TMRE Public Meeting

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Agenda

- Opening Remarks
- Industry responses to a subset of NRC technical questions (ML17235B148) regarding NEI 17-02, Revision 0
  - Robust Targets/Missiles
  - Target Characteristics
  - Missile Inventory
- Path forward

Appendix C Questions

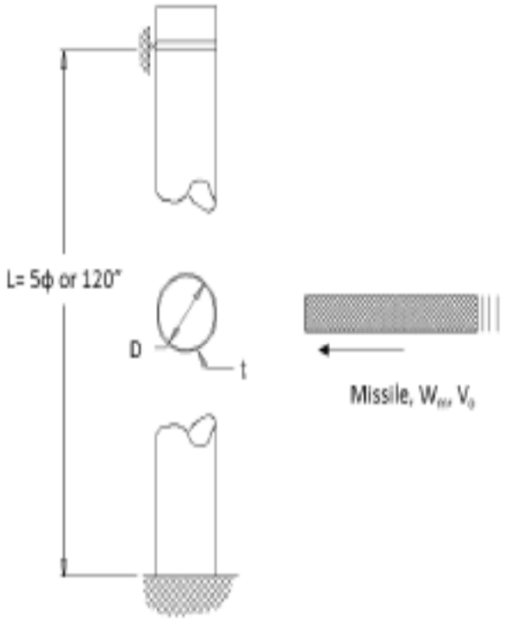
- Responses to Question 11 (a thru i) except 11.h (spalling secondary effect)

11.a

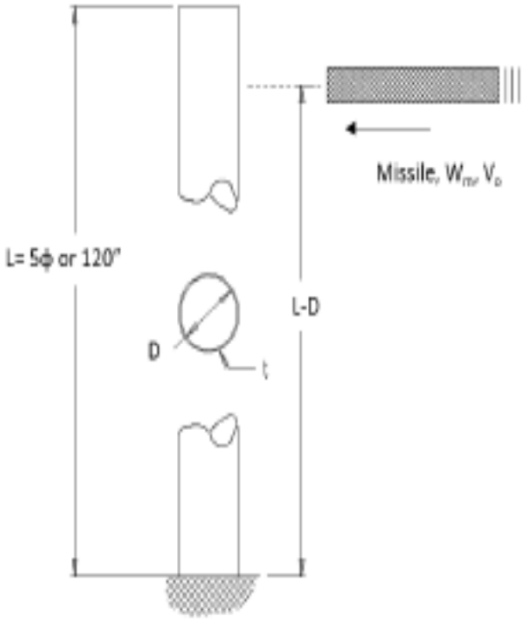
- Figure C-1 and Table C-1 do not appear to conclude that the assumptions are representative of plant targets. Specifically, the assumption for exhausts and stacks is described as having the exhaust/stack being supported on both ends. Generally, and specific to the example in Figure C-1, these targets are unsupported at the end. The guidance should ensure justification is provided to demonstrate the appropriateness of this assumption.

Response to 11.a

- Appendix C has been revised to include two cases:
  - Fluid filled pipe case that is supported on both ends of pipe
  - Vent pipe case that is supported by a cantilevered support
  - Table C-6 results reflect these cases



Fluid-Filled Pipe Case



Vent Pipe Case

11.b

- In Section C.3.1, it is the NRC staff's understanding that M should be the mass of the missile, vice the weight provided in the missile descriptions (mass = weight/32.2). For non-cylindrical missiles, the guidance should ensure that the equivalent diameter used is the diameter of a circle equal to the frontal area of the non-cylindrical missile.

Response to 11.b

- We are in agreement with the staff's understanding. While missile weight is referenced in the missile descriptions, the appropriate value of mass is used when required, such when the BRL equation for steel is used :

$$T = \frac{\left(\frac{MV_s^2}{2}\right)^{2/3}}{672 D_m}$$

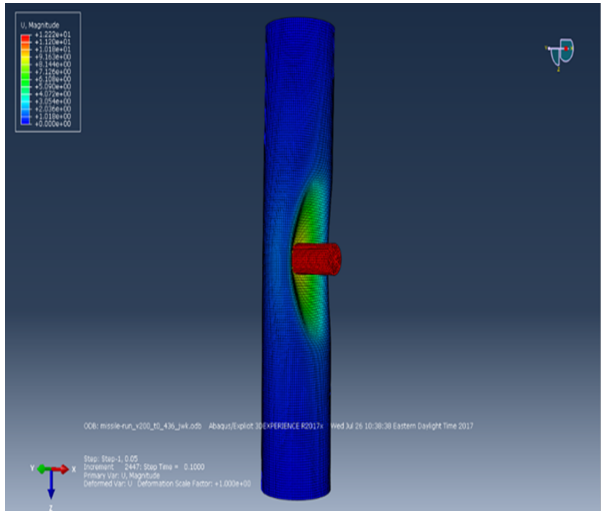
T = steel plate thickness to just perforate (inches)
M = Mass of the missile ($lb - sec^2/ft$)
V_s = striking velocity of the missile normal to target surface $\left(\frac{ft}{sec}\right)$
D_m = diameter of missile (in)

11.c

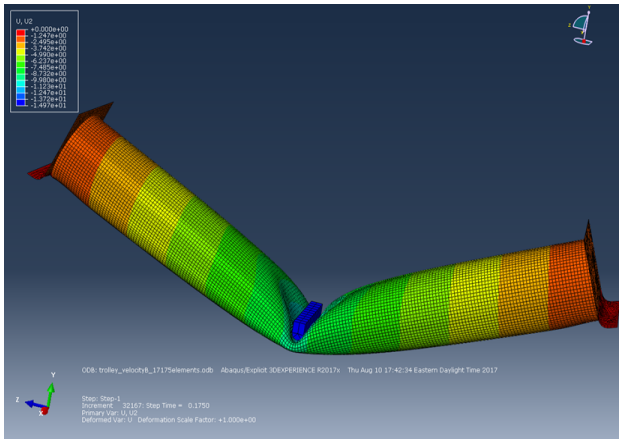
- The assumption that only steel missiles are capable of perforating steel targets, should be verified and a justification provided. Also, in the associated reference document that describes the equation above, it is said that the thickness of the steel barrier required to prevent perforation should exceed the thickness for threshold of perforations by 25 percent. It should be considered whether this assumption is significant enough to be added.

- Appendix C approach addresses both local and global effects on steel targets
- Local effects relate to penetration and deformation failures
  - Penetration failure is assessed using BRL equation (empirical)
  - Deformation failure is assessed using a mechanics-based approach
- Global effects are related to larger deformations

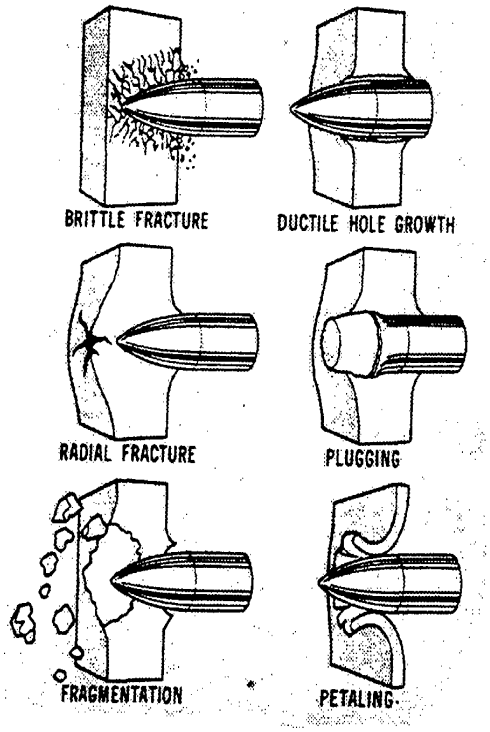
Deformation Failure Mode (Local)

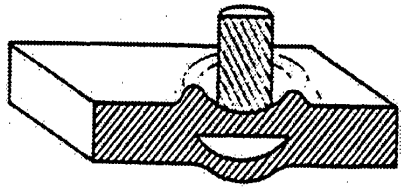


Deformation Failure Mode (Global)



Penetration Failure

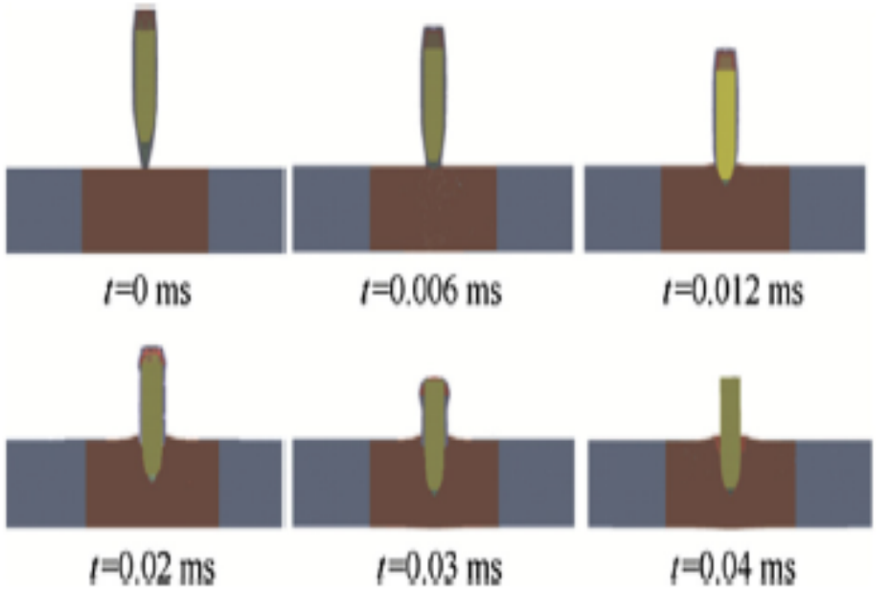


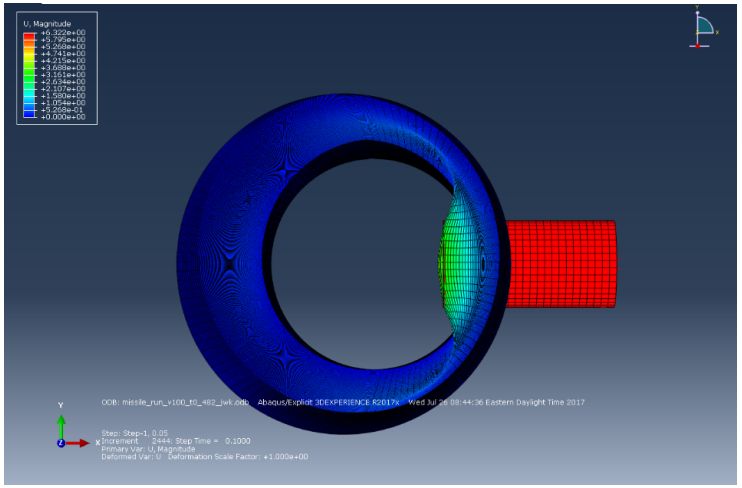


SPALL FAILURE (SCABBING)

- Penetration into a steel plate requires the missile to have a high areal density and strength to remain intact (e.g., steel-jacketed lead)
- DOE Standard 3014-96 recommends only using BRL equation for rigid missiles
- Thus, for assessing penetration failure, only steel missiles are considered
- However, all missiles are considered credible for deformation failure modes

Steel missiles considered for penetration





All missiles considered for deformation

11.d

- In Section C.3.1, the guidance should provide a table of values of perforation thicknesses for the different targets in question, or an example of this equation used to evaluate one of the targets.

Response to 11.d

- The following table summarizes three example cases indicating the parameters used in the concrete perforation using the BRL equation:

$$T = \frac{427}{\sqrt{f'_c}} \frac{W}{D_m^{1.8}} \left(\frac{V_s}{1{,}000}\right)^{1.33}$$

T = thickness of concrete element to be just perforated (in)
W = weight of missile (lb)
D_m = diameter of missile (in)
V_s = striking velocity of missile $\left(\frac{ft}{s}\right)$
f'_c = compressive strength of concrete (psi)

Parameter	Notes	# 8 Rebar	Utility Pole	4x12 timber
Missile Weight (lb)	Ref Report Table 5-2	8	1500	200
Missile Impact Face Dimensions	Ref Report Table 5-2	1" dia	13.5" dia	4"x12"
Assumed Missile Projected Area (in^2)	Ref Report Table 5-2	0.8	143.1	48.0
Equivalent Diameter, D (in) [Based on Projected Missile Area]		1.0	13.5	7.8
Assumed Concrete Design Strength, f'_c (psi)	Representative	3,500	3,500	3,500
Median Concrete Strength Factor , F_m	NEI 07-13; Section 2.3.1	1.15	1.15	1.15
Concrete Age Factor, F_{age}	NEI 07-13; Section 2.3.1	1.20	1.20	1.20
Dynamci Increase Factor, DIF	NEI 07-13; Section 2.3.1	1.25	1.25	1.25
Median Concrete Strength Factor'c (psi)	$f'c \times F_m \times F_{age} \times DIF$	6,038	6,038	6,038
Vertical Impact Velocity; V_{vert} (fps) $V_{vert} = (2/3\ V_{hor})$	Ref Report Figure C-3	225	179	219
Limiting Perforation Thickness; T (in)	BRL Equation; Report Section C3.1	6.1	7.7	3.6

- Summary Table C-5 reflecting results for each missile and target combination

Missile	Minimum Perforation Thickness (in)	4" Roof Slab Edge rotation [2]	8" Roof Slab Edge rotation [3]	Evaluation
# 8 Rebar	6.1			Perforation failure of 4" slab
Gas Cyl (290 lb)	3.3			No failure of 4" or 8" slab
Tank Drum (500 lb)	1.6			No failure of 4" or 8" slab
Utility Pole (1500 lb)	7.7			Perforation failure of 4" slab; 8" slab OK as equation conservative for timber missiles
Cable Reel (253 lb)	0.3			No failure of 4" or 8" slab
3" pipe (76 lb)	6.0			Perforation failure of 4" slab not likely due to low stiffness of pipe (30% reduction not credited). Steel decking also not credited
6" pipe (284 lb)	6.8			Perforation failure of 4" slab
12" pipe (744 lb)	5.0			Panel (global) failure of 4" slab
Tool bx (675 lb)	0.5			Flexural failure of 4"; No failure 8" slab
Paver (88 lb)	1.6			No failure of 4" or 8" slab
Conc blk (36 lb)	0.5			No failure of 4" or 8" slab
4x12 timber (200 lb)	3.6			No failure of 4" or 8" slab
2x12 plank (27 lb)	0.9			No failure of 4" or 8" slab
Metal siding (125 lb)	1.2			No failure of 4" or 8" slab
7/8" plywood (84 lb)	1.7			No failure of 4" or 8" slab
W14x26 (390 lb)	4.8			Flexural failure of 4" slab; No failure of 8" slab
C6x13 (195 lb)	11.4			Irregular cross-section results in unrealistic result. Alternative Chang formula (DOE-STD-3014-96) indicates limiting thickness of 3.4"; assume no failure as steel decking not credited
small motor (388 lb)	0.5			No failure of 4" or 8" slab
conc mixer (1,350 lb)	0.8			Flexural failure of 4"; No failure 8" slab
steel grating (74 lb)	2.5			No failure of 4" or 8" slab
pallet rack (1,040 lb)	0.2			Flexural failure of 4"; No failure 8" slab
vehicle (4,000 lb)	0.4			Panel (global) failure of 4" slab; 8" also assumed to fail as a conservative measure
20' tree (700 lb)	11.0			Perforation failure of 4" slab not likely due to low stiffness of tree branches
*Green is max rotation < 0.210 radians [ASCE 59-11]				
*Red is max rotation > 0.210 radians [ASCE 59-11]				
[2] 4 ft span assumed for 4" slab				
[3] 20 ft span assumed for 8" slab				

11.e

- On the Variation of Impact Velocity with Missile Weight (Figure C-3) plot provided shows how missile velocity assumed in this analysis varies with weight. The equation of the line provided represents the best fit line for the data (blue dotted line), but the model uses the green line, which is conservatively shifted up to a maximum velocity of 230 mph. The guidance should include the equation of the line for the green line in order to calculate any missile velocity given missile weight or vice versa.

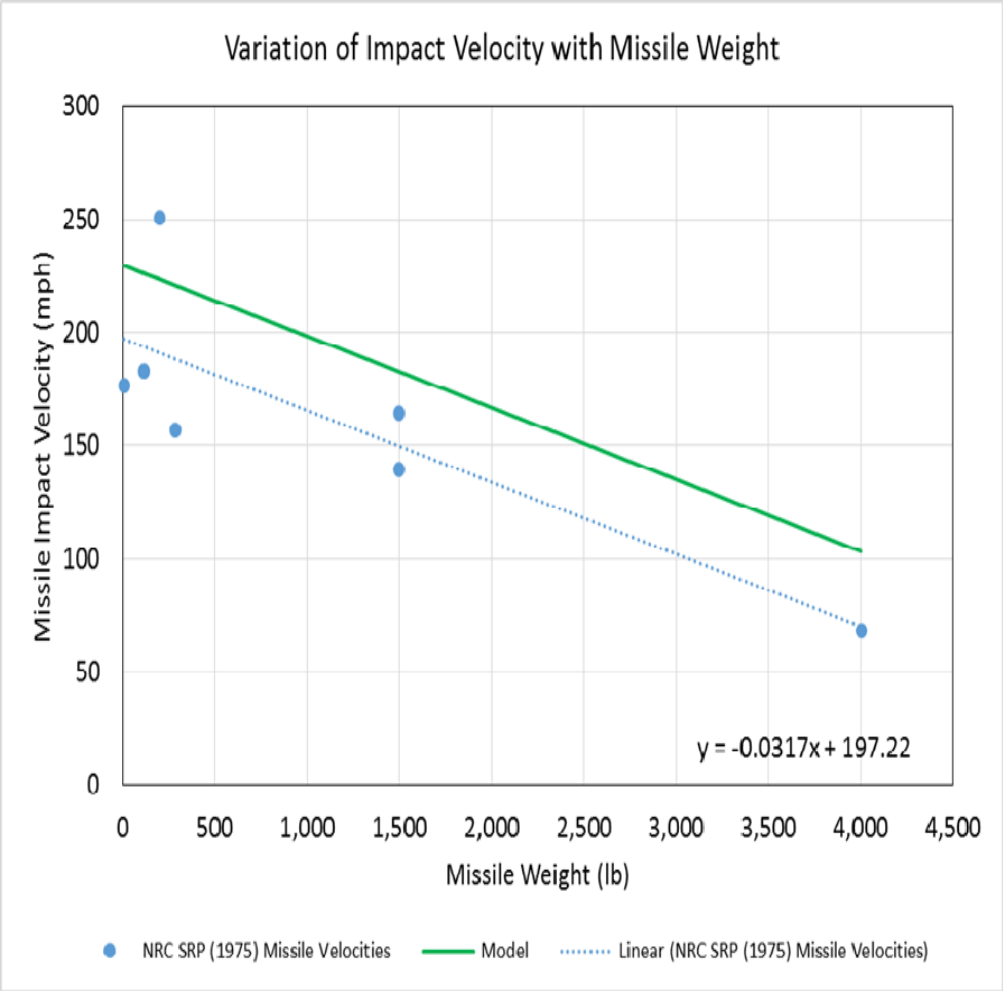
Response to 11.e

Report will be updated to better describe green line relationship as used in the model:

$V_i(W)= -0.0317W + 230.0$

Where,

V_i = Missile impact velocity (mph)
W= Missile Weight (lb)



11.f

- In section C.3.1, the assumption is that only like materials can cause perforation (steel to steel). The guidance should ensure that a justification is provided to support this assumption.

Response to 11.f

- Refer to Response to 11.c

11.g

- Figure C-14, should be reviewed to determine whether it can be used to estimate tank rupture

Response to 11.g

- This is a typographical error. Figure number should read “Figure C-13”

11.i

- The data in Table C-5, specifically the minimum perforation thickness in the first column, should be validated and more comprehensive guidance provided regarding the use of the Concrete Perforation equation. Additionally, the evaluations on the failure of the concrete using those values should be addressed should the validation demonstrate that the values should be changed. Similar validation efforts should be performed on vehicle impact and the tree impact evaluation.

Response to 11.i

- This issue is similar to that raised in Question 11.d

Responses to Appendix B and Robust Missile & Target Questions

5.d., 10.c., and 10.d.

- These comments refer to the development of Tables B-14 and B-18
  - Table B-14: Robust Target Missile Matrix
    - Matrix showing which missile types can damage which robust target category
    - 23 missile types (1 - 23) vs. 9 target categories (A – I)
  - Table B-18: Missile Damage Capability
    - Provides percentage of total missiles that can damage each robust category (A – I)
    - Results repeated in Table 5-2
- Tables B-14, B-18, and others in Appendix B, were updated in NEI 17-02, Rev. 1
- Table C.6 (Target Damage Approximations) has been updated but was not reflected in NEI 17-02, Rev. 1.

Table C.6

Robust Target Category	Target Description	Failure Modes Assessed	Missiles																							
			Rebar	Gas Cylinder	Tank/Drum	Utility Pole	Cable Reel	3" pipe	6" pipe	12" pipe	Storage Bin	Concrete Paver	Concrete Block	Wood Beam	Wood Plank	Metal siding	Plywood Sheet	Wide Flange	Channel Section	Small equipment	Large Equipment	Steel Frame/Grating	Large Steel Frame	Vehicle	Tree
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
A	Diesel Generator Exhaust Pipe	Deformation																							
A	SG Power Operated Relief Valve Tailpipe	Deformation																							
A	Turbine Driven Feedwater pump exhaust piping	Deformation																							
A	Steam Generator Power Operated RV Exh Pipe	Deformation																							
B	Diesel Generator Air intake (small)	Deformation																							
B	Diesel Generator Air intake (large)	Deformation																							
A	Diesel Generator Exh Silencer	Deformation																							
C	Condensate Storage Tank (t=0.25")	Perforation																							
D	Diesel Fuel Oil Tank (t=0.133")	Perforation																							
D	Diesel Fuel Oil Tank (t=0.145")	Perforation																							
C	Condensate Storage Tank (t=0.375")	Perforation																							
F	Well water piping (t=0.237")	Perforation and Deformation																							
F	Condensate Piping (t=0.237")	Perforation and Deformation																							
E	Main Steam Piping (t=0.985")	Perforation and Deformation																							
C	Diesel Fuel Oil Storage Tank (t=0.25")	Perforation																							
G	Room Door (t=0.1")	Perforation and Deformation																							
E	Service Water Piping (t=0.375")	Perforation and Deformation																							
E	Aux Feedwater Piping (t=0.432")	Perforation and Deformation																							
	Concrete roofs																								
H	8" reinforced	Perforation and Deformation																							
I	4" reinforced with steel decking	Perforation and Deformation																							

Low deformation (< or = 50% crush)
High deformation (> 50% crush)
Severe deformation (100% crushing)
Steel perforation or high deformation
Concrete perforation or high deformation

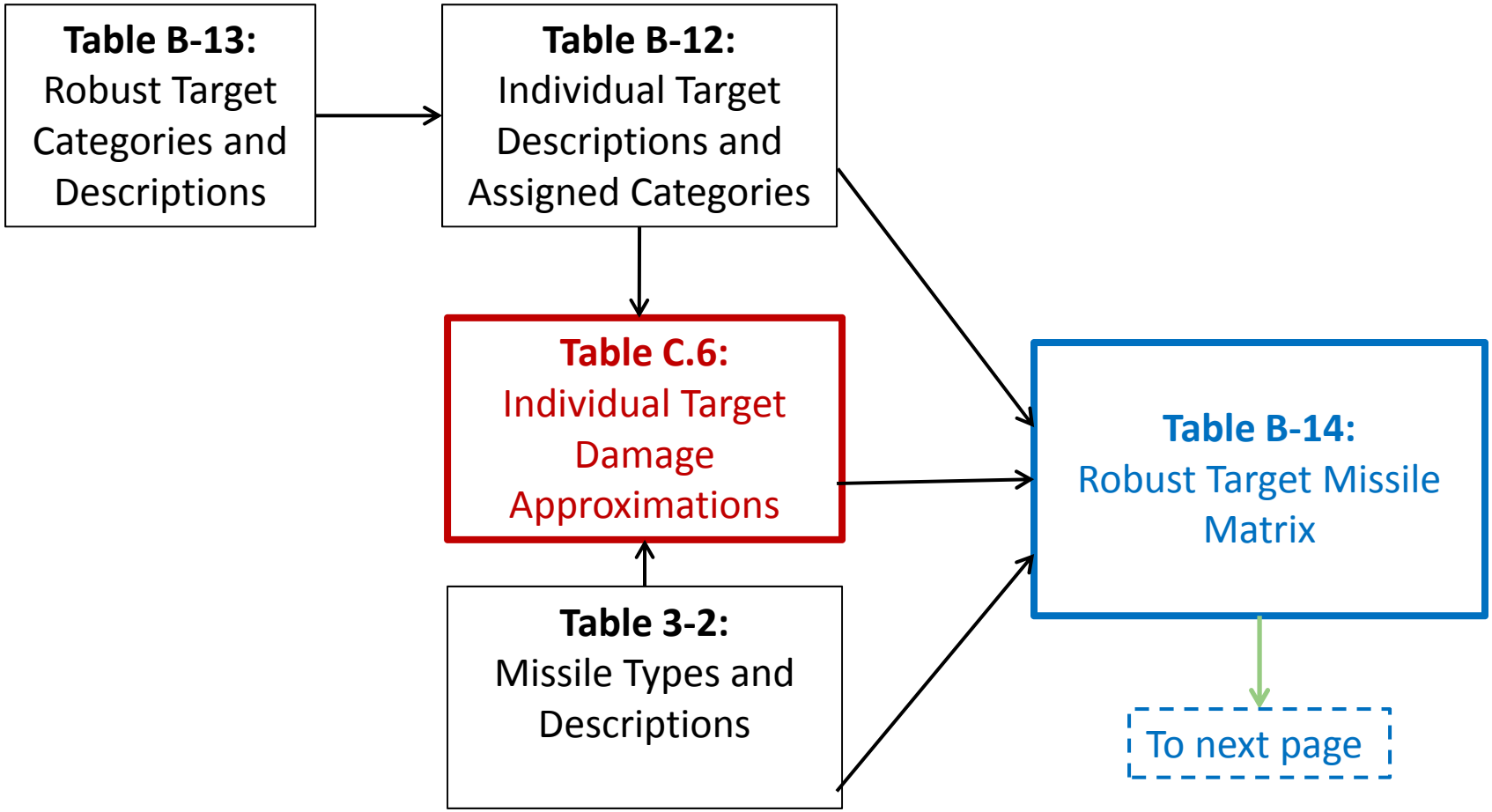
Tables B-14 and B-18

Missile Type	Robust Category Type								
	A	B	C	D	E	F	G	H	I
1 - Rebar			■	■	■	■	■		■
2 - Gas Cylinder	■	■	■	■	■	■	■		
3 - Drum, tank		■		■		■			
4 - Utility Pole	■	■	■	■	■	■	■		■
5 - Cable Reel		■		■		■			
6 - 3" Pipe		■	■	■	■	■	■		
7 - 6" Pipe	■	■	■	■	■	■	■		■
8 - 12" Pipe	■	■	■	■	■	■	■		■
9 - Storage bin	■	■	■	■		■	■		■
10 - Concrete Paver		■							
11 - Concrete Block									
12 - Wood Beam		■		■		■			
13 - Wood Plank									
14 - Metal Siding		■							
15 - Plywood Sheet									
16 - Wide Flange	■	■	■	■	■	■	■		■
17 - Channel Section		■	■	■	■	■	■		
18 - Small Equipment		■	■	■		■	■		
19 - Large Equipment	■	■	■	■	■	■	■		■
20 - Frame/Grating									
21 - Large Steel Frame	■	■	■	■	■	■	■		■
22 - Vehicle	■	■	■	■	■	■	■	■	■
23 - Tree		■		■		■	■		

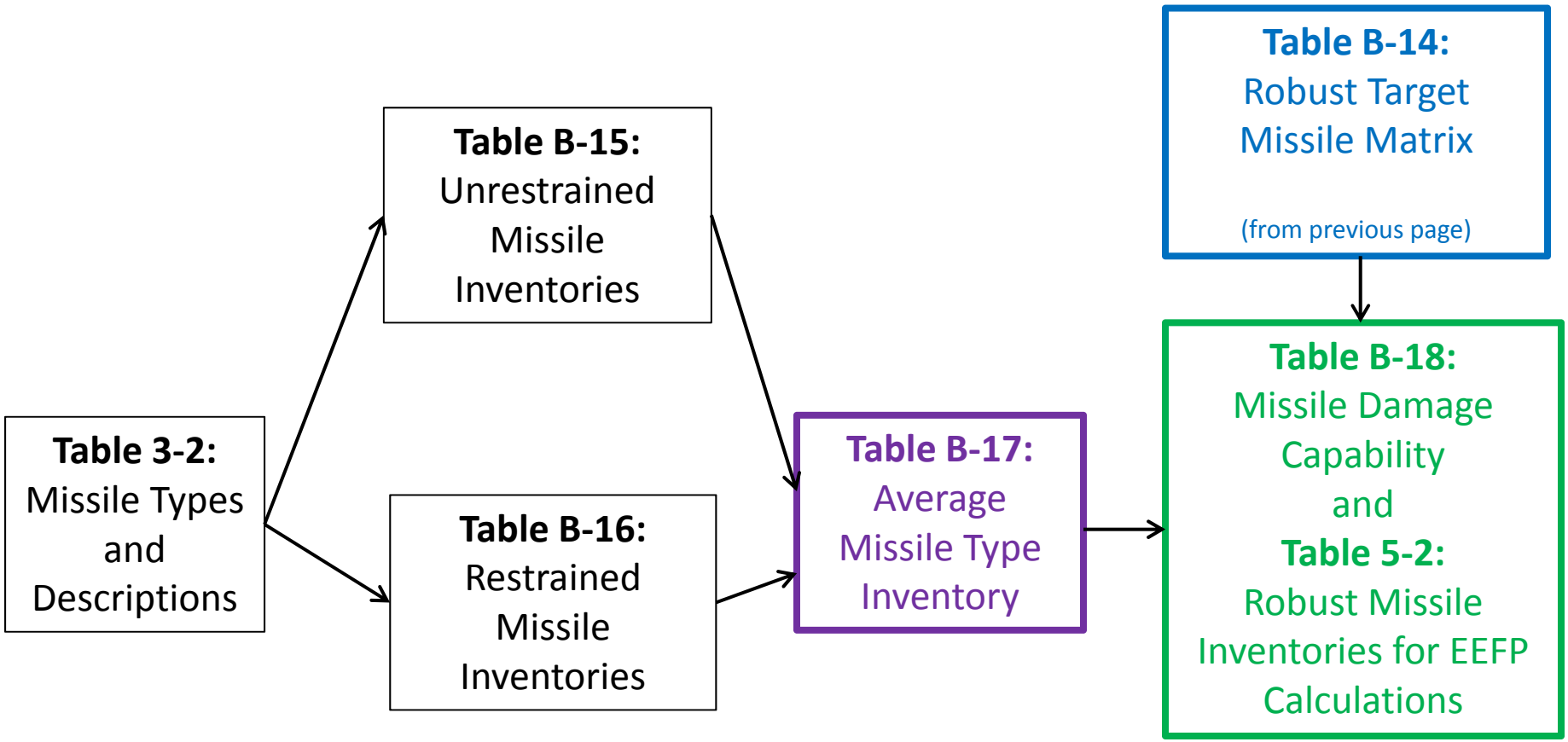
■ Indicates that missile type fails the target category

Category	Target Description	Failure Mode	Calculated Percentage	Final Percentage
A	Steel Pipe – at least 16" diameter and 3/8" thickness	Crushing/Crimping of > 50%	5%	5%
B	Steel Pipe – at least 16" diameter and thickness less than 3/8" but at least 0.125"	Crushing/Crimping of > 50%	53%	55%
C	Steel Tank – at least 0.25" thickness	Penetration or Global Failure	37%	40%
D	Steel Tank – less than 0.25" thickness	Penetration or Global Failure	46%	50%
E	Steel Pipe – at least 10" diameter and 3/8" thickness	Penetration or Global Failure	34%	35%
F	Steel Pipe – Less than 10" diameter or 3/8" thickness	Penetration or Global Failure	46%	50%
G	Steel Door	Penetration or Global Failure	44%	45%
H	Concrete Roof – Reinforced, at least 8" thick	Penetration or Global Failure	1%	1%
I	Concrete Roof – Reinforced, at least 4" thick	Penetration or Global Failure	17%	20%

Use of Table C.6 Results to Create Table B-14



Use of Table B-14 and B-17 to Create Table B-18/Table 5-2



Example

- Category B: Steel Pipe
  - At least 16” diameter and thickness less than 3/8” but at least 0.125”
  - Crushing/Crimping of > 50%
- Table C.6 worst case results – damaged by all missiles except: 1, 11, 13, 15, 20

Robust Target Category	Target Description	Rebar	Gas Cylinder	Tank/Drum	Utility Pole	Cable Reel	3" pipe	6" pipe	12" pipe	Storage Bin	Concrete Paver	Concrete Block	Wood Beam	Wood Plank	Metal siding	Plywood Sheet	Wide Flange	Channel Section	Small equipment	Large Equipment	Steel Frame/Grating	Large Steel Frame	Vehicle	Tree
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
B	Diesel Generator Air intake (small)																							
B	Diesel Generator Air intake (large)																							

Example – Category B (cont.)

- Damaged by all missiles except: 1, 11, 13, 15, 20
- Results shown in Table B-14

Missile Type	Robust Category	
	A	B
1 - Rebar		
2 - Gas Cylinder	■	■
3 - Drum, tank		■
4 - Utility Pole	■	■
5 - Cable Reel		■
6 - 3" Pipe		■
7 - 6" Pipe	■	■
8 - 12" Pipe	■	■
9 - Storage bin	■	■
10 - Concrete Paver		■
11 - Concrete Block		
12 - Wood Beam		■
13 - Wood Plank		
14 - Metal Siding		■
15 - Plywood Sheet		
16 - Wide Flange	■	■
17 - Channel Section		■
18 - Small Equipment		■
19 - Large Equipment	■	■
20 - Frame/Grating		
21 - Large Steel Frame	■	■
22 - Vehicle	■	■
23 - Tree		■

■ Indicates that missile type fails the targ

Example – Category B (cont.)

- From Table B-17, sum of missile percentages (excluding 1, 11, 13, 15, 20) is **53%**
  - Majority of missiles contributing to total are: 3" pipes, metal siding, channel sections and trees (42%)
  - Other damaging missiles have relatively small inventories at sites
- Table B-18 for Category B:
  - Calculated percentage = **53%**
  - Final percentage rounded up to **55%**
- Table 5-2 for Category B: **55%**

Missile Type	Percentage
1 - Rebar	
2 - Gas Cylinder	0.5%
3 - Drum, tank	0.2%
4 - Utility Pole	0.1%
5 - Cable Reel	0.4%
6 - 3" Pipe	11%
7 - 6" Pipe	0.6%
8 - 12" Pipe	0.1%
9 - Storage bin	1.6%
10 - Concrete Paver	2.7%
11 - Concrete Block	
12 - Wood Beam	1.5%
13 - Wood Plank	
14 - Metal Siding	17%
15 - Plywood Sheet	
16 - Wide Flange	0.3%
17 - Channel Section	7.2%
18 - Small Equipment	1.0%
19 - Large Equipment	0.5%
20 - Frame/Grating	
21 - Large Steel Frame	0.5%
22 - Vehicle	0.8%
23 - Tree	6.8%
TOTAL	**53%**

Tables B-18 and 5-2

- Most categories get a modest reduction in damaging missiles (factor of 2 to 3)
  - B, C, D, E, F, G
- Most robust targets are thick steel pipes (for crimping/crushing) and concrete roofs

Category	Target Description	Failure Mode	Calculated Percentage	Final Percentage
A	Steel Pipe – at least 16" diameter and 3/8" thickness	Crushing/Crimping of > 50%	5%	5%
B	Steel Pipe – at least 16" diameter and thickness less than 3/8" but at least 0.125"	Crushing/Crimping of > 50%	53%	55%
C	Steel Tank – at least 0.25" thickness	Penetration or Global Failure	37%	40%
D	Steel Tank – less than 0.25" thickness	Penetration or Global Failure	46%	50%
E	Steel Pipe – at least 10" diameter and 3/8" thickness	Penetration or Global Failure	34%	35%
F	Steel Pipe – Less than 10" diameter or 3/8" thickness	Penetration or Global Failure	46%	50%
G	Steel Door	Penetration or Global Failure	44%	45%
H	Concrete Roof – Reinforced, at least 8" thick	Penetration or Global Failure	1%	1%
I	Concrete Roof – Reinforced, at least 4" thick	Penetration or Global Failure	17%	20%

4.f. and 5.g.

- 4.f. – Number and description of missile types in Table 3-2 do not correspond with missile information in other tables
  - 23 missiles used in all tables except Tables 3-3 through 3-8
  - Tables 3-3 through 3-8 are missiles created from the deconstruction of buildings
    - Only the first 22 missiles are listed, since missile #23 is a tree
- 5.g. – Example EEFP calculations using different percentages for robust missiles than Table 5-2
  - Corrected

7.b

- Section 7.4 discusses using a smaller area if target is partially shielded; the guidance should address shielding considerations for area calculations
  - Section 5.3.2 discusses shielding examples and how shielding would be used to change target areas
    - Targets may be adjacent to Class 1 buildings or other structures that would preclude missiles hitting targets from those directions
    - Penetrations or openings may be partially blocked by piping or supports, reducing the effective opening size
  - The basis for how shielding is credited in reducing target areas should be justified and documented

Questions?