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Ballistic Trajectory Modeling for the Insensitive Munitions Type IV/V Hazardous Fragment Threshold

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(U) Currently, the 20J fragment projection curve in TB-700-2 [1] (which also appears in AOP-39 [2]) is being used by the Insensitive Munitions (IM) community to distinguish between Type IV (deflagration) and Type V (burn) responses, in conjunction with other experimental evidence. Each fragment is collected after an IM test, and its distance from the origin is compared to a critical throw distance which depends on its mass, defined by the 20J curve. If this distance is exceeded for any of the fragments, the reaction is deemed a Type IV. Substantial resources are being expended to obtain Type V reactions for various munition systems, and thus it is important for this criterion to be meaningful and sufficiently accurate, while also being practical and inexpensive to use.

(U) The current 20J curve is relatively restrictive in the sense that it is too massdependent, and thus causes Type IV designations due to large, slow-moving fragments which do not appear to be dangerous. For this reason, various efforts have recently been undertaken by the community to come up with an improved and more meaningful criterion for what a Type V should indicate. Some matters of contention included the intent of the curve (severity and mechanism of injury), the appropriate hazard metric (energy, energy per unit area, etc.), the conditions at which the metric applies (launch, impact, impact at some distance), if and how the criterion should vary for different shapes and materials, how many fragments must fail the criterion before a Type IV is declared, and the meaning of a 15m distance requirement which appears frequently in the documents [1, 2]. These ambiguities led to some exploratory trajectory modeling being performed to try to reproduce the curve, as there was no documentation available which adequately explained its origin. A point mass ballistic trajectory code similar to TRAJ [5] and a univariate optimization tool were written and validated for this purpose. It was found that the curve in [1, 2] represents the maximum distance a chunky steel warhead fragment [4] could travel with a 20J launch energy. While a 20J impact energy curve would be desirable, the hazardous distances associated with non-negligibly small masses become unbounded.

(U) The community decided to keep 20J as the hazard metric, but changed it to a 20J impact at 15m criterion, with a different curve for each of several fragment densities. This curve guarantees that if the criterion is violated, a person standing at 15m would be hit with a 20J impact if the trajectory were lowered. The authors have constructed the mass-distance curves being incorporated into the new version of AOP-39. This paper documents the methodology and assumptions involved in generation of the new curves. It is hoped that this work will help elucidate the details and limitations of the criterion as well as areas in which potential improvements can be made, since the criterion is currently of significant consequence to the success or failure of various IM programs.

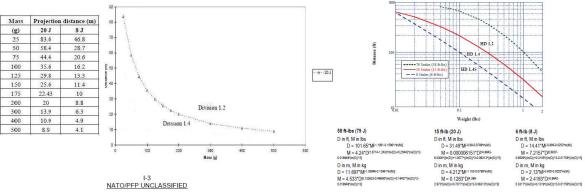
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(U) Background and Objectives

(U) All U.S. munitions are required by international agreement to be made Insensitive Munitions (IM) compliant to the extent practical. This entails that the munition in both its operational and logistical configurations must react nonviolently when subjected to a wide array of simulated threats encountered on the modern battlefield. These include fragment and bullet impact (FI/BI), fast and slow cookoff (FCO/SCO), sympathetic reaction (SR), and shaped charge jet impact (SCJI). Response severity is categorized as follows: detonation (Type I), partial detonation (Type II), explosion (Type III), deflagration (Type IV), and burn (Type V). The determination of reaction severity is made based on photographic evidence, witness plate damage, fragment size and throw distance, and blast gauge pressure readings.

(U) Currently, the 20J curve in TB-700-2 [1], which also appears in AOP-39 [2], is being used by the IM community to distinguish between Type IV (deflagration) and Type V (burn) responses. Fragments are picked up on the range after an IM test, and their distance from the origin compared to a critical throw distance, defined by the 20 curve, corresponding to the mass of each fragment. If this critical distance is exceeded, it is judged a Type IV. If this distance is not exceeded, it is judged a Type V (as long as other criterion are satisfied, such as absence of blast overpressure and witness plate gouging). The 20J curve as seen in AOP-39 and TB-700-2 is shown in Figure 1.



(U) Figure 1 – The 20J Curve, as it appears in AOP-39 (left) and TB-700-2 (right)

(U) Substantial resources are being expended to obtain Type V responses. However the 20J curve is currently too restrictive in the sense that it is too mass-dependent, and thus causes Type IV designations due to large, slow-moving fragments that are intuitively thought not to be dangerous. For this reason efforts were being undertaken by the community to come up with a better and more meaningful criterion for what a Type V should be. Discussions were had about whether the 20J curve should be used, or if the 79J curve in TB-700 should be used instead as a better indicator of, for example, danger to personnel. In doing so, there became confusion about what these curves meant, and there were conflicting reports indicating that the 20J referred to launch energy, impact energy, or something else. Additionally, a "20J at 15m" caveat is associated with the standard in some sources, which is also of ambiguous origin and adds additional confusion.

(U) These ambiguities led to some exploratory trajectory modeling being performed to try to reproduce the curves. A point mass ballistic trajectory code was written, validated and utilized to try various approaches to pinpoint what the curves might represent (launch energy, impact energy,

or something else) and why such a criterion was chosen. There was no documentation the authors were aware of which adequately explained the origin of these curves. The outcome of this modeling was that the 20J curve seemed to represent launch energy, and the 79J curve could not be reproduced in spite of considerable effort. When this was discovered, the originators of the curves were eventually contacted to explain what was done. An explanation for the 20J curve was provided, and it was discovered to be in error compared to the outcome that was intended. An explanation for the 79J curve could not be provided.

(U) After some deliberation the community decided to keep 20J as the lethality metric but changed it to a 20J impact at 15m criterion for different fragment densities. The authors have constructed the curve being incorporated into the new version of AOP-39. This paper documents the methodology and assumptions which are built into the generation of the new curve, as well as its limitations. It is hoped that this work will help bring attention to the state of the criterion and areas in which potential improvements can be made, since the criterion is currently of significant consequence to the success or failure of various IM programs.

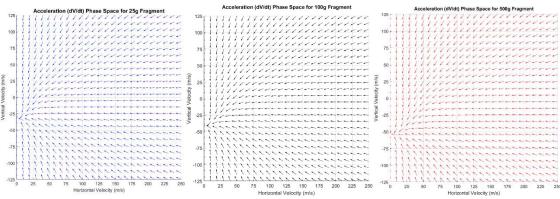
(U) Aeroballistic Trajectory Modeling

(U) Air drag is the primary consideration in determining whether debris from an explosion is hazardous. The so-called point mass model can be used to determine the trajectory of a fragment launched with a given velocity and angle if some parameters about the mass, size and shape of the fragment are known [3]. It is a vector equation which assumes the drag force to act against the direction of motion (with no wind assumed), as follows:

$$\frac{d\mathbf{V}}{dt} = -\frac{\rho S C_D}{2m} |\mathbf{V}| \mathbf{V} + \mathbf{g}$$
(1a)

$$\frac{dx}{dt} = V \tag{1b}$$

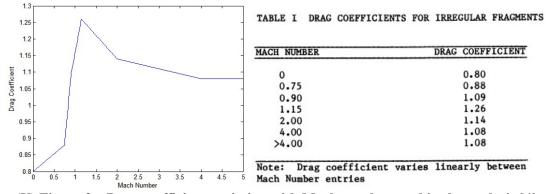
Where V is the velocity vector, |V| is its magnitude, x is the position vector, g is the acceleration of gravity, ρ is the density of air, S is the presented area of the projectile, C_D is the drag coefficient which is in general a function of the Mach number M, and m is the projectile mass. The system of first-order ordinary differential equations given by equation (1a) is nonlinear and autonomous, meaning the right-hand side (RHS) is a function of V only. Then the system represents a timeindependent direction field in phase space, and each initial condition has a unique trajectory. The system has a critical point where the RHS is zero (corresponding to terminal velocity) and its Jacobian there has real negative eigenvalues and two independent eigenvectors. This indicates that the system is asymptotically stable, and all trajectories terminate at the critical point. In addition nullclines appear where $dV_x/dt = 0$ or $dV_y/dt = 0$. Direction fields for equation (1a) are shown in Figure 2. The conclusion is that a trajectory calculation can be performed either forwards or backwards in time, provided the initial condition is sufficiently far from the critical points and nullclines. In the calculations to follow, this does not appear to be an issue, but backward trajectories in question should be checked for accuracy by running them forward in time.



(U) Figure 2 – Direction fields for Eq. (1a) with 25g, 100g, and 500g steel fragments

(U) Wind effects might also be present, as well as ricochets off the ground. These effects can be included in the analysis if desired, but this work does not include them. In general these equations are coupled and nonlinear, and have no analytical solution. Analytical solutions do exist for small launch angles with certain functional variations of the drag coefficient with Mach number (the so-called "flat fire" assumption) and vertical launch. Thus the analytical solutions can be used as a check to verify that the numerical solution of these equations is implemented correctly.

(U) Trajectory calculations require the density of air, drag coefficient, mass, and presented area of the fragment to be known. The density of air varies slightly with temperature and pressure, so a standard density of 1.2 kg/m³ is used. Fragments from an explosion are irregularly shaped and tumble through the air, and thus the presented areas and drag coefficients can vary wildly. Additionally, the drag coefficient of a given shape varies with Mach number. To try to take these complications into account, there are two approximations that are generally used for fragment trajectories: a functional dependence of drag coefficient vs. Mach number, and a functional dependence of presented area on mass. The drag coefficient vs. Mach number data for chunky fragments, which was taken from [4] to generate the curves, is shown in Figure 3. It also turns out to be the default drag data used in the TRAJ program [5]. It should be noted that for hypersonic velocities (M>5) a constant drag coefficient is considered a reasonable assumption [3], although the exact Mach number at which this data becomes invalid is unknown. Therefore in general the Mach number should be monitored when doing a fragment projection analysis to ensure valid results, although for the 20J curves this is never a concern.



(U) Figure 3 – Drag coefficient variation with Mach number used in the analysis [4]

(U) If the shape and orientation of a projectile is known, S in Equation 1a is simply its presented area. However in computing ballistic trajectories for irregularly shaped, randomly tumbling fragments, S is typically taken to be the average presented area. For an arbitrary convex shape, the average presented area is well-known to be $\frac{1}{4}$ of its total surface area and can be calculated as such. However for fragments from naturally fragmenting warheads the average presented area is typically assumed to depend on the fragment mass functional form which is as follows:

$$m = kS^{3/2} \tag{2}$$

To determine *k* experimentally for a given weapon, the average presented area has historically been measured using an icosahedron gage. Values of 2600 kg/m³ for fragmentation bombs and 2300 kg/m³ for demolition bombs are found in [6].

(U) The shape factor for steel warhead fragments is likely to perform poorly in the prediction of trajectories for fragments of shapes, sizes and densities different from steel warhead fragments. The drag coefficient data is also expected to differ for such debris. Fortunately, k can at least be modified to take into account the density of the fragment. For a fragment of a fixed size and shape, the shape factor is proportional to the fragment density, shown in equation (3).

$$m = kS^{3/2} \Rightarrow \rho V_{frag} = kS_{frag}^{3/2} \Rightarrow k = \frac{V_{frag}}{S_{frag}^{3/2}} \rho \equiv K\rho$$
(3)

(U) Limited correspondence with the originators of the curves indicated that a "chunky fragment with a shape factor of 0.33" was used. This likely refers to "B" in the following from [4, 5]:

$$m = \rho B A L \tag{4}$$

In equation (4) the shape factor *B* refers to the ratio of the actual fragment volume to the volume of the smallest rectangular box that can enclose the fragment. Then *A* is the presented area of the box, *L* is the box length in the direction of travel, and ρ is the density of the fragment. This is the formulation used in the TRAJ code. In general *AL* is not equal to $S^{3/2}$, but assuming it is results in

$$k = \rho B \tag{5}$$

which evaluates to ~2600 kg/m³ for steel fragments with B=0.33. Use of k=2600 kg/m³ gives excellent agreement with codes such as TRAJCAN. If a particular orientation of a projectile is assumed, and its mass and presented area are known, it is unnecessary to go through the shape factor model. In any case, the value of k being used in the legacy criterion is for steel fragments which resulted from a detonating warhead. Fragments resulting from sub-detonative responses commonly observed in IM tests can easily violate this assumption.

(U) The trajectories were solved numerically using MATLAB's "ode45" function [7]. The error tolerances (*AbsTol* and *RelTol*) were reduced to 1e-9 from their default values of 1e-3 to ensure accurate solutions. An event handler stops the integration at the timestep where the trajectory ordinate becomes negative, and the impact point is determined by linearly interpolating the trajectory between this timestep and the one immediately before it. The drag data was implemented

as a linear interpolation between various points on the C_D vs. M curve, which evaluates the drag coefficient based on the Mach number at each timestep. Details of the implementation and testing of this code can be found in [8], and it appears to accurately reproduce flat-fire analytical solutions as well as the outputs of several other computer programs.

(U) Lethality Criteria

(U) The objective of IM is to design munitions with exceptional lethality performance which do not react violently when subjected to ballistic and thermal threats commonly encountered in modern warfare. This is a difficult endeavor as higher-performance energetic materials are often more susceptible to violent reaction due to unplanned stimuli. IM is concerned with improving warfighter survivability in a combat scenario, although it provides important safety benefits as well. As such the survivability improvement gained from safer weapons must outweigh the opportunity cost of potentially more effective logistics operations and better performance. In this unique situation, improving munition system safety to the point that it too negatively affects combat effectiveness results in an overall decrease in survivability. Conversely, if munitions subjected to impacts and fires are allowed to react violently enough to have a high probability of causing damage and casualties which generate additional logistical burdens and IM hazards, survivability is doubly affected. As a result there ought to be an optimal level of acceptable hazard appropriate for IM design requirements, which is partially borne out in the fragment projection hazard criterion. It is a personnel hazard criterion, which might not be the only hazard worth considering but is in any case a conservative one. Clearly personnel hazard at an arbitrary distance is a poor metric of reaction violence, but attempting to reduce personnel hazard is why energetic reaction types are assigned in the first place [11]. Injury severity is often measured as an Abbreviated Injury Scale (AIS) score, and an appropriate one should be agreed upon by the IM community. Based on various discussions, a requirement similar to AIS 2 (moderate injury with 1-2% probability of death) is often favored, however a strong rationale for using this score is not usually provided.

(U) Currently the hazard criterion being used in the analysis is 20J. However, since there is much debate over whether this criterion is adequate, an energy density criterion was also considered. Utilizing an energy per unit area (energy density) criterion would seem an intuitive way to separate hazardous and nonhazardous impacts. What would be considered hazardous ought to vary wildly with the mass, material, geometry and hit location of the projectile. Impacts of sharp projectiles to fragile body areas would appear quite hazardous at low velocities. However besides introducing new and potentially burdensome data collection requirements for each fragment, [9] suggests that such a criterion is not conservative for masses above approximately 100g because the mechanism of injury becomes blunt trauma. They suggest, based on their own lethality modeling, that energy alone is a better indicator of this mechanism, and that 20J is a comfortably conservative number to use to prevent serious injury due to blunt trauma. Except for several old papers which suggested a skin penetration energy density of 7.9 J/cm², we were not able to locate any data in the open literature to confirm or dispute this. In any case, the 7.9 J/cm² criteria resulted in throw distances so large as to render the mass-distance curve mostly useless, as is discussed a subsequent section. Lethality modeling is currently being performed for the fragment masses of interest using stateof-the-art US simulation tools which take various types of injury and higher fidelity aeroballistics information into account.

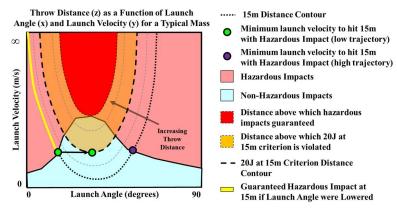
(U) Line Search Algorithms

(U) The numerical solution of the equations of motion provides a numerical output (landing conditions) as a function of a numerical input (launch conditions). In calculating the curves we often have to calculate maximum or minimum output quantities. Some of these include maximum distance for a given launch velocity, maximum distance for a given impact velocity, or minimum launch velocity to hit 15m with 20J. This can be done manually by, for instance, adjusting the launch angle until the maximum distance is found. However this is tedious and potentially inaccurate. Additionally, if for instance a particular impact velocity and throw distance are simultaneously desired, the launch angle and launch velocity would both need to be varied to achieve this. Fortunately, the ability to run trajectories backward in time from impact eliminates this difficulty. Efficiently searching for maxima or minima of an objective function using only numerical inputs and outputs is sometimes referred to as "nonlinear optimization". Algorithms to locate extreme values in a single dimension are referred to as "line searches".

(U) In particular there exist several highly efficient and well-established line search algorithms for so-called "unimodal" objective functions, which have a single maximum/minimum that all other points monotonically increase/decrease toward [10]. Some of these algorithms include simple bisection, the Fibonacci search, and the golden section search. If the objective function is known to be unimodal over a given interval, these algorithms may be applied directly. However if the objective function is not known to be unimodal, a local extremum near the starting point can be located by progressively extending the prospective search interval until the value of the objective function begins to increase, at which point the extremum has been bracketed and the objective function is unimodal over that interval. A line search is then performed within that interval to exactly determine the extreme value. In this work a simple bisection method is utilized for performing line searches, since evaluation of the ballistic trajectories is not very computationally intensive. Additionally it is robust and simple to program. Most of the objective functions of interest in this work are unimodal.

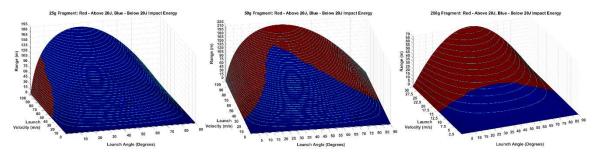
(U) Mass-Distance Curves and the AOP-39 Fragment Projection Criterion

(U) The new fragment projection criterion is 20J impact at 15m for several different fragment densities. It is a throw distance (ordinate) vs. mass (abscissa) curve which indicates that if the specified distance is exceeded for a fragment of a given mass (i.e., the criterion is violated), the fragment is guaranteed to have been launched with at least the minimum velocity required to impact 15m with 20J. It does not guarantee the actual impact was hazardous, but does guarantee that it would have been hazardous at 15m if the trajectory was lowered. A graphical representation of this is shown in Figure 4. The throw distance calculation is repeated for each fragment mass and density of interest, and is performed in two steps. First, the minimum launch velocity to hit the ground at 15m with a 20J impact is found. Then using that launch velocity, the launch angle is adjusted until the maximum distance is found. This is the distance which is used in the criterion, presented later in the paper. Also, if a mass is so large that it impacts with >20J at the minimum launch velocity to reach 15m, the curve is cut off at 15m. This is not an arbitrary cutoff because a person standing at 15m is still guaranteed to be hit with >20J if such a fragment is found at 15m; closer distances are considered irrelevant. This criterion first appeared in [9].



(U) Figure 4 – Graphical representation implications of 20J impact at 15m curve. Throw distance
 (z) plotted as a function of launch angle (x) and launch velocity (y) for a typical fixed mass. Color coded by whether impact was hazardous (pink) or not (blue).

(U) This is different from a 20J impact or 20J launch curve, which represents the largest distance a fragment of a given mass could travel having been launched or having impacted with 20J. The distances for the 20J impact at 15m curve end up being slightly larger than for the 20J launch curve. A 20J impact curve independent from the 15m restriction would be desirable since it guarantees hazardous impacts if violated. However below non-negligibly small masses (~50g for 20J impacts, ~125g for 79J impacts) the distances become very large and go off to infinity, shown in Figure 5. This is because smaller projectiles drag down significantly faster than large projectiles, and below a certain mass are never hazardous on impact at maximum range.



(U) Figure 5 – State space searches for 20J hazard criterion (red indicates hazardous impacts, blue indicates non-hazardous impacts)

(U) The most important problem with the mass-distance curves is that the curve becomes less meaningful the higher the allowable throw distances become. Mass-distance curves represent the maximum range a fragment with a given hazard criterion could possibly travel. Thus fragments that lie above the curve are guaranteed to be hazardous. However, the fragments that lie below the curve are not guaranteed not to be hazardous. This can be easily verified by launching a highly energetic fragment either vertically or directly at the ground. Thus as the hazard criterion is made less conservative, the ability to detect hazardous fragments is reduced. This consideration is as important as, if not more important than, the hazard criterion itself. If the distances specified by the curve are too large, and all the fragments lie below the curve, no useful information has been obtained. Indeed, for impact curves not associated with a distance (e.g., 15m), nothing can be

concluded at all about fragments below a given mass. In addition errors in the modeling assumptions have more of an influence on the answers as the throw distances are increased.

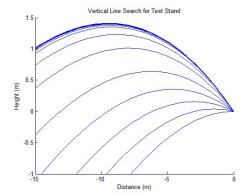
(U) Finally, for the probability of being hit while standing 15m away to be 1%, ~25 fragments would have to be thrown in random directions, assuming straight trajectories which are equally likely. Thus it would seem to make sense to allow a certain number of fragments to fail the criterion before declaring a hazardous energetic reaction. However, logistical configurations containing many munition items may project more debris for the same reaction, as appears noted in [9].

(U) We are thus driven toward a more conservative criterion. The best we can do with the massdistance curves is to ensure a low probability that a bystander is definitely exposed to hazardous fragments, rather than guaranteeing that a bystander is safe [11]. While the community has decided to stay with 20J as a hazard criterion for now, it is worth examining whether a somewhat different hazard criterion might be more appropriate, as well as how seriously violations of the criterion should be taken. This could potentially provide much-needed relief to IM programs without the standard becoming much less meaningful.

(U) Calculation of the Curves

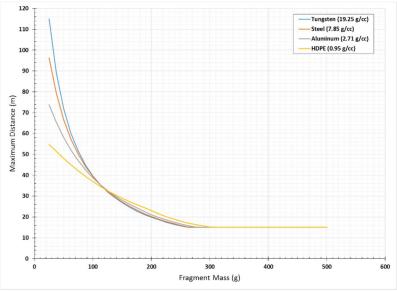
(U) The first step in calculating the curve is to search for the minimum launch velocity which could hit a person standing at 15m with a 20J fragment. The easiest way to do this is to search backward in time from the 20J impact at 15m, adjusting the impact angle until the trajectory intersects the origin. If the fragment was launched from a test stand (assumed to be 1m high), there are two ways to handle relocating the origin to the top of the test stand. A simple approximation that is easy to code is to assume the fragment impacts the person standing at 15m at the same height as the test stand. However in this case the cutoff for large masses is not 15m, but rather 15m plus the distance a fragment travels as it falls the extra 1m. This manifests itself as a small discontinuity in the curve near the cutoff. An easy way to handle the test stand is to assume the impact plane is a vertical wall at the origin and do a line search in the impact height for 1m off the ground. This simplified programming the event handler in the code since it is triggered only once for any trajectory. This was somewhat more involved to program but yielded the required answers.

(U) A description of the code used to perform the first step is as follows. The impact angle is assumed to start at zero, and is increased until the 1m launch height is exceeded. The absolute value of the distance between the current launch height and 1m is then minimized using a line search. It should also be noted that in general there are two trajectories which impact 15m at 20J, and thus the objective function is not strictly unimodal. The low trajectory usually produces a lower launch velocity to hit 15m, except for the larger masses. For some lower masses there is no high trajectory solution. Both trajectories are calculated, and the lowest launch velocity trajectory is used in the curve output. It should be noted that the error in the curve output is at most ~1m if the low trajectory is used exclusively. If the maximum launch height in the plane of the origin is below 1m, there is no trajectory connecting the test stand and the ground at 15m which can result in an impact of 20J. A cutoff of 15m is used for the curve in this case. The output of this first step is the launch velocity from the test stand required to hit the ground at 15m with exactly 20J. A diagram of the line search is shown in Figure 6.



(U) Figure 6 – Vertical line search for test stand

(U) The second step holds fixed the launch velocity determined in the first step, and varies the launch angle to determine the maximum distance a fragment could travel (forward in time from atop the test stand) if launched at that velocity. This resulting maximum distance is then recorded as a point on the final mass-distance curve. This entire procedure is repeated for each fragment mass, yielding the new 20J impact at 15m curves which are shown in Figure 7.



(U) Figure 7 – New AOP-39 mass-distance curve

(U) The crossover in the curves for the different densities is somewhat non-intuitive but makes sense. For small masses, the launch velocity required to impact 15m at 20J is large and the trajectories are relatively flat, so raising the angle for the second step results in a substantial increase in distance in which case denser fragments travel further. For larger masses, the velocities involved are lower, drag has less of an effect, and the trajectories are comparable in both steps. However less dense materials require a larger launch velocity to reach 15m with 20J in the first step. This higher launch velocity "wins out" for less dense materials when the launch angle is raised for the second step. The slight "knee" in the curves, most noticeable for HDPE, appears where the high trajectory begins to produce the lower minimum launch velocity. The cutoff at 15m is applied when the masses are so large that they impact with at least 20J by virtue of traveling

15m. The output values are listed in Figures 8-11. The launch energy is slightly less than the impact energy for some of the larger masses because of the 1m test stand.

	Mass (g)	Distance	Launch angle	Launch Velocity	Launch Energy	Impact Angle	Impact Velocity	Impact Energy	Range	Forwar Launch angle	Launch Velocity	Launch Energy	Impact Angle	Impact Velocity	Impact Energy	Ra
0250	25.0000	114.9833	-1.4048	42.8505	22.9521	-6.3340	40.0000	20.0000	15.0000	40.9622	42.8505	22.9521	-53.1818	27.7967	9.6582	114
1375	37.5000	89.0619	-0.1305	34.5466	22.3776	-7.6289	32.6599	20.0000	15.0000	42.2027	34.5466	22.3776	-50.8082	25.9192	12.5963	89.
500	50.0000	72.0147	1.1720	29.6459	21.9720	-8.9400	28.2843	20.0000	15.0000	42.8299	29.6459	21.9720	-49.4732	24.1387	14.5670	72.
25	62.5000	60.1222	2.5039	26.3197	21.6477	-10.2686	25.2982	20.0000	15.0000	43.1706	26.3197	21.6477	-48.6490	22.5752	15.9263	60.
50	75.0000	51.4186	3.8663	23.8718	21.3698	-11.6192	23.0940	20.0000	15.0000	43.3681	23.8718	21.3698	-48.1181	21.2256	16.8947	51.
75	87.5000	44.8027	5.2649	21.9723	21.1216	-12.9932	21.3809	20.0000	15.0000	43.4779	21.9723	21.1216	-47.7604	20.0600	17.6052	44.
00	100.0000	39.6180	6.7028	20.4419	20.8935	-14.3965	20.0000	20.0000	15.0000	43.5325	20.4419	20.8935	-47.5146	19.0472	18.1397	39
15	112.5000	35.4532	8.1863	19.1739	20.6798	-15.8335	18.8562	20.0000	15.0000	43.5541	19.1739	20.6798	-47.3481	18.1600	18.5505	35
0	125.0000	32.0382	9.7214	18.1003	20.4763	-17.3115	17.8885	20.0000	15.0000	43.5541	18.1003	20.4763	-47.2391	17.3766	18.8715	32
5	137.5000	29.1909	11.3191	17.1757	20.2816	-18.8350	17.0561	20.0000	15.0000	43.5325	17.1757	20.2816	-47.1663	16.6794	19.1265	29
0	150.0000	26.7808	12.9875	16.3676	20.0924	-20.4170	16.3299	20.0000	15.0000	43.4994	16.3676	20.0924	-47.1252	16.0543	19.3306	26
5	162.5000	24.6794	70.8544 68.9382	15.6406	19.8761 19.6294	-72.3322	15.6893 15.1186	20.0000	15.0000 15.0000	43.4558 43.4009	15.6406 14.9779	19.8761 19.6294	-47.1083 -47.1096	15.4798 14.9468	19.4695 19.5482	2/
0 '5	175.0000 187.5000	21.2200	66.8939	14.9779 14.3877	19.6294	-68.7014	14.6059	20.0000	15.0000	43.3462	14.3773	19.8294	-47.1321	14.9408	19.5482	2:
0	200.0000	19.8230	64.6846	13.8578	19.4089	-66.6971	14.8039	20.0000	15.0000	43.2692	14.5677	19.4089	-47.1521	14.4039	19.6824	19
5	212.5000	18,5946	62.2529	13.3783	19.0166	-64,5063	13.7199	20.0000	15.0000	43.2032	13.3783	19.0166	-47.1930	13.6310	19.7416	18
0	225.0000	17.5074	59.5033	12.9422	18.8437	-62.0454	13.3333	20.0000	15.0000	43.1268	12.9422	18.8437	-47.2365	13.2660	19.7984	17
15	237.5000	16.5397	56.2437	12.5436	18.6844	-59.1467	12.9777	20.0000	15.0000	43.0496	12.5436	18.6844	-47.2882	12.9305	19.7984	16
10	250.0000	15.6763	51.9570	12.1790	18.5409	-55.3580	12.6491	20.0000	15.0000	43.0450	12.1790	18.5409	-47.3465	12.6222	19.9151	15
15	262.5000	15.0000	NaN	NaN	NaN	NaN	NaN	NaN	15.0000	NaN	NaN	NaN	NaN	NaN	NaN	15
				(ID	Fierry		0				10 25 -	-/				
										ingsten (1						
	rve Resu	lts Distance		vard Search for Launch Velocity	Minimum Launo									unch Velocity (
0	Mass (g) 25.0000	96.3297	Launch angle -1.5911	45.5661	25.9534	-6.2359	Impact Velocity 40.0000	20.0000	Range 15.0000	Launch angle 38.6882	45.5661	25.9534	-56.8152	Impact Velocity 23.4733	6.8874	96
5	37.5000	79.3393	-0.3822	36,4488	24.9097	-7.4985	32,6599	20.0000	15.0000	40.4682	36.4488	23.9334	-58.8152	23.4733	9.7225	79
0	50.0000	66.7740	0.8603	31.1246	24.2185	-8.7788	28.2843	20.0000	15.0000	41.4674	31.1246	24.2185	-52.1408	21.8435	11.9285	66
5	62.5000	57.2818	2.1344	27.5359	23.6945	-10.0781	25.2982	20.0000	15.0000	42.0827	27.5359	23.6945	-50.9074	20.8847	13.6304	57
0	75.0000	49.9333	3.4405	24.9080	23.2653	-11.3994	23.0940	20.0000	15.0000	42.4674	24.9080	23.2653	-50.0311	19.9656	14.9484	4
5	87.5000	44.1128	4.7812	22.8765	22.8958	-12.7456	21.3809	20.0000	15.0000	42.7310	22.8765	22.8958	-49.4087	19.1115	15.9797	4
0	100.0000	39.4090	6.1625	21.2449	22.5673	-14.1182	20.0000	20.0000	15.0000	42.9063	21.2449	22.5673	-48.9500	18.3276	16.7951	3
5	112.5000	35.5398	7.5879	19.8966	22.2678	-15.5230	18.8562	20.0000	15.0000	43.0167	19.8966	22.2678	-48.6028	17.6115	17.4468	3
)	125.0000	32.3070	9.0620	18.7570	21.9892	-16.9673	17.8885	20.0000	15.0000	43.0937	18.7570	21.9892	-48.3491	16.9577	17.9727	3
5	137.5000	29.5708	10.5954	17.7773	21.7273	-18.4541	17.0561	20.0000	15.0000	43.1268	17.7773	21.7273	-48.1469	16.3600	18.4009	2
0	150.0000	27.2264	12.1952	16.9223	21.4774	-19.9951	16.3299	20.0000	15.0000	43.1483	16.9223	21.4774	-48.0048	15.8122	18.7520	2
5	162.5000	25.1967	13.8738	16.1671	21.2368	-21.6006	15.6893	20.0000	15.0000	43.1483	16.1671	21.2368	-47.8977	15.3085	19.0410	2
0	175.0000	23.2821	69.4092	15.4402	20.8600	-71.5517	15.1186	20.0000	15.0000 15.0000	43.1268	15.4402	20.8600	-47.8150	14.8045	19.1777	2
5	187.5000	21.6336	67.4154	14.7990	20.5322	-69.7267	14.6059	20.0000		43.0937	14.7990	20.5322	-47.7608	14.3476	19.2987	2
0	200.0000	20.2020	65.2765	14.2285	20.2450	-67.7828	14.1421	20.0000	15.0000	43.0496	14.2285	20.2450	-47.7272	13.9317	19.4093	21
5	212.5000	18.9479	62.9462	13.7168	19.9910	-65.6795	13.7199	20.0000	15.0000	43.0059	13.7168	19.9910	-47.7184	13.5516	19.5125	1
0	225.0000	17.8410	60.3497	13.2546	19.7646	-63.3514	13.3333	20.0000	15.0000	42.9507	13.2546	19.7646	-47.7188	13.2029	19.6105	1
5	237.5000	16.8592	57.3509	12.8354	19.5637	-60.6792	12.9777	20.0000	15.0000	42.8948	12.8354	19.5637	-47.7344	12.8823	19.7069	16
0	250.0000	15.9864	53.6392	12.4545	19.3893	-57.3906	12.6491	20.0000	15.0000	42.8299	12.4545	19.3893	-47.7542	12.5877	19.8064	1
5 0	262.5000 275.0000	15.2187 15.0000	47.9885 NaN	12.1123 NaN	19.2553 NaN	-52.4081 NaN	12.3443 NaN	20.0000 NaN	15.0000 15.0000	42.7640 NaN	12.1123 NaN	19.2553 NaN	-47.7813 NaN	12.3208 NaN	19.9240 NaN	15
0	275.0000	15.0000	INDIN	INDIA									INDIA	INDIA	INdia	1.
					(U) Fig	gure 9	– Out	put da	ata foi	r steel (7.	85 g/ce	c)				
0	rve Resu	lts	Backw	ward Search for	Minimum Laune								using Same La	unch Velocity (1m Launch Hei	ight
		Distance			Launch Energy									Impact Velocity		
0	25.0000	73.8584	-1.9605	52.4708	34.4148	-6.0322	40.0000	20.0000	15.0000	34.8771	52.4708	34.4148	-61.7570	18.4122	4.2376	7
5	37.5000	65.4265	-0.8881	41.2201	31.8580	-7.2232	32.6599	20.0000	15.0000	37.2060	41.2201	31.8580	-58.8720	18.5594	6.4585	6
5 0	50.0000	58,1843	0.2260	34.8028					10.0000			JA.0J00		10.3334	0.4000	
								20,0000	15,0000		34 8028	30 2809	-56 7284	18 4051	8 4687	
5					30.2809	-8.4375	28.2843	20.0000	15.0000	38.6995	34.8028	30.2809	-56.7284	18.4051	8.4687	
	62.5000	52.0592 46.8803	1.3761	30.5438	29.1538	-9.6738	25.2982	20.0000	15.0000	38.6995 39.7204	30.5438	29.1538	-55.0882	18.1020	10.2401	5.
0	62.5000 75.0000	46.8803	1.3761 2.5612	30.5438 27.4600	29.1538 28.2769	-9.6738 -10.9321	25.2982 23.0940	20.0000 20.0000	15.0000 15.0000	38.6995 39.7204 40.4573	30.5438 27.4600	29.1538 28.2769	-55.0882 -53.8203	18.1020 17.7232	10.2401 11.7791	5. 4
D 5	62.5000 75.0000 87.5000	46.8803 42.4808	1.3761 2.5612 3.7824	30.5438 27.4600 25.0969	29.1538 28.2769 27.5560	-9.6738 -10.9321 -12.2139	25.2982 23.0940 21.3809	20.0000 20.0000 20.0000	15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956	30.5438 27.4600 25.0969	29.1538 28.2769 27.5560	-55.0882 -53.8203 -52.8167	18.1020 17.7232 17.3074	10.2401 11.7791 13.1052	5: 4: 4:
0 5 0	62.5000 75.0000 87.5000 100.0000	46.8803 42.4808 38.7185	1.3761 2.5612 3.7824 5.0415	30.5438 27.4600 25.0969 23.2119	29.1538 28.2769 27.5560 26.9397	-9.6738 -10.9321 -12.2139 -13.5220	25.2982 23.0940 21.3809 20.0000	20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018	30.5438 27.4600 25.0969 23.2119	29.1538 28.2769 27.5560 26.9397	-55.0882 -53.8203 -52.8167 -52.0186	18.1020 17.7232 17.3074 16.8781	10.2401 11.7791 13.1052 14.2435	5: 4: 4: 3:
D 5 D 5	62.5000 75.0000 87.5000 100.0000 112.5000	46.8803 42.4808 38.7185 35.4782	1.3761 2.5612 3.7824 5.0415 6.3420	30.5438 27.4600 25.0969 23.2119 21.6630	29.1538 28.2769 27.5560 26.9397 26.3973	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594	25.2982 23.0940 21.3809 20.0000 18.8562	20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986	30.5438 27.4600 25.0969 23.2119 21.6630	29.1538 28.2769 27.5560 26.9397 26.3973	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644	18.1020 17.7232 17.3074 16.8781 16.4483	10.2401 11.7791 13.1052 14.2435 15.2183	5: 4: 4: 3: 3:
0 5 0 5	62.5000 75.0000 87.5000 100.0000 112.5000 125.0000	46.8803 42.4808 38.7185 35.4782 32.6669	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305	25.2982 23.0940 21.3809 20.0000 18.8562 17.8885	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.9289	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537	5: 4: 4: 3: 3: 3:
D 5 0 5 0	62.5000 75.0000 87.5000 100.0000 112.5000 125.0000 137.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426	25.2982 23.0940 21.3809 20.0000 18.8562 17.8885 17.0561	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38,6995 39,7204 40,4573 40,9956 41,4018 41,6986 41,9289 42,1042	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693	5. 4(4) 3) 3) 3) 3) 3)
D 5 5 5 5 5	62.5000 75.0000 87.5000 100.0000 112.5000 125.0000 137.5000 150.0000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986	25.2982 23.0940 21.3809 20.0000 18.8562 17.8885 17.0561 16.3299	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.9289 42.1042 42.2360	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830	5: 4: 4: 3: 3: 3: 3: 3: 3: 2:
D 5 5 5 5 5 5 5	62.5000 75.0000 87.5000 100.0000 112.5000 125.0000 137.5000 150.0000 162.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406 12.0639	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195	29.1538 28.2769 27.5560 26.3937 26.3973 25.9093 25.4615 25.0458 24.6544	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089	25.2982 23.0940 21.3809 20.0000 18.8562 17.0561 16.3299 15.6893	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38,6995 39,7204 40,4573 40,9956 41,4018 41,6986 41,9289 42,1042 42,2360 42,3354	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.9092	5: 4: 4: 3: 3: 3: 3: 2: 2: 2:
D 5 5 5 5 5 5 5 5 0	62.5000 75.0000 87.5000 112.5000 125.0000 137.5000 150.0000 162.5000 175.0000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406 12.0639 70.4445	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288	25.2982 23.0940 21.3809 20.0000 18.8562 17.8885 17.0561 16.3299 15.6893 15.1186	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6396 41.9289 42.1042 42.2360 42.2354 42.4124	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566 -49.5166	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.9092 18.3416	5: 4: 3: 3: 3: 3: 3: 2: 2: 2: 2: 2:
0 5 0 5 0 5 5 0 5 5	62.5000 75.0000 87.5000 112.5000 125.0000 137.5000 150.0000 162.5000 175.0000 187.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406 12.0639 70.4445 68.5398	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288 -71.9785	25.2982 23.0940 21.3809 20.0000 18.8562 17.0561 16.3299 15.6893 15.1186 14.6059	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38,6995 39,7204 40,4573 40,9956 41,4018 41,9289 42,1042 42,2360 42,2360 42,2360 42,2360 42,2360 42,2360 42,2360 42,2360 42,4574	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566 -49.5166 -49.3019	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.3830 17.9092 18.3416 18.5597	5: 4: 3: 3: 3: 2: 2: 2: 2: 2:
D 5 5 0 5 5 5 5 5 5 5 0	62.5000 75.0000 87.5000 112.5000 125.0000 137.5000 162.5000 175.0000 187.5000 200.0000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406 12.0639 70.4445 68.5398 66.5250	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661	29.1538 28.2769 27.5560 26.9397 26.3373 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288 -71.9785 -70.1412	25.2982 23.0940 21.3809 20.0000 18.8562 17.0885 17.0561 16.3299 15.6893 15.1186 14.6059 14.1421	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.9289 42.1042 42.2360 42.2354 42.4124 42.4424 42.4674	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.6544 23.5636 23.0012	-55.082 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566 -49.5166 -49.319 -49.1248	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.9092 18.3416 18.5597 18.7602	5: 4: 3: 3: 3: 3: 2: 2: 2: 2: 2: 2: 2: 2: 2: 2: 2: 2: 2:
0 5 0 5 0 5 0 5 0 5 0 5 5	62.5000 75.0000 87.5000 112.5000 125.0000 137.5000 162.5000 175.0000 187.5000 200.0000 212.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 112.0639 70.4445 68.5398 66.5250 64.3691	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615	29.1538 28.2769 27.5560 26.3977 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288 -71.9785 -70.1412 -68.1894	25.2982 23.0940 21.3809 20.0000 18.8562 17.8885 17.0561 16.3299 15.6893 15.1186 14.6059 14.1421 13.7199	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38,6995 39,7204 40,4573 40,9956 41,4018 41,6986 41,9289 42,2360 42,2350 42,2350 42,2350 42,2350 42,2350 42,2350 42,2452 42,2601	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615	29.1538 28.2769 27.5560 26.3977 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290	-55.0822 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566 -49.5166 -49.5166 -49.3019 -49.1248 -48.9916	18.1020 17.7232 17.3074 16.8781 16.4483 16.0258 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968 13.3541	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.9092 18.3416 18.5597 18.7602 18.9477	51 44 33 33 30 22 20 20 20 20 21 20 21 21 21
D 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	62.5000 75.0000 87.5000 112.5000 125.0000 137.5000 162.5000 175.0000 200.0000 212.5000 225.0000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406 12.0639 70.4445 68.5398 66.5250 64.3691 62.0265	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288 -71.9785 -70.1412 -68.1894 -66.0827	25.2982 23.0940 21.3809 20.0000 18.8552 17.0551 16.3299 15.6893 15.1186 14.6059 14.1421 13.7199 13.3333	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.99956 41.4018 41.6986 41.9289 42.1042 42.2360 42.2354 42.4124 42.4674 42.4674 42.4692 42.5001	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250	29.1538 28.2769 27.5560 26.9397 26.3373 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287	-55.082 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.0490 -50.0490 -49.7566 -49.3019 -49.1248 -48.9916 -48.8913	18.1020 17.7232 17.3074 16.6781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968 13.35541 13.0387	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.9092 18.3416 18.5597 18.7602 18.9477 19.1258	55 44 33 33 30 20 20 20 20 20 20 20 20 21 11 11
5 0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 5	62.5000 75.0000 87.5000 112.5000 125.0000 150.0000 162.5000 175.0000 187.5000 212.5000 225.0000 237.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986 17.5733	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 10.5406 12.0639 70.4445 68.5398 66.5250 64.3691 62.0265 5.9.4247	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250 13.5458	29.1538 28.2769 27.5560 26.3397 26.3973 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.5290 22.1287 21.7894	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288 -73.7288 -71.9785 -70.1412 -68.1894 -66.0827 -63.7569	25.2982 23.0940 21.3809 20.0000 18.8562 17.0561 16.3299 15.6893 15.1186 14.6059 14.1421 13.7199 13.3333 12.9777	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.2899 42.2042 42.2350 42.3354 42.4124 42.4574 42.4674 42.4692 42.5001 42.5001	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250 13.5458	29.1538 28.2769 27.5560 26.3977 26.3973 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287 21.7894	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.4049 -50.0490 -49.7566 -49.3019 -49.1248 -48.9916 -48.8913 -48.8059	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968 13.3541 13.0387 12.7480	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 17.3830 17.9092 18.3416 18.5597 18.7602 18.7602 18.9477 19.1258 19.2982	55 44 33 33 30 22 20 20 20 20 20 20 20 20 20 20 20 20
0 5 0 5 0 5 0 5 0 5 0 5 0 5 0 0	62.5000 75.0000 87.5000 102.0000 112.50000 137.5000 137.5000 175.0000 187.5000 202.0000 212.5000 237.5000 237.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986 17.5733 16.6672	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 9.0846 110.5406 110.5406 12.0639 70.4445 66.5350 66.5350 64.3691 62.0265 59.4247 56.4322	30.5438 27.4600 25.0669 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250 13.5458 13.1164	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287 21.7894 21.5051	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -20.6089 -73.7288 -71.9785 -70.1412 -68.1894 -66.0827 -63.7569 -61.0955	25.2982 23.0940 21.3809 20.0000 18.8552 17.8885 17.0561 16.3299 15.6893 15.1186 14.6059 14.46059 14.1421 13.7199 13.3333 12.29777 12.6491	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9995 41.4018 41.6986 41.0289 42.1042 42.2360 42.3354 42.4124 42.4674 42.4674 42.4692 42.5001 42.5001 42.5001	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250 13.5458 13.1164	29.1538 28.2769 27.5560 26.9397 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287 21.7894 21.7894 21.5051	-55.0882 -53.8203 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.5166 -49.5166 -49.5166 -49.5166 -49.3019 -49.1248 -48.8913 -48.8915 -48.8915 -48.8059 -48.7479	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968 13.35541 13.0387 12.7480 12.4805	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 16.7693 17.3830 17.9092 18.3416 18.5597 18.7602 18.9477 19.1258 19.2982 19.2982	55 44 33 33 30 22 24 24 24 24 24 24 24 24 24 24 24 24
0 5 0 5 0 5 0 5 0 5 0 5 0 5 5 0 5 5	62.5000 75.0000 87.5000 102.0000 112.50000 137.5000 162.5000 175.0000 20.0000 212.5000 225.0000 237.5000 263.5000 263.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986 17.5733 16.6672 15.8683	1.3761 2.5612 3.7824 5.0415 1.63420 7.6884 9.0846 10.5406 110.5406 12.0639 7.04445 66.5350 66.5350 64.3601 62.0265 5.9.4247 5.64322 5.27509	30.5438 27.4600 25.0969 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5615 14.0250 13.5458 13.1164 12.7324	29.1538 28.2769 27.5560 26.3397 25.9093 25.9093 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287 21.7894 21.5051 21.2774	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -20.6089 -73.7288 -71.9785 -70.1412 -68.1894 -66.0827 -63.7569 -61.0955 -5.7.8351	25.2982 23.0940 21.3809 20.0000 18.8562 17.8885 17.0561 16.3299 15.6893 15.1186 14.6059 14.1421 13.7199 13.3333 12.9777 12.6491 12.3443	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000	15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000 15.0000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.2289 42.1042 42.3354 42.4124 42.4574 42.4674 42.5001 42.5001 42.4674 42.4674 42.4674 42.4692 42.5001 42.4674 42.4674 42.4682	30.5438 27.4600 25.0669 23.2119 21.6630 20.3605 19.2444 18.2741 17.4195 16.6453 15.8539 15.1661 14.5515 14.0250 13.3458 13.1164 12.7324	29.1538 28.2769 27.5560 26.3977 26.3973 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287 21.7894 21.5051 21.2774	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566 -49.5166 -49.5166 -49.1248 -48.9019 -48.8913 -48.8059 -48.7479 -48.7030	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968 13.3541 13.0387 12.24805 12.2360	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 15.7693 17.3830 17.9092 18.3416 18.5597 18.7602 18.3416 18.5597 18.7602 18.9477 19.1258 19.2982 19.4705 19.6506	55 44 33 33 20 20 20 20 20 20 20 20 20 20 20 20 20
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D 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	62.5000 75.0000 87.5000 102.0000 112.50000 137.5000 162.5000 175.0000 20.0000 212.5000 225.0000 237.5000 263.5000 263.5000	46.8803 42.4808 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986 17.5733 16.6672 15.8683 15.8683	1.3761 2.5612 3.7824 5.0415 1.63420 7.6884 9.0846 10.5406 110.5406 12.0639 7.04445 66.5350 66.5350 64.3601 62.0265 5.9.4247 5.64322 5.27509	30,5438 27,4600 25,0969 23,2119 21,6630 20,3605 19,2444 18,2741 17,4195 16,6453 15,8539 15,3651 14,5515 14,0250 13,5458 13,1164 12,7324 NaN	29.1538 28.2769 27.5560 26.3937 25.3073 25.3093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5230 22.1287 21.7894 21.5051 21.1354 NaN	-9.6738 -10.9321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -73.7288 -71.9785 -70.1412 -66.1895 -66.827 -63.7569 -61.0955 -57.8351 -52.9670 NaN	25.2982 23.0940 21.3809 20.0000 18.8552 17.0561 16.3299 15.6893 15.1186 14.6059 14.421 13.7199 13.3333 12.9777 12.6491 12.2443 12.2443 NaN	20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 NaN	15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000 15.000	38,6995 39,7204 40,4573 40,9956 41,4018 41,6986 41,9289 42,2164 42,2360 42,2360 42,2360 42,2360 42,2361 42,4274 42,4674 42,4754 42,4754 42,42551 42	30,5438 27,4600 25,0969 23,2119 21,6630 20,3605 19,2444 18,2741 17,4195 16,6453 15,8539 15,3661 14,5615 14,0250 13,5458 13,1164 12,7324 12,3981 NaN	29.1538 28.2769 27.5560 26.3937 25.9093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5290 22.1287 21.7894 21.5051 21.1754 NaN	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.4049 -50.0490 -49.7566 -49.5166 -49.5166 -49.1248 -48.9019 -48.8913 -48.8059 -48.7479 -48.7030	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 15.2241 14.8466 14.4782 14.0702 13.6968 13.3541 13.0387 12.24805 12.2360	10.2401 11.7791 13.1052 14.2435 15.2183 16.0537 15.7693 17.3830 17.9092 18.3416 18.5597 18.7602 18.3416 18.5597 18.7602 18.9477 19.1258 19.2982 19.4705 19.6506	52 40 42 38 33 30 28 20 24 22 22 22 22 22 19 18 11 11 11 11 11 11 11 11
D 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	62.5000 75.0000 87.5000 100.0000 112.5000 125.0000 137.5000 162.5000 212.5000 212.5000 225.0000 237.5000 255.0000 262.5000 275.0000 287.5000	46.8803 42.408 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986 17.5733 16.6672 15.8663 15.1830 15.0000	1.3761 2.5612 3.7824 5.0415 6.3430 7.6884 9.0886 10.5406 11.05406 12.0639 70.4445 66.5250 64.3691 62.0205 5.94247 5.64322 5.27509 47.2415 NaN	30.548 27.600 25.069 23.2119 21.630 20.305 20.305 20.305 20.305 20.305 20.305 21.661 13.5453 15.8539 15.1661 14.6513 15.8539 15.1661 14.6250 13.5458 13.1164 12.7254 NaN	29.1538 28.2769 27.5560 26.3937 25.3939 25.4015 25.0458 24.6544 24.242 22.5590 22.1287 21.2754 21.5551 21.2774 21.1354 NaN	-9.6782 -0.0321 -12.2139 -13.5220 -14.8594 -16.2305 -17.6426 -19.0986 -20.6089 -20.6087 -20.6089 -20.6	25,2982 23,0940 21,3809 18,8562 17,0561 16,3299 15,1885 15,1186 14,6059 14,4421 13,7199 13,3333 12,9077 12,26491 12,3443 12,0605 NaN Outpu	20,000 20,00000 20,0000 20,00000000	15.000 15.0000 15.00000 15.0000 15.00000 15.00000 15.0000000000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.9289 42.1042 42.2360 42.3354 42.4374 42.4674 42.4674 42.4671 42.4501 42.4784 42.4255 42.3904 NaN	30.548 27.600 25.099 23.219 21.630 20.305 19.244 18.2741 17.495 16.645 15.8539 15.3651 14.5655 14.0520 13.3548 13.1164 12.7324 NaN	29.1538 28.2769 27.5560 26.9397 25.9033 25.9033 25.6415 25.0458 24.6544 24.2422 23.5636 23.0012 22.1287 21.1784 21.5051 21.2774 21.1354 NaN	-55.0882 -53.8203 -52.8167 -52.0186 -51.3644 -50.8368 -50.0499 -50.0499 -50.0490 -49.5166 -49.3019 -49.1248 -48.9313 -48.8913 -48.8913 -48.7479 -48.7637 -48.7637 NaN	18.1020 17.7327 17.3074 16.6781 16.4483 16.028 15.6248 15.6248 14.4782 14.4782 14.4782 14.4782 14.4782 13.5541 13.0387 12.2480 12.2480 12.2480 12.2480 12.0196 NaN	10.2401 11.791 13.1052 14.2435 15.2183 16.0537 15.693 17.3830 18.8416 18.8597 18.8416 18.8597 18.8416 18.9477 19.1258 19.4705 19.6506 19.6666 NaN	55 44 33 33 22 22 22 22 22 22 22 21 11 11 11 11 11
D 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	62.5000 75.0000 87.5000 100.0000 112.5000 112.5000 137.5000 162.5000 175.0000 212.5000 225.0000 237.5000 262.5000 262.5000 275.0000 287.5000	46.8803 42.408 38.7185 35.4782 32.6669 30.2098 28.0488 26.1353 24.3991 22.6206 21.0911 19.7625 18.5986 17.5733 16.6672 15.8663 15.1830 15.0000	1.3761 2.5612 3.7824 5.0415 6.3420 7.6884 10.5406 110.5406 8.5388 66.5250 64.3691 62.0265 56.4322 52.7509 47.7415 NaN	30.5488 27.4600 25.0699 23.2119 21.6630 20.3005 29.2044 18.2741 17.4795 15.664 15.6643 15.6644 15.76444 15.76444 15.76444 15.76444 15.76444 15.76444 15.76444 15.76444 15.76444 15.76444 15.764444 15.76444444444444444444444444444444444444	29.1538 28.2769 27.5560 26.3937 25.3073 25.3093 25.4615 25.0458 24.6544 24.2432 23.5636 23.0012 22.5230 22.1287 21.7894 21.5051 21.1354 NaN	-9.6738 -0.9321 -0.9321 -1.3220 -1.4.8594 -16.2305 -17.6426 -19.0986 -20.6089 -20.60	25.992 23.0940 21.13809 18.8562 17.0561 15.186 15.186 15.186 14.4621 13.799 15.6893 15.1186 14.4621 13.7399 13.7399 13.7399 14.1421 13.7399 13.7399 14.1421 12.2443 12.6605 NaV	20.0000 20.00000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.0000 20.00000000	15,000 15,0000 15,0000 15,0000 15,0000 15,0000 15,0000 15,0000000000	38.6995 39.7204 40.4573 40.9956 41.4018 41.6986 41.289 42.2002 42.2360 42.3354 42.4374 42.4674 42.4674 42.4692 42.5001 42.5001 42.4784 42.4561 42.4561 42.4255 42.3304 NaN Iuminum Forwal	30.5488 27.4600 25.0969 23.2119 21.6630 20.3005 29.244 19.244 19.244 19.244 19.244 19.244 19.244 19.244 19.244 12.7924 12.7924 12.2724 12.2981 NaN (2.2.71) d Search for M	29.1538 28.2769 27.7556 26.3937 26.3937 25.4635 25.4635 24.6544 24.2432 23.5566 23.0012 22.5280 22.1287 21.7894 21.0551 21.2774 21.1354 NaN g/CC)	-55.0882 -53.8823 -52.8167 -52.0186 -51.3644 -50.8368 -50.0409 -50.0409 -49.7566 -49.5169 -49.5169 -49.3169 -49.3169 -48.8913 -48.8913 -48.8059 -48.7030 -48.7030 -48.7037 NaN using Same La	18.1020 17.7232 17.3074 16.8781 16.4483 16.0268 15.6178 14.4782 14.0702 13.6668 13.3541 13.0387 12.7480 12.4805 12.0196	10.2401 11.7791 13.1052 14.2405 15.2183 16.0537 17.9830 17.9830 17.9830 17.9830 17.9830 18.8416 18.85597 18.8416 18.85597 18.8416 19.2582 19.2582 19.2582 19.2582 19.6566 19.8646 NaN	53 44 33 36 22 22 22 22 22 22 22 22 22 22 22 22 11 13 11 11 11 11 11 11 11 11
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(U) Summary and Conclusions; Future Work

(U) The legacy and newly updated AOP-39 fragment projection curves which determine hazardous fragments for IM vulnerability assessments were discussed. The legacy curve was a 20J launch curve, representing the maximum distance a fragment could travel when launched with 20J, and therefore guaranteeing a launch energy in excess of 20J when the criterion is violated. Replacing this with a 20J impact curve would appear to make sense, however such curves become unbounded for smaller masses, which make their use undesirable. The characteristics of mass-distance curves are discussed, and it is shown that such curves lose accuracy and usefulness as the lethality criterion becomes less conservative. Thus the new curve is a 20J impact at 15m criterion which was shown to manage these difficulties. This curve guarantees that a fragment which violates the criterion was launched in excess of the minimum velocity to impact 15m with 20J. This criterion results in slightly larger throw distances than the 20J launch curve, which is constructed similarly. In addition lethality criteria are discussed. 20J is thought by some to be qualitatively conservative enough for the mass-distance curve to be meaningful, while at the same time being hazardous enough to pose some risk of nonlethal blunt injury. However more lethality modeling should be performed for this set of masses and materials. The criterion is currently of significant consequence to the success or failure of various IM programs, and it is hoped that better understanding of this criterion and its characteristics can result in improved interpretation and development of IM tests and standards.

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