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RIMANA 5 – New Swiss Army Risk Analysis Tool for Ammunition Storage

Peter Nussbaumer, Dr. Daniel Oberle / Stephan Joss
Bienz, Kummer & Partner Ltd. / Staff of the Swiss Armed Frces

Abstract

The Swiss Armed Forces follow a risk-based concept for ammunition storage and transport safety. For each ammunition storage site, from large rock caverns to small freestanding magazines, the effective charge is defined, the explosion effects are calculated, the exposure of persons is assessed, and the probability of an event is determined. The resulting individual and collective risk numbers are then compared to the safety criteria defined by both the Swiss Armed Forces (WSUME) and the civilian Federal Office for the Environment (major hazards ordinance). It is evident that this process is complex and thus best supported by software solutions. Because the current version of the risk analysis tool of the Army Staff, FS SUME for ammunition safety is outdated, a new version – **Ri**sk Analysis and **Mana**gement (RIMANA 5) – is under development. It will incorporate a wide range of new functionalities, including the integration of publicly available GIS-layers today. Further the additional functionality will be implemented: a. new consequence models, some implementing new 3D debris throw models based on detailed topography to calculate realistic lethality zones, b. daily updated calculation of lethality zones based on the real quantity and composition of stored ammunition, to support first responders, c. automated simple, unclassified, risk assessment reports for civilian stakeholders, d. simplified calculation of danger zones for simulating ammunition stacks out in the field. Examples for these new features will be presented, and the new 3D debris throw model from adits of underground installations will be presented in more detail.

Introduction

In many countries, ammunition storages are typically situated far from villages and highways, with storage safety being regulated by safety distances based on the quantity of stored ammunition. This is not the case in Switzerland due to the limited available space.

Maintaining large uninhabited safety zones is not feasible. Instead, Switzerland relies on quantitative risk analysis and corresponding safety criteria for ammunition storage safety since 1991. In comparison to the quantity-distance approach, the exposition of persons (number and duration) in the surroundings is taken into account in detail. Storage safety is achieved by defining the quantity of stored ammunition (Q_{TNT}) in such a way that, including the probability of an event, the expected casualties and risks comply with the safety criteria.

The basic steps of a risk analysis are:

- Determining the quantity of explosives and calculating the probability of an explosion;
- Identifying the major explosion effects and their hazard zones and
- Assessing how many people are exposed, where they are located, and how long as well as when they are present

Based on this input, both the individual and collective risk can be calculated and compared to the safety criteria. These criteria are twofold: the first originates from the military side and comprise of upper thresholds for the individual risk of different risk groups (from mission-essential personnel to third parties), as well as of the marginal cost principle to evaluate the collective risk and the necessity of safety measures [1]. The second set of criteria was introduced in 2015, and stems from the civilian side. The Swiss Major Accidents Ordinance uses frequency/number-diagrams, which limit the number of tolerable fatalities as a function of event frequency [2].

Recently, the office responsible for ammunition storage safety (FS SUME) has adopted a broader perspective. While quantitative risk analysis – based on the lethality principle – is valuable for disaster prevention by identifying which exposures contribute to risk and by evaluating potential safety measures, it does not fully address the disaster management. Even when the calculated risk is within acceptable thresholds, additional context-specific factors should be taken into account.

The success of an intervention begins with prevention. The effectiveness of the emergency services is directly related to the expected hazard zones in case of an event. If the assessment of intervention risks reveals that the emergency services cannot adequately ensure disaster management in case of an event, the maximum capacity in ammunition storage facility belonging to the Swiss Armed Forces must be further reduced.

For example, when there is a retirement home in the hazard area with restricted evacuation options. Another example would be an international high-voltage power line just in front of the ammunition magazine that could result in large-scale power outages in case of an event. In the future, these broader considerations will influence the maximum quantity of ammunition permitted in a magazine (see Figure 1).

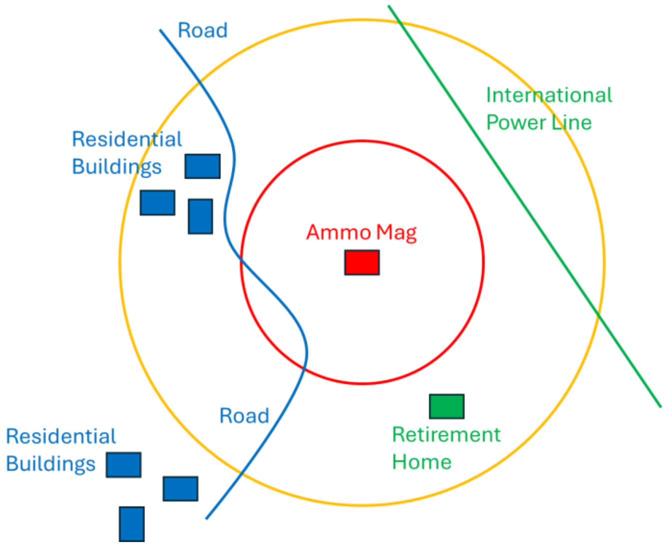

Figure 1. Example: Objects shown in blue are sufficiently covered by the risk analysis; objects in green may need further assessment under the broadened evaluation framework

RIMANA 5 – New Features

Overview

RIMANA 5 will be a dual-use IT application. RIMANA 5 simultaneously meets the civilian and military requirements of:
1. The Swiss Confederation – protecting civil society, and
2. The Swiss Armed Forces – ensuring resilience by strengthening defense capabilities in all situations.

RIMANA 5:
- Calculates the risks associated with storage of ammunition and explosives and maps the hazard zones on defined layers of the Military GIS.
- Is a database of all relevant ammunition storage locations (rock caverns of the Armed Forces Logistics Organisation, rock caverns and magazines of the Air Force, and all magazines of the Joint Operations Command as well as Training Command), which shows, among other things:
    1. Where the facilities are geographically located;
    2. How they are constructed;
    3. What safety precautions they possess;
    4. What legally compliant maximum storage capacity (Q_{TNT}) the facility has;
    5. How the ammunition inventory (for SAP-managed stockpiles) is broken down by quantity and ammunition type, and
    6. What information can be retrieved for intervention in case of an event.

- Is an IT application that also enables the Swiss Armed Forces to implement various scenarios for ammunition storage:
    1. the Armed Forces Logistics Organisation within the framework of war logistics (risk assessment in the event of a tactically necessary exceedance of the maximum possible storage capacity, or the simultaneous use of half-emptied rock caverns for ammunition storage by personnel and material) and
    2. the Joint Operations Command for operability (risk assessment temporary field storages of ammunition, etc.).

RIMANA 5 is being developed from scratch and not only incorporates new information and modern technologies, but also introduces entirely new features:
- Compliance with current IT standards
- Integration of updated risk analysis models
- Utilization of newly available data, such as the number of persons per building from GIS layers
- Use of high-resolution topographic data to compute the rock overburden or the reduction of debris hazard zones against a hill
- Automatic generation of simplified reports for stakeholders
- Daily updates of hazard zones based on the real amount and composition of stored ammunition, supporting first responders
- Calculation of simplified hazard zones for army commanders simulating stacks of ammunition in the open field

RIMANA 5 is therefore a major project. As a first step, Bienz, Kummer & Partner Ltd. is developing a testbed in Python, featuring its own standalone graphical user interface. This prototype is connected to the civilian GIS and is incorporating the full technical content of the Swiss army ammunition storage safety regulation [3]. In the next phase, a software development company will implement an independent system based on the testbed for the military platform for highly classified information that is connected to the military GIS and the ammunition storage database (SAP). This solution is based on its own architecture but will use the same core calculations through a shared API developed and validated within the testbed. The project was initiated 2020, the development only really started in 2024 and is scheduled for completion in 2027. Additionally, all the major ammunition storage installations will be 3D scanned due to the lack of precise documentation for the facilities built between the 1960s and 1980s. The resulting 3D scans will then be processed to 3D models which can be imported directly into RIMANA 5 to automate the entry of storage data for the risk calculation.

The remainder of this chapter presents these new features. The Chapter on "3D Debris Throw Model" will demonstrate how the current 2D model for debris throw from adits of underground installations will be upgraded to 3D by using Switzerland's high-resolution topographic model.

Updates

As mentioned above, RIMANA 5 will comply with current IT standards. Additionally, the underlying technical models will be reviewed and where appropriate updated. On the one hand, the existing consequence models for the different storage types, from large shallow-buried installations to small free-standing magazines will be reviewed and validated. This includes comparisons between different models, test data (notably the CUIRA test series with earth-covered magazines in 2022), and to similar models from the NATO risk analysis manual AASTP-4 [4]. If significant discrepancies are identified, these models will be revised prior to their implementation in RIMANA 5. On the other hand, new models for container storage and open ammunition stacks need to be implemented to enable RIMANA 5 to support army commanders for exercises and war scenarios (see chapter on "New Features").

New Information and Technologies

Geographical Information Systems (GIS) are populated with valuable data for risk analysis. Examples include estimates for the number of persons in a building and traffic volumes on roads.

Figure 2 illustrates such an application for building number 54, marked with a red circle. According to the GIS database of this layer, the building is classified as a holiday house with 2 small apartments on three floors. By combining this information with the statistical data, such as the average number of persons per apartment, based on floor area and state, available on the public web, the estimated number of persons in that building can be calculated automatically.

Figure 2. Example of a GIS layer for buildings (source: swisstopo.ch)

Topographic data can likewise be used to enhance the accuracy of consequence modelling. For example, in case of an event in a large rock cavern, the debris throw may extend several hundred meters to the front of the adit portal. The presence of terrain features, such as a hill between the portal and a populated area in that front sector, can significantly influence the size of lethality zones. The Chapter on “3D Debris Throw Model” will examine how such effects can be captured by the model.

New Features

Three key features will be introduced in this new version of RIMANA 5:

- Military and civilian stakeholders will receive short reports generated automatically using configurable text blocks and figures. These reports will be tailored according to a need-to-know basis and sanitized further, if necessary, to comply with lower classification levels.
- In case of an event, military and civilian first responders are provided with an intervention report detailing hazard zones – daily updated based on the real ammunition stored. This enables the first responders to implement tailored evacuations of persons and road closures in the affected area.
- Operational support for military commanders: RIMANA 5 will support tactical decision-making by visualizing hazard zones from ammunition storages, including temporary depots in the open field. For example, in situations where a radar system is positioned on elevated terrain above a temporary ammunition depot, RIMANA 5 can assist in assessing risks and possible safety measures such as barricades to protect the radar system from potential fragments.

RIMANA 5 – Examples of new Technical Models

3D Debris Throw Model from Adits of Underground Installations

Following the general overview of RIMANA 5, this section presents an example of a new technical model that leverages the enhanced IT capabilities introduced in the system. The Swiss ammunition storage regulations (TLM [3]) contain a model for debris throw from adit portals of underground rock caverns. However, this model is not taking the topology of the surrounding into account and is therefore assuming flat terrain (see Figure 3).

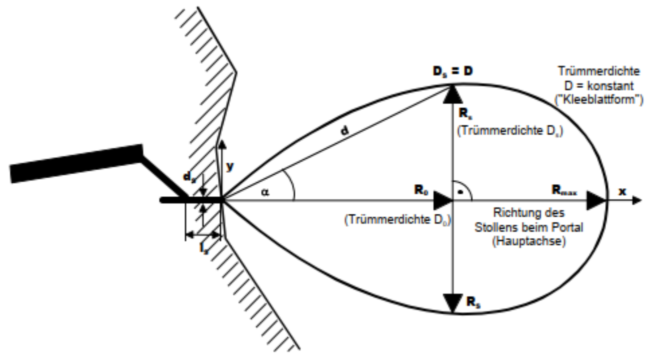

Figure 3. Lethality model for adit debris throw in Swiss TLM and NATO AASTP-4

To extend the existing 2D model to account for realistic terrain conditions, the debris trajectories must be simulated and their intersections with the surrounding topography computed.

One possible approach to simulate the various trajectories would have been to perform Monte Carlo simulations based on the estimated probability distributions for debris mass, initial velocity and launch angles. However, a preliminary test revealed that the size of the parameter space would result in prohibitively high computational costs, making this approach impractical for our use.

Instead, we developed a more efficient method using deterministic sampling of the launch parameters. The resulting trajectories are intersected with the terrain, and the debris densities are weighted according to the corresponding probability density functions (PDFs), as illustrated in Figure 4. This reduces the computational costs by more than two orders of magnitude.

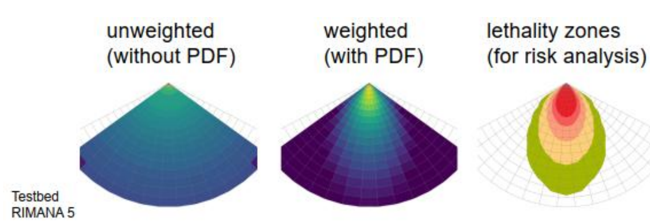

Figure 4. Use of the probability density functions (PDF) to “weigh” the trajectories

This new model is based on the simulation of 2D trajectories of tumbling concrete cuboids, using a deterministic combination of launch parameters:

- 12 masses ranging from 0.1 kg to 500 kg
- 15 initial velocities ranging from 20 m/s to 300 m/s
- 15 vertical launch angles ranging from -30° to 50°

This results in a set of 2,700 unique trajectories, which were then rotated around the horizontal launch angle to cover 13 azimuth directions between -50° to 50°. After computing the corresponding 35,100 terrain intersections using an efficient interpolation algorithm, the resulting debris densities on the ground were calculated by weighing each trajectory according to the PDFs, as illustrated in Fig. 4 These consist of the mass, initial velocity, launch angle as well as number density.

Figure 5 illustrates the effect of a hill in front of the adit portal in the new model. The farthest debris pieces are largely unaffected by the hill, because they fly above it. Near-field debris, which generates the highest densities, is also mostly unaffected due to the distance of the hill. However, at intermediate ranges, both the length and width of the lethality zones are reduced by this shielding effect.

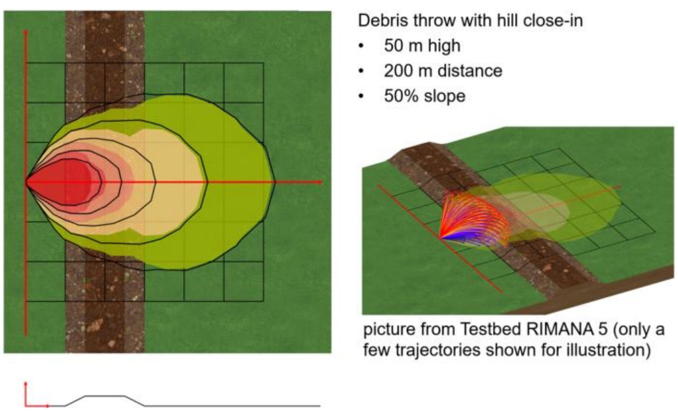

Figure 5. Effect of a hill in front of the adit portal (example)

As another example, Figure 6 and Figure 7 show a real Swiss topography with a fictitious installation. The uphill slope significantly reduces the extend of the different lethality zones.

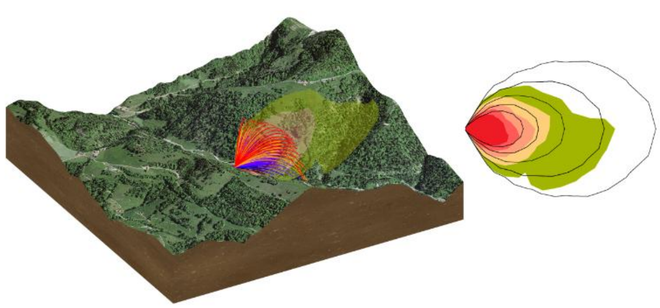

Figure 6. Installation in the valley, adit portal pointing to an uphill slope (black lines = lethality zones for flat terrain)

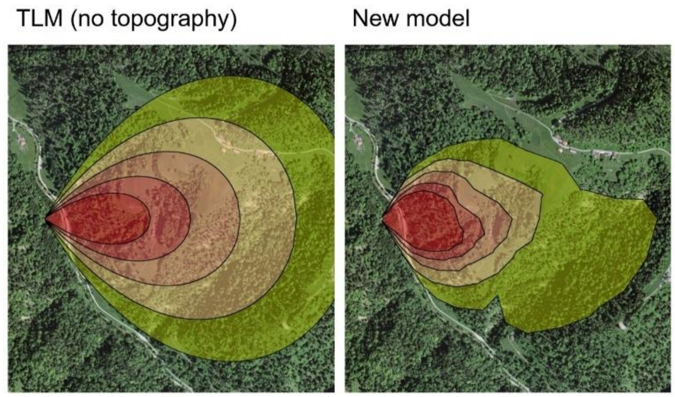

Figure 7. Comparison of 2D and 3D model

Figure 7 shows the comparison of the same case as Figure 6 with the current (2D) model. It is clearly visible that the valley in the lower right part of the image causes the outermost (green) lethality zone to bulge. Furthermore, several buildings located in the upper right part of the image are, according to the new 3D model, no longer within lethality zones.

Model for Air Blast in Adit Tunnels of Underground Installations

The adit tunnel of an underground ammunition installation can be highly complex, featuring turns, constrictions, expansions, crossings and blind tunnels. The TLM regulations and AASTP-4 provide a detailed catalogue of tunnel elements with equations to calculate their effect on the peak overpressure and blast duration in the adit. To determine the air blast at the adit portal based on the charge in the chamber, all the elements must be calculated in sequence, one after the other. The dimensions of each element can be derived from the 3D scans mentioned above.

Figure 8 shows a screenshot of the RIMANA 5 testbed with a chamber, a turn, a straight tunnel element, and an expansion chamber. These are selected and added from the pictograms of all available elements on the left-hand side, while the 3D model of the complete tunnel system is displayed on the right.

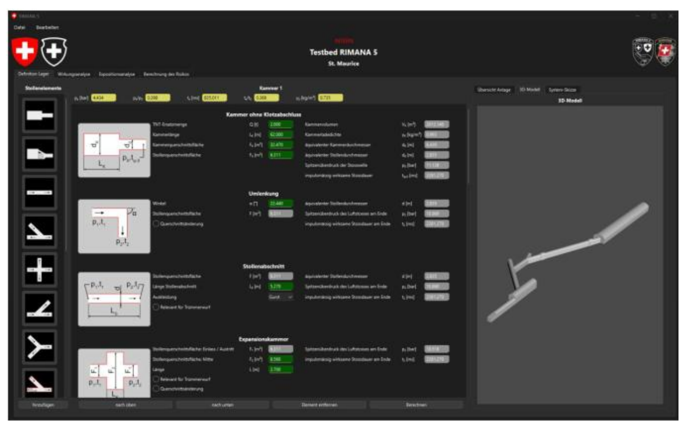

Figure 8. Screenshot of graphical user interface (GUI) for input of adit tunnel system in RIMANA 5 testbed

Quality control play a crucial role in such systems. Certain elements are subject to conditions that must not be violated. An example is illustrated in Figure 9: If a sequence consists of an expansion, a straight section, and a constriction, it can either be modelled by a single element (called expansion chamber) or by combining these three elements, depending on the length-to-diameter ratio. In the illustrated case, the first option is correct, because the element in-between is short. If the user choses the second option, RIMANA 5 will issue a warning and request the use of an expansion chamber instead.

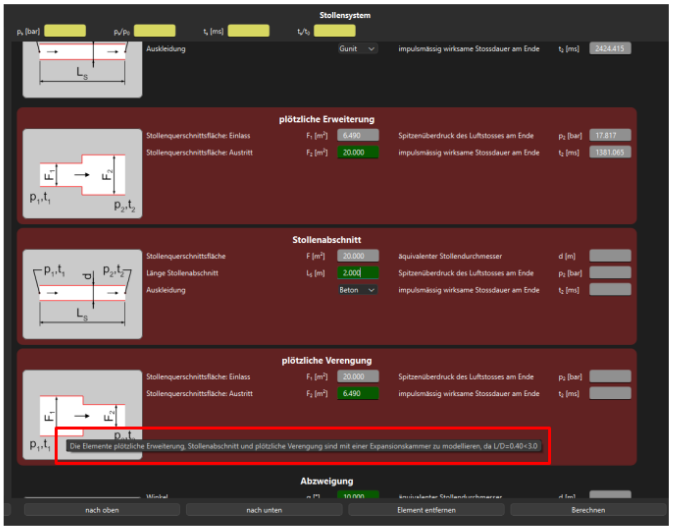

Figure 9. Example of a critical mistake where the user is warned (red colour)

Summary/Conclusions

RIMANA 5 will be a state-of-the-art risk assessment tool for ammunition storage safety, using the latest IT technologies, new GIS data, as well as updated consequence analysis models. In combination, these components provide the basis for 3D debris throw models. In Switzerland, where high population density is often a limiting factor for storage space, the new model's ability to account for complex topography such as hills and mountain slopes that shield surrounding areas may lead to substantial increases in storage capacity.

RIMANA 5 will also expand the scope of risk assessment for ammunition storage safety for both disaster prevention and disaster management:

- Disaster prevention: The assessment will no longer focus solely on fatality-based risk criteria. For example, if critical infrastructure in the surroundings of a magazine could be affected in case of an event, this can now be considered in the analysis and may result in a reduced storage capacity. Corresponding criteria for such cases have been developed and are currently being tested.

- Disaster management: RIMANA 5 will support first responders by providing accurate, daily updated hazard zones based on the real quantity and type of stored ammunition. If a magazine is only partially filled, emergency personnel — often operating under resource constraints — can prioritize evacuations and road closures in the areas where they are truly necessary.

References

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Contact Information

Peter, Nussbaumer, Bienz, Kummer & Partner Ltd, Culmannstrasse 37, 8006 Zurich, Switzerland, E-Mail: peter.nussbaumer@bkpswiss.ch,

Definitions/Abbreviations

WSUME	Weisungen über das Sicherheitskonzept für den Umgang mit Munition und Explosivstoffen *Directives on the safety concept for handling ammunition and explosives substances*
FS SUME	Fachstelle für Sicherheit im Umgang mit Munition und Explosivstoffen. *Expert Unit for Safety in Handling Ammunition and Explosives*
RIMANA	*Risk Analysis and Management*
API	*Application Programming Interface*
AASTP-4	*Manual on Explosives Safety Risk Analysis (NATO)*
TLM	Technische Richtlinien für die Lagerung von Munition *Technical guidelines for the storage of ammunition*