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FEASIBILITY STUDIES OF THERMONUCLEAR NEUTRON CAPTURE SYNTHESIS OF SHE*

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ABSTRACT

A variety of thermonuclear neutron sources and neutron capture targets have been investigated for their potential of allowing significant heavy, perhaps superheavy isotope production. The neutron sources considered range from inertial confinement microexplosives to (underground) macroexplosives. Optimal capture target appear to be composites containing uranium and protactinium.

INTRODUCTION

This paper is a review of two previous publications (Refs. 1 and 2) amended by the publishable part of some recent results.

Prompt neutron capture synthesis in thermonuclear explosions appears to be the major alternative to heavy ion fusion as a "Laboratory" approach to Superheavy Elements. In this approach, unfortunately, much of the "Laboratory" is blown up (a feature which makes it difficult to get sponsors for such experiments). Heavy element producing nuclear explosions have nonetheless made significant contributions to fundamental nuclear physics, viz.

- Discovery of several new neutron rich isotopes
- Discovery of symmetric low energy fission
- Other new information on properties of heavy nuclei, $\bar{\nu}$, σ_{fission}
- Insight into stellar processes
- Diagnosis of possible superheavy element structures.

REVIEW AND ANALYSIS

The most notable experiment in this area has been the Hutch event (ref. 3), an underground explosion involving the exposure of 17.8 g of ^{238}U and 8.8 g of ^{232}Th to a neutron fluence of about 30 moles/cm². Some major points for our discussion here can be explained with the use of Fig. 1. The curve labeled "medium" yield explosion -- with my apologies to the Hutch designers -- refers to the best shot so far. Neutron exposure time in a thermonuclear device of this type is less than 10^{-8} sec., i.e. much shorter than any beta decay. This will give a yield distribution of isotopes vs. atomic number as labeled here y_0 . This is the instantaneous, i.e. $< 10^{-6}$ sec. yield of isotopes with proton numbers equal to or one unit lower than the target. Then follows beta decay and we eventually -- in Hutch -- arrived at a yield curve y_∞ as shown here in Fig. 1. The disappointing feature of y_∞ is its abrupt termination at mass number 257. Currently this appears to be well understood from nuclear structure predictions giving an area of high spontaneous fission competition as indicated.

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Fig. 1. Heavy element yield in nuclear explosions and nuclear structure

This explanation is also supported by evidence from explosions involving higher Z targets such as Pu and Am. Further discussion on these structure questions can be found in References 1, 2 and, of course, in other papers, notably those of Sven Goesta Nilsson and Adam Sobiczewski, given at this meeting. Taking this picture for granted, we can ask what should be done to improve the heavy or perhaps superheavy isotope yield, given this basis? Several years ago, I had naively considered the possibility of modulating neutron sources time dependently (Ref. 4) similar to what astrophysicists now call dynamic or explosive r -processes. After doing some real work in the explosive design area, I postponed any thought of multi-exposure schemes in view of the formidable technological difficulties. Inertial confinement fusion micro-explosions (Ref. 2) will eventually provide enough controllability; unfortunately, that is a very futuristic question. In the interim -- perhaps for the next 10 years or so -- we might find it worthwhile to consider an easier solution, specifically a heavy isotope yield increase in macro-explosions, i.e. a shift to higher A as indicated in Fig. 1 by the dashed instantaneous yield curve. The major factors determining the length and population of an isotope chain are, of course, flux and cross sections (target compositions). In practice, flux limits are posed for instance by the amount of funds spent on the source device. A conservative view is then obviously that we can't go much beyond Hutch. The cross section chain of a given target is therefore crucial. Target optimizations are, in fact, the area where we made most of our progress recently.

Previous calculations were simplified in that a flash exposure was assumed without regard to dynamic effects; i.e., the time integrated flux from a thermonuclear explosion simulation code was used in a pseudo-static model. We found this to be very inaccurate in many cases and certainly it was too crude to allow any real design optimization. It appears that order of magnitude improvements are indeed possible by carefully studying all reactions time dependently in the explosion environment.

We started a major effort -- in collaboration with Ron Cusson (Ref. 5) -- in order to improve the prediction of the crucial cross sections here. As a result, a computer program, NIFPR, has been developed which uses semi-empirical nuclear theories for the calculation of all significant cross sections for isotopes exposed to typical thermonuclear neutron spectra. This code is especially useful for heavy elements where fission competition is significant.

The methods used are similar to those introduced by Cameron and Truran (Ref. 6) for r-process calculations. In addition, a new, "multiple chance" algorithm has been developed for high energy neutron reactions of very neutron-rich isotopes. Pre-equilibrium processes are taken into account via the Griffin model. The code is designed to predict multiple chance neutron induced fission, neutron capture, multiple neutron emission, (n,p) and (n, α) reactions. One application is the extension of the ENDL type cross section libraries used in thermonuclear Monte-Carlo calculations to include plutonium, uranium and protactinium isotopes up to A $\approx$ 260.

A NEW EXPERIMENT

Using the preliminary results from this nuclear theory program as input for large scale explosion simulations, we found a rather different target exposure scheme and different target compositions to be optimal. Specifically, it seems desirable to use about equal amounts of uranium and protactinium (instead of thorium). On the basis of our current knowledge we also suggest the following features for any new experiment:

- Small scale (fast) and large scale sample recovery
- $\bar{\nu}$ counting to determine isotope yield before decay

The fast recovery fraction should allow us to detect traces of heavy isotopes that fission during beta decay which might just take a minute or so. We expect, for instance, some characteristic fragments indicating large N parent nuclei. A major effort should be neutron multiplicity analysis of an early sample as discussed in more detail in Reference 1. We note, however, that high neutron multiplicities might not be as pronounced a fingerprint of super-heavy elements as was assumed in Reference 1. This is a recent result described in Darleane C. Hoffman's paper at this conference.

The large scale recovery mentioned above might require an explosion in a natural salt formation. This would produce useful quantities of ^{250}Cm and ^{257}Fm -- very promising heavy ion fusion target materials, as pointed out in various papers at this meeting.

CONCLUSION

This is an interim report of an on-going feasibility study. Many improvements seem to be possible in this approach and many important basic physics questions can be addressed this way. We hope to continue and even expand the international collaboration on the various nuclear theory questions involved.

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