CONF-770635--2

LA-UR-77-1304

TITLE: ON THE PROBLEM OF EVALUATING THE SAFETY OF AN EXPLOSIVE

AUTHOR(S): Louis C. Smith

SUBMITTED TO: Conference on the Standardization of Safety
and Performance Tests, Dover, NJ,
June 21-23, 1977

MASTER

los alamos
scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87545

Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

REA

ON THE PROBLEM OF EVALUATING THE SAFETY OF AN EXPLOSIVE

Louis C. Smith

University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

ABSTRACT

Some general considerations on the problem of evaluating the safety of an explosive lead to the reasons why the much-criticized drop-weight impact machine remains an important tool in most explosives research and development laboratories. Problems related to the design, calibration, and use of such machines, and certain misconceptions concerning the interpretation of the test data, are discussed. The results of an unsuccessful attempt to construct a more comprehensive hazards scale also are described.

ON THE PROBLEM OF EVALUATING THE SAFETY OF AN EXPLOSIVE

Louis C. Smith

University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

Any laboratory engaged in the development of explosives for military applications must devote some fraction of its efforts to the problem of devising reliable methods of assessing the sensitivity of an explosive under the various conditions of interest. Not only is it of local importance that those working with a new or modified explosive should have some method of gauging the relative degree of hazard involved, but further, in recommending any new material for use in a particular application, it is absolutely essential that it have been demonstrated as clearly as possible that the new material has a level of sensitivity compatible with that application, and with the production and loading techniques incidental to getting it into the weapon.

Unfortunately, the problem of measuring the sensitivity of an explosive is an exceedingly complex one. The reasons for its complexity can be stated in various ways, but fundamentally the situation seems to be as follows: The sensitivity of an explosive is not a property defined solely by the chemical composition of the material, but, on the contrary, depends more or less importantly on a variety of physical and mechanical details of the particular sample being studied, and of the particular sensitivity test being used. To anyone attempting to measure the sensitivity of an explosive, or attempting to determine the relative sensitivities of a series of explosives, the most annoying consequences of this state of affairs are, first, that many sensitivity tests exhibit nontrivial irreproducibilities, and, second, that different sensitivity tests will not, in general, arrange a given series of explosives in the same order of sensitiveness.

Explosives chemists struggled with these difficulties for many years before the elemental nature of their origin became generally recognized. As a result, considerable effort was devoted to the search for <u>the</u> sensitivity test, which would reproducibly place all explosives in their <u>correct</u> order of sensitiveness. This search we now recognize as hopeless, although the work was not without profit and, indeed, continues today, but with somewhat altered objectives. In any event, we now realize that when we speak of the sensitivity of an explosive, we are not talking about a single, well-defined property of the material, but about a complex pattern of its behavior. The last statement of the preceding paragraph implies that the sensitivity pattern of one explosive is not simply related to that of another.

Thus far we have discussed the problem mainly from the point of view of trying to measure sensitivity, but the same difficulties encountered there plague us from yet another, equally important direction, as follows: A primary objective of most practical work on sensitivity (and the ultimate justification for almost all work on sensitivity) is that of avoiding accidental explosions in the production, loading, and use of explosives. In a few cases, such as initiation by a static discharge, the nature of the hazard and the conditions under which it is likely to arise can be specified in sufficient detail that pertinent tests can be devised, and safe/unsafe criteria can be adopted on some basis or other. Unfortunately, after these relatively simple cases have been subtracted from the problem, we are still left with the bulk of it -- the miscellaney of blows, scrapings, crushings, etc, to which an explosive is subjected, deliberately and accidentally, singly and in combination, in the course of its travels through the various operations. We include perforce in this class those causes of accidents that are inherently isolable, but whose importance is not foreseen. The stimuli that contribute to this source of hazard are so varied in nature and so unpredictable in violence (particularly under those circumstances that are truly called "accidents"), and, finally, are applied to the explosive under such a wide variety of local conditions, that *we cannot even define what it is we are trying to measure except in the broadest terms*. Quite aside from the much debated statistical aspects of the problem, the sensitivity scale of interest here is one that represents some kind of a weighted average response of the explosive to a variety of stimuli, under a variety of conditions. The relevance of the difficulties, irreproducibility of response and nonconstancy of order, to the problem of defining the scale are obvious.

In one sense we have a method of ordering explosives on this sensitivity scale, for it is precisely this which an impact machine, properly designed, calibrated, and used, is intended to accomplish. The test has the further virtue that it can be carried out quickly by untrained personnel with only a few grams of sample. Thus while the test is the subject of widespread criticism, sometimes even for the *right* reasons, it continues to occupy a unique and essential place in most explosives research and development laboratories.

The key phrase in the preceding paragraph is "properly designed, calibrated, and used". The implications of those words seem to have escaped many people, and much of what follows will be devoted to a discussion of them.

First of all, what's so hard about designing an impact machine? Nothing! Anyone can, and many people have. The trouble is, when the machine is put into use, the results it produces are quite likely to be sheer nonsense. Having constructed this monster, however, the designer may continue to use it even though he knows it is producing unbelievable data. He uses it, he swears at it, and therein lies the cause of one of the unjustified criticisms of drop-weight impact machines.

The source of the problem is not hard to find, and it can be stated very simply: The sensitivity ordering of a series of explosives can be affected drastically by minor changes in the design of the critical parts of the machine. I once had the dubious distinction of designing a machine - a minor modification of the one we still use - that nearly inverted the commonly accepted order of sensitivity of a series of test explosives.

Let us look at a few other examples. In Fig. 1 I have plotted Figure of Insensitiveness data obtained with the ARD/Woolwich machine (picric acid = 100) vs the corresponding 50% points determined on the ERL Type 12 machine at Bruceton. The two sets of data were obtained on supposedly identical samples. The eye tells it all, but for those who like numbers the value of r^2 (r = coefficient of correlation) for this plot is 0.19.

Figure 2 is another example; data obtained from what was then the Naval Powder Factory at Indian Head are plotted against the ERL Type 12 data. The value of r^2 in this case is 0.12.

But, you say, the trouble might be in the ERL machine. What happens if we plot the ARD data against the NPF data? The answer to that, of course, is shown in Fig. 3. I must admit that this does look a little better, and the r^2 value is 0.43 - which still leaves much to be desired, especially in view of the fact that the critical parts of these two machines do have certain similarities.

Similar examples are the rule rather than the exception. During World War II, at the Explosives Research Laboratory at Bruceton, PA, Eyster and Davis discarded eleven different tool designs before they finally came up with the model many of us now use, the ERL Type 12 machine. As an example of the difficulties they encountered along the way, the Type 9 tools gave a 50% point of 131 cm for Comp A-3 and 143 cm for lead azide. I believe the NPF machine also gives a relatively high value for lead azide.

How, then, do we know when we have the right machine? Or, to put it another way, how do we calibrate the scale? I know of only one way. That is to test a series of explosives whose relative sensitivities (safety) we think we know and see if the design puts them in what we believe should be their approximate relative positions on the scale. If it does not, we discard the design and try again. If it does, we accept the design and proceed on faith that, having ordered the ones we know about in the "right" way, it will also order the ones we don't know about in the right way. That represents an important extrapolation, and one must ever be alert for the possible exception - a point I will return to later. Note, however, that if we use a machine that does not put the familiar explosives in the right order, we cannot have much confidence in its evaluation of new ones.

At this point I would like to digress a little to comment on the significance of the disagreements between machines of differing designs.

IMPACT MACHINES DON'T LIE!!!

What I mean by that is simply this: For the particular stimulus applied by a given machine, that machine will place all explosives in their correct order of sensitiveness! The trouble is, that stimulus may be almost totally irrelevant to the problem of evaluating the safety of an explosive. A corollary of this is that one cannot rely on any single test or even on the results of a single drop-weight impact test. At LASL we routinely run the test both with and without grit present - what we call the Type 12 and Type 12B tests, respectively.

We have now considered "designed" and "calibrated", and I now want to discuss "used". I will confine my remarks to just one part of the problem, a part that has been the subject of a great deal of confusion. The confusion typically arises in the form of the following statement: The trouble with impact machines is that we use them to determine 50% points or 10% points, whereas what we are really interested in are the very low percentage points - one in a million, say. The situation is illustrated in Fig. 4 for a normal distribution of mean (μ) zero and standard deviation (σ) one. Probabilities are given on the ordinate, σ units on the abscissa. The circles denote μ and μ ± σ, the + the 10% point determined by one of the commonly used staircase methods - the approximate lower end of the experimentally useful range. The bracket marks off the "accident" region on the probability scale - some four to five σ units from the mean. Obviously, then, if our machine is used to determine 50% points, what we should do is extrapolate the results to -5 σ and compare the relative sensitivities of our explosives at that point.

WRONG!!

AN INTEGRAL PART OF THE DESIGN AND CALIBRATION OF ANY IMPACT MACHINE IS THE STATISTIC DETERMINED AND THE PROCEDURE USED TO DETERMINE IT.

I will illustrate what I mean using some Type 12 data obtained for me at NOL while I was working there some years ago.

As most of you know, we use the Bruceton up-and-down method to estimate the 50% point and the standard deviation on the assumption that the underlying distribution is log-normal; it is one of the few staircase methods that gives an estimate of σ, perhaps the only one. Thus the machine is calibrated and used, and explosives are compared in terms of 50% points. What happens if we try to use our results to compare explosives at very low percentage points?

The data I will use consist of 1000-shot runs on six different explosives, generated to study various statistical aspects of the test. The estimates of the 50% points and standard deviations are as follows:

	h(cm)	s(log units)
PETN	12.4	0.1343
RDX	23.9	0.1123
Comp B	60.4	0.1306
Comp B, D-2	110.8	0.1324
HBX	95.7	0.1894
Comp A-3	58.8	0.0870

In Fig. 5 I have plotted the log of the drop height against log h_{50} - xs. What we find is that the lines cross. The ordering (decreasing sensitivity) at the 50% point is

PETN > RDX > (Comp A-3, Comp B) > (HBX, Comp B, D-2).

For $P = 10^{-6}$ we get

PETN > RDX > HBX > Comp B > (Comp A-3, Comp B, D-2).

I remind you that these are large runs on reasonably familiar materials. The situation can only get worse as I add the results of routine tests on experimental materials to the graph.

Let me put it another way. There are two possibilities:

a) The σ's are really all the same, in which case it doesn't matter at what percentage point I compare explosives, since the lines are parallel.

b) The σ's are not all the same, in which case if I have designed a machine to give the correct scale when it is used to determine 50% points, it must give an incorrect scale when operated at some other percentage point.

That is very fortunate, of course, since the 50% point is the one that's easiest to determine. Note also that estimates of σ are quite imprecise under the usual test conditions.

While we have a reasonable amount of confidence in the Type 12 machine, we are also certain that it may seriously misjudge some materials. It is for that reason that we routinely run both 12 and 12B tests on new materials. We are especially wary of explosives that appear moderately sensitive in the Type 12 test and even more sensitive in the Type 12B test; most explosives give the higher 50% points in the Type 12B machine.

Enough about impact machines! I would now like to discuss, very briefly, a different aspect of hazards analysis.

In many sensitivity tests (and in many situations of practical interest), the response of an explosive ranges more or less continuously over the scale completely inert, small partial, large partial, high-order detonation. In some tests, such as the drop-weight impact machine, the sensitivity of an explosive is determined on the basis of the ease with which a relatively mild, incomplete reaction of the sample is obtained. In other tests, such as the gap test, the comparison is made on the basis of the ease with which high-order detonations are obtained. With still other tests, such as the bullet impact test, it is sometimes possible to compare the sensitivities of various explosives in two ways -- ease of initiation to an observable reaction of any sort, and ease of initiation to a relatively violent reaction.

Both levels of response are of importance in evaluating the hazards involved in handling an explosive, for a relatively mild partial explosion can be a source of personal injury in itself, and also may, under favorable conditions (such as a high degree of local confinement), grow into a violent reaction or even a high-order detonation. Accidental high-order detonations, obviously, are hazardous in the extreme.

This suggests that in evaluating the safety of an explosive we must consider both its "ease of initiation" and its "ease of detonation". Qualitatively, an explosive may exhibit these properties, in combination, in the following four ways, listed in order of decreasing hazard:

a) Easy to initiate and easy to detonate.
b) Difficult to initiate, but easy to detonate.
c) Easy to initiate, but difficult to detonate.
d) Difficult to initiate and difficult to detonate.

We could, therefore, attempt to place an explosive in one of these classes on the basis of the results of our tests.

At first sight it might appear that combination b) should be excluded from consideration on the grounds that it is not a self-consistent classification. However, if we do attempt to omit it, we soon find ourselves in difficulty, as we will demonstrate by an example. The ease of initiation of TNT, as determined by our drop-weight test, is largely independent of the physical form of the sample. On the other hand, its ease of detonation, as determined by the LASL gap test, is strongly dependent on both the density of the charge and on whether it was made by casting or pressing. This is evident from the following data:

	50% Gap, mm (density, g/cm^3)	
	High Density	Bulk Density
Flake TNT		37.1 (0.87)
Cast TNT	28.3 (1.615)	
Granular TNT	49.4 (1.626)	60.1 (0.73)

Certainly TNT deserves to be classed as difficult to initiate, and cast TNT as difficult to detonate, but where do we put pressed (granular) TNT?

Simply admitting b) as a possible combination to be used in our classification scheme does not, of course, solve the problem. So long as we are comparing only two explosives, the idea of doing so on the basis of their relative ease of initiation and relative ease of detonation seems to be a useful one, but when we attempt to expand the comparison to include more and more explosives, we soon run into trouble. The difficulty is that the scales for ease of initiation and ease of detonation are continuous scales, and the possible combinations cannot be adequately represented, even in a qualitative way, by as few as four subclasses. The logical extension, then, is to look for a continuous scale that will represent a suitably weighted combination of these two properties (assuming we have some way of determining them in the first place).

A crude attempt at constructing such a scale is shown in Fig. 6, which is in the form of a nomograph*. For ease of initiation I have simply used the log of the 50% point, in centimeters, from the drop-weight impact machine. For ease of detonation I have used the log of the weight of 80/20 - PETN/silicone rubber required to detonate the explosive in our version of the minimum priming charge test; the test measures the ease of initiating a detonation from a highly divergent, hemispherical wave. Here we see a striking example of how different sensitivity tests produce different sensitivity orderings.

The question is, Can we construct a scale somewhere between the two outer ones that would provide us with some "index of potential destructiveness"? If, for example, we construct the scale at the point marked by the arrow, using the scale at the right, we obtain the following indexes:

9404	45
Pentolite	68
Comp A-3	95
Octol	128
Cyclotol	185
Comp B	243
DATB	560
TNT	1170
Exp D	1500

Is this a useful scale? I don't know. In a sense the impact machine is supposed to do this whole job for us - but the impact machine does not respond to the physical form of the explosive, and we know that, in shock-sensitivity tests, pressed explosives are much more easily detonated than cast ones are. To me that means that a pressed cyclotol charge is potentially much more hazardous than a cast one, and the combined scale will reflect that fact. Nonetheless, my personal opinion is that we cannot express the safety of an explosive by a

---

* An earlier version of this scale appears in a paper by A. Popolato, Proceedings of the International Conference on Sensitivity and Hazards of Explosives, Session 6; London, 1963. This paper also contains descriptions of the LASL versions of the drop-weight impact and gap tests.

single number, so I do not suggest this as a major breakthrough in the solution of the problem.

What, then, is our situation? To do an adequate job of determining the safety of an explosive, we must compare it with familiar materials in a variety of relevant, properly designed sensitivity tests. Inevitably, those tests will produce inconsistent data. There is no magic formula for resolving those inconsistencies. The final decision must still represent the subjective judgement of an experienced individual who carefully examines the data. I see no prospect that this situation will change fundamentally in the foreseeable future.

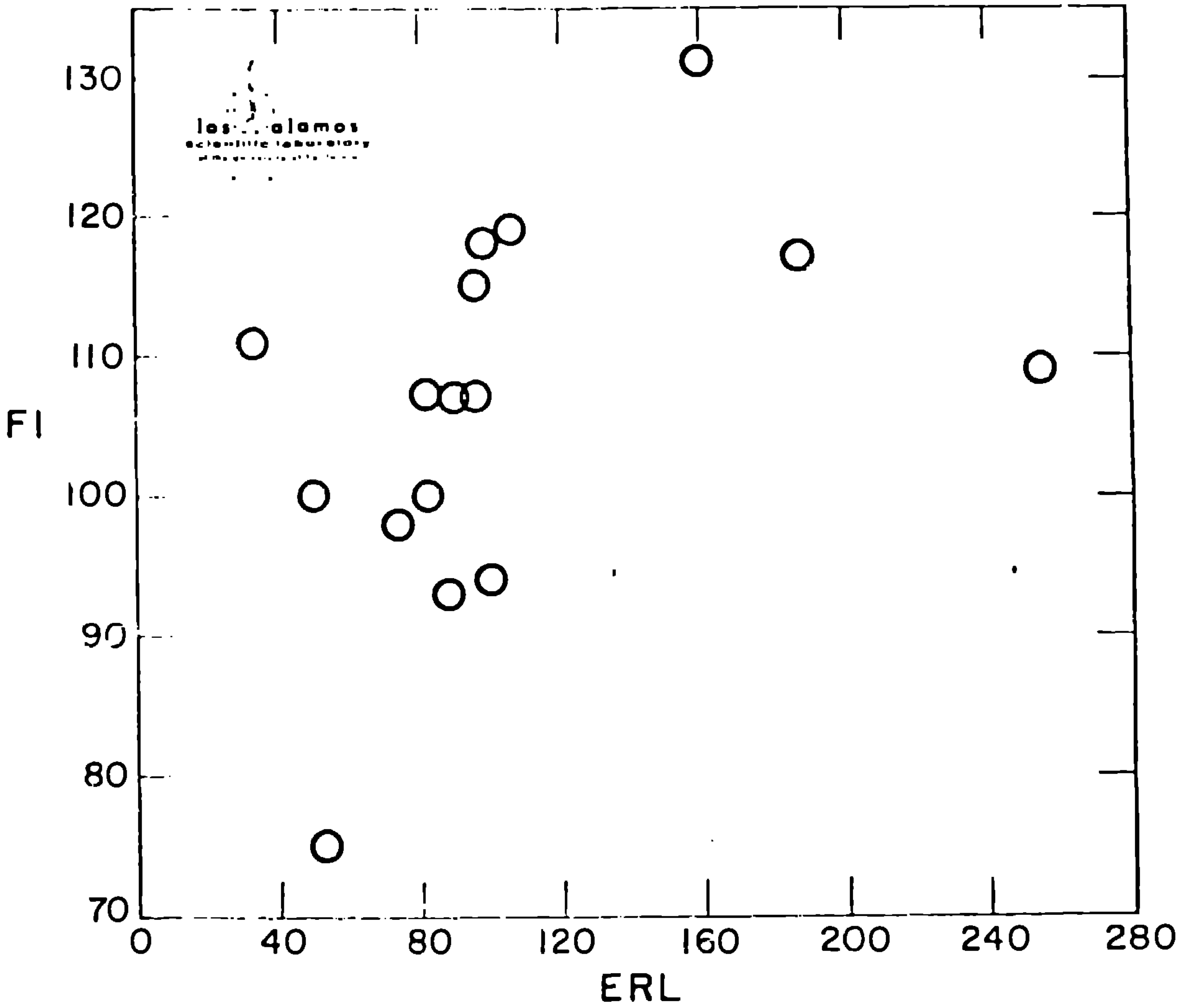

130
120
110
100
90
80
70
FI
0
40
80
120
160
200
240
280
ERL
los alamos
scientific laboratory

FIGURE 1

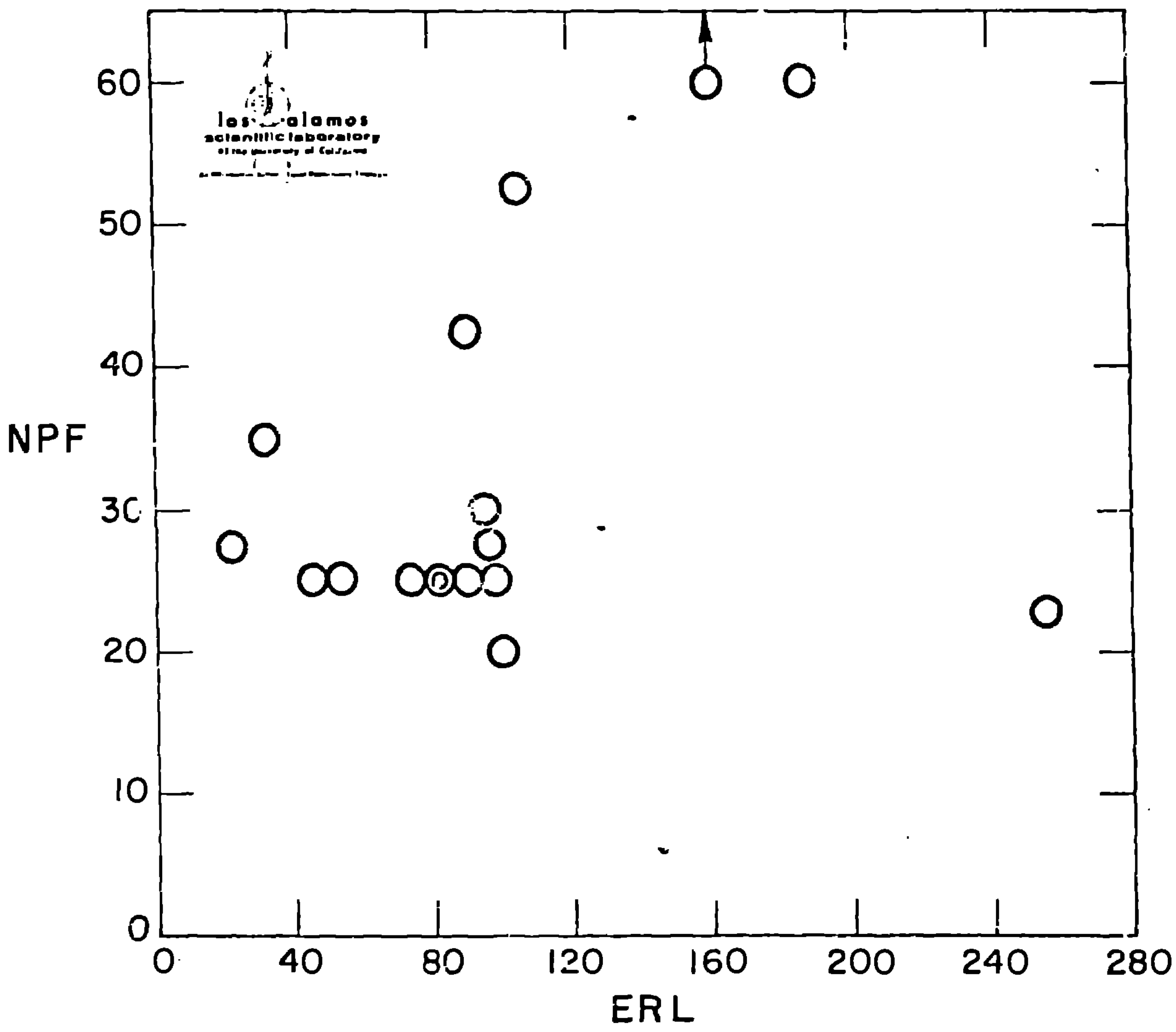
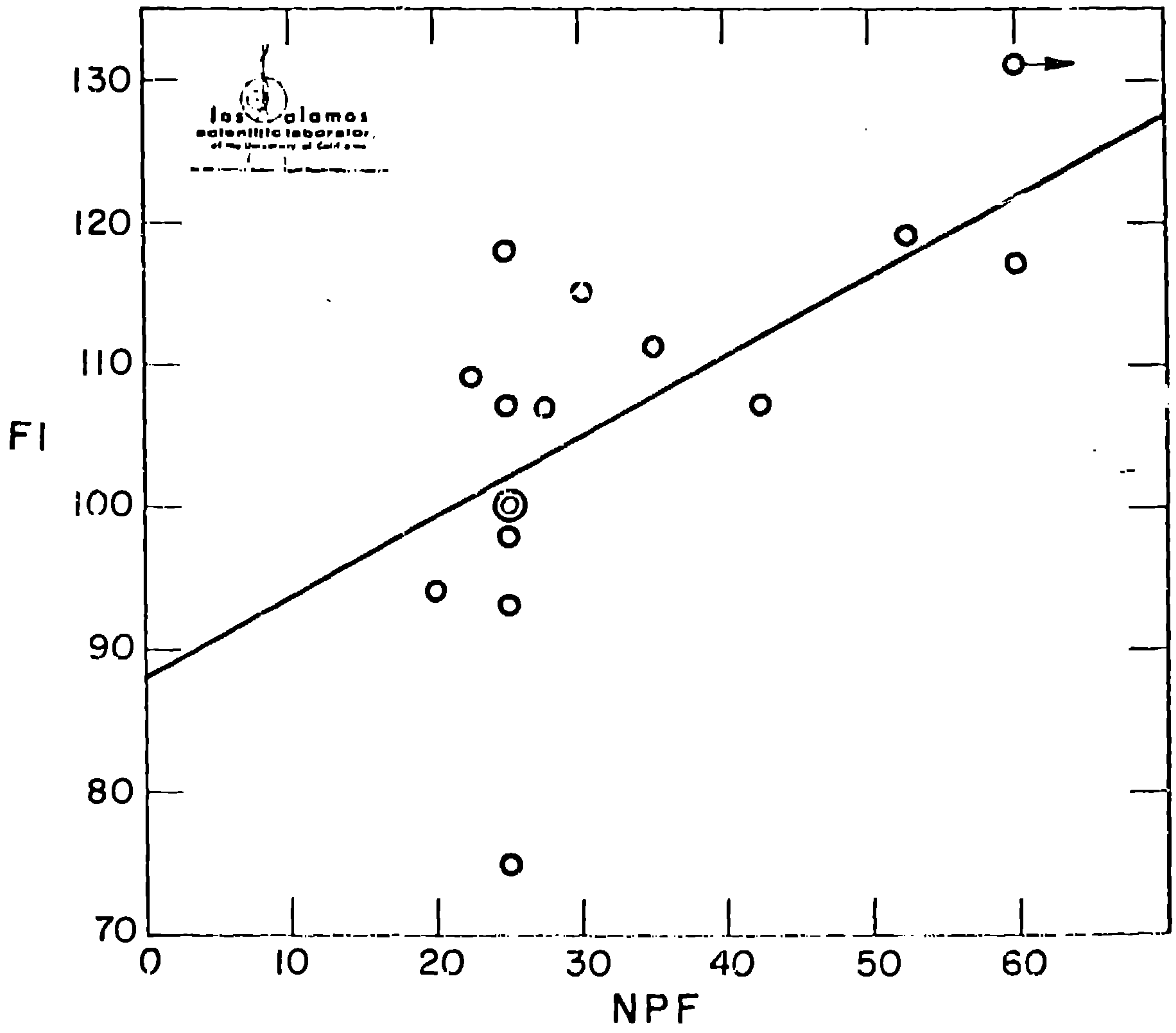

los alamos
scientific laboratory
60
50
40
NPF
30
20
10
0
0
40
80
120
160
200
240
280
ERL

FIGURE 2



130
120
110
100
90
80
70
FI
0
10
20
30
40
50
60
NPF
los alamos
scientific laboratory

FIGURE 3

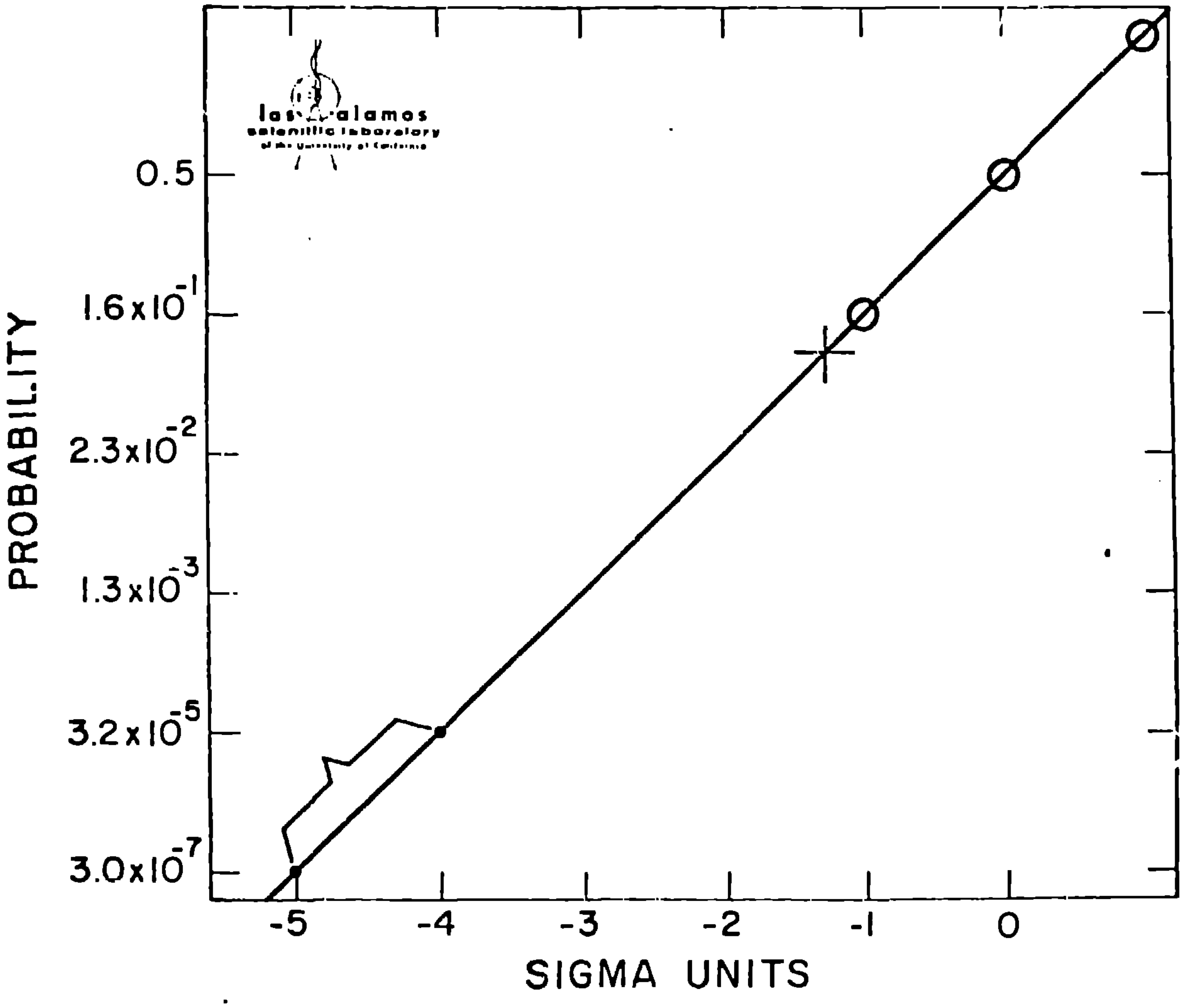

PROBABILITY
0.5
1.6x10^{-1}
2.3x10^{-2}
1.3x10^{-3}
3.2x10^{-5}
3.0x10^{-7}
-5
-4
-3
-2
-1
0
SIGMA UNITS

FIGURE 4

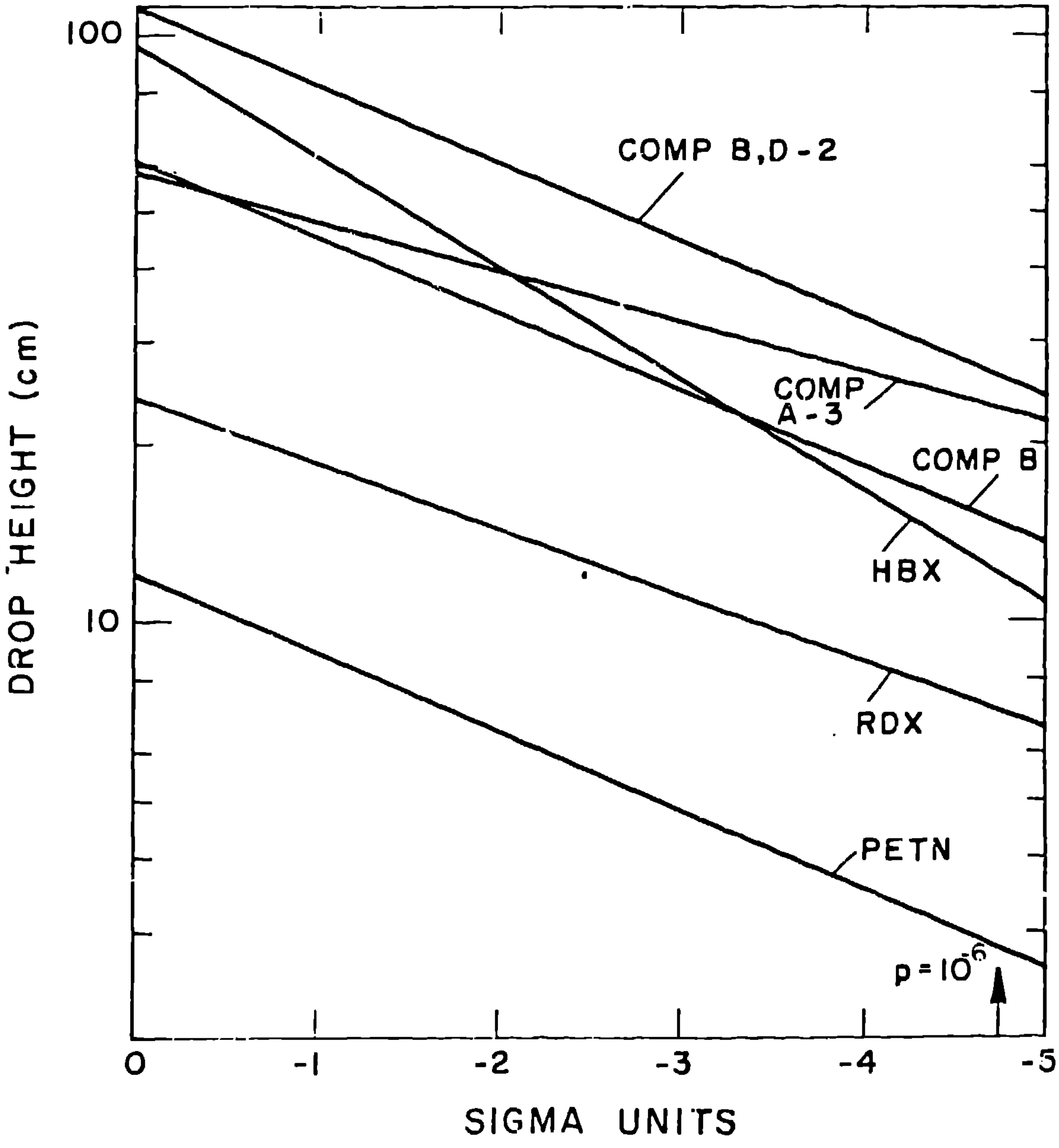

100
10
DROP HEIGHT (cm)
0
-1
-2
-3
-4
-5
SIGMA UNITS
COMP B,D-2
COMP A-3
COMP B
HBX
RDX
PETN
$p = 10^{-6}$

FIGURE 5

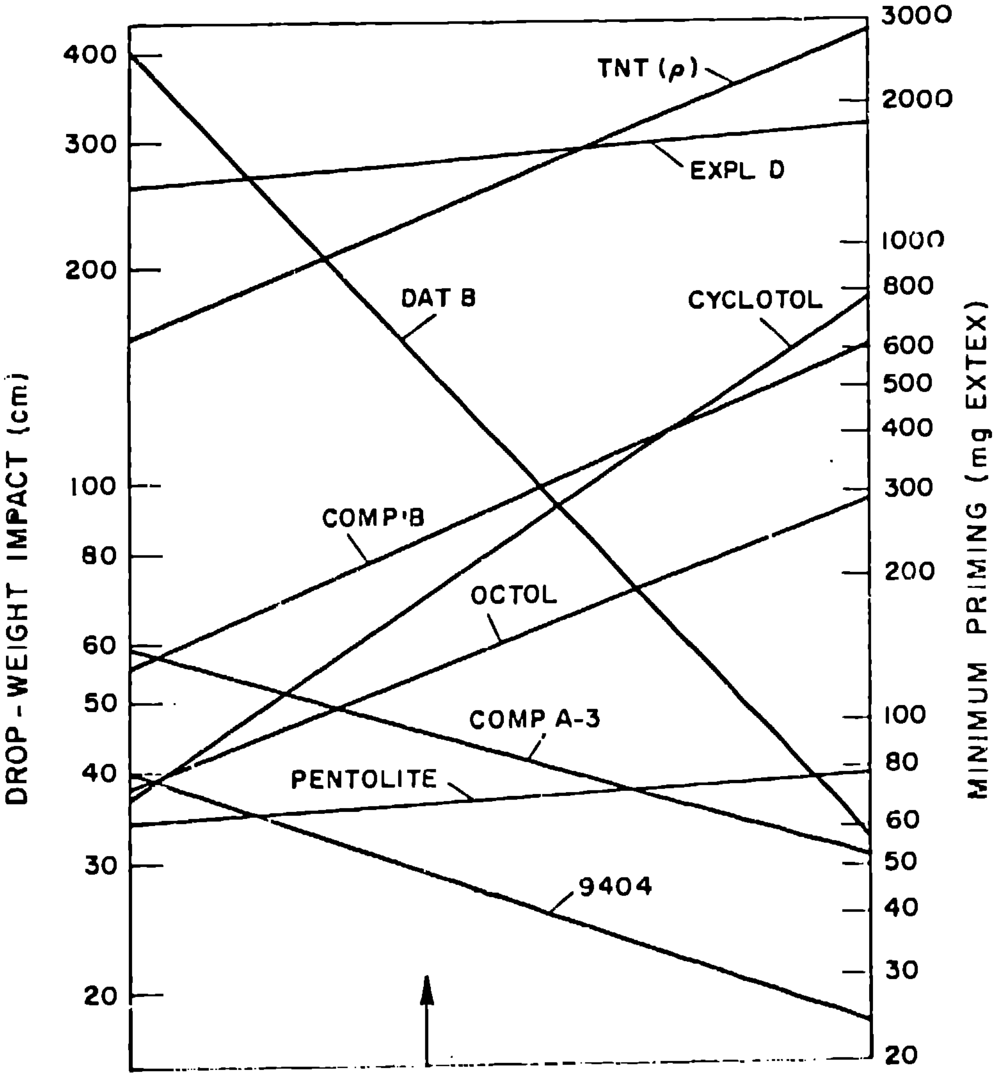

DROP-WEIGHT IMPACT (cm)
400
300
200
100
80
60
50
40
30
20
MINIMUM PRIMING (mg EXTEX)
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
TNT (ρ)
EXPL D
DAT B
CYCLOTOL
COMP B
OCTOL
COMP A-3
PENTOLITE
9404

FIGURE 6