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Evaluation of the debris throw from the 1992 explosion in the Steingletscher installation in Switzerland [1]

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Abstract

On 2 November 1992, a detonation with an approximate force of 225 tons of TNT happened in the Steingletscher ammunition and explosives storage installation in Switzerland. Six people lost their lives in this accident. The installation was destroyed completely, the rock cover above the underground chamber broke off and rock as well as concrete pieces were thrown over a wide range into the surrounding area. Despite the tragedy of this accident the Swiss Department of Defence decided to learn as much as possible from it. Part of this effort was dedicated to the analysis of the debris throw to add to the worldwide relatively thin database of accident data in this field. This paper summarizes the work performed until now concerning debris throw from the crater above the storing chamber. © 1997 Elsevier Science B.V.

Keywords: Explosion; Debris throw; Steingletscher installation

1. Introduction

On 2 November 1992, a detonation with an approximate energy of 225 tons TNT occurred in a Swiss underground installation for the storage of old ammunition and explosives prior to their destruction. Six people, all being inside the installation at the time of the explosion, lost their lives in this accident. The installation was destroyed completely. The rock cover above the underground chamber broke off and rock as well as concrete pieces were thrown over a wide range into the surrounding area.

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Despite the tragedy of this accident the Swiss Department of Defence decided to learn as much as possible from it. For the evaluation of the explosion effects and to study the impacts of this explosion on the existing regulations in Switzerland, Bienz, Kummer and Partner was selected as contractor. After the Klotz-Club was informed about this accident, US experts also showed their interest and supported on their own initiative the evaluation of the effects. On behalf of the Swiss Defence Technology and Procurement Agency, I would like to thank the USAF, Mr. J. Jenus Jr., Chief of the Explosives Hazards Reduction Program and his technical consultant, Dr. K. Bakhtar, again for their valuable help.

The collection of basic data, mostly debris data, was performed during summer 1993 when the site was accessible again after the annual thaw. Unfortunately, as often under

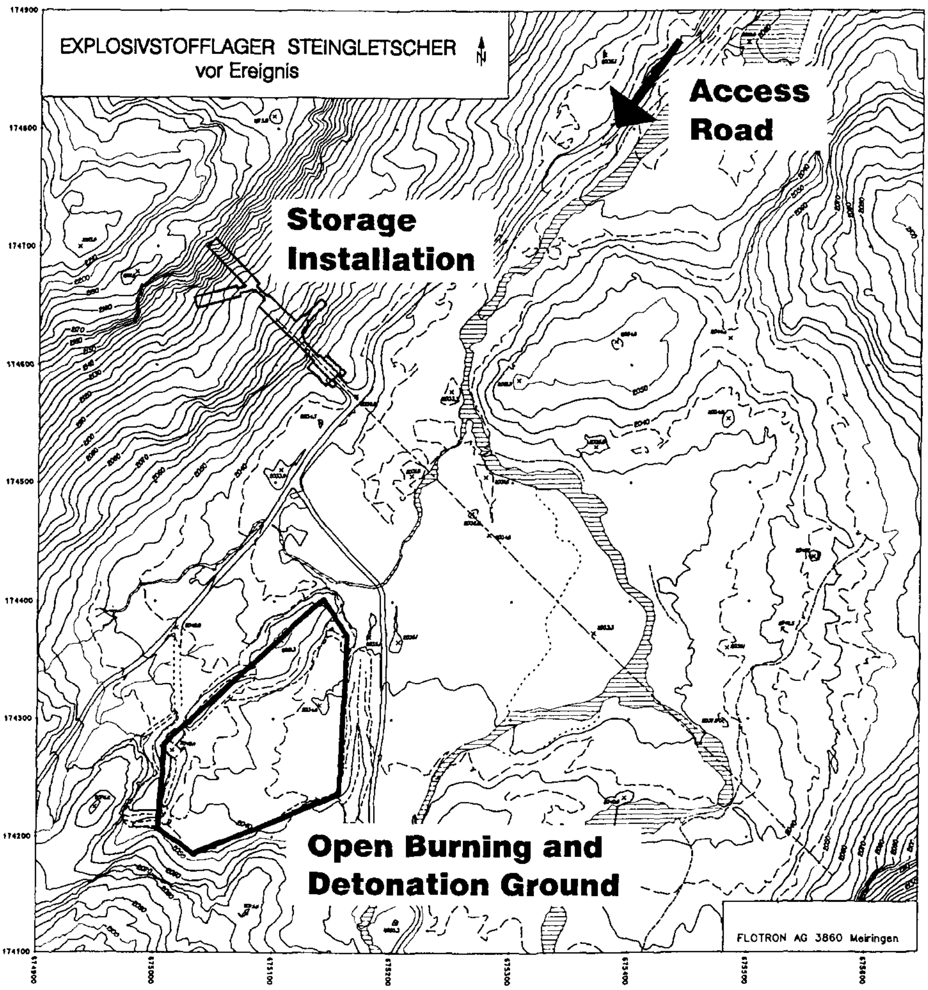


Fig. 1. Installation before the event.

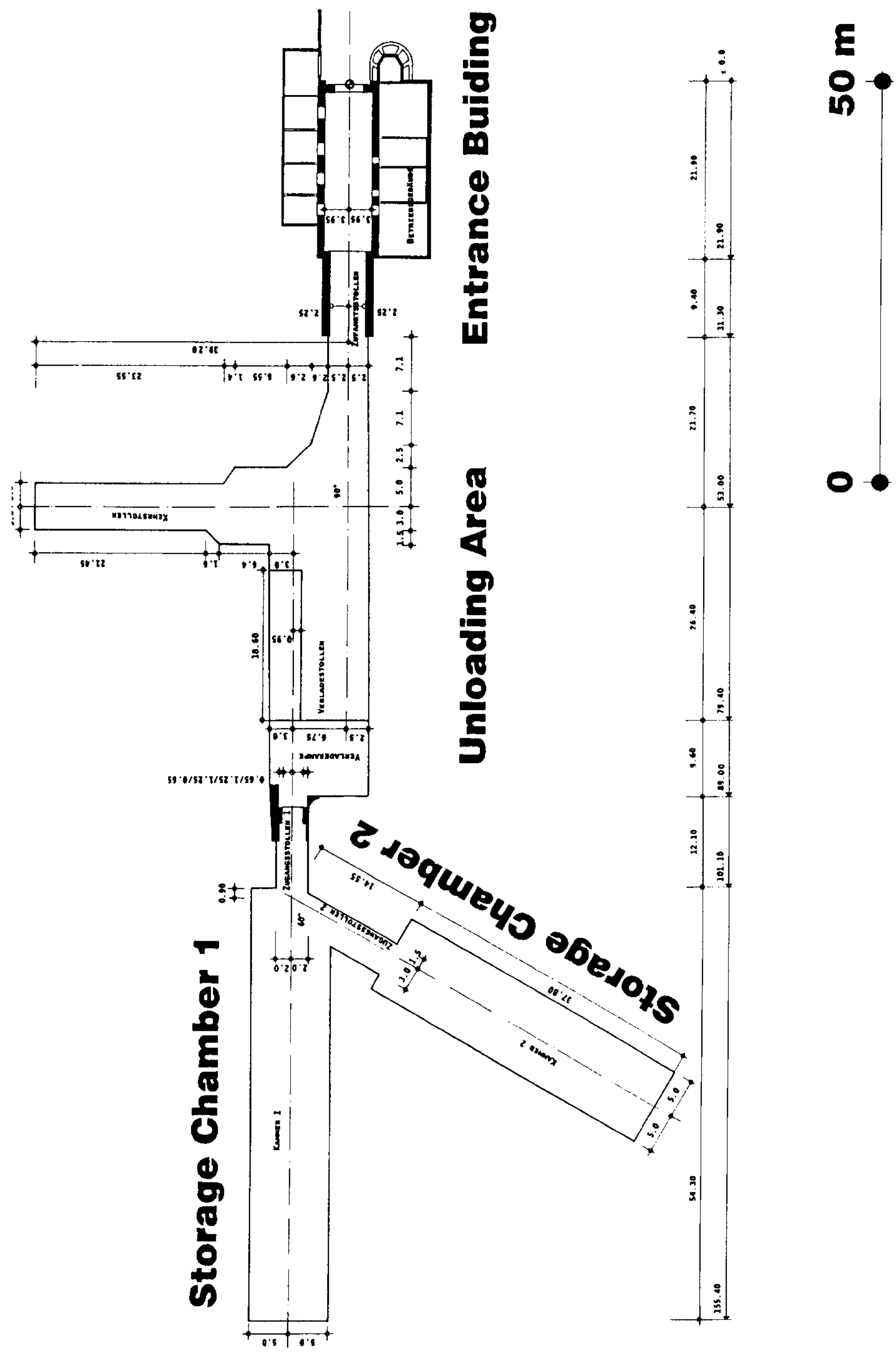


Fig. 2. Magazine layout.

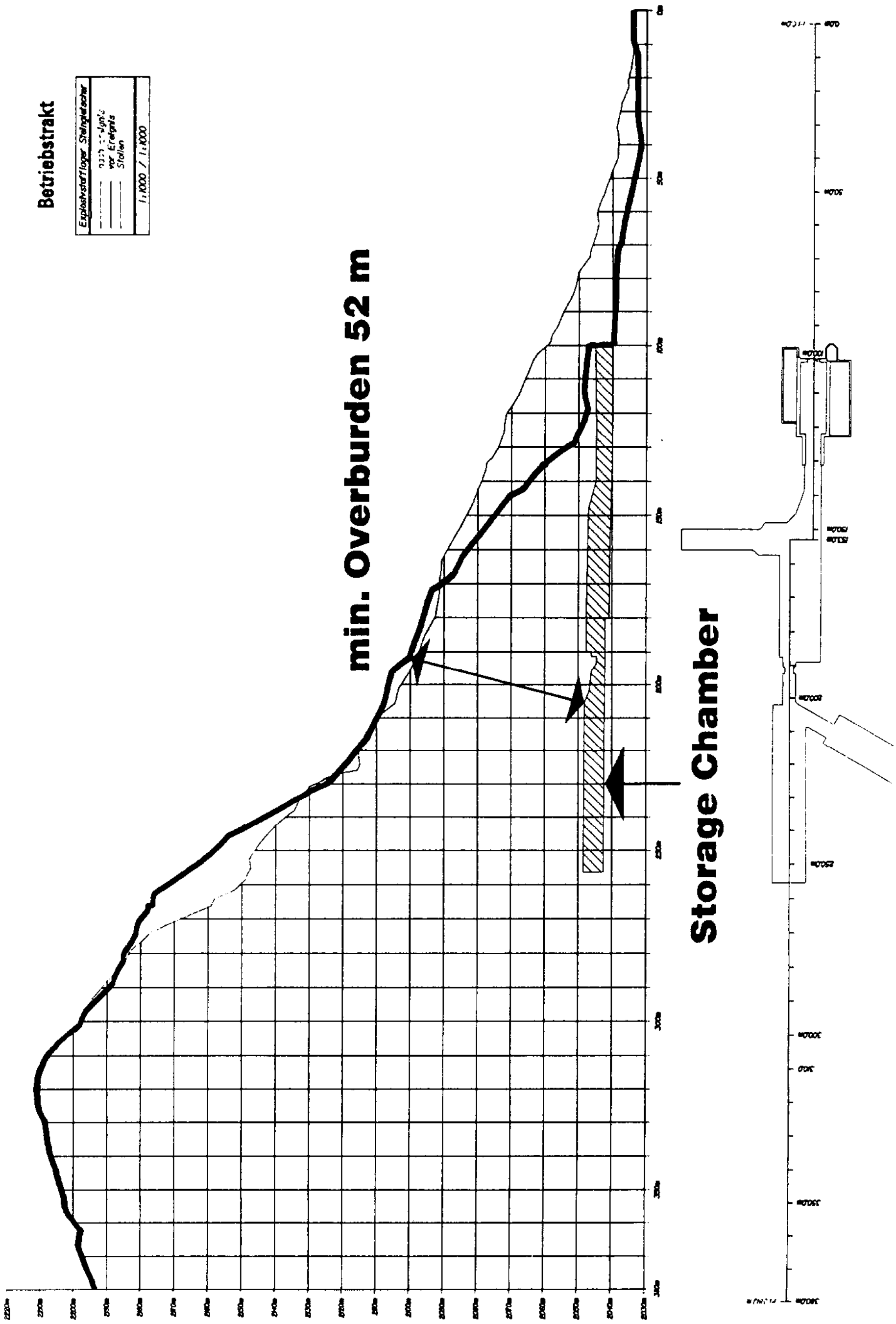


Fig. 3. Longitudinal section before and after the event.

such circumstances, the legal investigation, mainly interested in the cause of the event and the responsibilities, had priority and caused a delay of years in our technical work. Thus, it took a rather long time until some of the necessary data was made available and we could therefore only recently start with the evaluation.

Part of the effort was dedicated to the analysis of the debris throw, a field where worldwide only a limited amount of data exist as such tragic events are fortunately very seldom but tests very costly. As we know the installation and the contents of the chambers before the explosion quite well, we have the unique opportunity to bring the knowledge of the effects of such explosions a step further and therefore contribute to the safety of new or existing ammunition storage installations.

This paper summarizes the work performed until now concerning debris throw from the crater above the storing chamber. Section 2 gives a short overview of the installation and the accident. Afterwards, the debris recovery and basic data documentation are described in Section 3. Section 4 contains the evaluation of the basic data, first results concerning the debris density and an estimation of expected lethalities in this environment according to the NATO and Swiss criteria. Section 5 gives a summary and an outlook on planned future work.

2. Installation and summary of accident

The storage magazine called 'Steingletscher' (Stone-glacier) was located right in the centre of the Swiss Alps in an uninhabited area. It belonged to the Ammunition Factory Thun and was used to store old delaborated ammunition, outdated explosives and waste from the production of ammunition and explosives before their final destruction by open burning or detonation on the plain in front of the magazine. Fig. 1 shows the location of the installation as well as the burning and detonation ground.

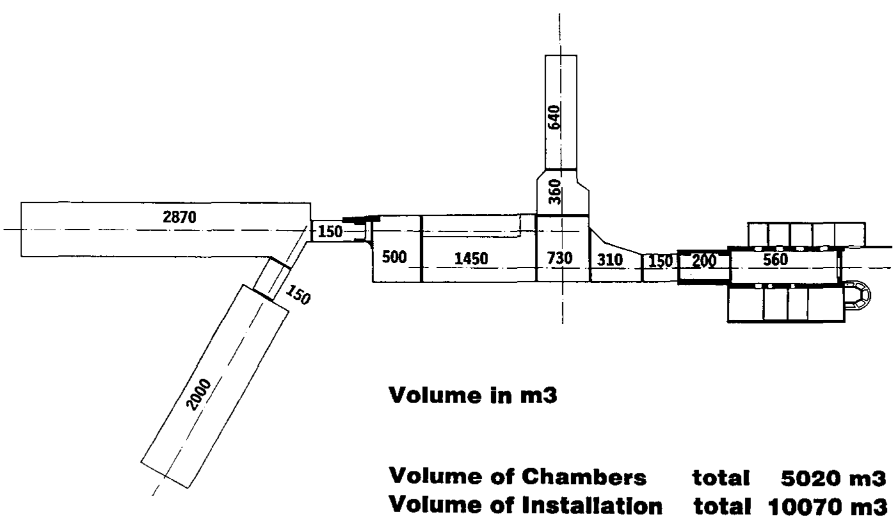
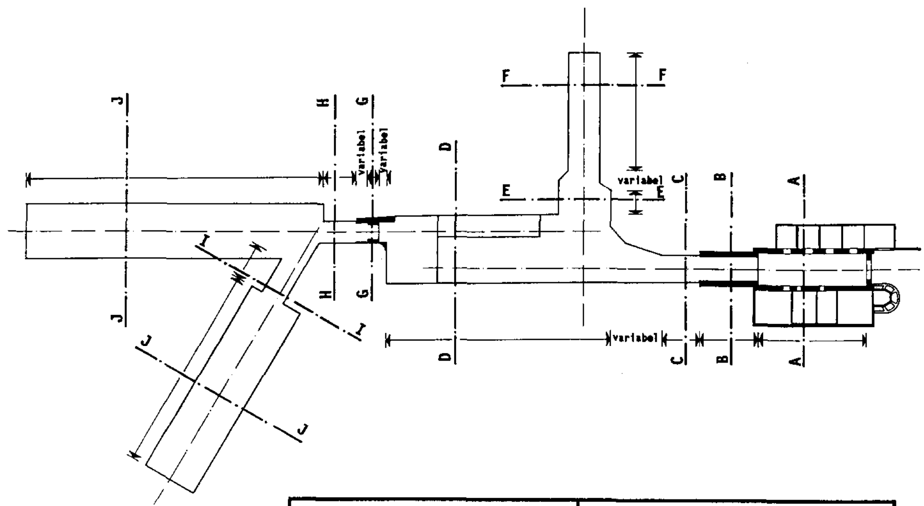


Fig. 4. Volume of chambers and tunnel sections.

The general layout of the magazine is shown in Figs. 2 and 3. As can be seen, the magazine consisted of three major parts: the two storing chambers, the unloading area (accessible for trucks) and the building at the entrance containing all the technical installations. Figs. 4 and 5 document the volume and cross-section of the different tunnel sections. The rock overburden of the storage chambers was minimally 52 m and consisted generally of very good rock, mostly granite. A more detailed description of the installation can be found in [3].

On the day of the accident the storage chambers were loaded with totally about 225 tons of explosives (TNT-equivalent). The largest part, about 190 tons, consisted of a lot of flaked TNT in cardboard drums. The average loading density in the two chambers was around 45 kg m^{-3}.



Section	Relevant Cross-Section-Areas [m^2]
A - A	27.9
B - B	19.4
C - C	20.6
D - D	68.3
E - E	49.9
F - F	29.9
G - G	6.0
H - H	15.9
I - I	21.7
J - J	52.8

Fig. 5. Relevant cross-section areas.

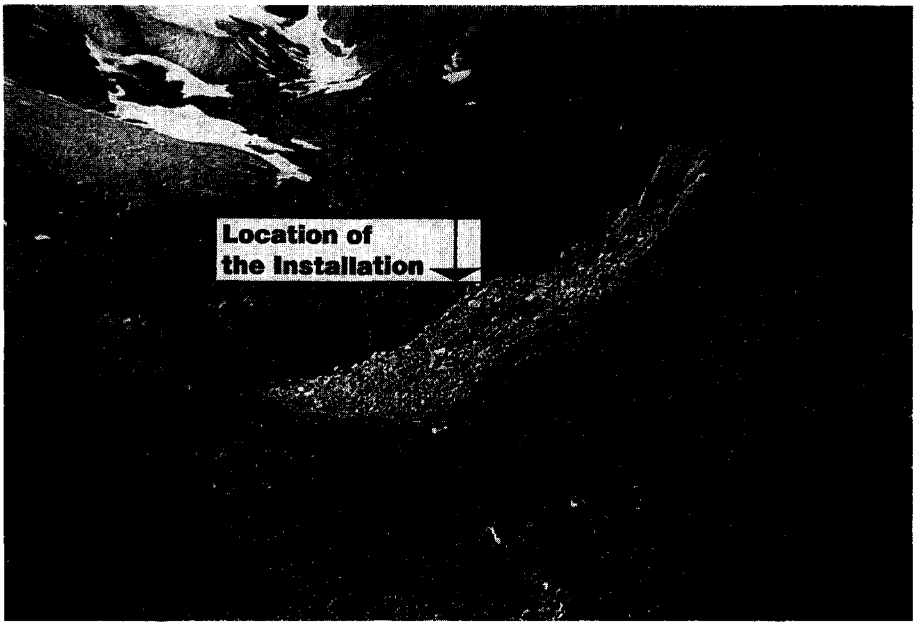


Fig. 6. Overview of the scene after the explosion.

Usual operations had been underway on 2 November 1992. At the moment of the explosion six persons were working inside the installation, at least one of them in one of the storing chambers, preparing material for destruction the same afternoon. Eleven

Fig. 7. Concrete block from entrance building weight 15 ton, 370 m from original place.

people were located in other areas outside of the underground part of the installation. At about 4 pm, a fire was reported by a worker in one of the storing chambers. Seconds later a huge explosion followed. The six people inside the installation were killed instantly; the workers in the surrounding area survived without any injuries by a miracle.

The installation was destroyed completely and the force of the explosion uncovered part of the rock above the chamber. Afterwards, probably due to the ground shock and the dislocation of material due to the forming crater, a large quantity of rock material, about 100 000 m^3, broke loose from the top of the mountain and covered the area where the installation had been located. Fig. 6 shows an overview of the scenery after the explosion. Rock debris from the crater were thrown in all directions into the surrounding area up to distances exceeding 500 m. Along the axis of the access tunnel, the debris throw consisting of rock material and concrete parts from the installation, especially from the entrance building, was even more dense up to a distance of about 800 m. Fig. 7 shows a block of concrete from the entrance building weighing 15 tons and found 370 m from its original place. There was no damage due to air blast however, as there were no above ground structures like houses, etc. in the immediate surrounding. A more detailed description of the accident can be found in [1,2,4].

3. Recovery and documentation of basic field data

The damage pattern as a basis for the evaluation of the physical explosion effects was recorded by topographical maps, terrain sections and aerial as well as terrestrial photos. Detailed documentations were elaborated for 53 large single debris and 40 'debris

Fig. 8. Debris collection areas.

collection fields' [4]. The data from these debris fields were used for the evaluation of the debris throw from the crater and are presented in this paper.

The following main steps were necessary for the recovery of the debris field data:

(1) First of all, suitable debris areas showing a characteristic debris distribution had to be selected. This was quite a difficult task as 'new' debris had to be found in a desert of stones. In the end however, it was easier than expected as the shape of the crater debris, the vegetation under them at the place where they were found and the 'clean' debris surface, without any lichens on it, made a distinction possible. Fig. 8 shows two of the chosen fields.

(2) The selected fields were marked, photographed and surveyed. The result of this step was an area map containing the installation and all the fields where debris had been

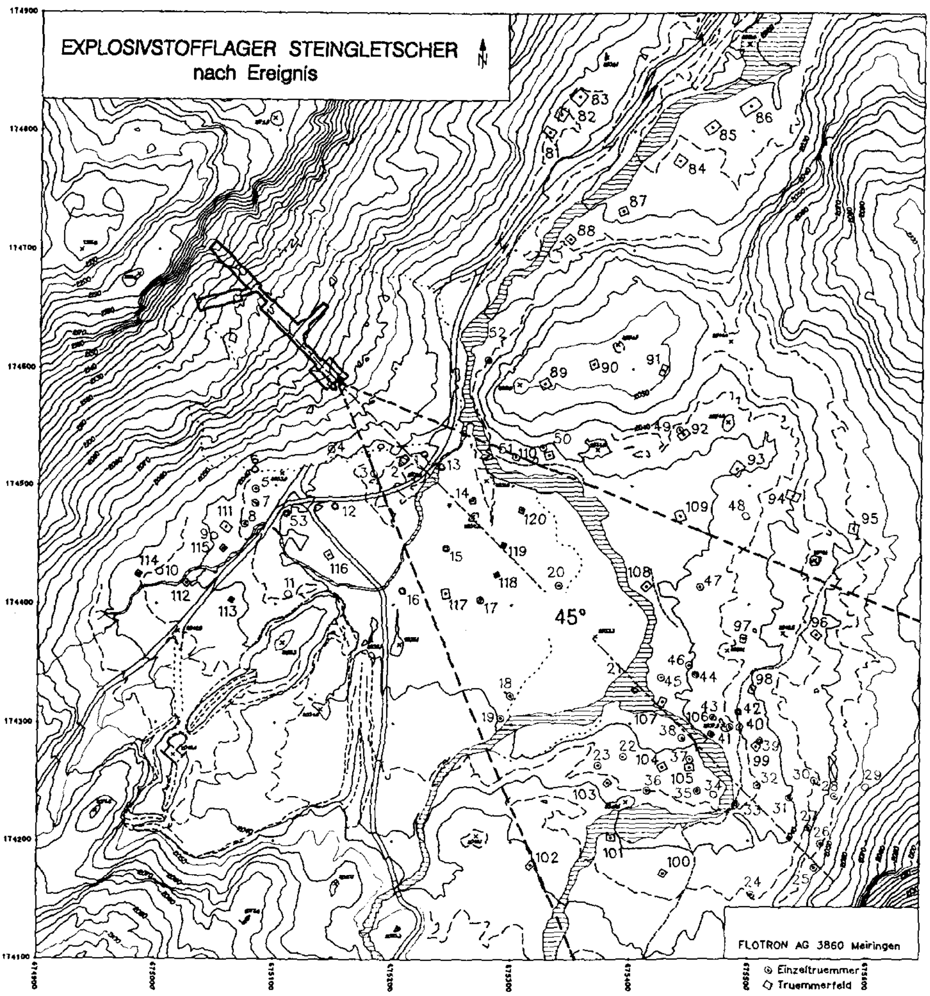


Fig. 9. New area map with 'debris fields'.

Fig. 10. Debris from a 'collection area'.

collected (Fig. 9: Nos. 81 to 120 indicate the 'debris collection fields', Nos. 1 to 53 show the location of the recorded large single debris).

(3) At last, all debris were collected, sorted out for different materials (rock, concrete, metal parts, etc.) and according to their size. Fig. 10 shows an example. The debris were counted and weighed. Back in the office, for each debris field a data sheet showing all details was elaborated and, as a first step of the evaluation, the debris mass density in kg m^{-2} was defined (Fig. 11). Fig. 12 gives an overview of the data of all debris fields.

Overall 25 man-days were invested in the data recovery on the spot. This is not as much as would have been desirable but financial and time constraints made a more extensive site investigation impossible. Two things have proved true again:

(1) After an accident there is an urgent need to clean up the mess as fast as possible, not only on the spot but also in order to make disappear the traces of the accident and to get the event out of the mind.

(2) For a number of reasons it is much easier to get a million dollars for a clean new test than 10000 for the evaluation of an accident.

4. Evaluation of basic data

Using the field data, so far the following initial evaluations have been made:

1. Development of a debris density contour map.
2. Determination of the number of hazardous debris per unit area.
3. Estimation of lethality based on the number of hazardous debris.

4.1. Debris density contour map

For the development of the contour map showing the density of debris coming from the crater above the storage chamber, only those debris fields could be used which were not influenced by debris coming out of the access tunnel. Using the fact that at the day of the explosion the surrounding area of the installation already was covered with snow and with the help of an aerial photo taken 4 days after the event, it was easy to sort them out. Therefore, all debris fields lying within 22.5 degrees to the left and right of the axis of the tunnel entrance were not used for further evaluation. This 45 degree angle is exactly the area in which our safety regulation TLM 75 [6] expects most of the debris

TRÜMMERFELD **NR. 88**

Beschreibung : Grünes Feld, 1/4 unter Wasser

Ort : Linke Flanke neben Gletscherbach

Abmessung : L = 7.45 m B = 6.35 m

Fläche : F = 47.30 m²

Art und Masse [kg] der Trümmer:

Anz.	Gewicht Einzel	Gewicht Total	Gew. / Art Total	Art	Bemerkungen
1	32.5	32.5		F	
1	20	20		F	
1	6	6		F	
2	4	8		F	
1	3	3		F	
3	2	6		F	
2	1.5	3		F	
2		2		F	
4		4		F	
12		8		F	
10		4		F	
10		3		F	
10		2		F	
Rest		10	111.5	F	
		0.05		M	
1	1	1	1.05	M	
		0.3	0.3	H	
Total		112.85			

Trümmerdichte [kg/m²] Total: 2.38

Fels: 2.36 Beton: H: 0.0063 Metall-/Munitionsteile: 0.022

Bemerkungen : - 1 Zünder 15,5 cm, ca 1 kg

Erhoben am : 28.7.93

Fig. 11. Data sheet of a 'debris field'.

(a)

OVERVIEW DEBRIS FIELDS							
Debris Field no.	Location	Coordinates Y [m]	X [m]	Distance to Portal [m]	Distance to Center of Crater [m]	Altitude Above Sea Level [m]	Debris Density [kg/m2]
81	a	5328.0	4799.7	276.3	279.0	2033.5	2.45
82	a	5337.6	4814.1	293.5	294.5	2032.6	1.00
83	a	5352.9	4829.3	315.0	315.5	2032.1	0.38
84	a	5437.7	4774.5	342.2	370.3	2022.9	1.03
85	a	5464.8	4803.1	380.7	405.1	2021.1	0.23
86	a	5497.5	4820.0	417.2	441.7	2021.1	0.06
87	a	5390.3	4732.8	279.9	313.6	2024.1	0.91
88	a	5346.2	4709.9	230.3	265.8	2026.7	2.39
89	a	5325.8	4587.6	174.7	253.1	2050.5	2.17
90	a	5366.4	4604.1	215.9	288.2	2050.5	3.69
91	a	5425.0	4598.4	274.1	346.8	2050.3	1.32
92	a	5442.8	4543.5	295.0	378.0	2036.3	1.23
93	a	5488.8	4514.3	345.5	431.1	2035.2	1.15
94	a	5536.1	4491.5	396.7	483.4	2040.5	0.76
95	a	5587.9	4464.4	453.8	541.5	2047.1	0.77
96	i	5557.2	4374.6	458.5	554.2	2044.2	1.38
97	i	5495.1	4371.0	406.4	504.3	2038.9	1.33
98	i	5503.3	4328.7	437.0	536.4	2039.8	3.38
99	i	5506.8	4280.7	469.7	570.2	2037.9	4.80

a = Debris fields outside 45° angle
i = Debris fields inside 45° angle (area where debris from access tunnel dominates)

(b)

OVERVIEW DEBRIS FIELDS							
Debris Field no.	Location	Coordinates Y [m]	X [m]	Distance to Portal [m]	Distance to Center of Crater [m]	Altitude Above Sea Level [m]	Debris Density [kg/m2]
100	i	5428.2	4172.3	499.1	599.7	2041.3	3.68
101	i	5383.5	4203.4	448.9	548.9	2040.7	3.09
102	(a)	5316.4	4180.5	439.2	536.0	2045.4	6.72
103	i	5380.6	4249.7	408.3	509.0	2038.7	5.86
104	i	5427.3	4263.2	425.9	527.2	2036.7	8.46
105	i	5450.2	4263.0	441.2	542.5	2035.6	4.63
106	i	5468.2	4290.9	434.1	535.0	2035.5	8.34
107	i	5426.6	4318.4	385.0	486.1	2034.3	9.29
108	i	5412.9	4415.2	313.3	411.9	2033.5	4.66
109	a	5440.6	4474.4	310.8	403.3	2034.0	1.38
110	a	5329.8	4526.5	188.8	281.1	2034.7	3.38
111	a	5057.8	4464.9	154.0	200.6	2039.7	4.26
112	a	5024.9	4417.2	211.9	253.6	2040.9	3.66
113	a	5062.8	4403.2	204.3	261.4	2041.2	3.54
114	a	4984.9	4424.8	232.5	258.8	2043.2	2.06
115	a	5055.8	4447.1	169.6	218.5	2039.7	8.30
116	a	5144.4	4441.5	146.1	230.1	2034.5	3.66
117	i	5243.4	4409.5	200.4	299.8	2033.6	5.39
118	i	5286.4	4425.5	211.0	312.3	2033.4	15.34
119	i	5292.1	4450.5	196.5	297.6	2033.1	11.22
120	i	5307.2	4480.1	189.4	288.7	2032.8	6.89
			Coordinates Portal:	5'151.13	Coordinates Cratercentre:		5084.42
				4'587.42			4663.68

Fig. 12. (a) Data of all debris fields Part I. (b) Data of all debris fields Part II.

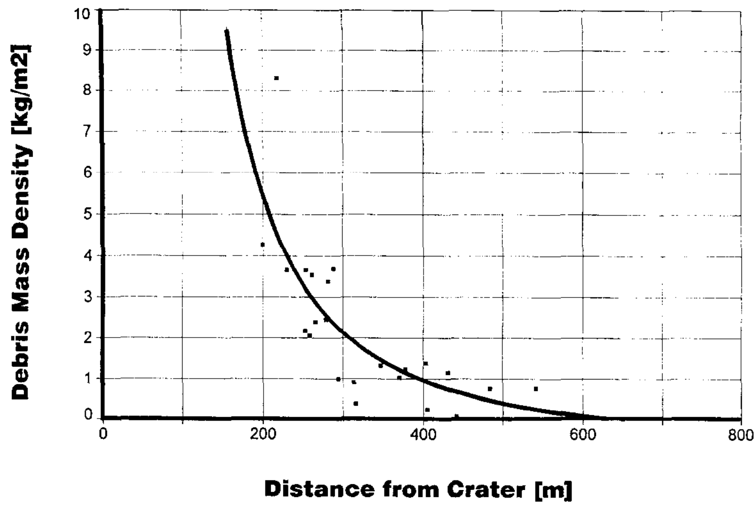


Fig. 13. Debris mass density versus distance from centre of crater.

coming from an access tunnel. For further evaluation of the debris throw from the crater, only the debris fields Nos. 81 to 95 and 109 to 116, (a total of 23) were used. Together with the fact that the maximum crater debris throw distance was on the order of 600 to 700 m, the graph in Fig. 13 was developed. Although the data scattering was not as small as we would have liked it, the debris mass density versus distance curve represents the physical facts, in our view, reasonably well. Based on this curve the debris mass density contour lines in Fig. 14 could be drawn as a final result.

4.2. *Defining of number of hazardous debris per unit area*

Debris mass density contour lines are only one step on the way to determining a safety distance or a lethality rate for a person exposed to this physical effect. In fact it is always one or a couple of debris which take life and not an abstract value like 'debris mass density'.

Thus, the next step in our evaluation was to establish the relationship between the number of hazardous debris and the debris mass density. Based on the data sheets of the debris fields (Fig. 11) a debris size summation curve was developed for each field. A summary of the curves of all 23 fields is shown in Fig. 15. A regression with these data points was made (Fig. 16) and a final average distribution of the debris size (mass) versus number of debris, standardized for an area of one m^2 and a debris density of 1 kg m^{-2}, was the result. The data was evaluated to see if the debris size distribution was dependent on the distance from the crater or the angle from the tunnel axis, but neither were determined to be of important influence.

But what is a hazardous debris? According to the NATO regulations a hazardous debris is a piece of material with a kinetic energy of more than 79 J. Taking into account an endballistic velocity in the range of 35–50 m s^{-1}, it can be concluded that all debris with a weight of more than 100 to 150 g are lethal. The long and the short of it is that in Fig. 16 you can read that for a debris density of 1 kg m^{-2} you get the average of 1 lethal debris m^{-2}. Of course, this value is not an universal constant, it is only exactly valid for this explosion accident, but it is representative for locations with similar rock types.

4.3. Estimation of lethality based on the number of hazardous debris

With the values from the initial evaluation, and according to the NATO safety principles, it is easy to calculate the 'safety distance' based on the criterion of one hazardous debris per 600 ft^2 or 55.7 m^2, respectively. According to Fig. 13 you would

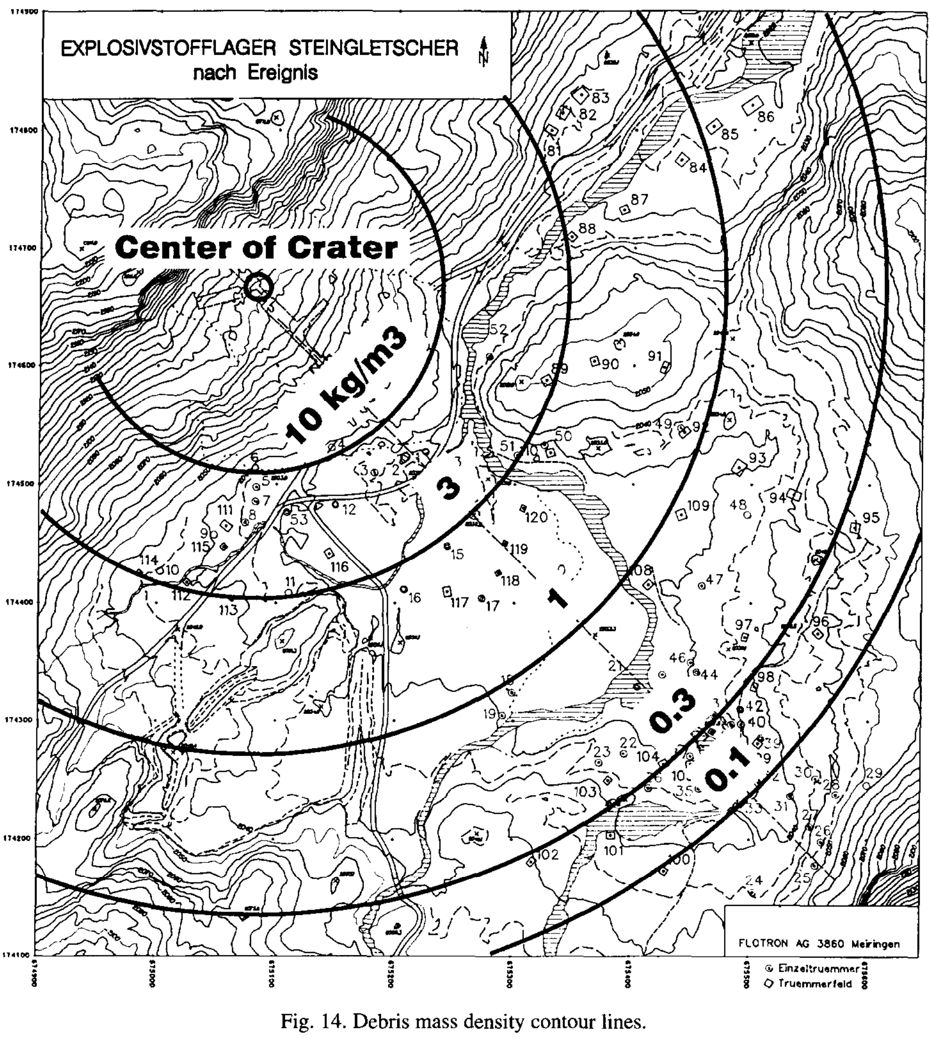


Fig. 14. Debris mass density contour lines.

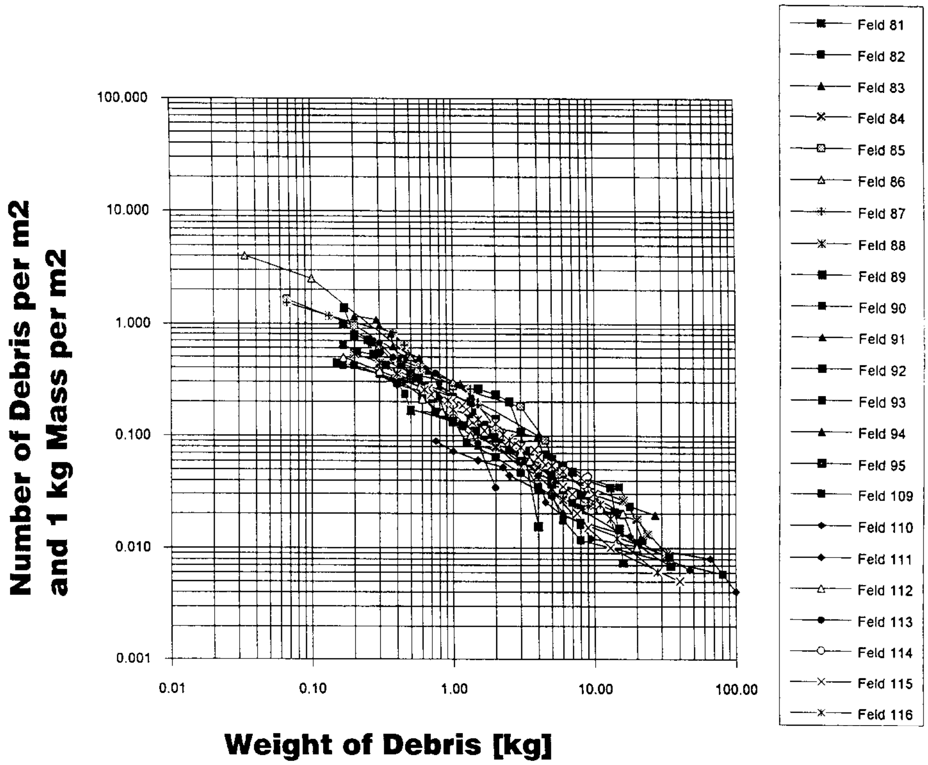


Fig. 15. Summary of debris size distribution of all debris fields.

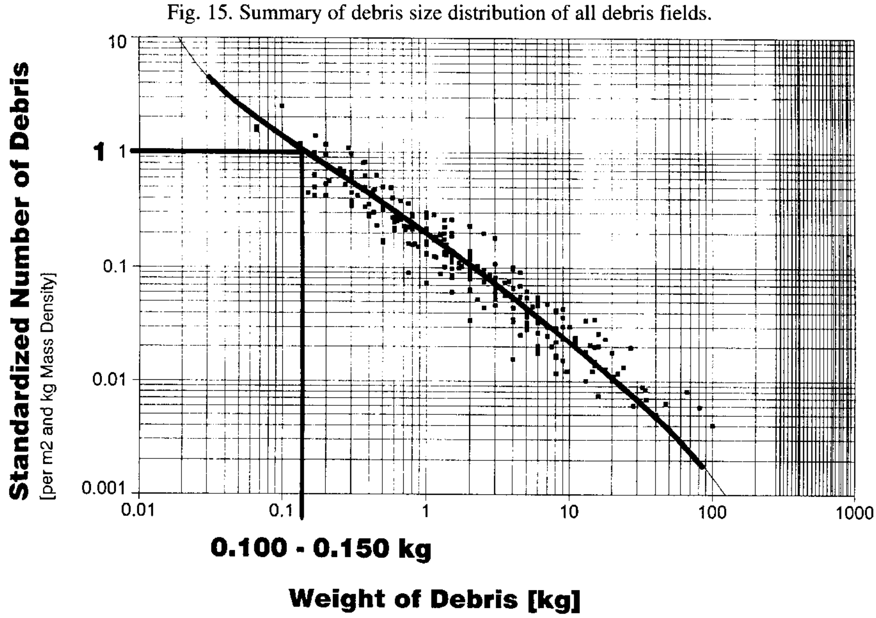


Fig. 16. Medium debris size distribution.

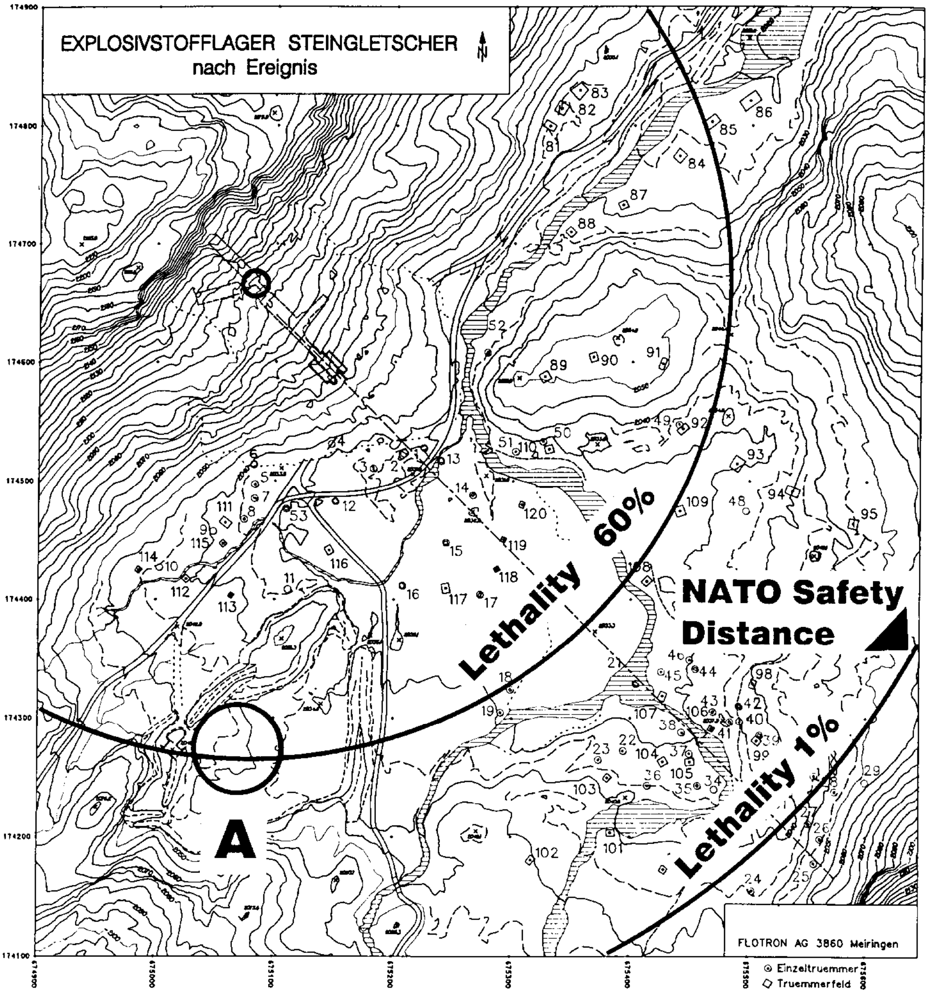


Fig. 17. Lethality according to NATO safety criteria.

come up with a safety distance of around 640 m (Fig. 17). Taking into consideration a lethal area for a person of 0.58 m^2 according to the NATO regulations (a relatively large area for a standing man facing the explosion), the lethality of a person standing in the open at that 'safety distance' would be around 1%. For the contour line indicating a debris density of 1.0 kg m^{-2} the respective lethality value would then be around 60%.

But how do these lethality Figures compare with reality? At the time of the explosion 6 workers were standing in the open at point A in Fig. 17. No one was hurt! Being aware that we are dealing with probabilities, the chance that this happens is not zero, however it is very little. That's why we are convinced that the NATO safety criteria are over conservative in this case.

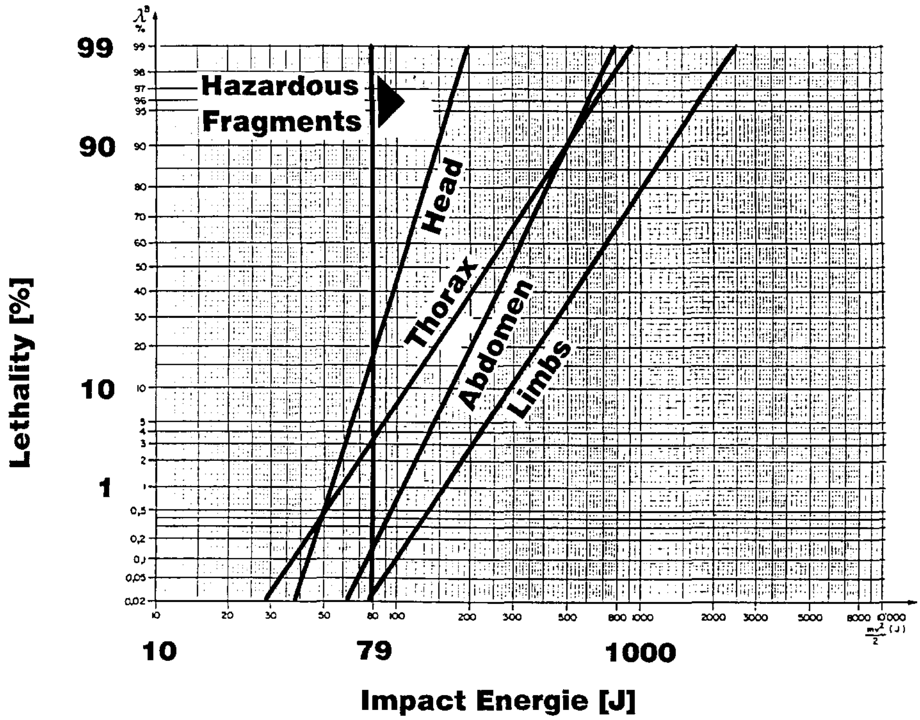


Fig. 18. Lethality versus impact energy.

How would we judge this situation according to the Swiss Safety Regulations? We do not have safety distances, but calculate the risk quantitatively [8,9]. This approach gives a much better picture of what really happens. Thus, the technical models such as lethality as a function of physical effects have to be more extensive and detailed than in a quantity-distance approach. Therefore, several years ago the lethality of persons due to debris throw coming from a crater was studied in-depth [5,7]. Taken into account were, for example, the impact angle of debris and the different susceptibility of different parts of the body. Fig. 18 shows that the impact of a debris with an energy of 79 J results in a considerable lethality rate only in case the head is hit. Other parts of the body are less sensitive to debris impact with respect to lethality. Based on that model and for the debris density measured at the Steingletscher site, taking into account the distribution of the debris size according to Fig. 16, the lethality was calculated. Coming up with a lethality of less than 10% at point A (Fig. 19), we are confident that this situation is more realistic than the NATO criteria.

5. Final remarks

This paper presented the technical evaluation of the crater debris throw coming from an explosion in an underground ammunition storage installation. As the Steingletscher

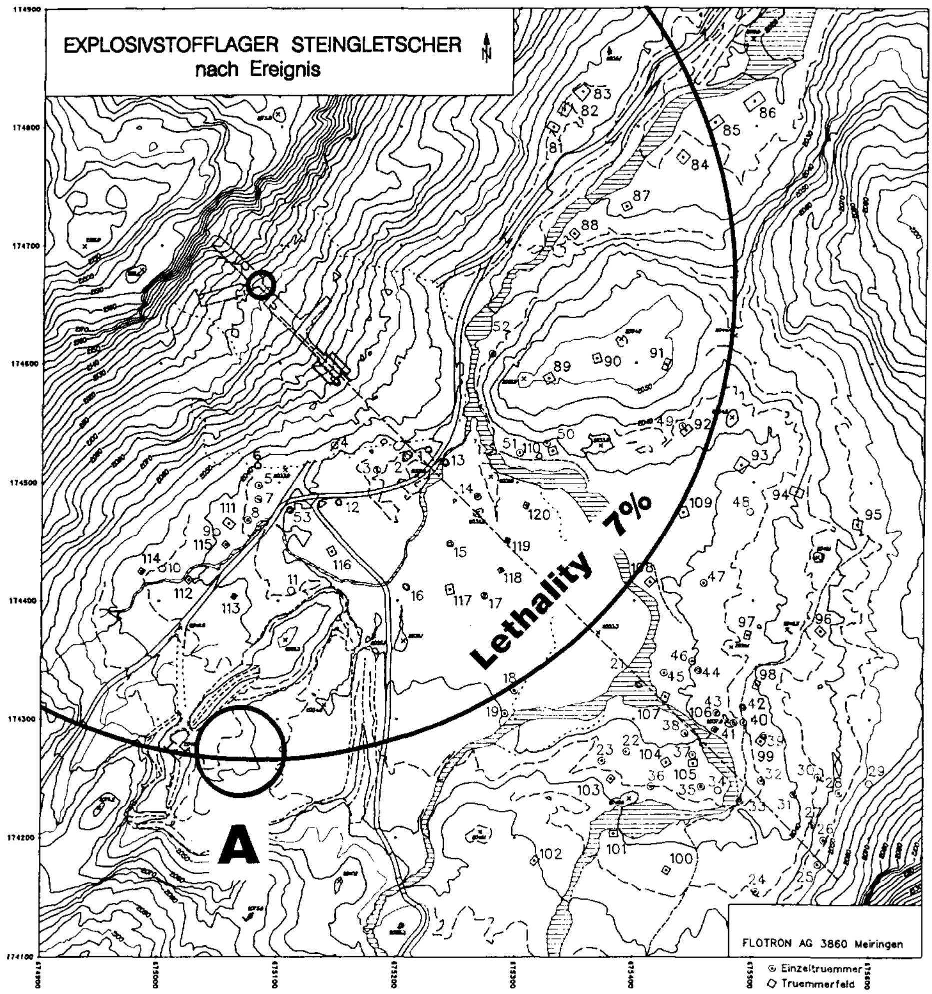


Fig. 19. Lethality according to Swiss criteria.

accident demonstrated however, debris throw from the access tunnel can be even more intensive than from the crater generated above the installation. In many cases this may even be the decisive effect. That is the reason why in a further step it is intended to evaluate the debris throw from the access tunnel in the same way, but this can only take place as soon as the judges and lawyers make the necessary data available.

Concerning this evaluation we could learn the following lessons:

(1) An accident is a tragedy for the victims. But it is an unique opportunity for the safety specialists to check and improve their methodical and technical instruments for the safety assessment.

(2) At times, it is not easy for a technical expert to get to the facts. There is an urgent need to clean up the site immediately, and judges and lawyers tend to lock away important facts for a very long time.

(3) Even with a limited set of data, valuable scientific findings can be made, for which prohibitively expensive tests would be necessary.

On a technical level, it could be shown based on a realistic case, that the NATO safety criteria for debris throw might be conservative, as suspected by many experts. Furthermore, it is shown that the Swiss approach for the lethality due to debris throw from a crater gives more plausible results. Therefore, together with the risk based approach, the Swiss criteria allow a more economic use of the installations.

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