Letters to the Editor

Comments on "Analysis of the Microfission Reactor Concept"

Cole and Renken[1] have recently discussed the feasibility of utilizing compressed fissionable pellets to produce fission microexplosions, and Winterberg has made some criticisms about that paper.[2] We would like to comment on these two papers.

First, the critical masses predicted by Cole and Renken are very close to ours,[3,4] and, moreover, they are consistent with the experimental data for solids (Los Alamos Scientific Laboratory zero-power critical facilities: Godiva, Jezebel, etc.). The methods and cross sections are, therefore, accurate enough. The burnup estimation, on the other hand, is rather coarse [Eq. (8) of Ref. 1]. One should introduce burnup reactivity feedback into the point kinetic model, as is done in Ref. 4 and already mentioned in Ref. 3, to get the burst width of the quenched neutronic excursion and to prove that this quantity is less than the confinement time. But above all one has to adopt a less pessimistic value for the initial neutron population N_0. One can make better than 10^3 if the fusion neutrons are used. Even for bare plutonium pellets, a small amount of DT material compressed at the same pressure (10^{18} dyn/cm^2) centrally located in a 1.5×10^{-3}-cm-radius sphere (14 times smaller than the critical radius) will provide an efficient neutron source giving the same results as an initial neutron population, $N_0 \sim 10^{15}$ (for an ion temperature of ~1 keV) (Refs. 4 and 5). Moreover, this source is built at the right time, just when the desired supercriticality is reached (end of the compression). It could also be shown[6,7] that there are no problems concerning the stochastical behavior during the beginning of the fast-rising chain reaction and that one can count confidently on deterministic development of the neutron flux and on a predictible energy yield within a narrow statistic margin.

Another point is related to the reflected pellets. The authors claim that this type of pellet is worse. This is true for usual reflectors *but not for absorbing* reflectors like ^{6}LiD blankets,[3] which provide at the same time tritium *in situ*. With the point kinetic model based on quasi-static multigroup transport calculations, it is always possible to derive a correct lifetime that includes all reflector properties.[4,8] One can see in the table the values that define the kinetic behavior of plutonium pellets around the critical state.

	M (g)	v_c (cm sec^{-1})	v_r (cm sec^{-1})	Λ (psec^{-1})
Bare	0.185	1.2×10^9	---	9.4
^{6}LiD-reflected	0.0767	7.8×10^8	3×10^8	13.7
TD-reflected	0.0082	1.2×10^8	3.5×10^7	~100

where

M = critical mass

v_c, v_r = one-group neutron velocities in core and reflector ($1/v$ weighting over the corresponding spectra)

Λ = correct lifetime for *the whole system* (which does not depend very much on the supercriticality).

The values of the kinetic parameter, Λ, are nearly the same for the first two pellets, but in the last case one sees an order of magnitude difference. An examination of the spectrum shows that the TD-reflected pellet behaves like an intermediate reactor.

Our basic calculations[3,4] deal with ^{6}LiD-reflected pellets. For a typical (and sufficient) supercriticality, $\rho = 0.20$, the initial Rossi-α_0 is 1.47×10^{10} sec^{-1}. For the same Rossi-α, one deduces from the previous table that the TD-reflected pellet should have a reactivity larger than 1. Krumbein[9] has reached the same conclusions. One concludes therefore that only absorbing reflectors can be accepted, among them the ^{6}LiD, which has the evident advantage of producing fusionable fuel (tritium) during the excursion *in situ*.

Thus, we think that Winterberg's criticism is not valid. The arguments he gave in Ref. 2 are based on a too high neutron velocity in the reflector, 1.4×10^9 cm/sec (which is, in fact, a core value for bare plutonium pellets), instead of 3.5×10^7 cm/sec as shown in our table. In such a problem it is really impossible to avoid multigroup calculations. The argument of a hot reflector is not a good one. First, if the reflector has reached 10 keV throughout at the high density (5×10^{26} A/cm^3) as we have adopted with him, then one does not need any fissionable triggering. This high temperature can be reached after but not before the chain reaction starts. Second, we have made calculations with lower energy boundaries of 3 and 130 eV in our multigroup scheme, and we have seen no important changes in the lifetime (perhaps 50%).

About the bootstrap mechanism: It is true that it has a positive effect as Winterberg has pointed out. But we think that one should not speak about a critical mass reduction.

[1]RANDALL K. COLE, Jr. and JAMES H. RENKEN, *Nucl. Sci. Eng.*, **58**, 345 (1975).

[2]F. WINTERBERG, *Nucl. Sci. Eng.*, **59**, 68 (1976).

[3]W. SEIFRITZ and J. LIGOU, *Nucl. Sci. Eng.*, **56**, 301 (1975); also, *Trans. Am. Nucl. Soc.*, **18**, 18 (1974).

[4]J. LIGOU, "Neutronic Studies of Micro Fission Chain Reactions," TM-RH-553, Eidg. Institut für Reaktorforschung, Würenlingen (1975).

[5]C. E. BAIRD, *Nature*, **253**, 525 (1975).

[6]W. SEIFRITZ, *Trans. Am. Nucl. Soc.*, **19**, 10 (1974).

[7]W. SEIFRITZ, "The Ignition Probability of Micro-Fission Explosions," TM-GL-14, Eidg. Institut für Reaktorforschung, Würenlingen (1975).

[8]G. I. BELL and S. GLASSTONE, *Nuclear Reactor Theory*, Sec. 9, pp. 468-472, Van Nostrand Reinhold Company, New York (1970).

[9]A. D. KRUMBEIN, *Trans. Am. Nucl. Soc.*, **18**, 19 (1974).

The definition of the critical mass has nothing to do with the presence of an extraneous source. The ion temperature (10 keV) is again too high, and probably in this case $\lambda = \beta_2 > (\alpha_2\beta_1)^{1/2}$, which means that for such a temperature the plutonium triggering is no longer necessary, and the pure thermonuclear system is able to grow exponentially. From the ignition point of view the fissile core is useful only if the compression does not bring DT to a temperature high enough for thermonuclear self-ignition.

Returning to Ref. 1 and the compression energy requirement, we agree with the value given by Cole and Renken. It is rather high, ~10 MJ, and is only a part of the total input energy (of order 1/10). Nevertheless, the gain on the fission side only is on the order of 1000 (Ref. 4).

In conclusion, we think that it would still be interesting enough to consider dry ^{6}LiD-reflected ^{239}Pu pellets for a high-yield-per-pulse system. However, one should think simultaneously about the containment problems that have to be solved even for energy yields on the order of 10^{10} to 10^{11} J (equivalent to 2.5 to 25 tons of TNT). The so-called "falling evaporating molten-salt blanket concept"[10] is one very promising possibility for an effective blast wave attenuation, so that the containment volume has reasonable technical dimensions. Furthermore, machines to produce highly intensive beams of relativistic electrons, ions, or neutrals have to be developed[11] to provide the necessary beam energy to initiate the gas dynamic ablation process in an outer shell of the pellet to compress the whole system. After the solution of all these problems, there might be a peaceful use of the microbomb system described that resembles, on a microscale, large hydrogen bombs. But then it would be perhaps better to speak about "miniexplosions" rather than "microexplosions."

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[10]W. SEIFRITZ and H. NAEGELE, *Trans. Am. Nucl. Soc.*, **21**, 18 (1975).

[11]M. V. BABYKIN, "Plasma Heating by High Power Relativistic Electron Beams," Seventh Conf. Controlled Fusion and Plasma Physics, Lausanne, September 1-5, 1975.

Response to "Comments on 'Analysis of the Microfission Reactor Concept' "

We are in substantial agreement with the comments of Ligou and Seifritz,[1] but would like to clarify two points.

Equation (8) in our original paper,[2]

$$N_0 \exp\left[\int_{t_c}^{t_c+\tau_l} \alpha(t')\,dt'\right] \approx N_A \quad , \tag{8}$$

was perhaps not adequately discussed there. We wanted to derive a simple estimate of the Rossi-α (or degree of supercriticality) necessary to achieve an explosive yield without entering a discussion of dynamics. It is necessary (but not sufficient) that Eq. (8) be satisfied. With the observation that the integral is *at most* $\approx\frac{1}{2}\,\alpha_{max}\tau_l$, this leads to the requirement

$$R_c\,\alpha_{max} \gtrsim 2v_s \ln (N_A/N_0) \ .$$

This is admittedly a very rough lower bound on α_{max}; the point is that for *no* dynamic development could the necessary α_{max} be substantially smaller. We agree that an explosive excursion will be terminated by burnup rather than by disassembly and wish to point out that the integral in Eq. (8) is therefore $\approx\frac{1}{2}\,\alpha_{max} t_{burnup} < \frac{1}{2}\,\alpha_{max}\tau_l$, which increases the requisite α_{max}. The logarithmic dependence of α_{max} on the initial neutron population N_0 is so weak that increasing N_0 from our value of 10^3 to the Ligou and Seifritz value of 10^{15} reduces the required α_{max} by only a factor of ~3. Interestingly, this is close to the ratio of our estimate, 3.5×10^{10} sec^{-1}, to their 1.47×10^{10} sec^{-1}.

With regard to the effectiveness of neutron-reflecting layers in reducing the size of explosively supercritical assemblies, there is actually no real difference of opinion between Ligou and Seifritz and ourselves. The *apparent* difference is simply a matter of interpretation and emphasis. Our precise statement was that a reflecting layer "does not significantly reduce the work necessary to produce a fission yield from a fractional-gram pellet."[2] Compared to the several orders of magnitude by which the work requirement must be reduced to achieve commercial practicality—or even near-term possibility—10 or 20% cannot be considered at all significant and a factor of 2 only marginally so.

We have performed additional calculations for a ^{6}LiD reflector, exactly as for the other materials discussed in Ref. 2, and included the case $\alpha = 1.5 \times 10^{10}$ sec^{-1} to permit direct comparison with results quoted by Seifritz and Ligou.[1,3] The results are shown in Figs. 1 and 2. In addition to data given in Ref. 2, we have used $\rho = 2160$ g/cm^3 and $\rho E = 1.35\ P$ for ^{6}LiD at a pressure of 10^{18} dyn/cm^2

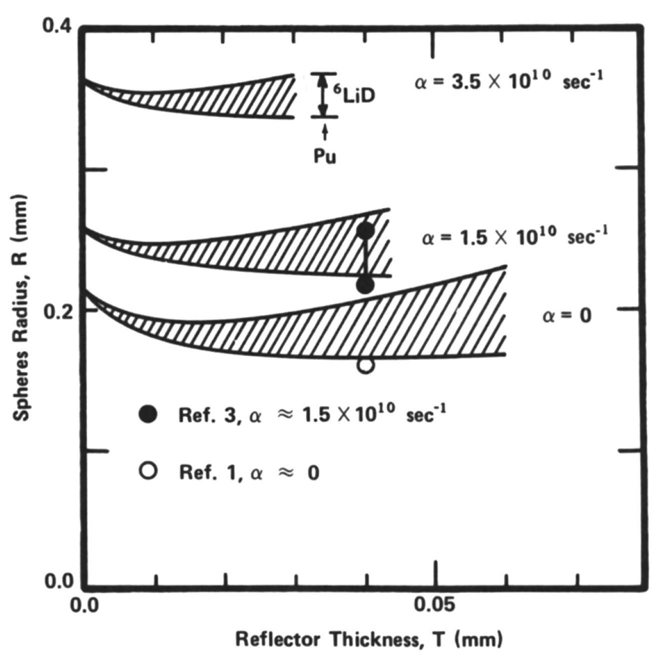

Fig. 1. Dimensions of ^{6}LiD-reflected spheres for various supercriticalities at 10^{18} dyn/cm^2.

[1]J. LIGOU and W. SEIFRITZ, *Nucl. Sci. Eng.*, **60**, 483 (1976).

[2]RANDALL K. COLE, Jr. and JAMES H. RENKEN, *Nucl. Sci. Eng.*, **58**, 345 (1975).

[3]W. SEIFRITZ and J. LIGOU, *Nucl. Sci. Eng.*, **56**, 301 (1975); also, *Trans. Am. Nucl. Soc.*, **18**, 18 (1974).