Nuclear Survivability- Too Much of a Good Thing or Misunderstood Blessing?

John H. Brand
Survivability Management Office, US Army Laboratory Command
2800 Powder Mill Road, Adelphi, MD 20783-1145

What is it?

The project manager is faced with a host of competing issues, each with its advocacy community, clamoring for his attention and resources. Regardless of the demands of each of these communities the PM must do what is necessary for a successful development program. Nuclear survivability is only one of these competing issues, but it is an extremely important one and it is the intent of this paper to demonstrate that it is both manageable and may have benefits beyond the immediate scope of the problem. In particular, there are groups who can help set up a program that requires little management attention, and others who will try to help clarify both the additional, non-nuclear survivability benefits that can be obtained and the tactical benefits from some lower level of survivability than the full specification value. In particular, the latter is part of the waiver process for cases where the project manager feels that the requirements for the system are too severe and seeks relief.

Let us address nuclear survivability by

- stating what it is, then
- discussing the regulatory mechanism that demands and enforces the attainment of nuclear survivability,
- discuss what can be done to tailor the requirement to the system, then mention
- what other, non-nuclear, problems might also be solved.

The foundation document for nuclear survivability at present is DOD Directive 4245.4, Acquisition of Nuclear Survivable Systems, 25 July 1988. The Army program is implemented by AR 70-60, Nuclear Survivability of Army Materiel, May 1984. (It should be noted that the DOD master document on acquisition, DOD Directive 5000.1, is under revision and may supersede both, but the Draft Directive so far is actually more rigorous than the two documents cited.) Nuclear survivability is defined in those two documents as the ability to sustain the effects of the initial nuclear
effects (those occurring within a minute of the burst) and perform the mission. Both documents state that nuclear survivability is required for mission essential equipment. Now, of importance for the system developer is the fact that hardening materiel is only one of four methods of attaining nuclear survivability. The methods of attaining nuclear survivability are:

- **Hardening** mission essential combat systems and ancillary support systems against nuclear weapon effects
- Providing system or component redundancy
- Providing timely and adequate resupply
- Nuclear effects mitigation techniques.

Some system developers will want to make a blanket statement that nuclear survivability will be attained by some means other than hardening. Such a course of action must be well thought out and justified. There are many hidden problems with tactical or doctrinal solutions, such as: a front line system may be hard to replace before the enemy attacks to exploit the damage and confusion from the burst; spares have to be identified and provisioned (a very expensive process); and mitigation techniques usually have some impact on non-nuclear operations and always involve some training impact. For example, sealing a fire control computer in a metal case because of a susceptibility to electromagnetic pulse is a mitigation technique, but can have considerable impact on use. On the other hand, leaving the power off all the time except the 5 minutes some electronic device must be in use may be acceptable operationally. It is necessary, however, to get that procedure into the manual or course syllabus.

For these and other reasons the most common approach to nuclear survivability is hardening.

**Nuclear Hardening and Criteria**

Nuclear hardening refers to the process of rendering materiel survivable to the initial nuclear weapon effects:

- blast/thermal effects
- transient effects of radiation on electronics (TREE)
- electromagnetic pulse.

Blast and thermal effects are linked together because they are synergistic. That is, the thermal pulse can weaken a structure so that the blast wave can damage it, when the blast wave alone might not do so.

TREE involves such things as photocurrents all through the device, lattice damage in the semiconductor domains, and regions of trapped electric charges altering the usual current flows.

Electromagnetic pulse is the intense burst of radio noise that accompanies the detonation of a nuclear weapon. People usually think only of the high altitude electromagnetic pulse (HEMP), but in
fact a surface or low airburst generates a large electromagnetic pulse. The HEMP is a serious concern due to its theatre wide coverage and potentially devastating effect on unprotected electronics. The risks of fratricide may in many people’s opinions make a deliberate curtain raiser burst seem less likely as a prelude to war or violent gesture, but the possibility due to an SDI type event or even high altitude terminal ballistic missile engagement coupled with the devastating consequences make HEMP a matter of concern to many others in the community. HEMP gained considerable notoriety when a large network did a doomsday TV movie, but protection from EMP is a relatively straightforward matter of engineering techniques well understood by a body of experts. There are other types of EMP generated by other burst geometries, as well as the high altitude case, which will accompany any nuclear detonation, and which are in many ways similar to the HEMP effects. Protection from some kind of EMP is an absolute concomitant of nuclear survivability, and the waveforms are spelled out clearly in the sets of criteria issued for the system.

The question is, how much hardening should a system have to assure mission survival? In the Army scheme of nuclear survivability the system should be as survivable as the crew. Specifically, the system should tolerate a level of nuclear effects as high as that level at which a large enough fraction of the crew will tolerate and be able to continue the mission for the necessary period. For instance, if a tank has four men and no automatic loader, the tank must continue to operate at a level at which, on the average, only one out of four of the crew is immediately incapacitated. In the case of some systems there may be other caveats: the system may be allowed to be shut off and re-started or re-booted; the system may be required to continue to operate without interruption; there may be time to pull out a clearly identified and accessible blown circuit card and replace with a spare carried just for that purpose, etc. Of some interest, the Army almost never builds a system in such a way as to make it harder to kill the crew by nuclear effects - no US system has a radiation liner, for instance, though that may change.

The philosophy leads to criteria based on the level of effects from a yield range specified by the intelligence community that will immediately incapacitate a given fraction of the crew. These criteria are issued by the US Army Nuclear and Chemical Agency (USANCA). The USANCA is required to issue criteria for all developmental systems for which nuclear survivability is required, regardless of whether the means of survivability chosen is hardening or not. (Incidentally, the PM does not himself approve the decision to attain survivability by a means other than hardening.) The methodology is based on a principle called the governing iso-damage curve. The governing iso-damage curve for exposed personnel for a
hypothetical system is shown below (courtesy of the USANCA) in figures 1-3. The first graph shows the range vs yield curves for incapacitation of a given fraction of personnel for each effect; the second shows the governing phenomena vs range and yield; the third constrains the yield according to intelligence estimates. The values of the nuclear environments under those conditions are the criteria which the system must meet. The methodology is explained in the Quadripartite Standardization Agreements 244 and 620, also in Allied Engineering Publication 4. These documents help the signatory nations to keep their survivability levels and methods coordinated.

What might these effects look like? Rather than set up a hypothetical set of criteria, let us consider the nuclear effects from a generic weapon, shown in figure 4. That is not how criteria are set, but it is illustrative of the sort of levels one might find. Shown here is the set of effects from a 1 kiloton weapon, with the 50 millisecond fireball drawn to scale (effects calculated with an IBM PC and the DNA supplied programs MORE, WE, and PSREMP). This series of sets of nuclear effects has several points of interest. The first is that low yield weapons are radiation killers- the second is that the electronic radiation dose, the dose in rads in silicon, is relatively low. This is illustrated by some data gathered by the Harry Diamond Laboratories on microprocessor chips. These data are shown in table 1. As can be seen, the chips are, in general, harder than the crew. The other electronic components might not be, but there are data bases with a great deal of data on piece part performance to avoid use of soft components. Circuit level effects can be circumvented by design. A further point of interest is the effect of blast. There are two rough values of interest to gauge the effects of overpressure, 4-5 pounds per square inch and about 10 psi. At the former a truck with shelter rolls over if struck broadside; at a value near the second exposed humans are incapacitated.

Implementation

The developmental road map starts with the DOD recipe for development of nuclear survivable systems, which at present is DOD Dir 4245.4. As mentioned above, the revised DOD Directive 5000.1, Major and Non-Major Defense Acquisition Programs, will probably supersede the DODD 4245.4 and possibly the AR 70-60. These mandate nuclear survivability for mission essential materiel. The process of acquisition of survivable materiel is driven to a large extent by the content of the series of requirement documents that describe and justify the system. The map of how the Army does its requirement documents is AR 71-9, Materiel Objectives and Requirements, 20 February 1987. It presently states that the requirement documents will "consider" nuclear and NBC survivability, and that they "will be a required characteristic for all mission-essential systems". These requirements are then traced.
through the requirements process. There is also an extremely detailed handbook for the acquisition process, AMC/TRADOC Pamphlet 70-2, which traces the survivability requirements through the development system in great detail. Logisticians are required to address the preservation of nuclear survivability through the life cycle of the system through the designation and management of nuclear hardness critical processes and items (HCPs and HCls) in drawings, configuration control, and the provisioning of spare parts. The AR concerned is AR 700-127, Integrated Logistic Support, 1 March 1988, and the road map is DA Pam 700-55, Instructions for Preparing the Integrated Logistic Support Plan, 1 March 1988. Of intense interest to the program management personnel, the AR governing the conduct of Army System Acquisition Review Councils (ASARCs) is also under revision, and will probably specify that the PM will report on survivability, including nuclear survivability, at the ASARC. The yardstick against which the system is measured are the nuclear survivability criteria issued by USANCA or some lesser levels approved through the waiver process.

Now, suppose the PM feels the criteria for the system under development are too severe. What is the next step?

There is a highly organized path to a waiver of requirements. The pathway must be documented and submitted through channels to the Nuclear and Chemical Survivability Committee. This Committee acts for the Chief of Staff in nuclear and NBC related issues. The procedure and content of a waiver request is detailed in the Ballistic Research Laboratories Report BRL-TR-3019, A Protocol for the Application of Operational Effectiveness and Cost Trade-Off Analyses to Nuclear and NBC Contamination Survivability, vols I and II. Volume I gives procedures and methodology; volume II gives examples.

The Protocol represents an attempt to determine in a systematic way what the survivability level of the system is, and to balance the operational effectiveness of that level of survivability against the criteria level. The costs of the two levels of survivability as well as other possible alternatives are also addressed explicitly and in a standard way.

Why might a PM feel that the system has too severe a criterion levied on it? There are a number of possibilities. One case involved a system designed to remain under tree cover- the original criteria were based on blast injury to the crew, who were incapacitated at half the overpressure level that covered the system with broken tree trunks. That, in this case would suffice to destroy the system. Since it was deemed impractical by the doctrinal community to come out of the woods, the materiel development community got a waiver, not to the level of hardness that was
convenient, but to the level that collateral damage also finished off the system. The waiver, based on blast, also essentially eliminated radiation hardening as a factor in development and testing. The PM may feel that the yield range is too wide. Such a change can change the criteria somewhat, if accepted.

In the past, in most cases waiver requests have been denied as unnecessary. Careful analysis has usually revealed a path to the desired level of hardness at an acceptable cost. In the future, use of the BRL protocol should substantially help the PM to actually attain the level of hardness required by the criteria or to firmly establish the applicability of a lower environment.

The process may appear somewhat daunting. There is, however, a group with the mission to provide support to the community. The Nuclear Effects Support Team at the Harry Diamond Laboratories will advise on procedures, contractual documentation to aid in a smooth development, and provide advice on testing to verify hardness.

"Collateral Survivability"

There are families of effects. One of the most important is the electromagnetic family. First, let it be said that hardness to HEMP will not guarantee hardness to high power microwave or other electromagnetic effects, but is likely to improve the resistance to the other effects in the family. The starting point for HEMP hardening is very similar to the starting point for HPM, and the shielding enclosure can protect against both phenomena and the other electromagnetic effects as well, if the effects are analysed together. As can be seen in figure 5 (courtesy of M. Claffy, SMO), the various electromagnetic effects overlap considerably in frequency and power levels. Treating them as a family makes considerable sense.

Another family is blast. A system can be subjected to blast from nuclear and conventional weapons. Some conventional weapons, such as the improvised fuel-air explosive of the Beirut truck bomb, are decidedly unusual, but the damage mechanisms are similar and the analysis to provide survivability is, too. Blast survivability can be enhanced with little weight by provision of good shock mounts or increased wall flexure distances, but the connection between blast hardening and ballistic hardening is compelling.

The Army Materiel Systems Analysis Activity (AMSAA) has performed analyses that have indicated large benefits to survivability of electronic equipment to fragmenting munitions by provision of light armor such as composite armor panels. These panels impose some weight penalty on the system, but also provide considerable structural support. There is the excellent possibility of using the ballistic panels to provide "free" blast hardening- one must be survivable to artillery, the Russian "God of War", so one may as well get...
some benefit from the fix for fragments. There is a story, possibly apocryphal, about a system manager who provided fragment protective panels for the system, but provided panels that were small and not continuous across the span of the enclosure. There may have been a very good reason for this, but the end result was weight without blast hardening from the support a continuous span would have given to the enclosure.

There are probably other cases of collateral benefits, such as lower life cycle costs due to increased robustness of structure, but the nuclear survivable systems have only recently, in life-cycle terms, reached the field. This may be impossible to quantify and prove.

What does all this cost?

If nuclear survivability has not been designed into a system and the system must be redesigned or retrofitted extensively, the cost can be extremely high. If the survivability is designed in the costs can be minimal. It should be pointed out, however, that the costs of brute force hardening can in some cases be extremely high. An example might be a system requiring a lightweight, automatically erecting, tall antenna mast. Building such a device to withstand 10 psi overpressure and still not overload a truck any more than it is would be a real challenge. There are other obvious difficulties, as well. In many other cases the costs are reasonable. The HDL collected PM estimates of system added cost due to nuclear survivability. The estimates for a missile system, a tank, and a radio were all on the order of a per cent or so during each phase of development. Why? Nuclear survivability really, except for surveillance- which is done anyway for other effects- often involves doing much the same kinds of things as for a non-survivable system, only differently. An example is a system that failed production line EMP testing- the reason was a different surface treatment for the metal around an access panel. If a conducting gasket or shielded cable is needed for EMP, it probably is also needed for electromagnetic interference (EMI) protection as well, only the specifications on an EMI gasket may be less stringent. Nonetheless, the cost is more strongly driven by the presence or absence of a gasket or shielded cable, and less on the type. For example, in one system that failed EMP testing, the fix was to procure a better shielded cable from a different vendor. After that, it passed.

Another issue is weight. At least one study has indicated that tactical truck mobility is driven less by weight than by several other parameters. Deployability needs a close look rather than automatically saying, too heavy! If the system is prepositioned, deploys by sea, or cubes out an airlifter rather than grosses it out, it may be better to pay a (say) 700 pound weight penalty rather than try to back-order a new system at a factory 12000 miles away. The 700 pounds of structure may act as armor
will probably be needed for protection from artillery fire anyway.

Conclusion

The title of this talk posed a question. The question was, is nuclear survivability too much of a good thing or a misunderstood blessing? That is, is there a benefit to less than the specified levels of nuclear survivability and at the same time a collateral benefit in other, unexpected areas of survivability? The answer can be: yes. The program manager may feel that the required level of nuclear survivability is too much for his system, but there is a very clear path within the prescribed nuclear survivability procedures to resolve the issue and perhaps justify a lower, more affordable level – or even show how to get the higher level at an affordable cost. There are also people in the nuclear community whose job is to provide help in setting up a program that will require minimal management attention and provide advice when needed on the progress of the program. In addition, there may be substantial opportunities to solve other critical survivability problems without substantial added cost.
FIGURE 1 - MAN'S VULNERABILITY TO NUCLEAR EFFECTS

FIGURE 2 - GOVERNING ISOCASUALTY CURVE

FIGURE 3 - THREAT CONSTRAINED GOVERNING ISOCASUALTY CURVE FOR DEVELOPMENT OF NUCLEAR SURVIVABILITY CRITERIA

(Source: Nuclear Survivability Bulletin, vol. 1, no. 2)
Nuclear environments to scale with the fireball at 50 milliseconds after burst.
Effects include tissue dose in rads (tissue), dose to electronics in rads (silicon), peak static overpressure in pounds per square inch, thermal fluence in calories per square centimeter, and the peak electric field intensity of the source region electromagnetic pulse at 1 meter above the ground in kilovolts per meter (for 1600 and 7800 rad distances).

Figure 4. Initial nuclear weapon effects vs distance for a hypothetical nuclear weapon.
Table 1. Microprocessor failure levels

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Lowest measured failure (krad)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>8085</td>
<td>4.2</td>
<td>5 parts, 20°C</td>
</tr>
<tr>
<td>8080</td>
<td>3.0</td>
<td>3 parts, 20°C</td>
</tr>
<tr>
<td>9080</td>
<td>1.8</td>
<td>6 parts, 20°C</td>
</tr>
<tr>
<td>8030</td>
<td>0.5</td>
<td>6 parts, 20°C</td>
</tr>
<tr>
<td>6800</td>
<td>8.9</td>
<td>7 parts, 20°C</td>
</tr>
<tr>
<td>1802</td>
<td>10.0</td>
<td>5 parts, 20°C</td>
</tr>
</tbody>
</table>

(Source: Nuclear Survivability Bulletin, vol. 1, no. 1.)

Figure 5. Overlap of electromagnetic effects in power density vs. frequency.

(Source: Nuclear Survivability Bulletin, vol. 2, no. 2.)