An Overview of Risk-Based Explosives Safety Siting

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ABSTRACT

A recent effort has been completed to incorporate hazard-consequence analysis tools into the Explosives Safety Siting (ESS) software as Risk-Based ESS (RBESS). ESS is an automated site planning tool developed by the Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC) and funded by the Department of Defense Explosives Safety Board (DDESB). The Department of Defense (DoD) has mandated the use of Automated Site Planning (ASP) by the military services for siting all facilities that store and handle explosives (i.e. potential explosion sites (PES's)). All DoD ammunition and explosives facilities around the world must be approved by the DDESB to ensure they present an acceptable level of risk to DoD personnel, assets and mission, as well as to the public. For situations when facilities cannot meet the DoD criteria the tools that are available in RBESS generate data on the consequences from an accidental explosion and are used to provide the proper acceptance authority with information required to assume risk for un-sited PES's. There are two tiers currently available in RBESS to perform a hazard-consequence analysis; RBESS Tier 1 and 2a. The Tier 1 tool is a qualitative risk management analysis that requires little to no additional input from a user beyond typical information required for an ESS analysis. The analysis uses hazard zones that correspond to explosives safety quantity-distances (QD) (i.e. intermagazine distance, intraline distance, inhabited building distance, etc.) to estimate consequences in terms of facility replacement cost, fatalities, and injuries. The Tier 2a tool is a qualitative risk analysis tool that calculates hazards and consequences based on the combination of methods and algorithms in DDESB Technical Paper (TP) 14 Revision 4 and TP-23. Most of the input required to run RBESS Tier 2a can be read from an existing ESS dataset, such as number of occupants and replacement cost, but some additional input is required to determine event probability; PES category, soil type, and more. Both RBESS Tier 1 and Tier 2a have been developed to generate risk information for a single PES that affects multiple exposed sites (ES's). The output for both Tier 1 and Tier 2a RBESS include color-coded maps that display information on replacement cost, fatalities, and injuries. The output also displays consequence information for individual ES's as well as summary information for all the ES's affected by the PES. Both tiers of RBESS automatically populate the Department of Army (DA) Form 7632 which is known as the Deviation Approval and Risk Acceptance Document (DARAD). RBESS is being released in ESS v6.1.4 and will be available to ESS users in the near future.

INTRODUCTION

A recent effort is near completion to incorporate hazard-consequence analysis tools into the DDESB funded ASP software tool ESS. The implementation of these hazard-consequence tools into ESS is referred to as RBESS. The development of RBESS has been accomplished by NAVFAC EXWC with their support contractors VSolvit and ACTA, under the direction of DDESB and the military service component representatives of the automated site planning working group and ESS configuration control board.

All organizations and military services that manage and operate DoD ammunition and explosives (A/E) facilities must comply with DoD requirements and regulations that are published in DoD 6055.09-M, "Ammunition and Explosives Safety Standards [1]." DoD 6055.09-M includes criteria for QD separation distances that are required between PES's and ES's. The DDESB is the approval authority for DoD explosives sites and grants authority for operation through a formal process that requires installation planners to prepare individual Site Approval Request (SAR) packages for a PES. This approval process is supported by military component explosives safety approval authorities, who have the authority to impose additional requirements over-and-above the DoD requirements. The DDESB will not approve SAR packages for facilities that do not meet QD separation distances because the risk associated with these deviations exceeds the risk commensurate with that of the DoD explosives safety regulations.

A common deviation or violation of QD criteria occurs when the required PES to ES separation distance exceeds the actual separation distance. Multiple measures exist to address QD violations, including compensatory measures, engineering analysis, DDESB approved risk-based explosives safety (i.e. SAFER, [2]) siting. Risk acceptance of a QD violation occurs when a military service component assumes the risk that a QD violation imposes on the related mission, operations, facilities, and people at the site. The level at which a risk acceptance occurs is governed by military service component regulations and policies. Depending on the service component, required risk acceptance level can vary from an installation level commanding officer up to the secretary of the military service (i.e. Secretary of the Army, Air Force, or Navy). The decision-making process needed for risk acceptance requires analysis procedures that quantify the hazards and consequences of an accidental explosion at the violating A/E facilities. Multiple tools exist for performing these analysis, two of which are being incorporated into ESS. The first is ASAP-X [3], which is a spreadsheet-based application that calculates hazard consequences based on general levels of damage and fatalities corresponding to QD exposures (i.e. magazine, intraline, inhabited building) as described in DoD 6055.09-M. The implementation of ASAP-X into ESS is referred to as RBESS Tier 1. The second tool is called HAZX [4], a risk analysis tool that calculates hazards and consequences based on the combination of methods and algorithms in DDESB TP-14 Revision 4 [5] and TP-23 [6]. The implementation of HAZX in RBESS is referred to as RBESS Tier 2a.

ESS is a geographic information system (GIS) software program that links graphic map data with non-graphic real property inventory (RPI) data and explosives data to build electronic GIS datasets. These maps are then analyzed using automated procedures to determine actual separation distances between facilities and compare against DoD explosives safety regulations for QD. ESS is used to identify QD violations when they are found to exist, and it provides tools to automate the creation of SAR package documentation that includes tabular and graphical information required by approval authorities. RBESS Tier 1 and Tier 2a are being incorporated into ESS because the DoD has mandated all A/E facilities that require explosives safety site plans must use automated site planning and ESS is the software that has been adopted by the DDESB and the ASP Working Group to accomplish this work; thus, databases of installations, needed to perform hazard-consequence analysis are being built in ESS. Furthermore, ESS has several capabilities that complement the hazard-consequence analysis tools which include mapping, geospatial analysis, accurate calculations of QD, and inclusion of military service components' GIS, explosives, and real property inventory data. Finally, proper management of explosives safety risks requires a process that is traceable and maintainable over the life-cycle of the A/E facility, which is more likely when the analysis used to make risk decisions is contained in an ESS dataset used to identify violations for the facility.

TECHNICAL APPROACH

RBESS has been implemented into ESS as an analysis option that has specific graphical user interfaces (GUI's) for Tier 1 and Tier 2a methods and new risk-based tables within the ESS database structure. Analysis parameters are input or collected for existing ESS datasets with the RBESS GUI. The hazard-consequence analyses for the different tiers are performed using the ASAP-X, HAZX Risk Tool (TP14-based), and the QD engine modules, which are all made available to RBESS through a shared common component library. The common library is used to preprocess input data and post process results. The output which includes GIS objects, charts, and reports is displayed through the RBESS user interface. The HAZX software also has access to the common library with the capability to assign input parameters and to display results that are output by the hazard-consequence modules. This system design was selected so that changes to either RBESS or HAZX are readily available to the other software tool. A schematic that illustrates the system design of RBESS and the common library is shown in Figure 1.

An RBESS analysis requires an ESS dataset with explosives, facility, and GIS data. Typically, a user will perform an ESS analysis to develop a site plan approval request package and encounter QD violations that cannot be mitigated by measures other than risk acceptance. At this point the user can select RBESS Tier 1 or 2a analysis as shown in Figure 2, which displays the training database for Alameda Air Station. The figure shows that the PES facility on the far right of the map has a QD violation that is indicated by the red arrow.

RBESS Tier 1 analysis uses six hazard zones that directly correspond to consequence descriptions defined within DoDM 6055.09 for facility damage in terms of cost and fatalities of people. The six hazard zones correspond to QD arcs generated by a PES for barricaded intermagazine distance (K6), barricaded intraline distance (K9), intermagazine distance (K11), intraline distance (K18), public traffic route distance (PTRD), and inhabited building distance (IBD). Consequences for an ES are determined relative to its position within the hazard zones.

Injuries are calculated as a function of the fatalities, but considerations are made such that the accumulation of injuries and fatalities does not exceed the number of people present The hazard zones are calculated using modified calls of the ESS QD engine, which is consistent with DoD and military service component QD criteria. The analysis uses interpolation to calculate damage, fatalities, and injuries for ES's that fall between hazard zones (where arcs and distance measurements are made from edge of PES polygon to edge of ES polygon). RBESS Tier 1 requires facility replacement cost and number of occupants for the PES and ES's:. this information is not required for ESS QD analysis, but the fields available in ESS input interface.

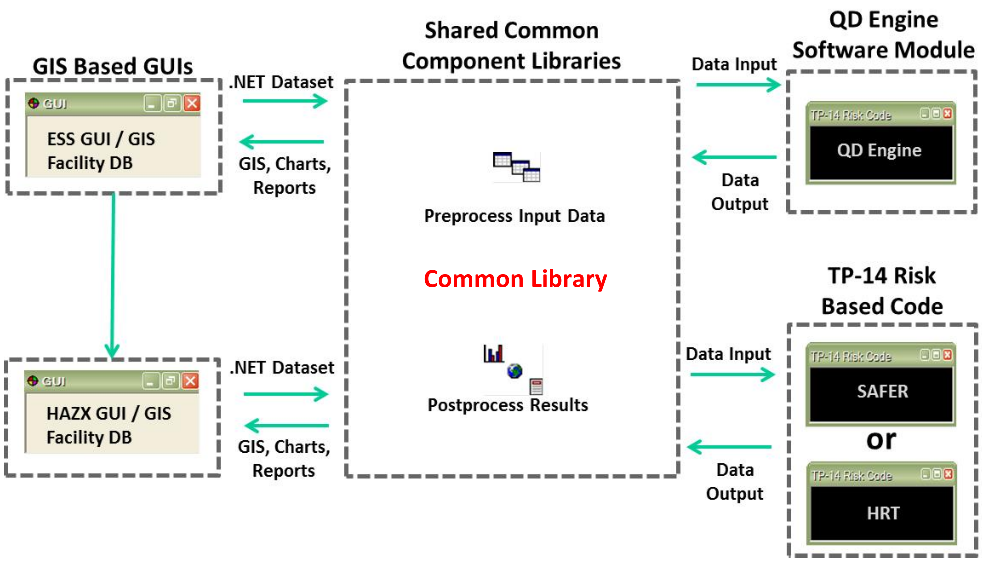


Figure 1. RBESS System Diagram.

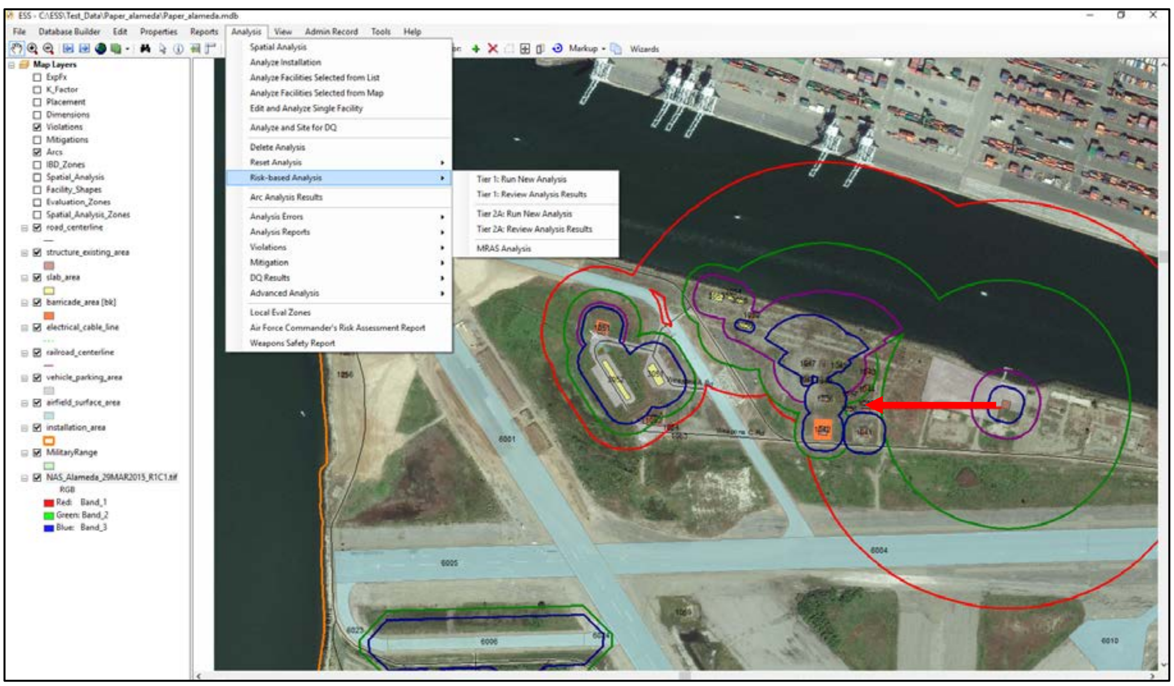


Figure 2. RBESS Analysis (Displayed maps and data do not represent existing explosives sites).

RBESS Tier 2a analysis uses TP14 algorithms developed by the DoD Risk Based Explosives Safety Team to determine consequences from accidental explosions at a PES to an ES facility. Consequences are calculated in terms of facility damage in cost and fatalities and injuries to people. RBESS Tier 2a algorithms are engineering models that were derived through the combination of empirical data and observations as well as analytical models. These models calculate consequence to non-transient ES's (i.e. buildings, structures, etc.) and transient ES's (i.e. vehicles on roads). The models also consider debris shielding effects from barricades. Analysis parameters include several fields that exist in the ESS database, but also require additional user input, including, but not limited to PES and ES building type, building category, PES soil type, A/E activity, mishap likelihood, weapon type, weapon description, barricade height, and road traffic density. RBESS Tier 2a algorithms are primarily based on separation distance and the algorithms were developed based on PES center to ES edge distance. This distinction is noted because ESS and QD calculations as prescribed in DoD 6055.09M are based on PES edge distance to ES edge distance.

VALIDATION

Validation of RBESS implementation in ESS was conducted to ensure proper incorporation of the Tier 1 and 2a HAZX tools using the common library. The validation effort was performed through a comparison of RBESS results with the results from ASAP-X (Tier 1) and HAZX (Tier 1 and 2a) for carefully selected scenarios to demonstrate equivalency or identify differences. The three tools were tested in two phases: Phase I and II. Phase I work concentrated on comparing Tier 1 analyses using ASAP-X, HAZX (Tier 1) and RBESS (Tier 1) tools. Phase II focused on comparing Tier 2a results between HAZX and RBESS.

Phase I Testing

The Tier 1 scenarios analyzed by all three tools were created by EXWC. The scenarios were built to test a general set of parameters to establish if there is consistency among the tools at a basic level of testing. The scenarios considered are shown in Table 1. Tier 1 scenarios consist of three PES types (*Earth Covered Magazines*, *Undefined*, and *Other*) with no specification of ES type (DoD 6055.09-M assumes light construction). In each scenario, seven ES's were placed at various distances from the PES (Figure 3).

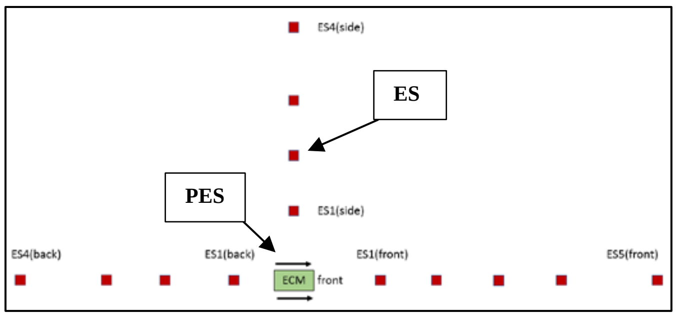


Figure 3. Example of PES-ES Locations for Evaluating ECM's .

The distances from the outside of the PES to the closest point of each ES correspond to scaled distances within each of the seven potential hazard zones: Barricaded Intermagazine Distance (IMD-B) at K6, Barricaded Intraline Distance (ILD-B) at K9, Unbarricaded Intermagazine Distance (IMD-U) at K11, Unbarricaded Intraline Distance (ILD-U) at K18, Public Traffic Route Distance (PTRD) at K24/30 or Debris PTRD, Inhabited Building Distance (IBD) at K40/K50 or Debris IBD, and beyond IBD.

Earth Covered Magazines (ECM) have different QD required distances for the front, side, and rear of the PES. Therefore, ES's along each of these PES orientations represent unique scenarios, whereas only one PES orientation is needed for the Open and Undefined PES types. Different levels of net explosive weights (NEW's) are intended to test the tools' robustness. All explosives were assumed to be Hazard Division 1.1. The Tier 1 testing therefore focuses on variation of four parameters: PES type, ES distance, PES orientation, and NEW.

The measurable output used for comparison are consequences quantified by fatalities, injuries and damage loss in dollars. In consideration of these outputs, each ES was generically assigned a population of 10 people and $100 replacement cost. The resulting consequences are therefore easily understood in terms of percent. The footprint dimensions of all ES's are 10 ft x 10 ft and the PES footprint sizes are defined in Table 2. For ECM's the front is along its width.

Table 1. Phase I: Tier 1 Scenarios & Distances (ft).

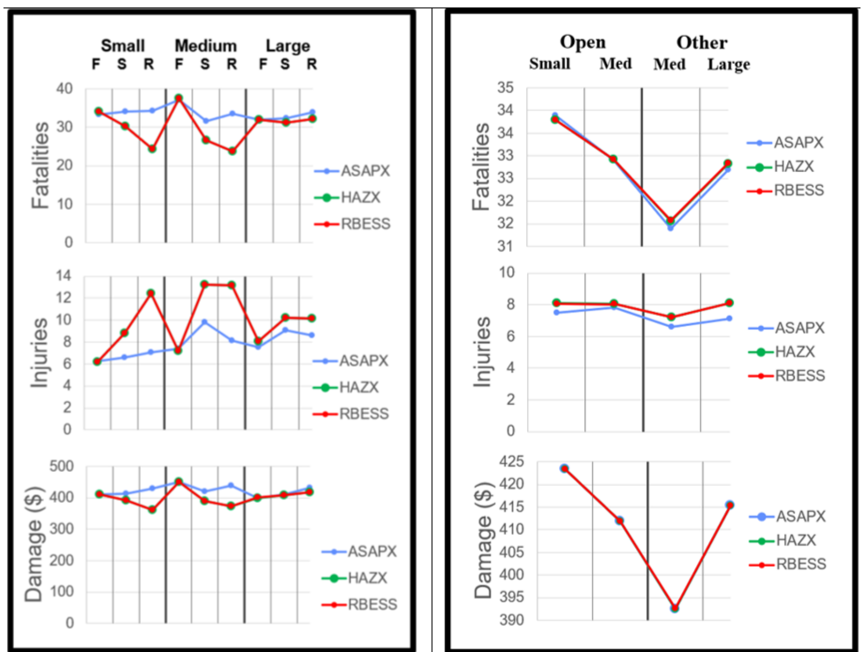
PES Type	Charge	ID	PES Orientation	IMD-B	ILD-B	IMD_U	ILD-U	PTR	IBD	> IBD
				ES 1	ES 2	ES 3	ES 4	ES 5	ES 6	ES 7
ECM	Small (1000 lb)	S1	Front	50	75	100	150	600	1000	1400
		S2	Side	40	65	95	140	500	1050	1300
		S3	Rear	30	70	105	115	400	850	1255
	Medium (70,000 lb)	S4	Front	200	300	400	500	800	1400	1600
		S5	Side	230	350	450	650	700	1300	1500
		S6	Rear	150	325	425	480	700	1000	1255
	Large (500,000 lb)	S7	Front	450	700	800	1300	2000	3800	4500
		S8	Side	400	600	750	1400	1600	3000	5000
		S9	Rear	475	500	870	1250	1500	2500	4000
Open	Small (500 lb)	S10	Front	40	60	80	120	400	900	1300
	Medium (30,000 lb)	S11	Front	150	250	300	500	650	1000	1400
Undefined	Medium (20,00 lb)	S12	Front	100	225	275	450	700	1200	1255
	Large (100,000 lb)	S13	Front	250	400	500	700	1000	1500	2000

Table 2. Phase I: PES Dimensions.

PES Type	Charge	Length (ft)	Width (ft)
ECM	Small (1000 lb)	40	25
	Medium (70,000 lb)	60	25
	Large (500,000 lb)	80	25
Open	Small (500 lb)	20	20
	Medium (30,000 lb)	20	20
Undefined	Medium (100,00 lb)	20	20
	Large (20,000 lb)	20	20

Phase I Results

The consequence results for each tool were compared by summing each of the consequence types for each scenario. The consequence types include the number of fatalities, the number of injuries or worse, and the dollar loss due to damage. The Phase 1 consequence comparisons are presented for ECM type PES's in Figure 4A and for Open- and Other-type PES's in Figure 4B.



A. ECM-type PES Scenarios

B. Open- and Other-type PES Scenarios

Figure 4. Summary of Phase I Consequence Results.

The results show nearly full agreement between HAZX and RBESS implying that the Common Library was implemented properly. ASAP-X results, however, are different than the other two tools in many cases, particularly for the ECMs. This disagreement can be more than 30% in some cases on fatality and injury. Percent difference in the damage consequence is less significant. Reasoning for the difference between HAZX and RBESS with ASAP-X is primarily due to the assessment of zones associated with an ES:

- ASAP-X does not use the DDESB QD Engine to compute the six hazard zone distances because it is a spreadsheet application that for distribution purposes doesn't use Macros; therefore, DDESB created internal spreadsheet tables to mimic the DoD 6055.09-M QD tables. For ECM's they did not include the complete QD tables which are directional for an ECM (front, side, rear).
- When an ES lies between two hazard zones, the damage, injury and fatality consequences are "linearly" interpolated by RBESS/HAZX; ASAP-X uses an inconsistent interpolation method and also rounds off injuries and fatalities to the nearest whole number.

Phase II Testing

The Phase II analyses compare Tier 2a results between HAZX and RBESS. ACTA suggested a list of test scenarios by identifying all potential PES/ES analysis parameters and factors (variations of the parameters) for approval by EXWC; a summary is presented in Table 4 for both PES and ES parameters. Some factors were not included in the proposed scenarios due to known issues or low priority. Although not shown in the table, testing was subsequently done for barricades between selected PES's and ES's.

Table 4. Phase II: PES and ES Parameters and Factors.

PES/NEW Parameters						
PES Category	**PES Type**	**Soil Type**	**Activity Type**	**NEW**	**Hazard Division**	**Weapon Type**
Aboveground Structure (AGS)	Small	Concrete	Destruction	S (< 1000 lb)	1.1	AIM-7 Missile
	Med	Loose Soil	Maint/Assembly	M (> 1000 lb)	1.2.1	Bulk/Lt Case
	Large	None (Ships)	Operations	L (≥ 100,000 lb)	1.2.2	M107
Earth Covered Magazine (ECM)	Small Steel Arch	Rock/Hard Clay	Storage		1.2.3	MK-82
	Small RC Arch		Testing		1.3	MK-83
	Med Steel Arch		Transportation		1.4	MK-84
	Med RC Arch				1.5	Unknown
	Large Steel Arch				1.6	MK1 (1.2.1)
	Large RC Arch					
Hardened AC Structure (HAS)	HAC					
Hollow Clay Tile	Hollow Clay Tile					
ISO Container	ISO Container					
Open	Open					
Operating Building (Concrete)	Small					
	Medium					
Steel PEMB	Steel PEMB					
Ship	Small					
	Medium					
	Large					

KEY
Considered in Phase 1
Recommended to be included
Not likely to be included

ES Parameters					
ES Category	**ES Building Type**	**ES Roof Type**	**Exposure Type**	**Glass**	**% Glass**
Mod Build/Trailer	Mod Build/Trailer	14" Reinforced Concrete	None	Annealed	Low (0-10%)
Open	Open	4" Reinforced Concrete	IBD	Tempered	Med (11-25%)
Vehicle	Vehicle	5/8" Gypsum Board	PTRD	Dual Pane	High (25-40%)
Reinforced Concrete	Small (Office/Comm)	3/8" Plywood + 2x10 joists	ILD		
	Medium (Office/Comm)	Light Steel Panel (22 gauge)	IMD		
	Large Tilt Up (Comm)	Lightweight Con and Steel Deck	On Base Rd		
Reinforced Masonry	Small (Office/Comm)	Medium Steel Panel (18 gauge)	Asset Presrv		
	Medium (Office/Comm)	Steel (Automobile)			
Steel PEMB	Small (Office/Storage)	Unknown			
	Medium (Office/Comm)	Wood Panelized (1/2" Plywd)			
	Large (Office/Storage/Hanger)				
Stud Wall (Wood Frame)	Small Wood Frame (Residence)				
	Med Wood Frame (Residence)				
	Medium Steel Stud				
Unreinforced Masonry	Small (Office)				
	Medium (Office)				
	Large (Office)				

KEY
Considered in Phase 1
Recommended to be included
Not likely to be included

The goal of the proposed run set was to test the correct functionality of each PES/ES factor and the interaction of each factor with other factors for each individual run. It was determined that all PES factors of interest (light red in Table 4) could be exercised in 15 basic scenarios. A PES group was defined by setting factors for each PES parameter pertaining to a single scenario. The same goes for an ES group. Fifteen PES groups were combined with 15 ES groups for a total of 15 scenarios. A second set of 15 scenarios was built by using the original 15 PES groups and combining them with a different set of ES groups for a total of 30 scenarios. Barricades were included in three randomly selected scenarios and an additional scenario including roads was added for a total of 100 runs.

Phase II Results

The testing was intended to verify the correct implementation of the common library in RBESS. Indicators of proper implementation captured in the testing included:

1) Ensuring functionality (absence of run errors)
2) Direct comparison of the consequence results with the HAZX
3) Verification of visual outputs
4) Comparison of risk matrix outputs, maximum probable loss and ES consequence reports
5) Checking Deviation and Risk Acceptance Document (DARAD)

The emphasis of the comparison was geared toward the direct comparison of consequence results with HAZX (item 2). Functionality (item 1) was tested in the process of building the RBESS project and carrying out the runs to obtain the consequence results. The visual display, such as color-coding, pressure contours, reports/forms were spot checked for correctness by comparing HAZX and RBESS outputs.

The reported consequences include the number of fatalities, major injuries and greater, minor injuries and greater, and equipment value loss in dollars. Due to the large number of results, only the fatality comparisons are shown (Figure 5). Comparisons of major injuries and worse, minor injuries and worse, and equipment loss all show similar comparisons, in which there are no noticeable differences between RBESS and HAZX. Initial findings indicated RBESS provided a higher expected value loss than HAZX by a factor of about 10 for all roads but this issue was later fixed by correcting how parameters were passed into the common library by RBESS.

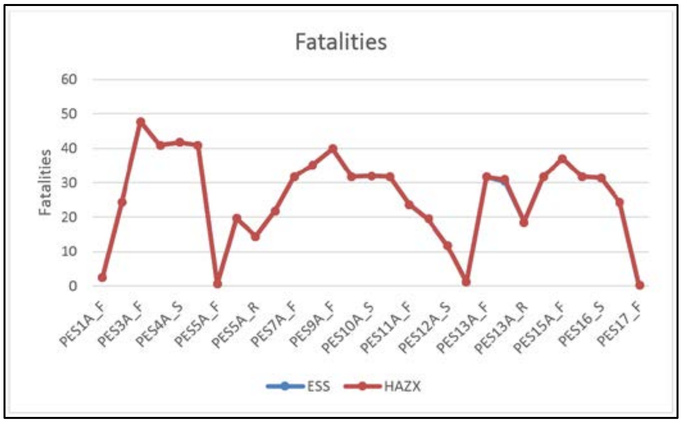


Figure 5. Comparison of Group A Fatalities.

The Maximum Probable Loss and Risk Assessment Code, RAC (from the Risk Matrix) were also compared between HAZX and RBESS for selected scenarios and agreed. DARAD forms for HAZX and RBESS were also spot-checked; all checks showed agreement for all fields. Initial testing indicated that Expected Potential Fatality, in RBESS DARAD forms did not report the fatalities from people in the PES but this issue was fixed.

RBESS DEMONSTRATIONS

Figure 6 shows a GoogleEarth aerial view of a portion of the Alameda Air Station, CA and an enlargement of an area adjacent to the airfield. It should be noted that the data displayed is for demonstration and training purposes and does not represent an actual explosives safety site. An explosion accident at aboveground magazine (AGM) 1041 is used to demonstrate an explosion assessment using: a) RBESS Tier 1, and b) RBESS Tier 2a.

Figure 6. Alameda Air Station View showing AGM 1041 (Displayed maps and data do not represent existing explosives sites).

RBESS Tier 1

Both RBESS Tier 1 and Tier 2a use ESS and a ESS facility database to perform a risk-based siting analysis; the ESS splash screen is shown in Figure 7. For the example, we have opened ESS and loaded in the facility database prepared for Alameda Air Station. Figure 8 shows ESS's GIS display of the area adjacent to AGM 1041 including the facility numbers.

Figure 7. ESS Splash Screen.

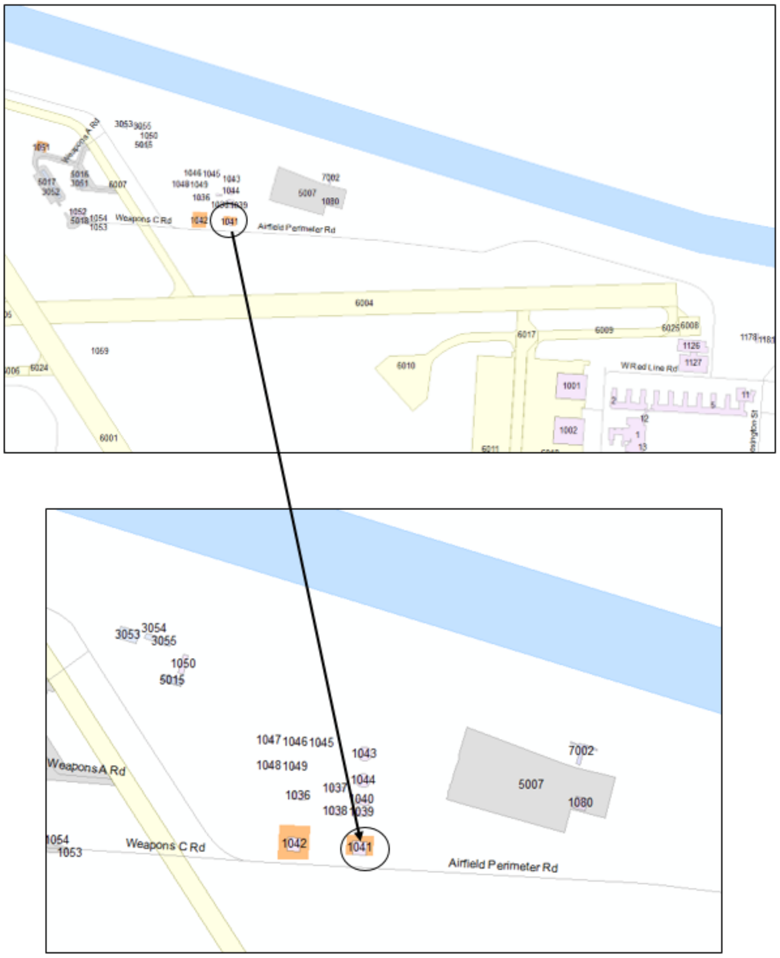


Figure 8. ESS Display of Area Adjacent to AGM 1041 (Displayed maps and data do not represent existing explosives sites).

To start a RBESS Tier 1 analysis, click on the ESS menu bar "Analysis" option, then on "Risk-Based Analysis", "Tier 1: Run New Analysis" (Figure 9) to view a PES Selection screen (Figure 10). Select PES 1041 and click OK to view the Scenario Selector screen. A new scenario can be defined; for our example, however, we simply clicked on the existing scenario and then "Select" to bring up the Scenario Setup Screen (Figure 11). The "Scenario" Tab displays ESS PES description data; the analyst can add additional information to help define the scenario in the "Notes" text box. When complete, click on Save Information and then on the "PES" Tab (Figure 12).

Figure 9. Starting RBESS Tier 1 Analysis (Displayed maps and data do not represent existing explosives sites).

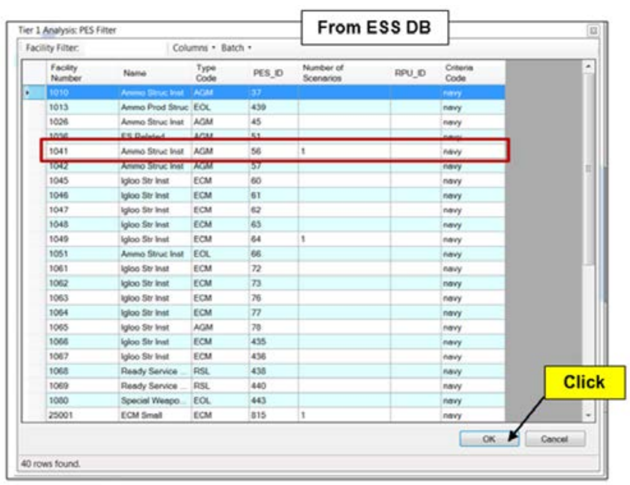


Figure 10. PES Selection Screen.

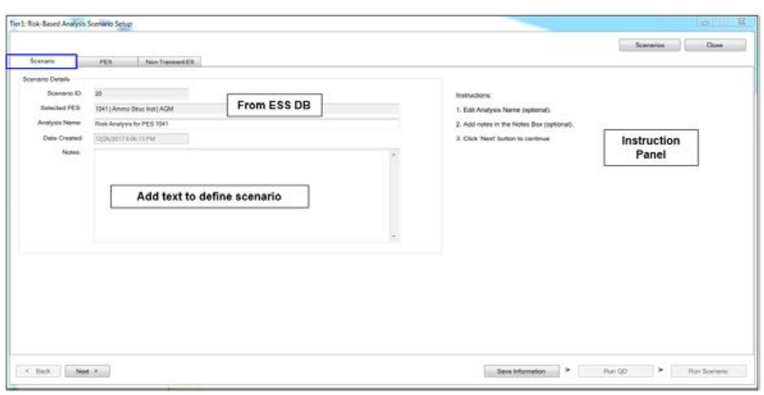


Figure 11. Scenario Setup Screen – Scenario Tab.

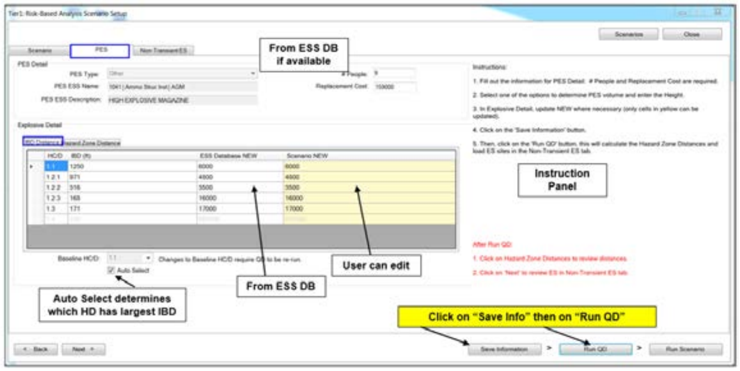


Figure 12. Scenario Setup Screen – PES Tab.

Additional ESS PES detailed data are displayed in the "PES Detail" frame; those in "grey" cannot be modified but, the # People and the Replacement Cost parameters can be modified by the analyst. The "ESS Database NEW" column in the "Explosive Detail" frame lists the NEW's stored in the ESS database by Hazard Division (HD). For the AGM 1041 example, ESS reports that there are potentially five HD's stored at the facility. The analyst, if desired, can change the NEW's that are stored in the ESS database to perform a "what-if" analysis; for our example we have chosen to use the ESS database NEW's. Note that only "one" Hazard Division can be selected for analysis; below the HD data frame, the analyst can:

1. Check the "auto select" box and RBESS will use the HD that generates the largest IBD distance, or,
2. Click on the drop-down list to select the desired HD.

Finally, the analyst can enter any HD in the "scenario NEW" column; for example, if mixing rules are to be applied, the analyst would sum up the appropriate HD's and enter it under the proper HD (e.g., HD 1.1). Once the data have been entered, click on the "save information" button" and then on the "Run QD" button.

RBESS will run the DDESB QD engine to get the Hazard Distances for six zones: 1) IMD-Barricaded, 2) ILD-Barricaded, 3) IMD-Unbarricaded, 4) ILD-Unbarricaded, 5) PTRD, and 6) IBD. To view the hazard zone distances, click on the "hazard zone distance" tab (Figure 13). RBESS computes distances for the PES Front, Left Side, Right Side, and Rear; the distances will differ for PES's such as an ECM or HAS. For our AGM example, all distances are the same.

At the same time the Hazard Zone Distances are computed, RBESS populates the "Non-Transient" Tab as shown in Figure 14; Non-Transient means stationary ES's such as buildings. RBESS loads the ES data from the ESS facility database using the "RBESS Eval Zone" factor (the default is 1.2 times the computed IBD distance) but the analyst can edit this if desired, then save the revised information and re-run the QD analysis. The drop-down list under "additional options" allows the analyst to filter which ES's are to be included in the analysis; again, if the default is changed, click on save information and re-run the QD analysis. For our AGM example, we have stayed with the RBESS defaults.

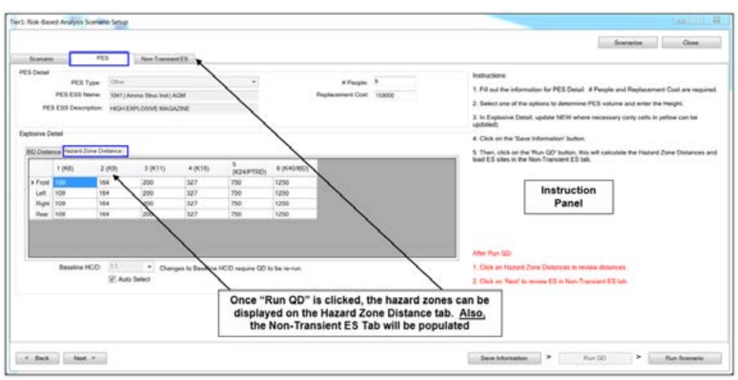


Figure 13. PES Tab – Hazard Zone Distance Sub-Tab.

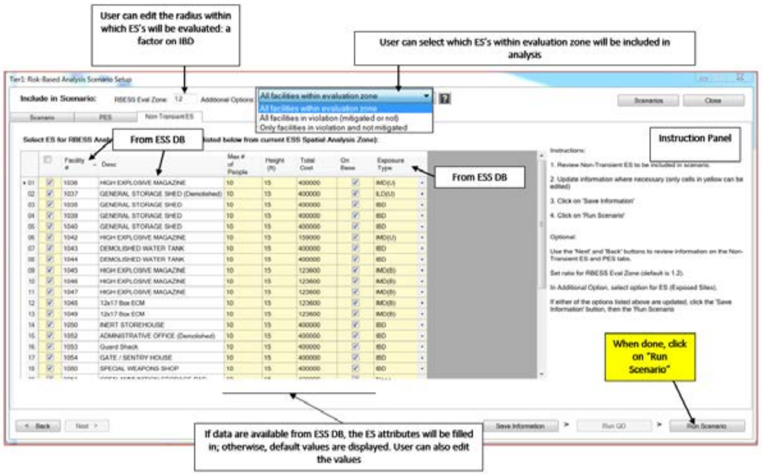


Figure 14. Setup Screen – Non-Transient ES Tab.

Figure 14 lists the ES's included within the evaluation zone and the attributes required to perform a Tier 1 analysis. RBESS will use all ESS facility data available but will insert default values for attributes not stored in the ESS database; missing Tier 1 attributes are usually the number of people and the replacement cost, which are not required for QD analysis. Note that the analyst should check the ES attributes carefully and edit them if better data are available. Finally, the analyst can check or uncheck ES's on a case-by-case basis for inclusion in the consequence analysis. When done, click on the "Run Scenario" button" to perform the Tier 1 analysis.

When the Tier 1 analysis is complete, the GIS screen will be refreshed, and various display and report options will be shown in the right-hand panel (Figure 15). For example, the analyst can display the six hazard zones or, by clicking on the "Percent Fatality" button, the ES's included in the evaluation will be color-coded (Figure 16) A summary of the ES consequences can be displayed by clicking on the "Results by ES" button (Figure 17) and the results can be printed or exported to Excel for inclusion in other documents. Finally, clicking on the "View DARAD Form" button will insert the Tier 1 consequence analysis results into the Army's Deviation and Risk Acceptance Document (DARAD); RBESS will automatically fill in the Page 3 (Figure 18) and compute the "delta" risk (residual risk due to QD violations).

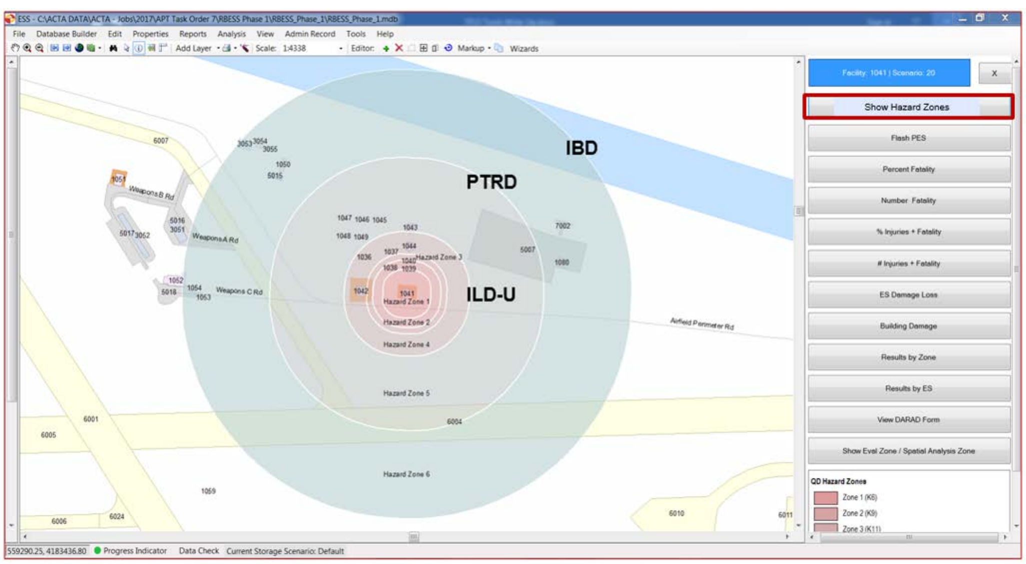


Figure 15. RBESS Tier 1 Analysis Results – Hazard Zone Display (Displayed maps and data do not represent existing explosives sites).

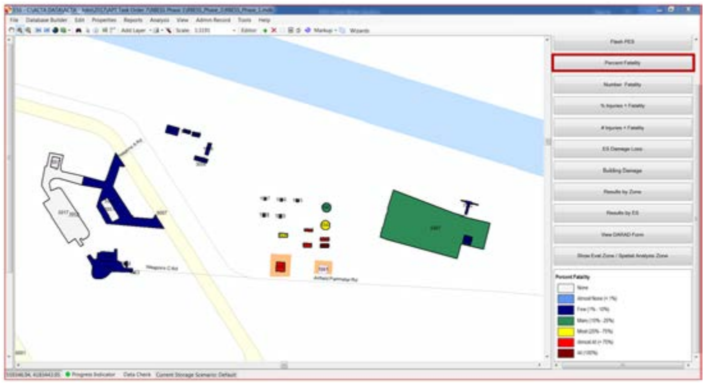


Figure 16. RBESS Tier 1 Analysis Results – Percent Fatality Display (Displayed maps and data do not represent existing explosives sites).

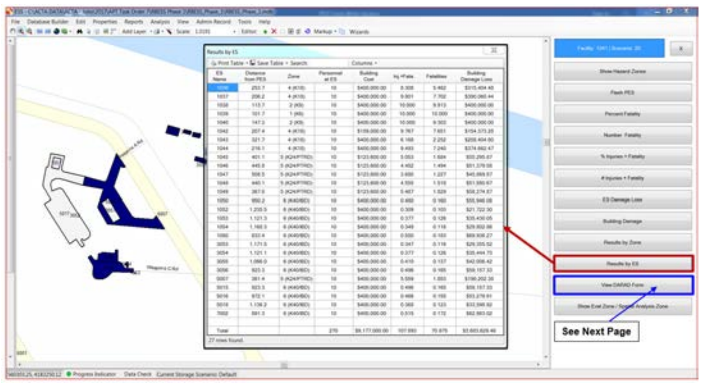


Figure 17. RBESS Tier 1 Analysis Results – ES Consequence Summary Report (Displayed maps and data do not represent existing explosives sites).

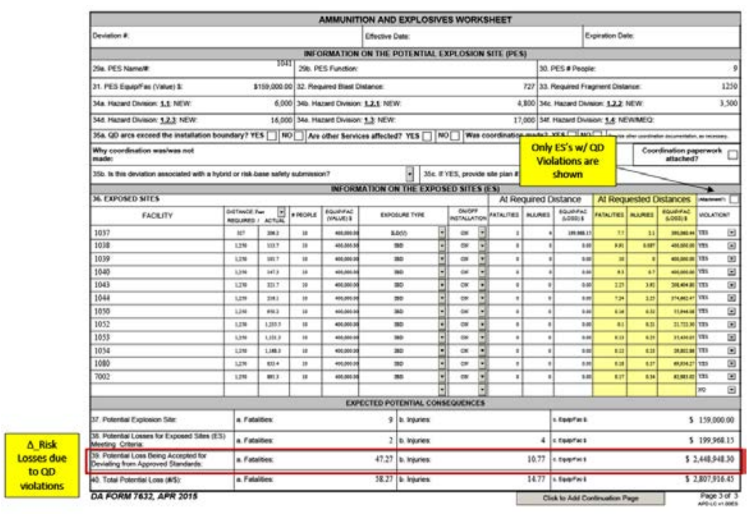


Figure 18. RBESS Tier 1 Analysis Results – Army DARAD: Page 3.

RBESS Tier 2a

Unlike the Tier 1 consequence analyses that are based on the location of an ES within six hazard zones, a Tier 2a analysis uses physics-based air blast and debris models to calculate the potential for damage, injury and fatality (as documented in DDESB Technical Paper No. 14, "Approved Methods and Algorithms for DoD Risk-based Explosives Siting," Rev. 4).

A Tier 2a analysis requires additional PES and ES input data:

- Tier 2a Inputs:
  - NEW (air blast): HD 1.1, 1.2, 1.3, etc.
  - PES Type (to consider secondary debris): Various size/types of ECMs, AGBS's, Operation buildings, Ships, etc.
  - Weapon Types (to consider primary frags): MK Bombs, Bulk/light case, Missile, Projectiles
  - ES's: construction (wall/roof) type, window type/size/amount, population, replacement cost
- Tier 2a Outputs:
  - %/$ damage, injuries, fatalities are calculated due to probability of primary/secondary debris impact, air blast, and thermal hazards
  - Fragment/debris impact damage, fatality & injury based on probability of impact, ES penetration & blunt trauma
  - Air blast damage, fatality and injury based on overpressure & impulse
  - Various ES hazard/risk displays and reports (including overpressure contours)
  - Risk Matrix and DARAD form

The same RBESS project developed for Tier 1 can be used to run a Tier 2a analysis once the additional PES and ES data are input. To start a RBESS Tier 2a analysis, click on the ESS menu bar "Analysis" option, then on "Risk-Based Analysis", "Tier 2a: Run New Analysis" (Figure 19) to view a PES Selection screen. Following the same process as for Tier 1, select AGM 1041 and the default scenario; the Tier 2a Scenario Setup screen will be displayed as shown in Figure 20. The PES Tab has options for Floor Area (default is to use the ESS PES dimensions) and Event Probability (used to develop the Risk Matrix); to set the probability, the user selects an Activity Category and Activity Type and an internal table will assign one of the five likelihood levels (frequent, likely, occasional, seldom, unlikely) as shown in Table 5. Click on "Save Info" and then on the Explosives Tab (Figure 21). For a Tier 2a analysis, the NEW's by hazard division stored in the ESS facility database will be displayed and the analyst can modify them to perform a sensitivity analysis if desired. Because Tier 2a uses physics-based models to predict fragment and debris effects, the analyst must also select a Weapon Type and Description from drop-down lists for each Hazard Division. As for Tier 1, the user can check the "Auto Select" box and let RBESS determine the controlling hazard division (based on the largest IBD) or override and select the hazard division of interest.

When complete, click on "Save Information" and then on "Run QD"; RBESS will perform the QD calculations in the background and inform the analyst that data for the "Non-Transient ES" "Transient ES" and "Barricade" Tabs were loaded. Figure 22 shows the Non-Transient Tab (stationary ES's) and as for Tier 1 the user can set the evaluation zone.

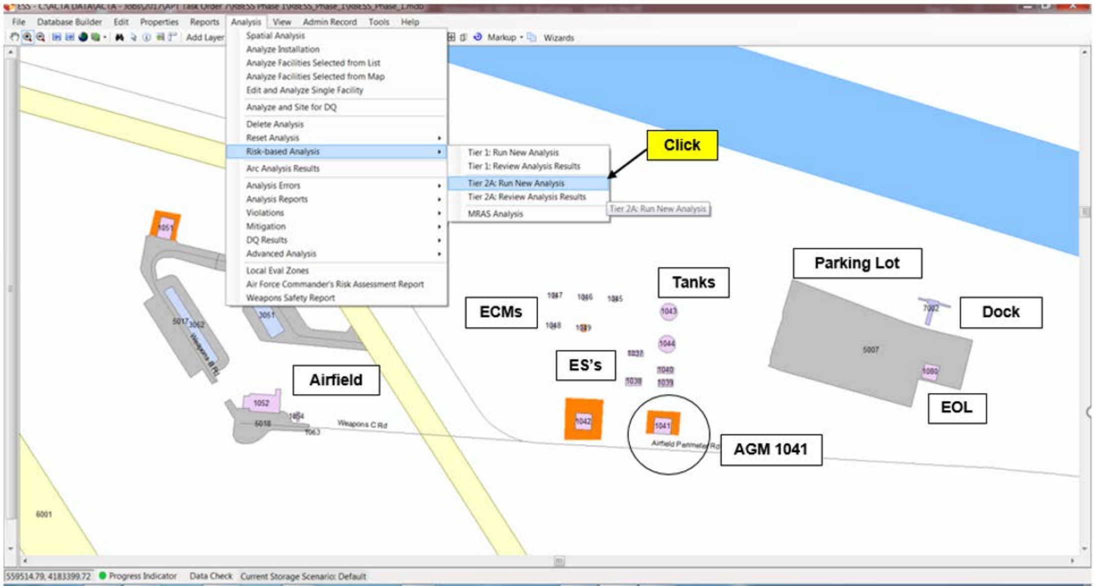


Figure 19. Tier 2a RBESS Project for AGM 1041.

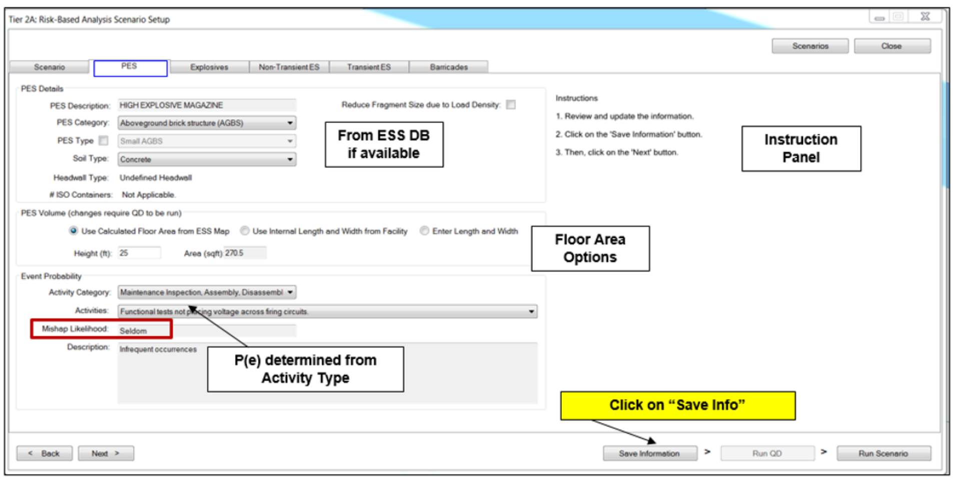


Figure 20. Tier 2a Scenario Setup Screen.

Table 5. Event Probability/Likelihood versus Hazardous Activity.

Operation / Likelihood	Storage	Maintenance, Inspection, Assembly, Disassembly	Operations	Transportation	Destruction	Testing
Frequent over a typical career, a mishap can be expected to occur on an intermittent basis within the Service organization		Dangerously unserviceable items awaiting destruction				Initial tests of new systems
Likley over a typical career, a mishap can be expected to occur randomly with the Service organization	Any operating stocks in an area subject to hostile action such as rockets, missiles, air attacks, or terrorists	Any operating stocks in an area subject to hostile action such as rockets, missiles, air attacks, or terrorists	Any explosives operations in an area subject to hostile actions such as rockets, missiles, air attacks, or terrorists			
	Dangerously unserviceable items awaiting destruction	Hazardous environments with gases, fibers, etc.				
Occasional over a typical career, a mishap can be expected to infrequently within the Service organization		Unserviceable (but not dangerous) items	TDY operations during exercises, contingencies, or alert		Burning, detonation and static firing areas	
		Circuit Checks	Hot Cargo missions of unserviceable or unpackaged material			
		TDY during contingencies or exercises				
Seldom over a typical career, a mishap will rarely occur within the Service organization	Operating stocks in storage requiring handling more than once a month	Home station during contingencies or exercises	Home station activities during exercises, contingencies or alert	Railheads requiring application of QD		Testing operational systems
	Unserviceable (but not dangerous) items in storage	Pyrotechnics	TDY operations during peacetime			
		Functional tests not placing voltage across firing circuits	Flightline holding areas/ready service storage locations outside munitions storage areas			
		Outdoor operations during inclement weather	Deployed ground-based missile for a non-mobile mission			
Unlikely So rare a mishap is not expected to occur during a typical career	Serviceable items in extended storage requiring handling less than once a month	Painting and packing	ICBM launch facilities			
		Operations involving no exposed explosives	Home station activites during peacetime			
			Hot Cargo missions of serviceable material			

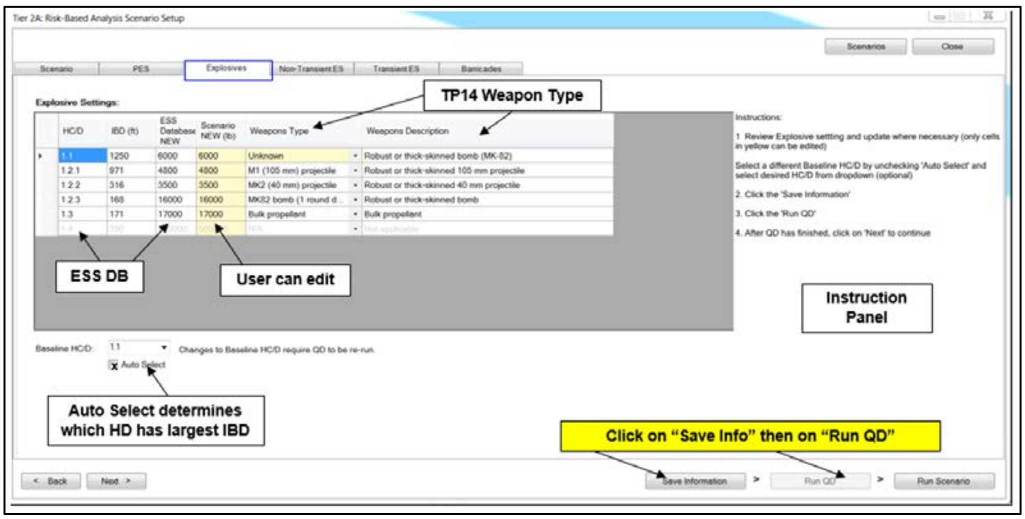


Figure 21. Tier 2a Explosives Tab.

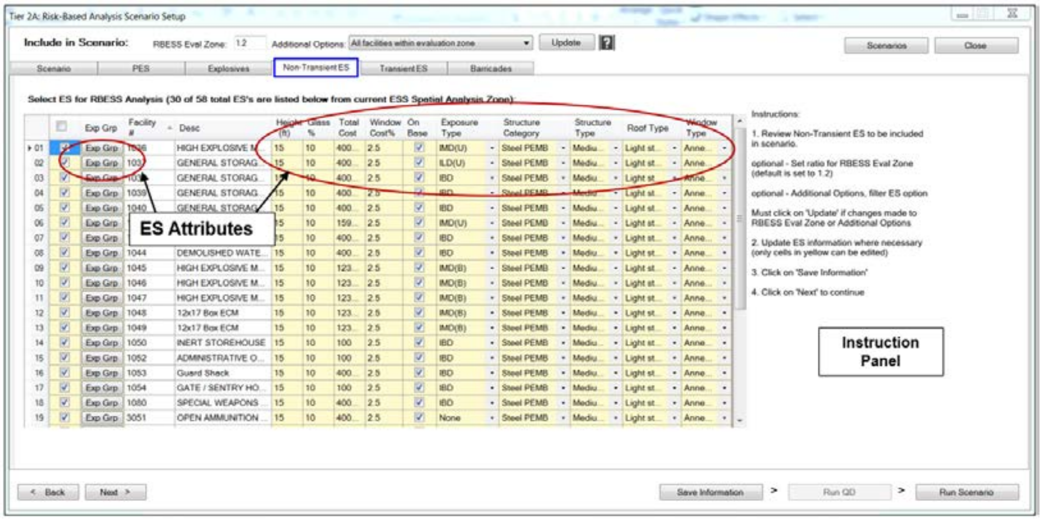


Figure 22. Tier 2a Non-Transient ES Tab.

For a Tier 2a analysis additional ES attributes are required as shown by the "red" ellipses. RBESS will fill in the attributes if they are stored in the ESS facility database; for attributes not stored in the database, RBESS will enter default values:

1. Height = 15'
2. Glass % (percent of glass covering the wall elevations) = 10%
3. Replacement Cost = $400,000
4. Window Cost (% of replacement cost) = 2.5%
5. Structure Category = Steel PEMB (pre-engineered metal building)
6. Structure Type = Medium-size
7. Roof Type = Light steel panel
8. Window Type = Annealed (single pane)
9. Personnel at ES (see Figure 23): 10 people, 8 hours/day, 5 days/week, 50 weeks/year (note that the current version of RBESS allows only analyses 1 group)

The analyst should review these default Non-Transient values to insure they are reasonable and edit the data if actual ES survey data are available.

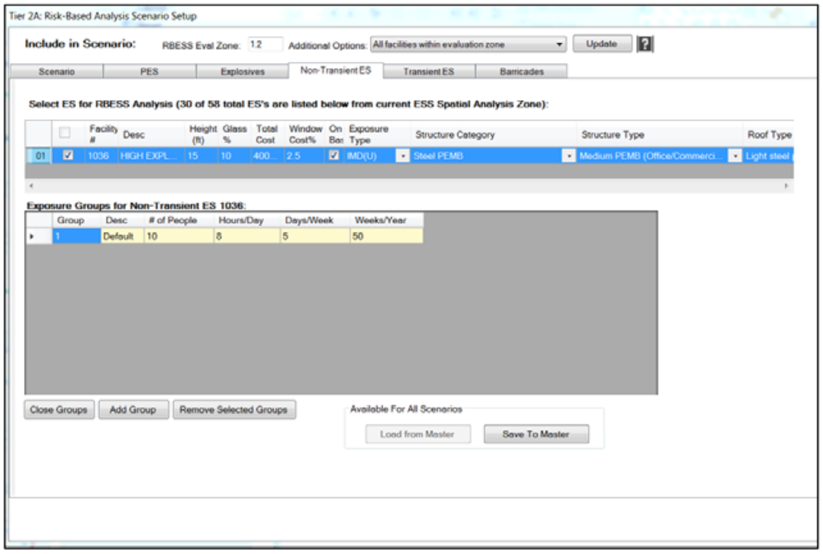


Figure 23. Tier 2a ES Exposure Group Screen.

Transient (or moving ES's) can also be evaluated such as roads, runways, shipping lanes, etc.; Figure 24 shows the Non-Transient Tab with five roads from the ESS facility database located within the ESS evaluation zone. The attributes shown in the "red" ellipses are required to perform a Transient analysis. The default values are:

1. Vehicle Interval = 500' (distance between ES's placed along the road.
2. Vehicle Length, Width, Height = 12', 5', 4.5'
3. Vehicle Replacement Cost = $20,000
4. Window Cost = 2.5% of replacement cost
5. Glass Percentage = 25%
6. Window Type = Tempered
7. Vehicle exposure (see Figure 25): average people in vehicle = 1.5, average speed = 50 mph, # cars per hour = 2000, hour/day = 20, days/week = 5, weeks/year = 50 (note that the current version of RBESS allows the analysis of only one group)

RBESS uses the attributes to place vehicles at the specified interval along the road segment and determine the average number of people exposed given an explosion occurs. The analyst should review the default Transient values to insure they are reasonable and edit the data if actual ES survey data are available.

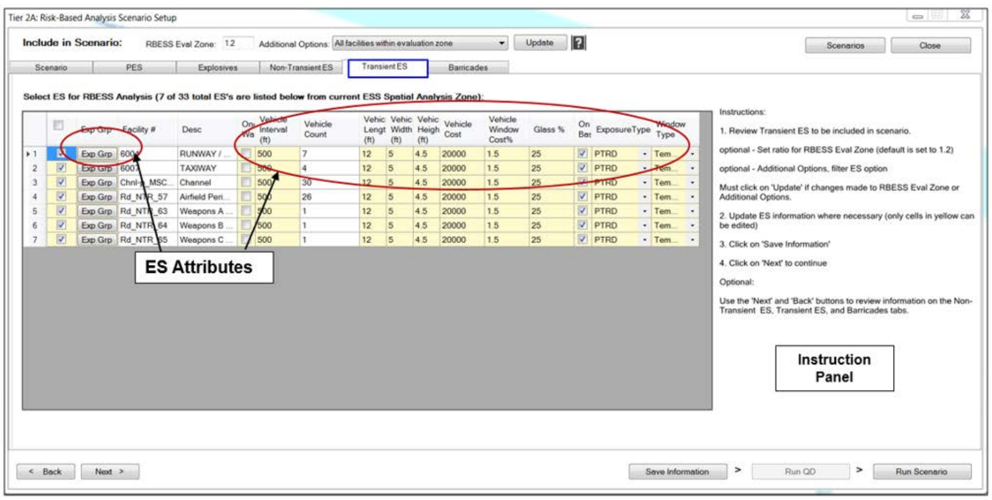


Figure 24. Tier 2a Transient ES Tab.

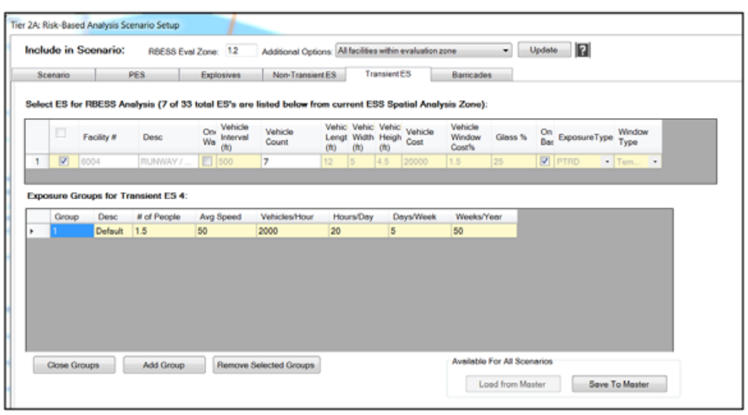


Figure 25. Tier 2a Transient Exposure Group Screen.

RBESS Tier 2a can consider the presence of barricades that potentially block fragments/debris thrown from the PES (Figure 26). For our example, a barricade has been placed around the sides and rear of AGM 1041. The only attribute for a barricade is its height which the analyst can edit if desired. When all the data has been entered the analyst clicks on the "Run Scenario" button to start the Tier 2a analysis.

When the analysis is complete, the ESS screen will be updated to include a Panel on the right-hand-side as shown in Figure 27 where the Show Overpressure button has been selected. The analyst can view a host of intermediate results; Figure 28 shows the "Structural Damage" results that color-codes each ES and Figure 29 shows the "Percent Fatality". Figure 30 shows the "Facility Risk Matrix"; the consequences in terms of $loss, fatality and injury have been converted into a Severity Category (Catastrophic, Critical, Moderate, Negligible). Table 6 shows the consequences summarized by non-transient, transient, and people in the open and Table 7 shows the consequences tabulated for all ES's. Finally, Table 8 shows the DARAD form filled in with the Tier 2a results.

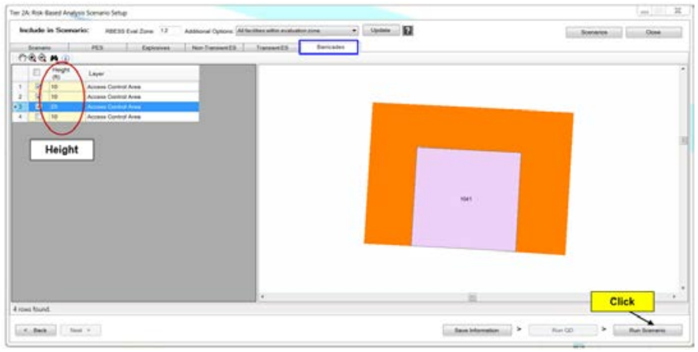


Figure 26. Tier 2a Barricade Tab.

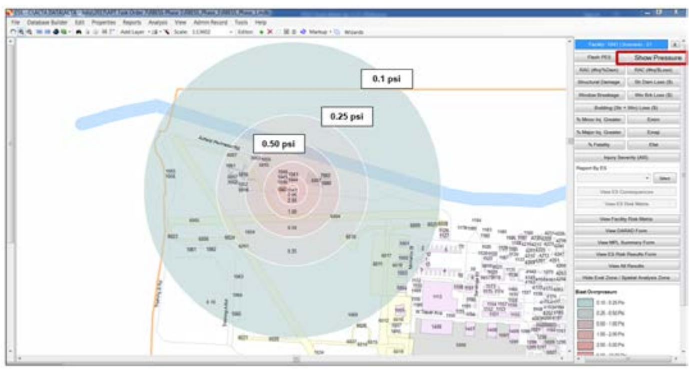


Figure 27. Tier 2a Analysis Results (Overpressure Contours) (Displayed maps and data do not represent existing explosives sites).

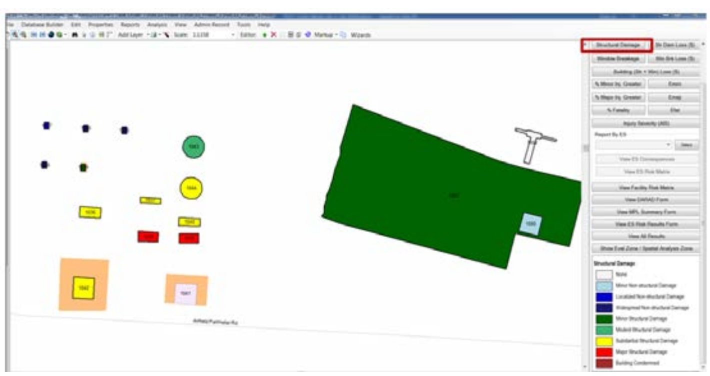


Figure 28. Tier 2a Analysis Results (Structural Damage) (Displayed maps and data do not represent existing explosives sites).

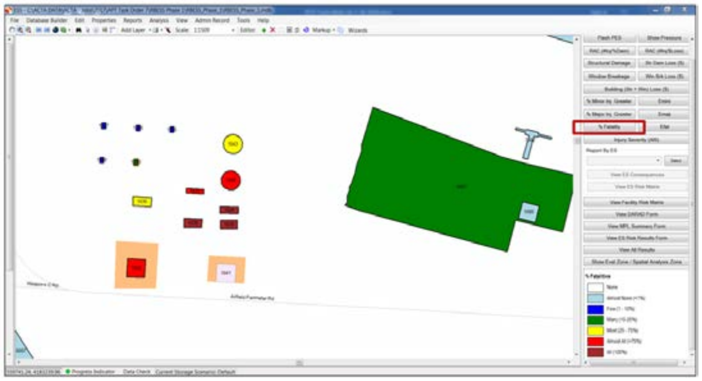


Figure 29. Tier 2a Analysis Results (Percent Fatality) (Displayed maps and data do not represent existing explosives sites).

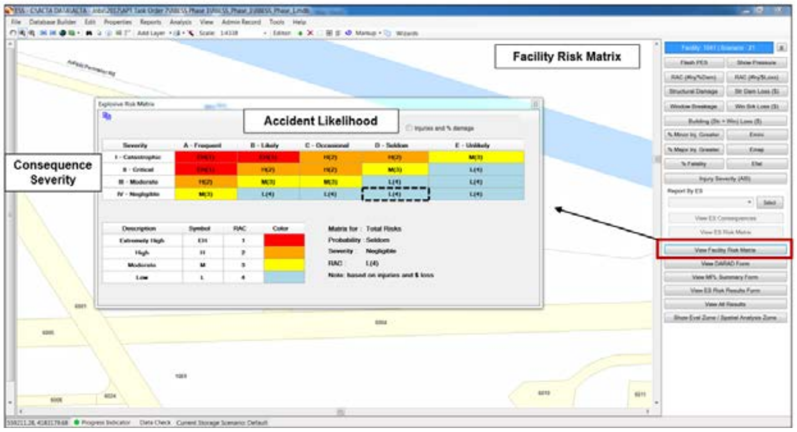


Figure 30. Tier 2a Analysis Results (Risk Matrix) (Displayed maps and data do not represent existing explosives sites).

Table 6. Tier 2a Analysis Results (View MPL Summary Form).

Maximum Probable Loss (MPL)

Print Table ▾ Save Table ▾ Search: Columns ▾

Receptor Type	No. of People	Equip/Fac Value ($)	Fatalities	Major Inj.+Fata.	Any Inj.+Fata.	Equip/Fac Loss ($)
Buildings	300	$7,977,600	70.12	92.25	115.52	$1,378,010
Moving Vehicles	327	$4,356,543	2.08	3.17	4.25	$5,686
Open Areas						
Total	627	$12,334,143	72.2	95.42	119.77	$1,383,696

5 rows found.

Table 7. Tier 2a Analysis Results (View ES Risk Results Form).

FacilityNumber	Distance from PES	No. of People	Equip/Fac Value ($)	Fatality	Major Inj.+Fata.	Any Inj.+Fata.	Equip/Fac Loss ($)
1036	291.6	10	$400,000	5.65	9.96	10	$124,500
1037	239.2	10	$400,000	9.28	10	10	$152,000
1038	150.1	10	$400,000	10	10	10	$207,300
1039	129.1	10	$400,000	10	10	10	$220,400
1040	173.7	10	$400,000	10	10	10	$192,200
1042	235.2	10	$159,000	9.44	10	10	$62,480
1043	347.9	10	$400,000	2.77	7.89	10	$94,730
1044	242.3	10	$400,000	9.15	10	10	$150,800
1045	435.9	10	$123,600	0.83	3.13	7.81	$18,760
1046	483.0	10	$123,600	0.22	0.9	3.59	$14,530
1047	546.5	10	$123,600	0.15	0.55	2.07	$9,491
1048	478.1	10	$123,600	0.23	0.94	3.72	$14,940
1049	405.1	10	$123,600	1.15	4.27	8.99	$21,970
1050	988.4	10	$100	0.0011	0.0043	0.013	$1
1052	1,263.4	10	$100	0.00017	0.00067	0.0021	$1
1053	1,150.8	10	$400,000	0.00034	0.0013	0.004	$83
1054	1,196.3	10	$100	0.00026	0.00099	0.0031	$1
1080	866.4	10	$400,000	0.0019	0.0075	0.024	$4,059
3051	1,284.4	10	$400,000	0.00012	0.00048	0.0015	$1,191
3052	1,478.1	10	$400,000	3.9E-05	0.00015	0.00047	$1,006
3053	1,209.6	10	$400,000	0.00025	0.00096	0.003	$922
3054	1,159.2	10	$400,000	0.00034	0.0013	0.004	$500
3055	1,104.2	10	$400,000	0.00047	0.0018	0.0055	$623
3056	961.4	10	$400,000	0.0013	0.0051	0.016	$2,326
5007	398.8	10	$400,000	1.23	4.57	9.23	$78,340
5015	961.4	10	$100	0.0013	0.0051	0.016	$1
5016	1,004.2	10	$100	0.00088	0.0034	0.01	$1
5017	1,446.6	10	$100	4.7E-05	0.00018	0.00058	$1
5018	1,165.1	10	$400,000	0.00031	0.0012	0.0037	$2,176
7002	927.4	10	$400,000	0.0012	0.0049	0.016	$2,678
6004	648.3	40	$530,480	0.072	0.26	0.74	$0
6007	604.5	27	$359,910	0.034	0.13	0.37	$0
Chnl-p_MSC_8002	961.4	172	$2,296,480	0.00084	0.0032	0.0099	$0
Rd_NTR_57	117.0	79	$1,048,208	1.97	2.77	3.12	$5,686
Rd_NTR_63	1,056.6	2.9	$39,080	5.2E-05	0.0002	0.00062	$0
Rd_NTR_64	1,451.4	2.9	$39,249	6.8E-06	2.7E-05	8.5E-05	$0
Rd_NTR_65	587.5	3.2	$43,136	0.00099	0.0038	0.012	$0

Table 8. Tier 2a Analysis Results (DARAD Form).

AMMUNITION AND EXPLOSIVES WORKSHEET

Deviation #:	Effective Date:	Expiration Date:

INFORMATION ON THE POTENTIAL EXPLOSION SITE (PES)

29a. PES Name/#:	1041	29b. PES Function:		30. PES # People:	9
31. PES Equip/Fac (Value) $:	$159,000.00	32. Required Blast Distance:	0	33. Required Fragment Distance:	0
34a. Hazard Division: 1.1: NEW:	6,000	34b. Hazard Division: 1.2.1: NEW:	4,800	34c. Hazard Division: 1.2.2: NEW:	3,500
34d. Hazard Division: 1.2.3: NEW:	16,000	34e. Hazard Division: 1.3: NEW:	17,000	34f. Hazard Division: 1.4: NEW/MEQ:	500000

35a. QD arcs exceed the installation boundary? YES ☐ NO ☐ Are other Services affected? YES ☐ NO ☐ Was coordination made? YES ☐ NO ☐ Provide other coordination documentation, as necessary.

Why coordination was/was not made: Coordination paperwork attached? ☐

35b. Is this deviation associated with a hybrid or risk-base safety submission? 35c. If YES, provide site plan #:

INFORMATION ON THE EXPOSED SITES (ES)

36. EXPOSED SITES (Attachment?) ☐

FACILITY	DISTANCE: Feet REQUIRED	ACTUAL	# PEOPLE	EQUIP/FAC (VALUE) $	EXPOSURE TYPE	ON/OFF INSTALLATION	At Required Distance: FATALITIES	INJURIES	EQUIP/FAC (LOSS) $	At Requested Distances: FATALITIES	INJURIES	EQUIP/FAC (LOSS) $	VIOLATION?
1037	436	306.2	10	400,000.00	ILD(U)	ON	0.82	2.3	59,980.00	9.28	0.72	152,000.00	YES
1038	1,250	113.7	10	400,000.00	IBD	ON	0.00019	0.00056	526.40	10	0	207,300.00	YES
1039	1,250	101.7	10	400,000.00	IBD	ON	0.00019	0.00056	513.30	10	0	220,400.00	YES
1040	1,250	147.3	10	400,000.00	IBD	ON	0.00019	0.00056	478.30	10	0	192,200.00	YES
1043	1,250	321.7	10	400,000.00	IBD	ON	0.00019	0.00056	720.30	2.77	5.11	94,730.00	YES
1044	1,250	216.1	10	400,000.00	IBD	ON	0.00019	0.00056	720.30	9.15	0.85	150,800.00	YES
1052	1,250	1,233.3	10	100.00	IBD	ON	0.00017	0.00049	0.69	0.00017	0.00049	0.69	YES
1053	1,250	1,121.3	10	400,000.00	IBD	ON	0.00019	0.00053	73.22	0.00034	0.00096	83.14	YES
1054	1,250	1,168.3	10	100.00	IBD	ON	0.00019	0.00053	0.70	0.00026	0.00074	0.74	YES
1080	1,250	833.4	10	400,000.00	IBD	ON	0.00019	0.00056	728.80	0.0019	0.0056	4,059.00	YES
3051	1,284.4	1,252.4	10	400,000.00		ON	0.00012	0.00035	1,191.00	0.00012	0.00035	1,191.00	YES
3052	1,478.1	1,448.3	10	400,000.00		ON	0.000039	0.00011	1,006.00	0.000039	0.00011	1,006.00	YES
5007	398.8	361.4	10	400,000.00		ON	1.23	3.34	78,340.00	1.23	3.34	78,340.00	YES

EXPECTED POTENTIAL CONSEQUENCES

37. Potential Explosion Site:	a. Fatalities:	9	b. Injuries:		c. Equip/Fac $:	$ 159,000.00
38. Potential Losses for Exposed Sites (ES) Meeting Criteria:	a. Fatalities:	2.12	b. Injuries:	5.83	c. Equip/Fac $	$ 147,095.84
39. Potential Loss Being Accepted for Deviating from Approved Standards:	a. Fatalities:	54.53	b. Injuries:	11.13	c. Equip/Fac $	$ 1,112,653.41
40. Total Potential Loss (#/$):	a. Fatalities:	65.65	b. Injuries:	16.96	c. Equip/Fac $	$ 1,418,749.25

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Deviation #:

INFORMATION ON THE EXPOSED SITES (ES) CONTINUATION WORKSHEET

Exposed Sites (continued from block 36)

FACILITY	DISTANCE: Feet REQUIRED	ACTUAL	# PEOPLE	EQUIP/FAC (VALUE) $	EXPOSURE TYPE	ON/OFF INSTALLATION	At Required Distance: FATALITIES	INJURIES	EQUIP/FAC (LOSS) $	At Requested Distances: FATALITIES	INJURIES	EQUIP/FAC (LOSS) $	VIOLATION?
5015	961.4	923.3	10	100.00		ON	0.0013	0.0038	1.38	0.0013	0.0038	1.38	YES
5016	1,004.2	972.1	10	100.00		ON	0.00088	0.0025	1.22	0.00088	0.0025	1.22	YES
5017	1,446.6	1,416.8	10	100.00		ON	0.000047	0.00014	0.55	0.000047	0.00014	0.55	YES
5018	1,165.1	1,136.2	10	400,000.00		ON	0.00031	0.00088	2,176.00	0.00031	0.00088	2,176.00	YES
7002	1,250	891.3	10	400,000.00	IBD	ON	0.00019	0.00056	655.30	0.0012	0.0036	2,678.00	YES
6004	750	615.8	40	530,480.00	PTRD	ON	0.037	0.1	0.00	0.072	0.19	0.00	YES
6007	750	566.4	27	359,910.00	PTRD	ON	0.016	0.046	0.00	0.034	0.093	0.00	YES
Rd_NTR_57	750	78.9	79	1,048,208.00	PTRD	ON	0.0096	0.027	0.00	1.97	0.8	5,685.70	YES
Rd_NTR_65	750	557.1	3.2	43,136.00	PTRD	ON	0.0009	0.0026	0.00	0.00099	0.0028	0.00	YES

CONCLUSION

RBESS Tier 1 and Tier 2a have been developed to generate risk information for a single PES that affects multiple exposed sites (ES's). The output for both Tier 1 and Tier 2a RBESS include color-coded maps that display information on replacement cost, fatalities, and injuries. The output also displays consequence information for individual ES's as well as summary information for all the ES's affected by the PES. Both tiers of RBESS automatically populate the Department of Army (DA) Form 7632 which is known as the Deviation Approval and Risk Acceptance Document (DARAD). RBESS has been validated through comparisons with ASAP-X and HAZX for Tier 1 and 2a and has been shown to generate the expected results. RBESS is being released in ESS v6.1.4 and will be available to ESS users in the near future.

REFERENCES

[1] DoD Ammunition and Explosives Safety Standards, Department of Defense Manual 6055.09, February 2008; re-issued August 1010; incorporating changes April 2012.

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