-240 INDUCED PRE-IGNITION PROBLEM IN A NUCLEAR DEVICE

In a recent article, Şahin and Ligou[1] tackled the problem of fissile yields of nuclear devices when commercial plutonium with up to 25% ^{240}Pu is used as the fuel. The erroneous idea behind their approach attacking the problem of pre-ignition is their belief that the neutron kinetics can be treated in a purely deterministic manner. However, the problem is in reality a stochastic one and cannot be solved by using only first moment equations. Methods of reactor noise analysis must be applied.

For instance, it is not self-evident that the neutron density as function of time in a supercritical assembly necessarily develops as described by Eq. (10) of Ref. 1. Many years ago, Dragon-type[2] bursts in the Godiva facility experimentally demonstrated that the time for the power buildup in the Godiva reactor to 2.7×10^{11} fiss/s, following a large step increase of reactivity to $\Delta k/\beta = 0.7$ dollars, varied substantially in the range from 25.4 to 43.9 s (Ref. 3). This behavior is by no means deterministic.

This vivid example leads to the real question that must be asked: What is the time-dependent probability of a source neutron sponsoring a persistent chain reaction? What is the time required for the neutron population associated with this chain to grow to a maximum or to another fiducial value? Or more generally speaking, what is the effect of the probabilistic nature of the processes of neutron loss, production, and branching processes, involved in a chain reaction, on the yield of a nuclear excursion?

Solving these problems by applying some selected stochastical methods of reactor noise analysis, one finds that both the average yield and the "jitter" of the yield, i.e., the variance of the probability density function, are dependent on the unavoidable neutron background during reactivity buildup. This latter property becomes an important issue when the use of reactor-grade plutonium as the fuel for nuclear devices is considered.

It is obvious that one cannot get the appropriate answers to these questions by simply applying the standard deterministic kinetic first moment equations as was done in Ref. 1. In addition to the pre-ignition problem, there are also other effects that give rise to an uncertainty in the energy yield, e.g., the Raleigh-Taylor instability.

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REPLY TO "REMARKS ON THE PLUTONIUM-240 INDUCED PRE-IGNITION PROBLEM IN A NUCLEAR DEVICE"

The criticism of Seifritz[1] on our work[2] is essentially focused on the deterministic manner of the treatment of neutron kinetics. To justify his standpoint, Seifritz mentions the experiments done on the Godiva facility, a ^{235}U-type supercritical assembly with a very weak spontaneous neutron background. We agree that the neutron kinetics problems associated with the spontaneous neutron production in a ^{235}U-type nuclear weapon are of a stochastic nature. This is also the reason why an additional neutron

TABLE I

Neutron Production Due to the Spontaneous Fission of ^{240}Pu in the Core of the Nuclear Bombs in Ref. 2

^{240}Pu (%)	5	15	25
S_0[a] (n/s)	4.96×10^5	1.49×10^6	2.48×10^6
M[b]	28.96	30.47	32.6
S[c] (n/s)	1.44×10^7	4.53×10^7	8.08×10^7

[a] S_0 = neutron production in the far undercritical state [see Eq. (2) in Ref. 2]. The spontaneous fission half-life of ^{240}Pu = 1.2×10^{11} years (Ref. 3). Neutrons per spontaneous fission in ^{240}Pu = 2.07 (Ref. 4).

[b] M = subcritical neutron multiplication factor by arriving at the criticality [see Eq. (14) in Ref. 2]. (Compacting time T_c = 1 μs.)

[c] S = neutron production at the state of criticality.

source, for example, in the form of a polonium-beryllium source with low gamma background, will be necessary to start the nuclear chain reaction at the optimal time in such nuclear explosives.

However, the spontaneous fission neutron yield in ^{240}Pu is five and six orders of magnitude higher than in ^{238}U and ^{235}U, respectively,[3] so this can be considered as a continuous process, which suggests the deterministic treatment of neutron kinetics. Table I shows some data to underline this statement.

The neutron flux level in the core of the investigated nuclear explosives is calculated to be 10^4 and 10^5 (n/cm^2·s) for the far undercritical state and 10^5 to 10^6 (n/cm^2·s) by arriving at the criticality.

The main objective of our analysis in Ref. 2 was to assess in a qualitative way the order of magnitude of the energy yield in a nuclear explosive consisting of reactor-grade plutonium, through a comparison with weapons-grade or nearly weapons-grade plutonium assemblies. In this presentation, the coupled neutronic-thermohydraulic calculations could have been avoided by preserving the same thermohydraulic properties in all assemblies.

The disadvantage of using even-plutonium isotopes in a nuclear explosive stems from different physical factors, which might be underestimated if considered separately. An example of this is the effect on the critical mass (neutron multiplication and balance)[5,6] or neutron generation time.[6,7] Our analysis in Ref. 2 considers

1. neutron multiplication factor
2. surface leakage
3. neutron generation time
4. subcritical multiplication by approaching the criticality
5. neutron background due to spontaneous fission.

The main conclusion of this deterministic treatment is that the energy yield of a nuclear explosive decreases by one and two orders of magnitude if the ^{240}Pu content increases from 5 (nearly weapons-grade plutonium) to 15 and 25%, respectively.

We invite Seifritz to evaluate, in a separate paper, the stochastic treatment of this problem and compare its results with those of our deterministic treatment. We believe this would be a valuable contribution to the general subject of nonproliferation.

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