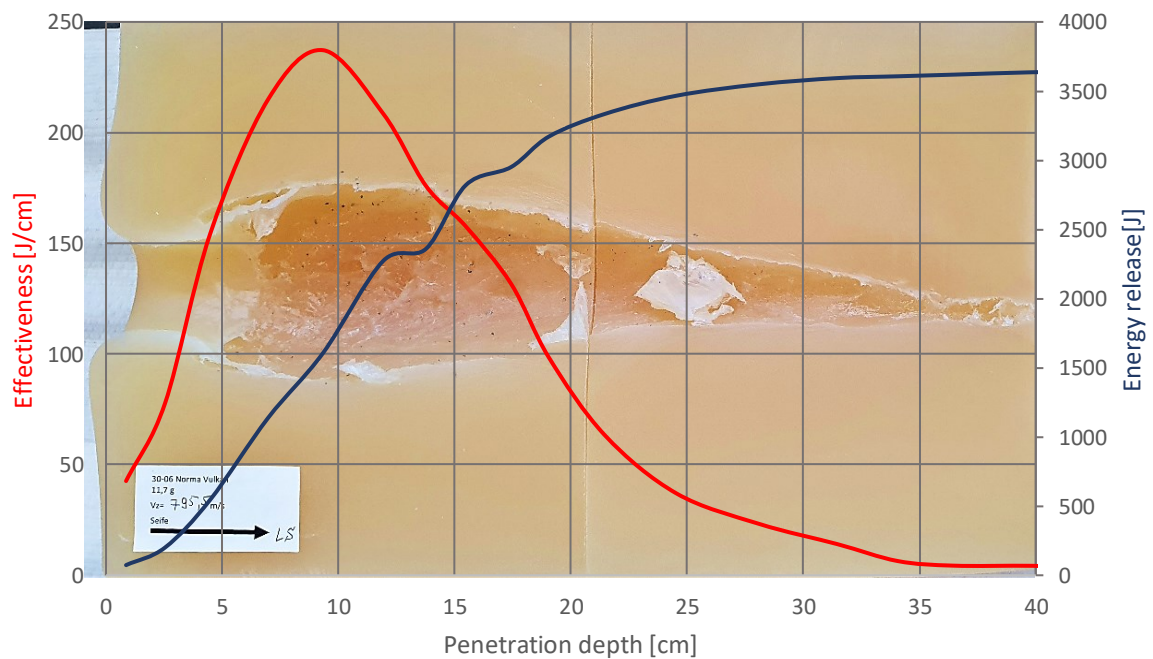


Bundesinstitut für Risikobewertung

Guideline for a standardized evaluation method for ballistic soap as a test simulant to determine the wound ballistic potential of the bullet



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BfR-Autor:
Ingo Rottenberger

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Bundesinstitut für Risikobewertung
Anstalt des öffentlichen Rechts
Vertreten durch den Präsidenten Professor Dr. Dr. Andreas Hensel
Max-Dohrn-Straße 8–10
10589 Berlin

Telefon: 030 18412 - 0
Telefax: 030 18412 – 99099

E-Mail: pressestelle@bfr.bund.de

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1 Introduction

Ballistic soap is an internationally recognized simulant that behaves similarly (i.e. with regard to cavern formation, tissue damage) when fired with bullets from short and long gun weapons, as has already been determined in a comparison of gunshot wounds to body tissue with experimental reconstructions [1]. This comparability is possible because during the manufacture of the ballistic soap, a density is achieved via its components and quantitative composition that comes very close to the density of musculature. Soap is therefore suitable for modelling the physical-ballistic aspect of wound ballistics [2]. Kneubuehl et al. [2] point out a simple method of volume determination in soap that can be implemented without great technical effort by cutting the soap, whereby the size of the volume of the wound cavern reflects the course of the energy release in the simulant. Pirlot et al. [9] also describe that the plasticity of the soap allows the wound cavern by slicing the bombarded block to be recorded and the amount of energy introduced can be calculated.

Measurement of the cavern volume using Archimedes' principle is described by Burgos-Díez et al. [7] as too inaccurate as well as a tedious and time-consuming procedure. Tsiatis et al. [8] consider the use of soap as an alternative to ballistic gelatin and come to the assessment, that very accurate numerical analysis of wound caverns by computed tomography (CT) is possible when soap is used. A volume determination in soap by silicone casts the cavern was described by Gremse et al. [10] with hunting rifle bullets and Burgos-Díez et al. [7] with hand gun bullets, whereby the latter question the suitability of the method because due to a fast drying of the silicone smaller cavities are partly not filled. Thus, they are not available for a volume determination. A comparison of the volumes calculated using CT and the silicone pouring method resulted in [7] that the silicone pouring method had too large standard deviations and the non-invasive CT method only very small standard deviations. Despite the great advantages of the CT method in terms of accuracy when evaluating wound cavities, it is disadvantageous that it is only available to well-equipped laboratories due to the high costs. In addition, their applicability for demonstrating the energy conversion of hunting projectiles in the body of the game animals is well established [3,10]. In the recent past there have been further research activities, on the one hand the draft of a technical guideline for hunting bullets [3] and, on the initiative of the German Federal Institute for Risk Assessment (BfR), based on technical discussions with national and international experts [4], firing tests in a state proof house.

A number of material standards as well as proofing and evaluation procedures were established for gelatin many years ago. Although soap has also been used as a test simulant for many years, detailed descriptions of the procedure and reports of practical experience of its use have only been published to a limited extent. A publication on the standardization of the procedure when using the ballistic soap as a test simulant is not yet available. The aim of this work is to define corresponded specifications for the simulant material soap, to enable a standardized bombardment method and to achieve reproducible results in soap block bombardment. The instructions also point out possible sources of error within the test series.

This guideline serves to represent and calculate the volume of a cavern without great technical effort and thus to close a gap in the field of experimental wound ballistics.

2 Materials and Methods

The following work steps must be carried out when ordering the soap, handling the delivered soap, checking the consistency before shooting (air rifle test), preparing for work to shooting, cutting open and photographing as well as evaluating the soap blocks.

2.1 General information on soap production¹

2.1.1 Soap components, parameters and test methods

Table 1: Soap ingredients based on the Permatin recipe from Walde KG, Innsbruck

Components	Percentage by weight [%] – Range
Sodium Cocoate	20–40
Alcohol denat.	10–20
Aqua	10–20
Sucrose	5–10
Sodium Tallowate	1–5
Sodium Ricinoleate	1–5
Sodium Stearate	1–5
Glycerin	1–5
Sodium Hydroxide	0–1

The colour of the soap is dark yellow (not transparent).

Table 2: Information on characteristic values and test methods

Test Characteristic	Test Method/Mean	Target Values
pH value	Haake viscosity tester	10.0–10.9 [mPas]
Free alkali	titration with 0.1 N HCl	0.01–0.1 [%]
Titer of fatty acids	pour point	28.5–32.0 [°C]
Fatty acid	Lüring'sche Burette	37.0–42.0 [%]

Block size

The block size is: 25 cm x 25 cm x 40 cm (width x height x length).

2.2 Ordering, shelf life and handling of the soap

The properties of this soap have been adapted to the requirements of a shooting in terms of composition and viscosity by Permatin² in a long development process together with Dr. Beat Kneubuehl since the 1970s. It has been used in this recipe for bombardment tests for several decades.

The soap can be ordered from the manufacturer (e.g. Walde KG, Innsbruck, Austria) with reference to the “Permatin recipe”. To the best of the author's knowledge, the company Walde KG is currently the only supplier of soaps for ballistic shooting in consistent quality. The delivery times are approx. two to three weeks for normal order quantities. Upon delivery, typical

¹ Manufacturer's information provided by Carl Alois Walde KG, Innsbruck.

² The company Permatin was located in Switzerland. After the plant was closed in 2012, the formula for the bombardment soap was taken over by Enzian-Seifen in Metzingen and later by Walde KG in Innsbruck.

parameters and indicators of quality should be checked. In the example of the above-mentioned "Permatin recipe", a dark yellow color of the soap indicates a correct preparation according to the recipe.

The blocks weigh 27 kg. According to the manufacturer, the soap has a shelf life of at least three years. During this time, a change in density and appearance is possible.

Manufacturer's recommendation for use: Store and use the soap blocks for a maximum of six months in the packaged version, in compliance with the storage conditions for ballistic tests. Work gloves are recommended when handling the soap.

2.3 Bombardment and evaluation of the cavern in the soap block

2.3.1 Work preparation for quality control

Materials that are partially elastic have proven to be suitable for supporting the blocks. The soap blocks, with a mass of 27 kg, lie firmly on the surface and do not sink in, as is the case when a too soft a base is used (e.g. foam). During firing, the underlay material can, within certain limits, absorb the energy input of the bullet along the path of the firing channel, thus allowing a more uniform expansion of the cavity than when supported on a non-elastic base. Based on many years of experience, a Regupol³ sheet is recommended as a partially elastic pad, but any other partially elastic underlay can also be used.

The diablo test (also known as the air rifle test) must be carried out for quality control. This deviates from the previous test procedures, which are carried out for gelatin, for example, with steel balls with a diameter of 4.5 mm [11]. The use of a standardized diablo is justified by the fact that at high bullet velocities a corresponding shot channel is created and maintained in the soap. At low velocities, there is a possibility that, compared to gelatin, the round ball in soap reaches greater penetration depths due to the lower friction between the bullet and the simulant [2]. Due to a high fat content in the soap, the surface friction is probably lower than in the gelatin, so that here round balls "glide" the last part of the way in the simulant and thus "fake" a greater penetration depth. For the diablo test, at least two blocks of soap must be unpacked from the delivery before the shooting date and a shot fired in accordance with the specifications of the diablo test with the air rifle into the top right corner of the blocks of soap (Figure 1).

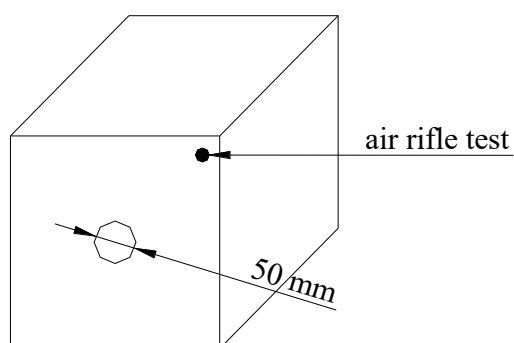


Figure 1: Hit zone (Ø 50 mm) in the center of the soap block (front side) for the later shooting with a hunting bullet and in the upper right corner for the air rifle test at a distance of approx. 30 mm from the respective outer edge.

³ Regupol is a product of Berleburger Schaumstoffwerke, Am Hilgenacker 24, D-57319 Bad Berleburg, Germany.

Technical requirements for shooting with the diabolo:

Flat head diabolo:	0.53 g
Bullet diameter:	4.5 mm \pm 0.25 mm
Bullet velocity:	300 m/s \pm 10 m/s
Required penetration depth:	90 mm \pm 10 mm
Distance between muzzle and face of soap:	5 cm + 5 cm

After the air rifle test, the penetration depth is measured. The soap does not meet ballistic and reliable standards if the required penetration depth is not met.

Further work steps:

- Determine the depth of the penetrated diabolo and note it in the data sheet.
- Pack again blocks in foil and cardboard for later shooting test
- Storage: dark and dry at 15 °C to 20 °C
- Prepare labels for soap blocks or soap block halves

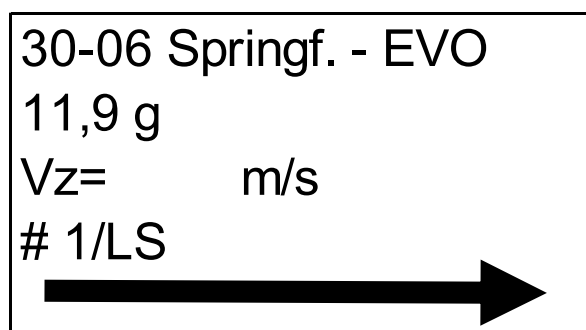


Figure 2: Example of a prepared label.

Legend:

- 1st line – caliber and bullet
- 2nd line – bullet mass
- 3rd line – target velocity (to be entered later by hand!)
- 4th line – shot no. and indication of the half of the block to be evaluated
- 5th line – arrow with defined length

Sources of errors during the preparatory work steps

For quality control, the air rifle test must be performed. The institution carrying out the shooting can normally not carry out independently a test of the components of the soap and the characteristic values (see point 2.1.1)

If the manufacturer's recommendation to use the soap within 6 months cannot be complied with, it is possible to check its use by means of the air rifle test. If the values are within the specified tolerance, the soap can still be used for shooting.

If the penetration depth of the diabolo is slightly less than 80 mm, the soap can be used if the entire shot channel is imaged in the soap block in connection with a test shot and a comparison with the soap characteristic value.

After firing a hunting bullet, the "soap characteristic value" is determined. It is the reciprocal of the proportionality factor, which is calculated from the ratio of the volume of the shot channel to the energy delivered [2]. When evaluated in an Excel file, it can be calculated automatically and thus shows the ratio of energy delivered to the cavern volume formed. In a range of 4 J/cm³ to 6 J/cm³ the soap characteristic value is optimal for bombardment tests. Kneubuehl et al. [2] describe values between 4 to 6.25 J/cm³, Tsiatis et al. [8] values of 4.15 \pm 0.5 J/cm³ and Pirlot et al. [7] a value of 5 J/cm³. A slight deviation is permissible if the entire kinetic energy in the soap block was delivered.

2.3.2 Preparation for the shooting test

Work steps:

- Set up experiment according to experimental design (see Figure 3), without soap blocks
- Ambient temperature: 17 °C to 23 °C
- Test shot on indicator paper⁴ for comparison of the aimed point with the point of impact and repetition of test shot if necessary.
(The center of the block is at muzzle height with the barrel in horizontal alignment in order to realize an angle of impact of 90°, see Figure 3).

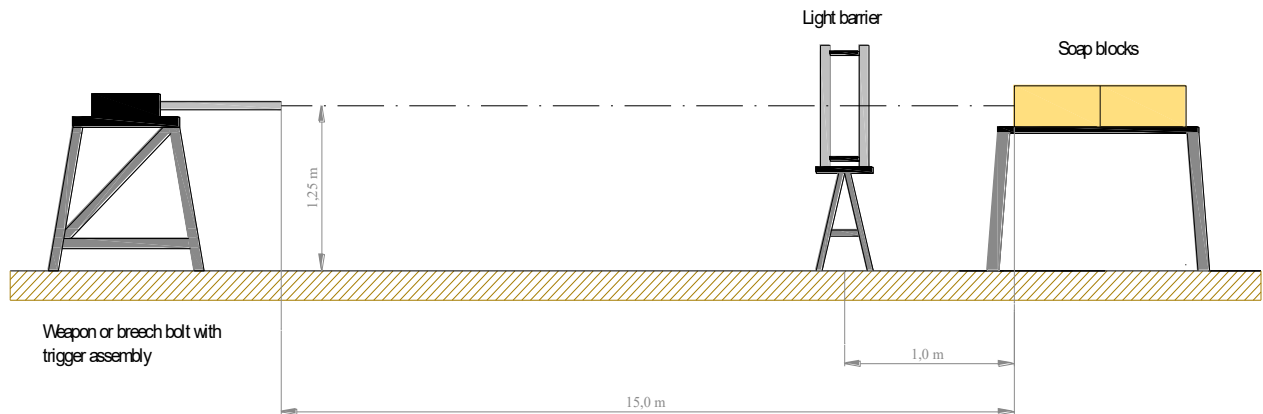


Figure 3: Experimental set-up for shooting ballistic soap (drawing not to scale).

Since it is not certain whether one soap block can absorb the entire kinetic energy of the bullet, two soap blocks should always be unpacked and used one behind the other (see Figure 3).

- The air rifle test is now performed with each block to be shooting (see Figure 1).
- Determine the depth of the diabolo and write it down in a prepared data sheet.
- Position soap blocks on the underlay (see Figure 3).
- Align the soap blocks in a straight line to the shot.
- On the top of both soap blocks, carve a cross in the diagonal (see Figure 4).

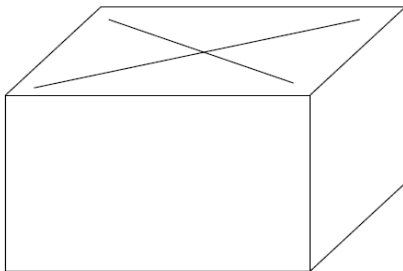


Figure 4: Marking the soap block on the top before cutting. This facilitates the later assignment of the block parts.

⁴The indicator paper is a cardboard or a cardboard box located on the target plane. The test shot is used to check whether the laser and the point of impact of the barrel match. If not, the laser will be corrected towards the shot. Then the cardboard is removed, the soap blocks are positioned in the firing position and the barrel is aligned with the center of the soap block.

2.3.3 Shot to the blocks

Temperature for shooting (ambient): 17 °C to 23 °C

Working steps:

- Aligning the weapon on the center of the front side of the soap block.
- Safety interrogation to the surroundings.
- Loading of the weapon/firing device.
- Firing the shot.
- Security create (open the bolt of the weapon/ firing device).
- Check that the bullet has not left the second block.
- Note: A lateral exit is generally not permissible, since in this case not all the energy of the bullet is absorbed in the block and a complete cavern volume cannot be generated – an evaluation would be highly error-prone and the shot must be repeated.
- If the bullet has also completely penetrated the second block, repeat the test with three blocks.
- Note the target velocity of the bullet on the prepared stickers.

Sources of error when shooting to the soap blocks

The hit should occur in the center on the face side in a circle with a diameter of 50 mm (see Figure 1).

If the shot is outside the specified hit area, it must be checked whether the soap block is bulging strongly on one of the outer sides. When the bulge is only slight⁵, as in Figure 5, the shot can be evaluated. Further if the bulge is greater, the evaluation should be dispensed with and the shot repeated, since edge effects cause a changed (larger) cavern volume for the same amount of energy than when a hit is made in the center of the simulant [7].



Figure 5: The curvature of the outer sides is only slightly pronounced. An evaluation is permissible.

⁵ Based on practical experience, a bulge can be classified as minor if it does not protrude more than 1 cm to 2 cm outward.

2.3.4 Cutting the blocks

Working steps

- Transport the bombarded blocks to the cutting table with a trolley (note: use gloves).



Figure 6: Laboratory table with cutting support and an already cut soap block. The support surface is open in the middle (see arrow) to allow complete cutting. The picture further shows that the block was cut just behind the stuck bullet.

- Cut through the foremost soap block completely on the long side in the center and as perpendicularly as possible to the bearing surface (see Figure 7)⁶.

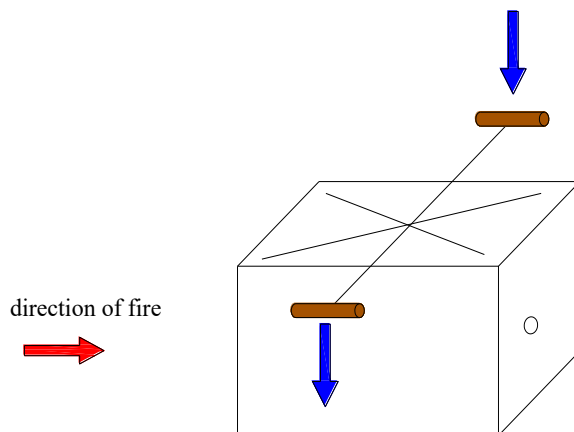


Figure 7: Guidance of the cut when bisecting the bombarded block.

⁶ Guitar strings of the middle and upper register are particularly suitable as cutting wire due to their high tensile strength.

- Pull blocks apart (see Figure 8).

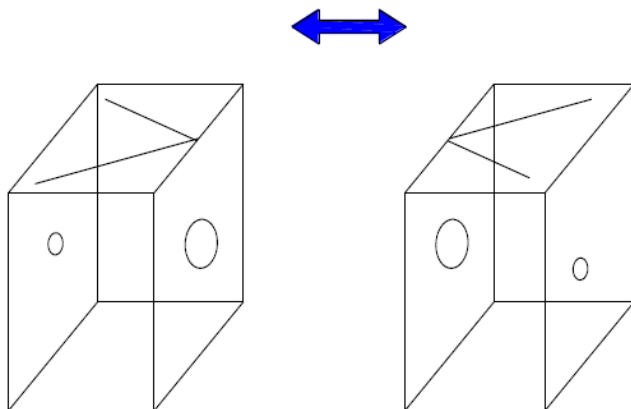


Figure 8: Pulling the block halves apart

Remove the right block half from the cutting table

- Rotate left half of the block by 90° on the underlay.
- Position cutting wire vertically above the highest points of the cavern on both sides (see Figure 9)

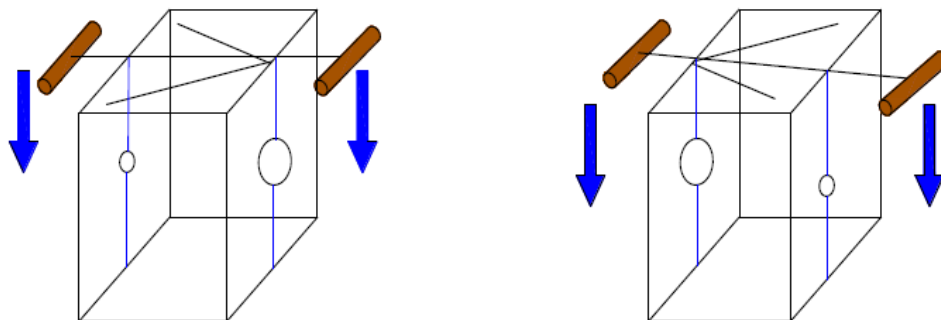


Figure 9: Cutting the block halves exactly above the highest point of the cavern in the direction of the lowest point of the cavern.

When reaching the cavern, slow down the cutting speed and guide the cutting wire towards the lower extension of the cavern.

- Cut through the block completely.
- Place the left half of the block on the put down.
- Place the right half of the block on the cutting table and cut as described.
- Place the right half of the block on the put down.
- Then cut the rear block in the same order as the front block.
- In the case of an oblique bullet cavern, the course of the cut follows the cavern.
- Pull both halves apart and place them on the put down (Figure 10).

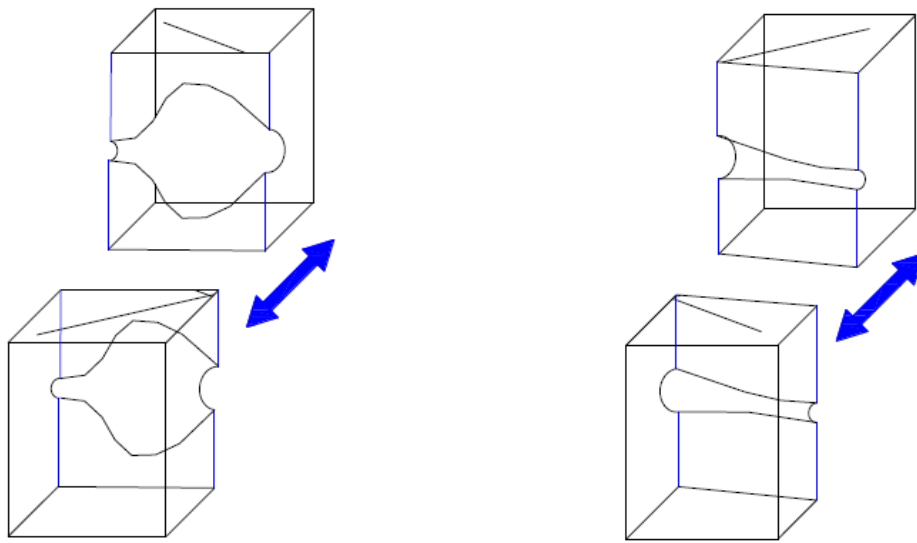


Figure 10: Pulling the block pieces apart.

Notes on cutting the blocks

If the highest point of the cavern is not hit exactly during cutting, there are three possibilities:

- 1) The soap material bordering the shot channel is usually darker than the material protruding into the shot channel. If the boundary of the cavern is clearly visible, no further steps are necessary.
- 2) If the boundary is poorly visible, a sharp knife can be used to carefully remove the material protruding into the cavern. **It is essential to ensure that, if possible, only the knife tip is used and that the wall of the cavern is not damaged or even enlarged.**
- 3) If the shot channel was not hit during cutting, it must be carefully recut.

When cutting the block make sure that the block can be shortened behind the bullet after one to two centimeters. This undamaged part of the soap block does not have to be cut open any further and can be used for further experiments (see Figure 6 and Figure 22).

When cutting the block, make sure that the cutting wire is carefully guided past the bullet without the wire getting caught or the residue being pulled along.

2.3.5 Preparation for the evaluation procedure

Working steps:

- Joining the right and left block cuts along the shot channel (see Figure 11)

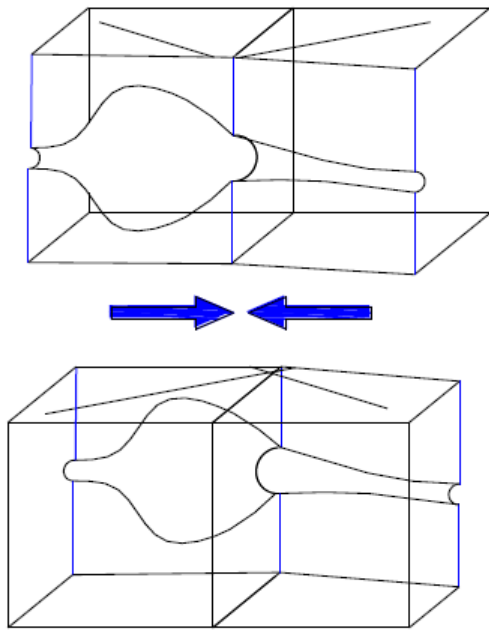


Figure 11: Merged block sections along the shot channel.

- Place the cut blocks over to the respective outer side (Figure 12).

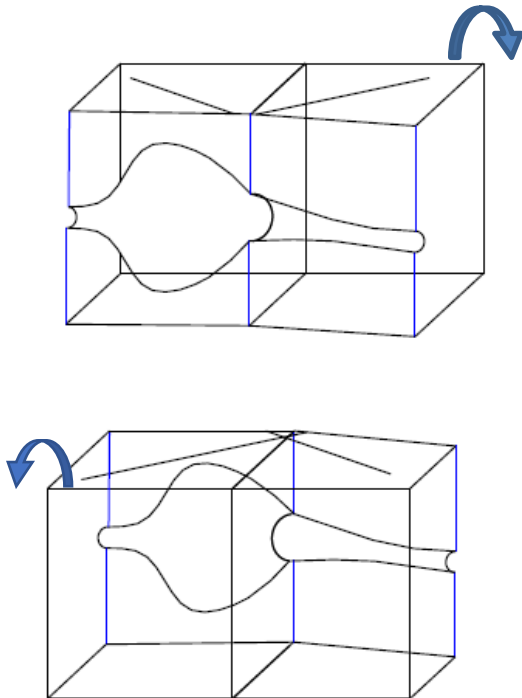


Figure 12: Place the entire right and the entire left block cut on the respective large outer surface so that the cut surface of the cavern faces upwards.

- Attach the labels parallel to the top or bottom edge of the block (Figure 13)

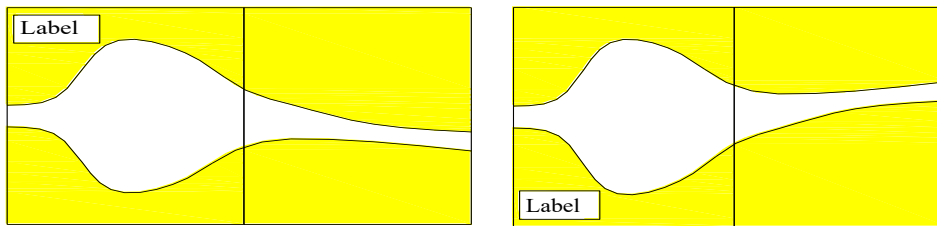


Figure 13: Labelling the block cuts.

A longitudinal half of the two blocks for photographing should be placed on an underlay. If the center was not completely hit, the protruding soap material at the edge can be carefully removed with a knife for better visibility without damaging the cavern/ballistic wound cavity (see Figure 14 – Arrows).

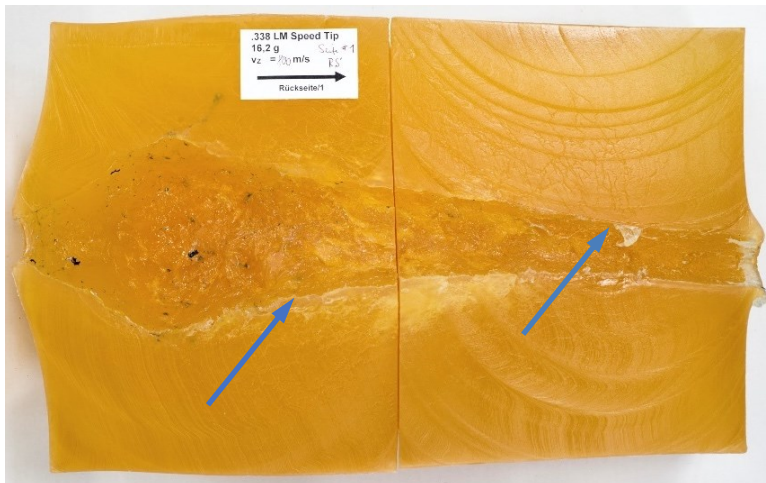


Figure 14: Soap material protruding into the cavern. The soap material does not have to be removed if, as in the photo, the actual extent of the cavern is visible.

All block halves must be aligned longitudinally on the respective end faces without any intermediate distance on the base (if necessary, place something underneath) – the cavern must be completely closed in itself!

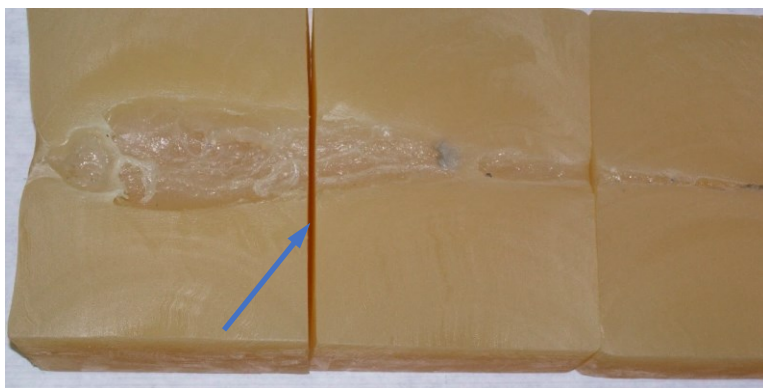


Figure 15: The visible gap (blue arrow) can be eliminated by placing narrow strips of cardboard underneath on the left side (bullet hole area).

Photography

The photography technique is to be set up. The following should be observed:

- Use of a suitable camera (for example SLR camera) and a suitable lens, a camera tripod and two cold light lamps.
- Ensure good lighting while avoiding shadows cast by the blocks.
- Position camera vertically and centrally over the longitudinal half.
- The entire block must be visible on the image.
- Align the camera so that the block is parallel to the bottom edge of the picture.
- Take several photos.
- Check the pictures to see if the above requirements are met.
- Photograph the second long side of the block in the same way as the first one.
- Upload the pictures to the PC.

Sources of errors when photographing the blocks

For later evaluation, it has proven useful that the shot is on the left and the residue of the bullet is on the right.



Figure 16: Pushing the blocks together for photography.

There must be no gap at the joints of the blocks. The cavern would then not be closed in itself (see Figure 15).

The lower edge of the soap sections should be aligned parallel to the edge of the underlay. This facilitates the alignment of the camera and reduces reworking of the photo. The prepared labels can be affixed to the top left corner or the bottom left corner of the block in the bullet entry area (see Figure 13). It is essential to ensure that the labels are fully inscribed (entry of the target velocity) and that the arrow to scale is of the exact length.

The label should be attached parallel to the top or bottom edge of the soap block. This, in conjunction with the alignment for photographing on the underlay, facilitates later calibration via the arrow length.

Two additional light sources, to the right and left of the blocks, improve the image quality. The camera is also located centrally above the blocks, ideally between the two light sources to avoid parallax errors.

The camera should be mounted on a tripod so that the image is not blurred and high image quality is achieved. Several recordings should be made.

Preparation of the photographs of the cavern for evaluation

Working steps:

- Selection of the best photo from both halves of the block.
- Editing of the photos (cropping of the image, alignment of the cut parallel to the bottom edge of the image, brightness, contrast).
- Save the edited photo.

2.3.6 Evaluation procedure

Various image measurement programs are available on the market for measuring the cavern (e.g.: <https://www.heise.de/download/product/bild-vermessen-86566>). It should also be possible for a testing institute to develop its own software for image measurement and subsequent evaluation. At this point, the use of the “k-analyzer” program is described as an example for determining the size of the cavern.

Measurement of the cavern using the software program “k-analyzer” [5]

Working steps:

- The “k-analyzer” program has been published [5,6] and can be downloaded free of charge from the Internet at the following address: <https://bpk-thun.ch/de/services/k-analyzer>⁷ and additional information about this program.
- Open the “k-analyzer” program.
- Insert the prepared image under “File” and “Open image file”.
- Adjust the size of the image to the available space in the program.
- Drag the line scale (red) label “1.000” into the area of the sticker and shorten it.
- Reduce image section for the area of the sticker (slider to the left of the image).
- Place the starting point of the red scale line exactly on the end of the arrow.
- Position the end point of the red scale line exactly on the arrowhead.
- Enter the arrow length in “mm” under “Edit” and “Define scale length” (for example: 50'000 – the display shows: 50.000).
- Enlarge the image section again for the entire block.
- Use the mouse to draw the coordinate lines (horizontal and vertical) in the center and position the center in such a way that the horizontal line is a few centimeters below the cavern and the vertical line ends on the left side with the soap block.
- Soap material that protrudes on the left side in the area of the shot entry is not included in the consideration.

⁷ All the following steps refer to the currently available version (2023).

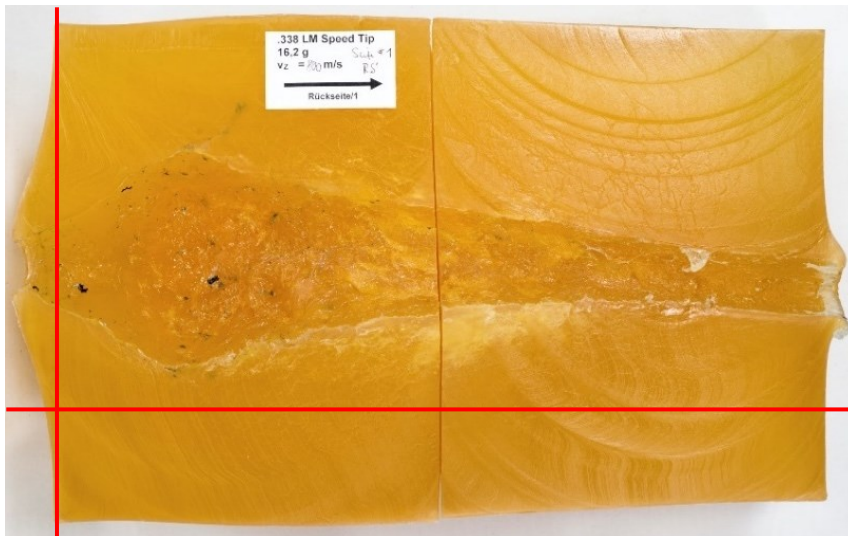


Figure 17: Positioning of the coordinate system.

- Switch via “Mode” to “Edit Points”.
- Use the mouse to capture and click on the lower boundary of the cavity.
- Then capture and click on the upper boundary of the cavity on the same vertical line.
- Important: coordinates of the X-axis must be identical for the lower and upper point!
- Under “View” select the setting “Vertically engage”.
- Move the mouse in the direction of the shot and set the lower boundary point for the next contour change.
- Set the upper boundary point of the cavity on the vertical line upwards.
- The calculation is structured as a truncated cone calculation.
- Important: Do not select distances that are too large, especially in the area before and during the greatest cavern expansion, and do not extend the distances over 40 mm after the maximum, if possible.
- Repeat the process until the end of the cavern/bullet is reached.
- Select “Copy coordinates” under “Edit”.
- Paste data into the Excel evaluation table in an area that is not highlighted (sheet 3) and check whether a “comma” ensures decimal separation.

Working with the evaluation file

The values determined from the image measurement are to be converted into a volume calculation. It is possible for each institute to create its own file for this purpose. A combination in just one program is also conceivable. At this point, the Excel file attached (Appendix II) should be used as an example for the volume calculation based on truncated cones.

Working steps:

- Enter the penetration depth of the diabolo in the header lines of the Excel evaluation table
- Insert only the X- and Y-coordinates under “Values from k-Analyzer” in the evaluation file.
- The calculations for “depth” and “diameter” are deposited in the Excel file.
- Copy all values from this area and paste them into the data sheet “Shot 1” under “Measured values”, starting at the yellow highlighted field.
- Enter all values in the header, whereby the bullet energy is deposited as a formula and does not have to be entered.
- With this completion, all values are calculated independently by the Excel spreadsheet and the function progression of effectiveness and delivered energy is also displayed in the diagram.

- Check that the values and function curve are plausible.
- The photo of the shoot block is to be inserted under "Graphic".
- If necessary, the photo of the bullet residue can also be added.
- Save the evaluation.

Notes on evaluating the soap block using "k-analyzer" and the evaluation file

After opening and inserting the block photo, the image will be resized to fit the available space in the program, if necessary.

The next step is to adjust the line scale (1'000) to the arrow length. If the block and the label are aligned horizontally, this also results in a straight scale line. If this is stepped as in Figure 18, there is a possibility that the scale line does not correspond to the arrow length.

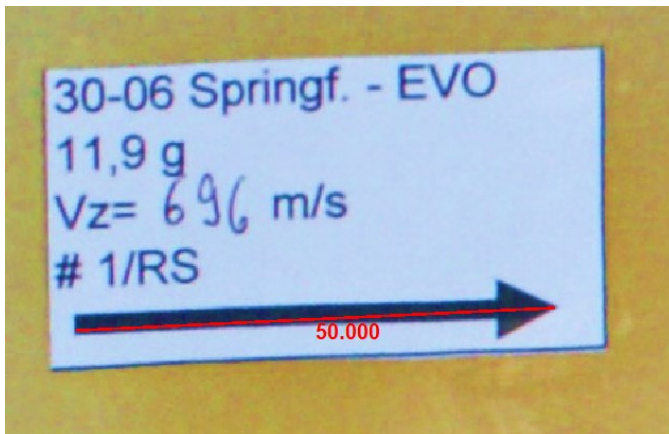


Figure 18: Stepped scale line.

The scale line must end exactly with the end of the arrow and the arrowhead, otherwise the measured distances are smaller/longer than the real expansion in the cavern. After adjusting the scale line, the scale length is set. To do this, change the arrow length to 50 mm, for example.

The next step is to set the coordinate zero point. Here, the Y-axis closes with the left, non-deformed boundary of the soap block. The characteristic curvature of the material on the outside is caused by material displacement when the bullet hits and the subsequent pressure/vacuum when it penetrates the soap. This is not included in the evaluation. The evaluation starts at the original outer edge of the soap block (see Figure 17)

The X-axis of the coordinate system is positioned a few centimeters below the deepest point of the cavern. On this outer, left boundary, the first distance is recorded in the Y-direction, **first from below and then too upwards**. Each time the cone section changes, the next measurement is taken.

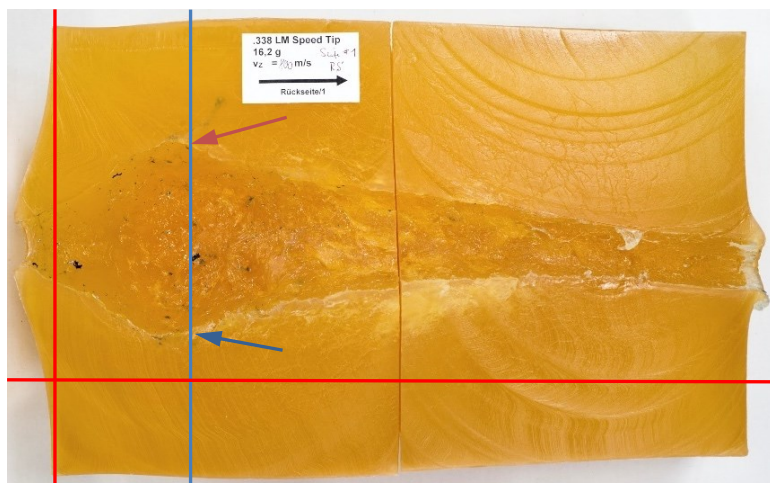


Figure 19: Detection first of the lower (blue arrow) and then of the upper extent (brown arrow) of the cavern.

If the points are recorded from top to bottom, the evaluation file cannot calculate the cone volume. Therefore, always record the points from the lower value to the upper value.

When capturing the two points of a vertical plane, make sure that the X-axis “stops”, otherwise errors may also occur in the evaluation file. Here the setting “snap vertically” in the program is helpful.

For each change of the cone geometry, the points are to be determined. In the area before, in and shortly after the cavern maximum, short distances are to be chosen because the geometry changes are most frequent here. After the largest expansion of the cavern, the step size should not exceed 40 mm. If too large a section is chosen, there is a possibility that finer cone gradations will not be included.

During the transition from the first to the second block, a conical widening of the cavern usually occurs at the transition points in both edge areas.

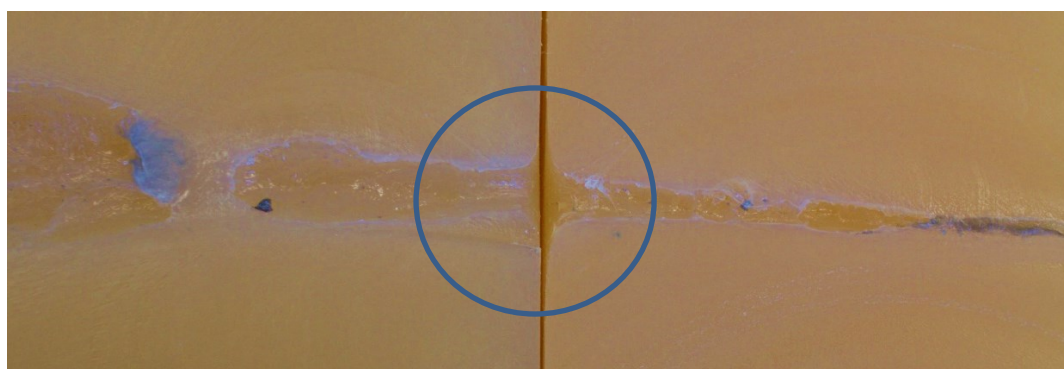


Figure 20: At the transition of the storey from the front to the rear soap block, mostly funnel-shaped expansions occur.

These funnels are not included because they do not represent the real course of the bullet passage. Despite closely spaced blocks, there will always be a minimal distance between each other because the faces of the blocks are not completely flat. Due to the displacement of material at the bullet tip, the resistance at the edge of the soap changes. Soap material is “entrained” on the side of the bullet exit and causes deformation on re-entry into the second block. Therefore, these cones are not taken into account and the cavern course is considered to be straight in this area.

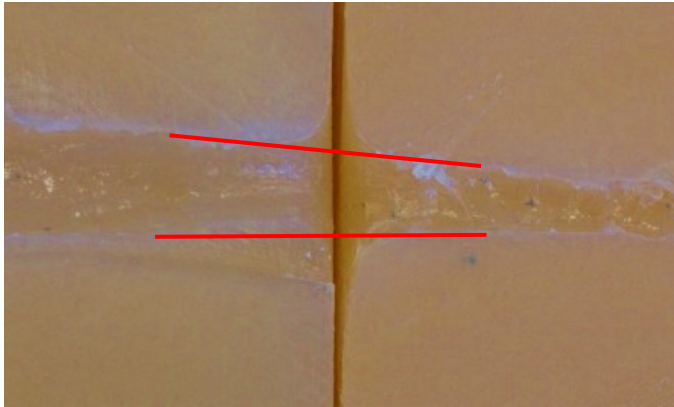


Figure 21: During the evaluation, these cones are not taken into account, but a straight-line course of action is assumed.

In the course of the bullet's passage through the soap, the bullet fragments produced by partial fragmentation and fragmentation bullets can create small to very small caverns. These volumes represent a minor uncertainty because bullet fragments only have a minimal part of the total energy of the bullet. If the course of the soap cut falls within this range, it can be recorded up to the edge of the cavern for evaluation. However, the entire course of splinters in the soap cannot be recorded. Due to the very low energy output of the splinters, this is not necessary with the background of determining maximum effectiveness.

In the course of the bullet's passage through the soap, not only monolithic bullet constructions tend to overturn as stabilization decreases. This creates caverns that are no longer circular but rather elliptical in shape. Due to the bullet rotation around the longitudinal axis, the larger part of the depression in the form of an ellipse will at some point coincide with the section course or after a few centimeters the smaller part of the ellipse will be visible in the section course. On average, the volumes will almost correspond to the actual course. Since this often occurs only shortly before the standstill of hunting bullets is reached and the generated volumes are small, the determined expansions of the cavern can mostly be taken into account without further recalculation.

The bullet passage is evaluated up to the foremost point of the bullet position in the soap. In the last section of the path, the bullet or bullet residue left behind only a cavern the size of a caliber or slightly more than the size of a caliber. This is to be recorded up to its end (see Figure 22).



Figure 22: The bullet path must be recorded up to the outer edge of the bullet (see arrow).

After copying the coordinates into an Excel evaluation sheet, check whether decimal separation by a comma is ensured, as decimal separation by a point causes incorrect results. Afterwards, these can be inserted into the evaluation file.

Final examination

Finally, the plausibility of the results and the graphical representation must be checked. In the graphical representation, especially the height and the penetration depth of the bullet at maximum effectiveness are to be checked against the calculated values. The check also includes the course of the energy output and the effectiveness function at the end of the bullet path.

Furthermore, it must be checked whether the soap characteristic value is in a range of 4 J/cm^3 to approx. 6 J/cm^3 . An analysis of the bombardment and affecting factors, such as the consistency of the soap, shall be carried out.

If all the energy is released in the soap blocks, small deviations in the soap characteristic value are permissible with reference to Martel's generally applicable law. Therein it states that when the cavern is formed, the volume is directly proportional to the energy expended in the process.

If both longitudinal halves of the block are evaluated, the one with the highest effectiveness (J/cm) must be selected for further consideration. It is not permissible to calculate an average value from the right and left halves of the block, as a maximum effectiveness is to be determined. Due to the cut in the soap, two different values for the effectiveness may well result. The side with the largest cavern expansion (maximum effectiveness) must always be taken into account for further evaluation.

Finally, the results are to be saved.

3 Summary

The present work provides instructions for bombardment of ballistic soap, as a standardized procedure is essential for the reproducible and comparable determination of the wound ballistic potential of bullets in the soap test simulant. This allows reproducible results to be achieved in comparative investigations a part of energy release studies with this test simulant. The individual work steps for the preparation, execution and evaluation of bombardments on ballistic soap are described and supplemented by information on possible sources of error in the procedure.

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Appendix I – Standard operation procedure for soap bombardment (tabular)

Sequ.no:	Work operation	Scope of activity	Notes on the work operation	Additional information	Images
1	Work preparation	Soap order (only if not zentral!).	Manufacturer: Walde Company, Innsbruck	Important: Order "according to Permatin recipe" from Walde. Dimensions of the soap block: 40cm x 25cm x 25cm (LxWxH). Soap is yellow to ochre in colour. Storage temperature: 15°C to 20°C (dark and dry).	
		Carry out diabolos test with air rifle (LG).	Schedule goods delivery shortly before the shooting test. Incoming goods inspection on two blocks. Bullet: flat head diabolos 0,53 g Projectile diameter: 4,5 mm ± 0,25 mm Projectole velocity: 300 m/s ± 10 m/s Requiered penetration depth: 90 mm ± 10 mm Distance between muzzle and face of soap: 5 cm ± 5 cm	Composition check according to certificate and technical delivery conditions. Soap should not be older than 6 months. LG test: Shot frontally into the upper right corner of the soap blocks. Hit zone for LG test 30mm from the edge in each case - see illustration. (The hit zone for hunting bullets is in the centre of the block).	
		Determine the depth of the penetrated diabolos. Note depth in data sheet.	Repack the blocks in foil and cardboard.		
		Prepare stickers for soap blocks.	Sticker includes: 1. line - calibre and bullet 2nd line - bullet mass 3rd line - target velocity (to be entered later by hand!) 4th line - shot no. and indication of the block half to be evaluated 5th line - arrow with defined length	Block half only if both halves are to be evaluated. Arrow length, e.g.: 50.0mm - accuracy is the most important basis for evaluation!	
2	Preparation for shooting	Set up experiment according to experimental design.	See the illustration in the appendix.	Structure initially without soap blocks. Ambient temperature: 17°C to 23°C. If necessary, correct and repeat the test shot.	
		Test shot on indicator paper.	Matching the breakpoint with the meeting point position.	Bullet energy must be completely absorbed in the test simulant!	see illustration in the appendix below
		Position soap blocks.	Always use two soap blocks behind each other. Align the soap blocks in a straight line to the Shot direction. On the top of both soap blocks, carve a cross across the diagonal.		
		Perform diabolos test. Determine the depth of the penetrated diabolos. Note the value in the data sheet.	Instructions see above!	Information see above.	see illustration above
3	Shooting to the blocks	Setting up the weapon/shooting device.	On the center of the front of the front soap block.		
		Security query.			
		Loading the weapon/shooting device.			
		Shot fired.	Open the breech of the weapon/shooting device.	Shoot into the centre of the block in a 50 mm diameter circle.	
		Create security.	Bullet must not have left either the first or the second block!	Bulge on the outer sides not more than 3cm! If the bullet has left the second block or has exited sideways, the shot must be repeated with new blocks.	
		Checking the soap blocks.			
		Complete sticker	Enter the target velocity of the projectile.		
4	Cutting the blocks	Transport of the shooted blocks to the cutting table.		Recommended aid: thin guitar strings.	
		Cut front block.	Cut through the block centrally to the long side and perpendicular to the block support.		
		Pull apart the block halves.			
		Remove the right half of the block from the cutting table			
		Rotate the left half of the block by 90° on the underlay.			
		Cut left half of block.	Position the cutting wire vertically above the highest points of the cavern on both sides (see illustration). When reaching the cavern, slow down the cutting speed and guide the cutting wire towards the bottom of the cavern. Cut the block completely.	If the centre was not hit exactly - carefully recut without damaging or enlarging the cavern!	
	Place the left half of the block on the support.				
	Cut right half of block.	As described for the left half of the block, cut the right half of the block. Place the right halves of the block on the support.	In the case of an oblique bullet cavern, the course of the cut follows the cavern.		
	Cut rear block.	Analogous to the order of the front block. Carefully guide the cutting wire past the bullet.	In the case of an oblique bullet cavern, the course of the cut follows the cavern. Shorten the length of the block - approx. 2 cm behind the bullet.		
	Pull both halves apart and place them on the support.				

5	Prepare evaluation	Joining the right and left block cuts along the shot channel (see illustration).			
		Place cut blocks on the respective outer side.			
		Apply the labels parallel to the upper or lower edge of the block (see fig.)		Facilitates evaluation and minimises sources of error.	
		Structure of the photographic technique Place one long side half of the two blocks on a surface for place to photograph.	If the centre is not completely hit, the excess soap material can be carefully removed with a knife, without damaging the cavern/ballistic wound cavity (see illustration - arrows).		
		All block halves must be aligned longitudinally on the respective front sides without any intermediate distance on the underlay.	The cavern must be completely closed in itself.		
		Position the camera vertically and centrally over the longitudinal half.	The entire block must be visible in the picture. Align the camera so that the block is parallel to the lower edge of the picture. The block pieces must lie close together and have no gaps (Illustration shows incorrect position).	Ensure good lighting, avoiding shadows cast by the blocks.	
		Photographs Checking the images to see if the above requirements are met if necessary. Photograph the second long side of the block in the same way as the first and loading the images on the PC.		Avoid parallax by photographing vertically! Recommended position: Firing direction from the left - bullet (rest) on the right side of the picture. It is advisable to take several photos.	
6	Evaluation on PC	Selection of the best photo from each of the two halves of the block. Editing the photos. Saving the edited photo.	Crop the image, align the crop parallel to the bottom edge of the image, adjust brightness and contrast.		
7	Work with "k-analyser"	"k-analyser" - free download	https://bpk-thun.ch/de/services/k-analyzer		
		Open the program.			
		Insert the prepared picture, under "File" and "Open image file"			
		Adjust the size of the image to the available space in the program.			
		Drag the line scale (red) with the inscription "1,000" into the area of the sticker and shorten it.			
		Reduce the image section for the area of the sticker.	Slider to the left of the image.		
		Place the starting point of the red scale line exactly on the end of the arrow.			
		Position the end point of the red scale line exactly on the arrowhead.		The red scale line must not be stepped - source of error!	
		Enter the arrow length in "mm" under "Edit" and "Set scale length".	For example: 50,000		
		Enlarge image section again for entire block.			
		Pick up the coordinate lines (vertical and horizontal) in the centre point and position the centre point.	The horizontal line is a few centimetres below the cavern, the vertical line ends on the left side with the soap block.	Soap material that protrudes on the left side in the area of the bullet hole is not included in the consideration!	False:
		Change via "Mode" to "Edit points"			
		Click on the lower boundary of the cavern with the mouse.		Always enter the point at the bottom first and then at the top - otherwise errors in the programme! Use of the function "Snap vertically". (See illustration: First click on the blue arrow, then on the red arrow.)	
Then click on the upper boundary of the cavern on the same vertical line.	Important: Coordinates of the X-axis must be identical for lower and upper point!				
Under "View", select the setting "Snap Vertically".					
Move the mouse in the direction of the shot and set the lower boundary point at the next contour change.					
Set the upper boundary point of the cavern on the vertical line upwards.	The calculation is structured as a truncated cone calculation. Important: Do not select distances that are too large, especially in the area before and during the greatest cavern expansion, and do not extend the distances beyond 40 mm after the maximum, if possible!				
Repeat the process until the end of the cavern/bullet is reached.		In the transition from the first to the second block, the funnel-shaped extension is not to be included, but is to be recorded as a straight shot channel. The smallest caverns caused by secondary splinters are not included. Elliptical cross-section caused by bullet rotation, detect as circular cross-section.			
Select the command "Copy coordinates" under "Edit".					
Insert data into the Excel evaluation table in an area that has not been deposited.					
Check whether decimal separation is ensured by a "comma".		Decimal separation by "point" results in incorrect values when calculating.			

8	Work with evaluation file	<p>Enter penetration depth of the diablo in the headers</p> <p>Insert only the X- and Y- coordinates under "Values from k-Analyser" in the evaluation file.</p> <p>Copy all values from this area and paste them into the data sheet Shot 1 under "Measured values", starting at the yellow highlighted field.</p> <p>Entering all values in the header.</p>	<p>The Excel file contains the calculations for "depth" and "diameter".</p> <p>The bullet energy is stored as a formula and is not entered.</p>	<p>All values are calculated independently by the Excel spreadsheet!</p> <p>The function curve of effectiveness and delivered energy is displayed in the diagram.</p>	
		<p>Check whether values and function progression are plausible.</p> <p>Under "Graphic" the photo of the shot block is to be inserted.</p> <p>Add photo of the bullet remnant (if available).</p> <p>Saving the evaluation.</p>	<p>Check whether the soap characteristic value is in the range of 4 J/cm³ to 6 J/cm³.</p>	<p>Small tolerances upwards and downwards are permissible!</p> <p>Values < 4 J/cm³ indicate relatively fresh soap.</p> <p>Values > 6 J/cm³ indicate a longer storage period of the soap.</p> <p>Check admissibility in connection with Diabolo test and other results!</p> <p>If both halves of the block are evaluated, the half with the greatest effectiveness is to be used!</p> <p>Averaging the values of the two halves of the block is not permitted.</p>	
9	Appendix	<p>Experimental set-up for shooting ballistic soap</p>  <p>Weapon or breech bolt with trigger assembly</p> <p>Light barrier</p> <p>Soap blocks</p> <p>15,0 m</p> <p>1,25 m</p> <p>1,0 m</p> <p>Drawing not to scale.</p>			

Appendix II – Soap bombardment evaluation form

Soap bombardment evaluation form - Excel file – Sheet 1

Evaluation of soap shooting										Site 1	
to determine bullet effectiveness											
Caliber:		mm		Order:							
Caliber (nominal):		mm		Attempt date:							
Bullet type:				Evaluation date:							
Manufacturer:											
Bullet mass		g		Penetration depth Diabolo:		mm					
Shot:				Real dimension [mm]:							
Impact speed:		m/s		Image dimension [mm]:							
Impact energy:		0,0 J		Scale factor:							
No.	Messwerte		Segment		Volume sum [cm ³]	Energy profile		Energy output [J]	Values for graphic		
	Depth [mm]	Diameter [mm]	Length [cm]	Volume [cm ³]		Depth [cm]	Effectiveness [J/cm]		Effectiveness	Energy output	Penetration depth
0			0,00			0,00	0,00	0,00	0,00	0,00	0,00
1			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
7			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
9			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
10			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
12			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
13			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
15			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
16			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
17			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
18			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
19			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
20			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
22			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
25			0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	Soap characteristic value experimental:		#DIV/0!	J/cm ³							
25	Soap characteristic value for calculate:		#DIV/0!	J/cm ³							
	1/Soap characteristic value:		#DIV/0!	cm ³ /J							

Bullet (name, diameter, weight, targetvelocity)

Soap bombardment evaluation form – Excel file – Sheet 3

	Values from k-Analyzer			Entry in table	
	No.	x	y	Depth	Diameter
1				0,000	0,000
2				0,000	0,000
3				0,000	0,000
4				0,000	0,000
5				0,000	0,000
6				0,000	0,000
7				0,000	0,000
8				0,000	0,000
9				0,000	0,000
10				0,000	0,000
11				0,000	0,000
12				0,000	0,000
13				0,000	0,000
14				0,000	0,000
15				0,000	0,000
16				0,000	0,000
17				0,000	0,000
18				0,000	0,000
19				0,000	0,000
20				0,000	0,000
21				0,000	0,000
22				0,000	0,000
23				0,000	0,000
24				0,000	0,000
25				0,000	0,000
26				0,000	0,000
27				0,000	0,000
28				0,000	0,000
29				0,000	0,000
30				0,000	0,000
31				0,000	0,000
32				0,000	0,000
33				0,000	0,000
34				0,000	0,000
35				0,000	0,000
36				0,000	0,000
37				0,000	0,000
38				0,000	0,000
39				0,000	0,000
40				0,000	0,000
41				0,000	0,000
42				0,000	0,000
43				0,000	0,000
44				0,000	0,000
45				0,000	0,000
46				0,000	0,000
47				0,000	0,000
48				0,000	0,000
49				0,000	0,000
50				0,000	0,000