ALLIED ENGINEERING PUBLICATION

AEP-23 (Edition 2)

PRESSURE MEASUREMENT BY CRUSHER GAUGES NATO APPROVED TESTS FOR CRUSHER GAUGES

NATO ARMY ARMAMENTS GROUP SURFACE TO SURFACE ARTILLERY

MARCH 2005

NORTH ATLANTIC TREATY ORGANIZATION

NATO STANDARDIZATION AGENCY

NATO LETTER OF PROMULGATION

March 2005

1. AEP-23 (Ed.2) - PRESSURE MEASUREMENT BY CRUSHER GAUGES NATO APPROVED TESTS FOR CRUSHER GAUGES is a NATO/PfP UNCLASSIFIED publication. The agreement of nations to use this publication is recorded in STANAG 4113.

2. AEP-23 (Ed.2) is effective on receipt.

J. MAJ
Brigadier General, POL(AR)
Director NSA

NATION	SPECIFICATION RESERVATIONS

RECORD OF CHANGES

Change Date	Date Entered	Effective Date	By Whom Entered

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CHAPTER 1

NATO APPROVED CRUSHER GAUGES

0101. Aim and objectives

1. The aim of this Allied Engineering Publication is to provide methodology for dynamic firing and laboratory simulation tests of crusher gauges and a list of NATO approved crusher gauges. This will enable authorized agencies within participating nations to provide data on breech pressures in Large Caliber Weapons Systems that are acceptable in terms of accuracy to the Approving Authorities of other participating nations. From this data, the Approving Authorities can make decisions regarding the Safety and Suitability of those systems when related to their own national criteria.

2. In this, the 2nd Edition, reference to National Standard Operating Procedures for Crusher gauges has been introduced. This is in an effort to create consistency between nations in the way the gauges are used, thus enhancing the value of the data supplied in international fora.

3. Simulation has been added to the calibration trials as a way of increasing the data available while reducing the overall costs.

4. Full reference to the calibration and deployment of piezoelectric gauges has been introduced.

0102. Approved Gauges

1. NATO approved crusher gauges are used to provide the means to measure the peak chamber pressure of a gun during the firing of a round. Crusher gauges are normally used in place of electrical gauges because they don’t require drilling the gun tube to use. The crusher, housed within the gauge body, is plastically deformed by a piston subjected to the transient gas pressure. After firing, the remaining length of the crusher is measured and by referring to mastercurves for specific temperatures, the applied pressure can be obtained.

2. Before a crusher gauge is submitted to take part in the taraging trial, a statement of suitability must be provided by the gauge design authority that the gauge, as designed, is acceptable for the purpose of providing pressure data and can be produced consistently to the design as submitted, from which there will be no subsequent deviation

3. A list of NATO approved crusher gauges with their ranges and limitations are detailed in Annex A (UK 1998/US 2002) and Annex B (Bourges 1990). Word definitions and terms used in this AEP to describe the test are found in Annex C.

4. The original of this AEP along with the master disk resides with NATO/HQ, Brussels.

0103. Characteristics of Each Approved Type of Gauge

1. All approved crusher gauges must be described by the appropriate nation in accordance with the following guidelines:

a. Manufacturing nation, designation and date of national approval.

b. Manufacturing specifications and a set of fully dimensioned manufacturing drawings, including assembly drawings and a components list. Drawings will conform to current international standards.

c. The drawing numbers for the UK 1998/US 2002 tested gauges are listed in the table, Annex A, Page A-1.

CHAPTER 2

INSTRUCTIONS FOR MANUFACTURE AND USE OF GAUGES

0201. Manufacture of gauges

1. Gauges will always be manufactured to the build standard as accepted by the WG for the Taraging Trial. Subsequent deviations or manufacturing concessions are to be avoided, as the results gained will not be acceptable under the terms of STANAG 4113.

2. Components shall be measured in accordance with their respective current specifications and manufacturing drawings. This procedure shall be fully described in the manufacturing specification. Reference to critical measurements must be included in the specification, but must include piston and bore diameter (and piston presented area, if different) and the parallelism between piston and anvil faces. Each gauge when completed will have a unique identity (usually a serial number), a "Certificate of Conformity" and an optional "History Sheet" which will be retained until the gauge is discarded.

0202. Standard Operating Procedures (SOPs)

1. The Organizations, Agencies and Companies engaged in the field of Ordnance/Ammunition R&D, and as a consequence providing pressure measurement data, must work to a formal quality plan.

2. The responsibility for the creation of the SOPs, should, in the first instance, lie with the designer of the gauge. Liaison with the majority user is to be encouraged.

3. The Standard Operating Procedures for each gauge will cover, but not be restricted to the following activities.

   a. Storage of the gauge, protection from corrosion and hostile environments.
   b. Preparation of the gauge for use.
   c. Assembly of the gauge with the crusher. Limitations on the time spent stored as a complete assembly.
   d. Environmental conditioning and its movement from the conditioning area to the gun.

e. Storage at the test firing location.

f. Assembly into "crowns", if required.

g. Placement in the chamber of the weapon. Limitations on the length of time between insertion and firing.

h. Recovery and transport to the point of disassembly.

i. Disassembly.

j. Cleaning and storage.

k. Measurement of remaining length of the crusher.

l. Measurement of gauges, condemnation limits in terms of dimensional analysis and numbers of rounds fired.

4. At the test firing location, the method of deploying the gauges in the gun chamber should be unique for each propelling charge type. This gauge/charge configuration will be documented in order to maintain repeatability.

5. After use in a weapon the crusher gauge shall be carefully dismantled and the remaining length of the crusher shall be measured as required by the SOP. The pressure, for the crusher gauge firing temperature shall then be read from the mastercurve obtained in accordance with procedures detailed in this publication.

CHAPTER 3

CRUSHER SPECIFICATIONS

0301. Material

1. The purity of the raw material used for the crushers shall be specified and checked before manufacture in accordance with national quality assurance procedures.

2. If a material requiring heat treatment is used for the crusher, the procedure shall be precisely specified and rigidly followed to minimize differences in crusher hardness.

3. Crushers will be manufactured in accordance with the declared specification. Batches within the main Lot will be uniquely identified (if applicable).

4. Crushers shall be selected in accordance with national quality control methods.

5. The remaining length of a compressed crusher depends essentially on the following parameters:

   a. Hardness (mechanical strength)

   b. Level of load applied

   c. Speed of application of the load (Strain rates)

   d. Conditioning temperature of crusher

6. Under given load conditions, dimensional and hardness homogeneity determines the reproducibility of compressive deformation of a new crusher lot and hence the repeatability and accuracy of pressure measurements by crusher gauges.

7. The main factors affecting crusher homogeneity are:

   a. Differences in heat treatment from one batch to another.

   b. Random and / or systematic changes in crusher manufacturing process.

0302. Lotting and pre-tarage testing of Crushers

1. By carrying out tests it is possible to determine the influence of strength and strain rates on pressure measurements and to remedy these shortcomings.

2. These tests fall into two groups: static tests and dynamic tests. Static and/or dynamic tests must be carried out to evaluate the within and between batch homogeneity of the crushers.

3. The purpose of the static test is to evaluate crusher homogeneity. The procedure to be followed in this test will depend on national experience and preference. Statistical processing of the remaining length data will enable batches to be classified. Dynamic testing using either a laboratory generator or a weapon may be used to examine the homogeneity of the crushers and where appropriate draw up dynamic calibration tables.
It may be used to group batches into a single lot or if this is not possible then to regroup batches into several lots.

4. Dynamic testing enables a more realistic comparison of batches to be made than is the case with static tests where the mechanical properties of the material are not fully taken into account. It is desirable that several applied load levels and temperatures are used in order to obtain comparison data over the full operating range of crusher. The load-time profile of the dynamic generator should simulate as closely as possible the range of values from a real weapon firing. Statistical processing of the remaining lengths observed can be used for drawing up dynamic calibration tables.

5. Static and/or dynamic tests must be conducted in accordance with any relevant national procedures. These procedures must be presented in the dossier supplied by each nation before the comparative firing trial for NATO approval.

CHAPTER 4

PROCEDURE FOR SUBMISSION AND TESTING OF CRUSHER GAUGES FOR NATO APPROVAL

0401. Submission procedure for gauges

1. To cover the pressure range from 50 MPa to 850 MPa and the temperature range from -40°C to +63°C, a number of different types of crusher gauge may be required or alternatively the same gauge components may be used with different crushers. If more than one crusher gauge design is required to cover the range 50 MPa to 850 MPa then an overlap of at least 60MPa between adjacent pressure ranges is necessary.

2. A country submitting one or more crusher gauges or crushers for approval shall provide to the WG:

   a. Manufacturing drawings and specifications of the gauge components and its associated crusher for each type of crusher gauge.

   b. Present test data in the form of an Annex to the report giving the results of the dynamic firing tests. The results shall be analyzed by the WG.

0402. Approval of Crusher Gauges

1. Approvals can only be granted by the agreement of the members of the WG.

2. The comparative tests defined in this publication for submission of crusher gauges for approval shall be carried out in accordance with this publication at approximately five year intervals, on a date and in a place determined by AC/225 Land Group 4.

3. The firing tests shall not be carried out twice in succession in one country.

4. Any country must notify Land Group 4 of its intention to submit a crusher gauge for NATO approval. Subsequent to the comparative test, if a participating nation (or a new member nation) intends to carry out its own firings (in accordance with CHAPTER 6 of this publication), the firings must be carried out in conjunction with another crusher gauge already approved. The Land Group shall take the necessary steps to ensure that another country supplies enough crusher gauges of a previously approved type for use during the firings.

5. If, following approval of a crusher gauge by NATO, a new lot of crushers is to be brought into service, the new lot must be compared with the previously approved lot by an appropriate dynamic test method approved by the WG. The method, the results of these tests and the tests described in CHAPTER 3 of this publication shall be submitted to Land Group 4 for approval.

CHAPTER 5

CALIBRATION OF PIEZOELECTRIC GAUGES

0501. Background

When a crusher gauge is exposed to static oil pressure, the remaining length of the crusher element is found to be different than when the gauge is exposed to transient gas pressure of the same maximum value in a gun.

Electronic pressure transducers are available which give the same maximum pressure reading when static and transient pressures are applied. These transducers can be used to provide a measurement of transient gas pressure that is traceable to international standards

1. Type approval of transducers

Transducers for chamber pressure measurement must be insensitive to transient gas temperature and mounting stresses. The output must be highly repeatable with little hysteresis but need not be linearly related to pressure.

The most successful current designs are based on either quartz or tourmaline crystals. Quartz has the advantage that near perfect crystals can be reliably manufactured, however design of the body to eliminate sensitivity to mounting stress and transient diaphragm temperature is difficult. Tourmaline offers simplicity of gauge design but natural crystal quality is variable and the pyroelectric signal can lead to spurious thermal outputs.

The performance of piezoelectric transducers at gun pressure levels currently sets the limit on the accuracy with which crusher pressure measurements can be traced to ISO pressure standards. Following extensive testing in guns and simulators using transducers based on different physical principles, the WG select one design of transducer for the NATO dynamic firing test. This transducer, heat shield and mounting adaptor then becomes the reference for "true pressure" within a large caliber gun chamber.

2. Reference transducer

The current reference transducer is the Kistler 6213B fitted with type K1181 thermal protection plate and type K6563A heat shield. This transducer has satisfactory reproducibility but has some sensitivity to mounting stresses. The transducer is therefore mounted in the gun adaptor shown in Annex D prior to calibration and use in a gun for measurement. The approved adaptor may be machined with a thread and front seal to suit the type of gun used in the test provided the gas port and wall thickness remain similar. The K6213B is mounted in the adaptor using the method and torque recommended in the Kistler (Swiss) data sheet.

3. **Approved transducers**

The WG will review evidence from gun trials and simulators tests that compare new transducers with the reference transducer. The reference transducer and the test transducer must be exposed to the same pressure for example by means of co-planar ports in a gun chamber.

The data submitted to WG must comprise static calibration and pressure-time waveforms and include:

a. Gun firing of 2 samples of the proposed transducer, i.e.

b. Five samples of the proposed transducer against at least 2 samples of the reference transducer. Five data points in nominally equal increments covering the proposed working range.

WG will approve transducers that exhibit less than 1% mean deviation from the reference transducer and which exhibit good reproducibility with a range of less than +-2% about the reference transducer within the data submitted. NATO will accept data obtained from approved transducers as valid measurements for all purposes.

4. **Reference Information**

INTERNATIONAL TEST AND OPERATIONS PROCEDURE (ITOP) 3 – 2 - 810 "ELECTRICAL MEASUREMENT OF WEAPON CHAMBER PRESSURE"

This document gives detailed operating instructions for transducer installation and testing also defines interior ballistics terms and its Appendix gives useful guidance on interior ballistic phenomena.

0502. Calibration

1. **Maintenance of records**

A complete history of calibration and use shall be maintained from new. This history shall be used to monitor sensitivity and linearity changes that occur when the transducer is exposed to pressure and temperature. A transducer shall be withdrawn for further investigation if there is a:

a. Change of mean sensitivity of more than 5% from first calibration.
b. Change 2% from the previous calibration.
c. Significant change in linearity.

2. Pre-trial inspection and calibration

When the transducer is first manufactured and also when the transducer is removed from the adaptor for cleaning and inspection after a series of firings, a linearity test shall be carried out. The linearity test comprises determination of the charge versus pressure transfer function using a pressure generator traceable to international standards. The transducer is calibrated without the K1181 thermal protection plate to reveal the internal transfer function. The overall uncertainty of measurement of the calibration system including the charge measuring electronics shall be less than 1%.

3. Pressure balance calibration

One pressure cycle at the highest pressure is used to settle the transducer and wet the diaphragm. The output is noted but is not used in computation of the transducer sensitivity. The pressure cycle is repeated and if the output differs by more than 0.5% this cycle is also excluded from computation. When a stable reading is obtained the mean of at least two pressure cycles is recorded. The calibration continues with a minimum of 5 reducing pressure levels spanning the firing range.

4. Transient pressure comparison

When difference pressure measurements are required, the reproducibility of approved transducers can be improved by matching pairs using a dropping weight oil pressure generator with multiple pressure ports. This equipment generates repeatable pressure pulses. Transducers, which have similar transfer functions, are selected and used as matched pairs. Pressure balance (static) calibration does not reveal all types of internal transducer damage therefore the transient pressure tests are a useful quality control.

The results of the pre-trial inspection and calibration are used to track the performance of individual transducers as a quality control measure. The data is not used to generate the transfer function used to process trial data because of the significant effect of the K1181 plate.

0503. Calibration before firing

1. The transducer is assembled in the gun adaptor with the required components (seal, protection plate and heat shield for K6213B). The calibration is repeated when the transducer is removed from the gun. This shall take place after 20 rounds have been fired or at the end of each days firing.

2. The complete transducer/gun adaptor is mounted on the pressure balance for calibration. One pressure cycle at the highest pressure is used to settle the K1181 thermal protection plate and wet the transducer diaphragm. The output is noted but is not used in computation of the transducer sensitivity. The pressure cycle is repeated and if the output differs by more than 0.5% this cycle is also excluded from computation. When a stable reading is obtained the mean of at least two pressure cycles is recorded.

3. The calibration may then continue either by 5 reducing pressure levels spanning the working range generated by a pressure balance, or by use of a dropping weight pressure vessel to generate a transfer function by comparison with a specially selected K6213 reference gauge which is not fitted with a K1181 plate. The dynamic test provides a more complete transfer function, does less damage to the transducer and clearly shows hysteresis that accompanies internal damage. Dynamic test data are scaled by the pressure balance maximum pressure result.

4. Calibration values were obtained at specific pressures over the firing range. These values were applied directly to the data acquisition system to reflect the anticipated pressure. No fitting of the calibration data was undertaken.

0504 UK98 Instrumentation and data processing

1. **General**

The pressure measurement was conducted according to the AEP-23 Edition 2 and ITOP 3-2-810. The instrumentation chain consisted of 2 Kistler 6213B, fitted in UK adapters connected to a 5011 Kistler Charge Amplifier. The output of which was connected to the differential input of a Nicolet Multi-channel analog to digital converter (Pro 20 DSO used for the drop tests and a Multipro for the gun firings). Recorded waveforms were zeroed just before the start of signal to remove any offset, smoothed by 100 point rolling average and the resulting maximum of the waveform quoted as the peak pressure. This method was agreed by the WG nations at a meeting during week 2/2/98.

2. Kistler Gauge Selection

Each nation supplied three Kistler 6213B transducers. A selection process was performed to establish gauge performance. A Kistler 5001 manual drop tower was used to compare the dynamic performance of these gauges at 500 MPa against the UK 6213BK reference. In addition, each gauge was calibrated at 500 MPa on a Desgranges & Huot dead weight Test Bench. Of the 6213B gauges available, 20 were selected which produced a peak pressure closest to that measured by the reference transducer.

Each Kistler gauge was allocated its own dedicated adapter and fitted with thermal protection and shield before calibration on the Desgranges & Huot dead weight tester bench. Two gauges were selected for each day firings. These Kistler gauges were changed at the end of each firing day or when the Kistler gauges pressure difference exceeded ±1% from the mean value. After each firing day the used gauges were recalibrated before being remove from their adapters checked, refitted into their adaptors then calibrated before returning to the pool of available gauges (Reference Annex D: UK 1998 Kistler adaptor drawing). Gauges were not paired for the lifetime of the trial.

Gauges were only calibrated over the range for which they would be used (eg FTMA gun pressures 520MPa to 850MPa). The Sensitivity used for each pressure level was the one nearest to the calibration point on the certificate e.g.

50-80 MPa	used the 50 MPa pC/MPa value
100-140 MPa	used the 100 MPa pC/MPa value
170-230 MPa	used the 200 MPa pC/MPa value

and similarly over the rest of the pressure range to 850Mpa

3. Temperature Calibrations for the Drop Vessel

Kistler gauges (in their adaptors) needed to be pre-fitted to the oil vessels to prevent oil leaking out. As a consequence, when the vessels were heated/cooled to –13C, +21C, +52C and + 63C the gauge and adaptor were also conditioned to the temperature of the vessel. The temperature coefficient of the 6213B gauge is approximately +0.03% per ^{o}C. To minimise the effect of heated/cooled vessel Kistler gauges were also calibrated at approximately the vessel temperatures by pre-conditioning them in an oven or freezer. There was no easy way to maintain the gauges at the required temperature throughout the calibration, as the oil within the tester could only be used at ambient. It should thus be noted that the non-ambient calibrations have a tolerance of approximately ±15^{o}C over the calibration pressure range.

0505. US 2002 Instrumentation and data processing

1. General

The pressure measurement was conducted according to the AEP-23 Edition 2 and ITOP 3-2-810.

2. Calibration of US Piezoelectric Transducers Kistler 6213B, YPG E30MA, etc.

Piezoelectric transducers are calibrated using the DH dead weight tester. The pressure release method is used. Pressure is brought up to a known level, so that the piston 'floats', the dead weight tester is isolated, the charge amplifier is grounded, and a reading is taken as the pressure is released from the known level to zero pressure. The pressure release time is typically less than 10 milliseconds.
Kistler and other gauges were used in the US 2002 test.

6213B		E30MA	
<u>Serial No's</u>		<u>Serial No's</u>	
6362968	US	596	US
6362969	US	597	US
6362970	US		
588833	SP	N5TS	
367367	SP	<u>Serial No's</u>	
367368	SP	1013	US
533392	UK	1014	US
533393	UK	1015	US
533390	UK	1016	US
		1017	US
986924	GE		
986927	GE		
986935	GE	T8MTS	
		<u>Serial No's</u>	
618981	FR		
397931	FR	910	US
397935	FR	911	US
		912	US
566550	NL	913	US
566551	NL	914	US
566554	NL		
570525	NL		

3. **Criteria For US Transducer Use**

It is typical to use a minimum of 3 different pressure levels (typically 5 different pressure levels are used) to establish the linearity of a transducer. Criteria for sending a transducer back into service after calibration are:

Sensitivity Shift from previous calibration	Sensitivity Shift from Original Baseline	Action
0% to 0.5%	0% to 1%	Return to service
.5% to 1%	1% to 2%	Examine linearity. Determine if re-calibration is necessary.
1% - 2%		Must be re-calibrated. Determine if shift is stable. Examine linearity. May or may not be removed from service.
2%	4%	Must be removed from service

CHAPTER 6

DYNAMIC FIRING TESTS OF CRUSHER GAUGES

0601. General

1. Details of the Firing Trial matrix for the UK 1998 and US 2002 tests are in Annex E.

2. The pressure levels for the firing test shall be at approximately 30 MPa intervals up to 230 MPa (LP crusher gauges) and approximately 70 MPa intervals above 170 MPa (MP and HP crusher gauges).

3. If it proves necessary to conduct tests on a single crusher gauge in two different weapons, the pressure ranges covered by the weapons shall overlap by at least two pressure levels. The pressure limits may be adjusted according to circumstances subject to the agreement of Land Group 4. Also, if a single country submits a third type of crusher gauge, the pressure ranges and levels for the test shall be decided by Land Group 4.

4. It is essential that the crusher gauges and electrical gauges are located within the same section of the chamber in order to minimize error due to pressure gradient. The crusher gauges shall be orientated with their sensitive ends facing the muzzle and their sensitive axes parallel to the gun axis. The sensitive ends of the crusher gauges shall be located to within ±25 mm of the plane containing the sensitive faces or axes (depending on orientation) of the electrical gauges. Every effort must be made to ensure that the crusher gauges do not move during firing.

5. Each day's firing shall begin with a freshly calibrated set of electrical gauges. The Kistler 6213 was the standard piezoelectric reference gauge. Each participating country supplied gauges for the Trial. Also, at least two electrical gauges shall be used for each firing. The calibration relationship for the electrical gauge must be used in order to calculate pressure.

6. In order to produce a tarage table or mastercurve for pressure in terms of remaining length and temperature, firings shall be carried out with the crusher gauges conditioned at -40°C, -33°C, -13°C, +21°C, +52°C, +63°C and any other temperature decided by Land Group 4. These temperatures must be maintained to within ±2°C after a conditioning time of 24 hours.

7. To provide basic data for production of the tarage table or mastercurve, each crusher gauge shall be subjected to firings over a measurement range compatible with its design table.

8. The tables shall be drawn at 50-micron intervals for the remaining length and at temperatures, to which special values may be added; in particular, the firing temperatures must be included. All remaining lengths shall be measured with an instrument with such characteristics and resolution as to ensure a maximum uncertainty not exceeding ±5 microns.

9. Two electrical pressure measuring systems, operating independently of one another and if possible using gauges based on different physical principles, shall be used to record chamber pressure-time history. The measuring systems shall have an upper 3dB cut-off frequency of 20kHz. The gauges shall be located in the chamber in such a way that their expected signals are highly comparable, i.e. at the same distance from the breech face. If the difference between the two maximum pressure readings for a single round does not exceed 2% of their mean, this mean value shall be taken as the "true pressure". Otherwise, the data from the round shall be discounted and the round repeated.

10. During the gun firing at the UK 1998 Tarage Trial, it was found that the piezoelectric pressure had a downward bias as great as 3% when comparing pressure values to crusher data from the Bourges 1990 Test. The UK 1998 simulator data was internally consistent and is was good agreement with the data obtained at Bourges in 1990 in the range -13°C to +63°C, 50MPa to 650MPa.

11. As a result UK 1998 Tarage Trial bias, the US and GE joined together for additional firing at the Aberdeen Test Center. The 2002 US firing test was designed with checks and balances on the pressure measurement techniques to generate validated pressure values for the gauges crush values produced during the UK trials.

The US/GE test in 2002 determined true pressure values for the gun firings in UK 1998.

12. The UK 1998 Tarage Trial piezoelectric pressures were corrected in the following manner: gun firing data (test i=3) and the UK simulator data (test i=1&2) were then used to generate the associated coefficients for the planned temperatures using the Roke Manor Software for each country through the LP and MP range (50MPa to 650MPa).

13. Results of the Firing Trial are an annex to the agreement entered into by all participating nations.

14. During the UK 1998 initial Tarage Trial, the GE tested high pressure gauges (600Mpa - 850Mpa) and experienced a the piezoelectric pressure downward bias that was corrected in the following manner: tarage tables for GE high pressure gauges were derived from the raw gun data with the piezo pressures shifted by +2.4%. There has been no merging of simulation data with shifted gun data.

0602. Simulation trials on crusher gauges

1. Simulation has been added to the calibration trials as a way of increasing the data available whilst reducing the overall costs. It is not envisaged that simulation will ever remove the need for gun firings. Simulation provides interpolation points to improve fitting and statistical confidence and allows broader pressure spacing in the gun firings. The methodology for these trials is that there will be one series, covering all pressures and temperatures, fired in guns. In addition, two further series produced in simulators will cover as many pressures and temperatures as possible. Areas not covered by simulation will be covered by additional gun firings.

2. There are three types of simulation that must be considered as being suitable for testing Crusher gauges, these being: Vented Vessel, Gas generator and Drop Tower/Oil Bomb. WG considered, that the Drop Tower/Oil Bomb (DTOB) combination was the lowest technical and financial risk. It was apparent during the investigation that Crusher gauges gave good results in simulators and rarely failed functionally. Simulators provide interpolation data to support the gun firing data, which reveals gas wash failure and precision, under gun chamber conditions. For these reason simulators should only be used as a supplement data to gun fired data, not stand alone data. The main features of a DTOB are shown in Fig 1. The weight is raised to a suitable height and then dropped onto the piston. The resulting piston movement generates the pressure. The weight rebounds and is caught on the catcher system, preventing a double impact.

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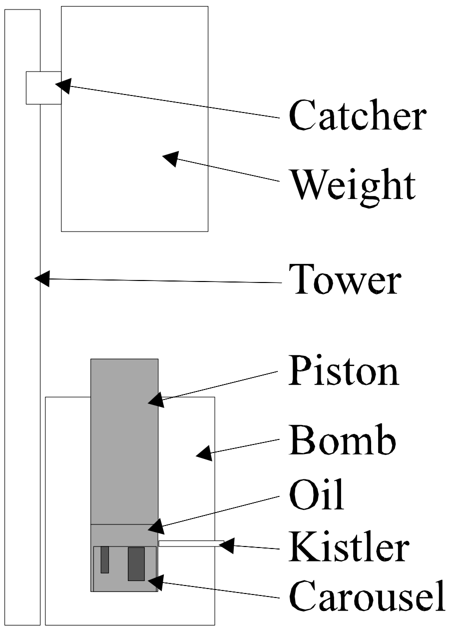


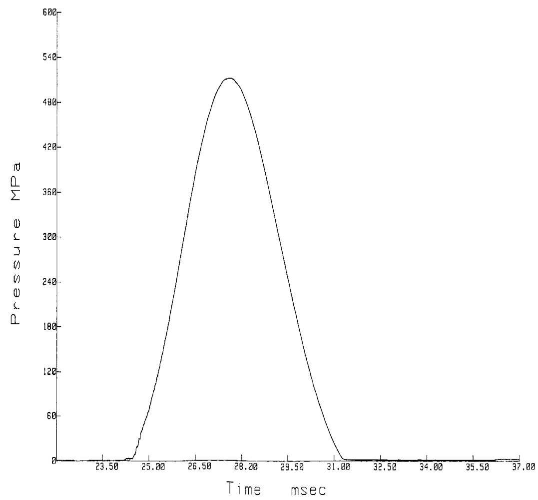


Figure 1 Drop tower oil bomb curve.

Figure 2 Oil bomb typical P/T

3. The DTOB produces a pressure time curve similar to that seen in a gun. Fig 2 shows a typical DTOB pressure time curve obtained using Kistler 6213B pressure gauges mounted close to the sensitive surface of the crusher gauges. The maximum pressure and the rise time/pulse width obtained in a simulator can be matched to that obtained with the gun. By varying the mass of the weight, the drop height and the volume of the oil, the magnitude and the width of the pulse can be altered.

A formula for calculating the pressure and pulse width is shown at Fig 3.

Oil Vessel Equations:

$$P = \sqrt{\frac{2HMKg}{V}}$$

$$T = \frac{Pi}{A}\sqrt{\frac{MV}{K}}$$

P	Pressure
T	Duration
H	Height of drop
M	Mass of drop weight
K	Bulk modulus of oil
V	Volume of oil
A	Area of piston
g	Acceleration of gravity
Pi	3.14

Figure 3 Oil vessel equations

4. Gauges to be tested are mounted in the base of the oil bomb in a carousel. Different gauges from the approved NATO list are also present during testing to ensure consistency. The carousel has been machined to allow a 2mm clearance, on diameter, between the gauge and the carousel and to ensure that the gauge top is flush with the top of the carousel. Fig 4 shows a typical layout (note that oil is allowed to flow around the gauges but does not come in contact with the grease in the gauge). This whole assembly is conditioned to the required temperature. With the oils currently being used, waxing of the oil takes place below –13°C. For this reason DTOB testing is restricted to -13°C minimum temperature. Once conditioned, the carousel assembly is added to the oil vessel. The oil vessel is maintained at the conditioned temperature ± 2°C. The weight is then dropped.

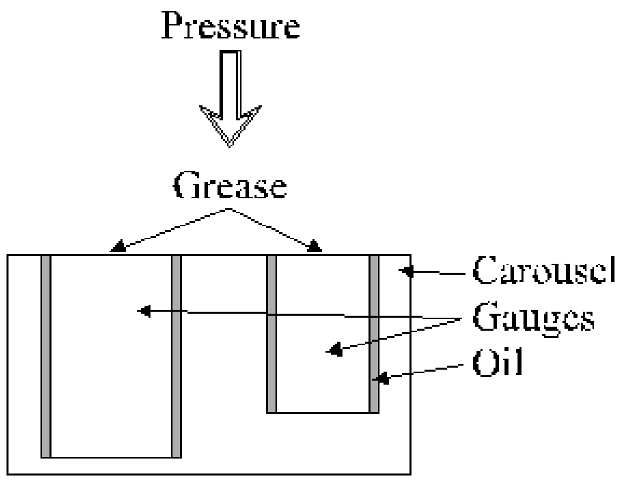


Figure 4 Carousel

Typical pressure time curves for a high-pressure tank gun and an artillery gun are shown at Figs 5 and 6.

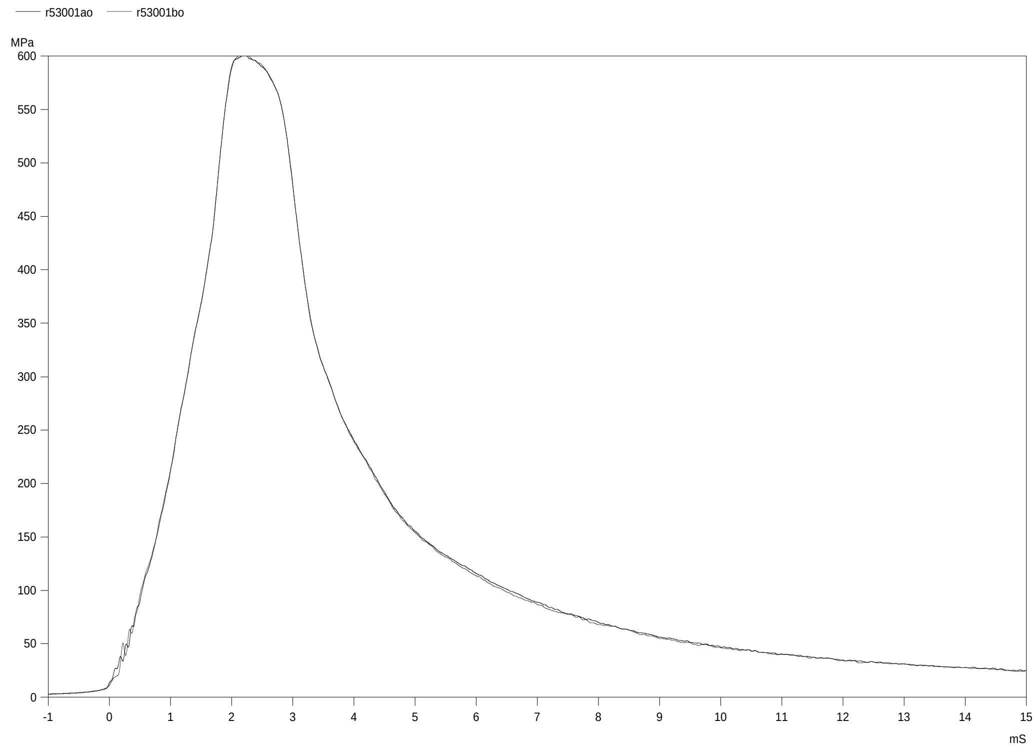


Figure 5 Typical tank gun P/T curves from UK98 Tarage trial

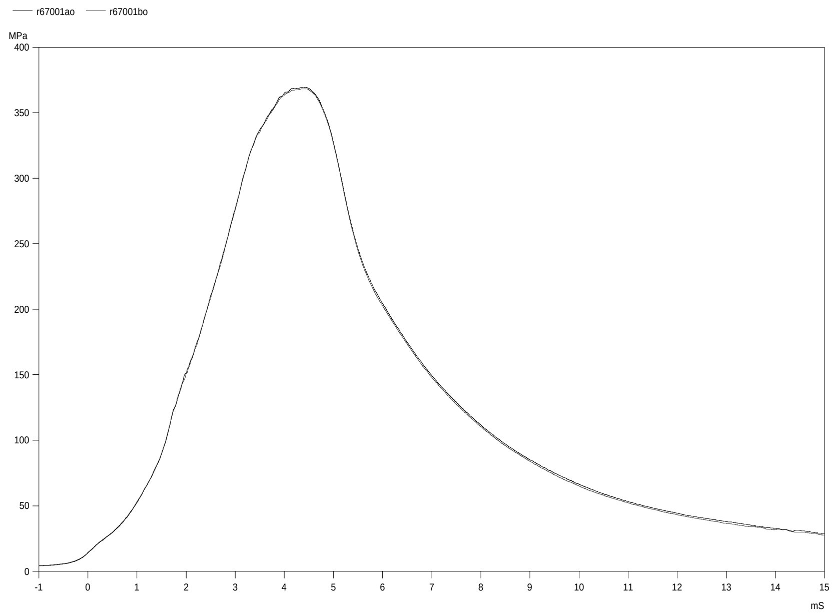


Figure 6 Typical artillery gun P/T curves from UK98 Tarage trial

0603. Use of the 1998 & 2002 crusher test data

The additional firing test 2002 was analyzed in accordance with the GE report WTD 91-2 Nr.4/02 presented at a working meeting in Bourges on January 2002.
The test set-up was planned to get harmonized reference tables between countries and to compare to the 1990 Bourges trial data. Therefore the following steps were done to analyse the 2002 data:

Step 1. French produced from the 1990 Bourges fired data coefficients of a 3rd degree polynomial function. The coefficients P= f (L), taking the tests where the US and GE gauges were together in the 1990 gun (named trial 1 for GE and trial 3 for US during Bourges trials) for low and medium pressure.

Step 2. For the US gauges and the GE gauges, the Bourges temperature factors (21°C = 1.000) are used to shift the UK 1998 gun pressure data without changing the remaining lengths. With the temperature factors from Bourges data, the US 2002 21°C data was used to shift the pressures for the UK data for all low pressure gauges data (50 to 230 MPa).

Step 3. For the medium pressure range (170 to 650 MPa), this procedure was applied to the temperature curves –33°C and 52°C. At the fired temperatures, the US 2002 firing data was used (instead of correction factors) as proposed and agreed during the October 2002 SG2 meeting to shift UK 1998 medium pressure data.

Step 4. The pressure/remaining length data was merged with the UK 1998 simulator data for low and medium pressure ranges as agreed during the March 2003 Madrid working meeting.

Step 5. Roke Manor software compatible input data were produced (named: CountryCode_0298_merged_LP (MP).dat) at all common UK fired pressure steps with the original remaining lengths from UK 1998 firings and simulator data. Pressure steps where gauges were not in with the US/GE gauges were deleted from the UK 1998 Roke Manor input files.

Step 6. A Roke Manor control file was used to calculate for all gauges with the new input data coefficients at temperatures –40°C, -33°C, -13°C, +21°C, +52°C and +63°C. In some cases countries may have excluded temperatures or pressure ranges from its gauges data file.

Step 7. These coefficients were used to set up an EXCEL program called MASTERCURVE (named: country code_mastercurve_2003) for each gauge (see ANNEX A pages A2 to A3). This table is the harmonized NATO crusher gauges reference pressures and will be produced on a CD under SG2 authority. The mastercurve data for each country will be used to as the basis to exchange gun chamber pressure measurements from country to country. Each country is free to produce tarage tables for other then fired temperatures but should be aware that the calculation by Roke Manor Software may slightly shift the fired temperature curves.

1. US 2002 crusher gauge firing test

The US firing test was performed with German and US crusher gauges at the low and medium-pressure range from 50 Mpa to 690 Mpa at the Aberdeen Test Center. Accurate pressure measurements in the 2002 test were assured by changes and supplementation of the pressure measurement techniques. Direct mounted 6213B piezoelectric transducers were used in the 120-mm gun tube versus the two Kistler 6213B gauges fitted in UK adapters in the 1998 test. The Aberdeen test also used two different types of piezoelectric transducers (quartz and tourmaline). The Yuma E30MA functions with a tourmaline crystal and meets the AEP23 requirement of measuring pressure with gauges operating independently on different physical principles. Also, six strain gauges were attached to both the 120-mm and 155-mm tubes to confirm the round-to-round pressure variation and standard deviation. The strain gauges were set to equal the mean of the valid piezoelectric measurements obtained during the charge assessment.

2. Charge establishment

The charge establishment firings for the 120-mm gun were done with the ‘super slug’ rounds. Six rounds each were fired at -40 C, + 21 C, and + 63 C. The M30 propellant was used with different charge weights to obtain a range of pressure values. The M14 propellant was only used at the low temperature for the 690 MPa pressure value. The charge weights for the test firing conditions were then calculated from the eighteen rounds fired in the charge establishment. The M106 round was used in the 155-mm gun with a canister charge. The propellant in these rounds was fired at ambient while the crusher gauges were temperature conditioned. Eighteen rounds were fired at –40 C, + 21 C, and + 63 C from 50 MPa to 370 Mpa and the charge weights were then calculated for all the NATO firing conditions.

NATO APPROVED CRUSHER GAUGES – UK 1998/US 2002

Country	Gauge	Drg N° & Issue	Crusher Lot N°	Crusher Dimensions mm	Type & (Pressure range) MPa	SOP Reference
France	FAN	MT8201 00	Cylinder Lot 2/93	Ø 3.0 x 4.9	LP & MP (50 – 650)	MT 8210 07
Germany/ Netherlands	31/7.1	66-189-000/2	Sphere Lot No 979101	6.000	LP (40 – 230)	WTD 91: 200 – Nr. 391/2000
	38/3.91A	66-217-000/2	Sphere Lot No 979101	6.000	MP (170 – 650)	WTD 91: 200 – Nr. 391/2000
	38/3.5A	66-219-000/2	Sphere Lot No 979101	6.000	HP (520 – 850)	WTD 91: 200 – Nr. 391/2000
Spain	MT 43	9644 - 0	Cylinder 040/96	Ø 3.0 x 4.5	LP (50 – 230)	NM M-2891 EMG
	MT 43	9644 - 0	Cylinder 025/96	Ø 5.0 x 7.0	MP (170 – 520)	NM M-2891 EMG
United States	T19	DS-3756E – 1	Sphere Lot No 2-85	4.763	LP (40 – 230)	USCD1
	M11	DS-4412E – 1	Sphere Lot No 2-85	4.763	MP (170 – 650) (positive Temp)	USCD1
	M12	DS-4412E – 12	Sphere Lot No 2-85	4.763	MP (170 – 650) (negative Temp)	USCD1

The following table contains the **reference coefficients** for NATO approved crusher gauges for each country at the available test temperatures. The Mastercurves have been produced for each participating country and placed on a CD.

FRANCE LP Fan
file = frbp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 4.200 4.900
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	3.533971e+004	-2.258429e+004	4.908505e+003	-3.612900e+002
-33.0	1.867250e+004	-1.185705e+004	2.606462e+003	-1.965777e+002
-13.0	3.941728e+004	-2.553795e+004	5.605146e+003	-4.151077e+002
21.0	2.935931e+004	-1.909151e+004	4.227124e+003	-3.168792e+002
52.0	3.472745e+004	-2.271346e+004	5.037691e+003	-3.770989e+002
63.0	2.571183e+004	-1.671785e+004	3.709550e+003	-2.791129e+002

FRANCE MP Fan
file = frmp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 2.600 4.600
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-13.0	2.948198e+003	-1.294970e+003	2.343200e+002	-1.855975e+001
21.0	2.065215e+003	-8.140313e+002	1.485298e+002	-1.360101e+001
52.0	2.216265e+003	-1.002465e+003	2.070221e+002	-1.900318e+001
63.0	2.367515e+003	-1.147230e+003	2.500202e+002	-2.308653e+001

GE/NL LP 31/7.1
file = gebp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 3.500 5.400
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	1.797812e+003	-7.852717e+002	1.271124e+002	-7.752898e+000
-33.0	1.722772e+003	-7.484210e+002	1.211069e+002	-7.418648e+000
-13.0	1.600208e+003	-7.013829e+002	1.157047e+002	-7.258948e+000
21.0	1.552288e+003	-6.953203e+002	1.183745e+002	-7.670863e+000
52.0	1.486349e+003	-6.590890e+002	1.104729e+002	-7.032060e+000
63.0	1.427199e+003	-6.240675e+002	1.032623e+002	-6.524431e+000

GE/NL MP 38/3.91A
file = gemp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 3.500 5.400
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	1.658527e+004	-8.984441e+003	1.700435e+003	-1.112428e+002
-33.0	8.622328e+003	-4.072083e+003	6.857165e+002	-4.115281e+001
-13.0	5.975379e+003	-2.693161e+003	4.511079e+002	-2.824509e+001
21.0	4.632366e+003	-1.917456e+003	2.982215e+002	-1.803428e+001
52.0	4.935678e+003	-2.188295e+003	3.657970e+002	-2.321102e+001
63.0	4.241149e+003	-1.743508e+003	2.708386e+002	-1.645612e+001

SPAIN LP MT43
file = spbp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 2.500 4.300
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	1.520580e+002	2.423915e+002	-9.372514e+001	7.382889e+000
-33.0	1.086377e+003	-5.472378e+002	1.232716e+002	-1.213774e+001
-13.0	5.280744e+002	-1.048767e+002	3.953001e+000	-1.293078e+000
21.0	9.679695e+002	-5.122074e+002	1.221677e+002	-1.230936e+001
52.0	1.075025e+003	-6.168143e+002	1.526090e+002	-1.509209e+001
63.0	1.007529e+003	-5.650174e+002	1.387754e+002	-1.382370e+001

SPAIN MP MT43
file = spmp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 4.600 6.500
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	1.207558e+003	1.860463e+001	-3.084332e+001	5.395283e-001
-33.0	-7.935378e+003	4.746459e+003	-8.472145e+002	4.751444e+001
-13.0	3.623691e+003	-1.296847e+003	1.939047e+002	-1.174015e+001
21.0	3.024071e+003	-1.038996e+003	1.536546e+002	-9.481485e+000
52.0	2.595713e+003	-8.455820e+002	1.217067e+002	-7.588285e+000
63.0	3.709642e+003	-1.485823e+003	2.423266e+002	-1.505657e+001

US LP T19
file = usbp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 3.000 4.400
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	1.743710e+003	-8.495493e+002	1.519789e+002	-1.057919e+001
-33.0	1.618289e+003	-7.656373e+002	1.329552e+002	-9.094098e+000
-13.0	1.937526e+003	-1.063949e+003	2.194528e+002	-1.711252e+001
21.0	1.665120e+003	-8.754508e+002	1.746691e+002	-1.348288e+001
52.0	1.574207e+003	-8.188989e+002	1.614902e+002	-1.235892e+001
63.0	1.460777e+003	-7.330749e+002	1.396031e+002	-1.048780e+001

US MP M11/M12
file = usmp CRUSHER 2.4 crusher.con 06/04/2003
tarage lengths = 3.000 4.400
trial = combined

theta	coeff[0]	coeff[1]	coeff[2]	coeff[3]
-40.0	6.771453e+003	-4.431909e+003	1.059573e+003	-9.062970e+001
-33.0	4.603357e+003	-2.635840e+003	5.575197e+002	-4.349150e+001
-13.0	4.251041e+003	-2.477393e+003	5.452409e+002	-4.489762e+001
21.0	4.616224e+003	-2.831011e+003	6.508290e+002	-5.499746e+001
52.0	3.408095e+003	-1.868664e+003	3.898687e+002	-3.111793e+001
63.0	3.986500e+003	-2.403345e+003	5.509968e+002	-4.703600e+001

UK98/US2002 Ranges and Limits - FR Gauges

FAN

Pressure MPa	Reproducibility %						Uncertainty %						Bias %					
Temperature °C	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63
230	0.70	0.77	0.67	0.73	0.41	0.59	1.70	1.85	2.11	1.84	1.37	1.61	-0.07	-0.06	0.60	-0.17	0.36	0.25
200	0.68	0.68	1.12	0.56	0.58	0.43	2.18	2.50	2.83	2.48	1.97	2.16	0.59	-0.92	0.06	-1.10	-0.57	-1.05
170	0.71	0.52	0.71	0.81	0.68	0.35	1.71	2.60	2.22	2.19	1.76	1.09	-0.05	-1.34	0.62	-0.40	0.23	0.19
140	0.87	0.64	0.82	0.57	0.72	0.50	2.74	1.95	2.84	1.97	2.23	1.67	0.72	0.42	0.94	-0.58	-0.54	0.43
110	1.53	0.90	1.22	0.82	2.10	0.90	3.50	3.14	3.79	2.10	4.94	3.41	0.07	-1.08	1.03	-0.21	0.16	1.25
80	1.92	0.81	0.84	1.09	1.18	1.01	4.36	2.35	2.31	2.67	3.65	2.74	-0.04	-0.39	-0.35	-0.20	-0.93	-0.46
50	1.94	1.77	0.91	1.65	1.58	1.58	5.61	5.38	3.07	3.79	4.48	3.98	1.14	-1.38	0.88	-0.08	0.87	-0.34

FAN

Pressure MPa	Reproducibility %						Uncertainty %						Bias %					
Temperature °C	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63
650			0.58	0.55	0.32	0.45			2.18	1.40	1.08	1.30			-0.73	0.09	-0.20	0.19
600			0.58	0.14	0.50	0.37			1.64	0.70	1.25	1.05			0.26	0.08	0.01	0.04
520			0.33	0.52	0.14	0.34			1.06	1.46	0.75	1.14			-0.15	-0.17	-0.15	-0.24
440			0.30	0.41	0.29	0.25			0.96	1.14	1.02	1.03			0.12	-0.07	0.19	-0.28
370			0.24	0.20	0.36	0.37			1.20	0.77	1.65	1.03			0.47	-0.10	0.69	-0.08
290			0.49	0.37	0.22	0.26			1.23	1.44	1.25	0.79			-0.06	-0.47	0.54	-0.03
220			0.79	0.65	0.53	0.33			1.83	1.54	1.23	1.37			-0.09	-0.05	-0.01	-0.51
170			0.77	0.45	0.54	0.49			1.88	1.30	1.57	1.32			0.17	-0.19	0.32	0.17

UK98/US2002 Ranges and Limits - GE Gauges

31/7.1

		Reproducibility %						Uncertainty %						Bias %					
Pressure	230	0.42	0.33	0.26	0.24	0.42	0.55	1.25	1.58	1.17	1.05	1.11	1.42	0.19	-0.68	0.40	-0.32	-0.06	0.09
MPa	200	0.40	0.28	0.41	0.29	0.24	0.28	1.62	1.36	1.23	1.01	0.93	0.86	0.60	-0.56	0.19	-0.20	-0.18	0.06
	170	0.43	0.34	0.44	0.45	0.42	0.39	1.17	2.01	2.47	1.22	1.17	1.06	0.09	-1.10	1.31	0.09	0.10	0.03
	140	0.51	0.57	0.46	0.47	0.63	0.23	1.88	1.77	1.72	1.93	1.58	0.81	0.61	-0.41	0.58	-0.77	0.10	0.09
	110	0.52	0.50	0.47	0.40	0.35	0.49	1.57	1.90	1.26	1.23	1.09	1.26	0.30	-0.68	0.11	-0.20	0.16	-0.05
	80	0.60	0.45	0.56	0.56	0.75	0.62	2.05	2.18	2.02	1.42	1.87	1.47	0.61	-1.06	0.67	-0.07	-0.14	0.00
	50	0.90	0.70	0.96	0.38	0.40	0.56	3.31	3.20	2.38	2.15	1.18	1.60	1.24	-1.53	-0.20	1.16	-0.16	-0.25
		-40	-33	-13	21	52	63	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63
		Temperature ^{o}C						Temperature ^{o}C						Temperature ^{o}C					

38/3.91A

		Reproducibility %						Uncertainty %						Bias %					
Pressure	650	1.19	0.71	0.36	0.54	0.36	0.36	2.69	2.33	0.98	1.36	1.23	1.18	0.04	-0.66	-0.02	0.06	0.28	-0.25
MPa	600	0.97	0.85	0.46	0.50	0.45	0.31	2.54	2.24	1.61	1.62	1.93	1.89	-0.12	-0.26	0.46	-0.39	0.82	-1.00
	520	0.83	0.93	0.35	0.55	0.32	0.63	2.20	2.37	0.96	1.59	1.30	1.91	0.30	0.26	-0.03	-0.27	0.42	-0.41
	440	0.53	0.54	0.57	0.50	0.51	0.67	1.33	1.61	1.45	1.42	1.81	2.05	0.05	0.30	-0.10	-0.19	0.57	-0.47
	370	0.71	0.62	0.23	0.45	0.46	0.33	2.00	2.16	1.12	1.39	2.07	1.13	-0.45	0.77	-0.42	-0.29	0.93	-0.26
	290	0.60	0.59	0.55	0.50	0.54	0.40	1.83	2.19	1.74	1.76	2.07	1.20	-0.48	0.86	-0.43	-0.57	0.81	-0.21
	220	0.64	0.57	0.54	0.42	0.69	0.57	1.52	1.66	1.79	1.59	1.74	2.19	0.01	0.31	-0.48	0.52	0.13	-0.84
	170	0.80	0.83	0.53	0.38	0.49	0.54	3.11	3.89	1.98	1.71	2.05	2.15	1.27	-1.96	0.69	0.70	0.81	-0.84
		-40	-33	-13	21	52	63	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63
		Temperature ^{o}C						Temperature ^{o}C						Temperature ^{o}C					

UK98/US2002 Ranges and Limits - SP Gauges

MT43

		Reproducibility %						Uncertainty %						Bias %					
Pressure	230	1.62	0.78	0.63	0.49	0.94	0.61	3.77	1.88	1.88	1.59	2.47	1.52	-0.16	-0.07	-0.39	0.39	-0.32	0.07
MPa	200	1.64	0.76	1.29	0.51	0.37	0.40	4.47	2.45	3.62	1.71	1.02	1.35	-0.79	0.67	-0.72	0.47	0.06	-0.32
	170	1.19	0.91	1.25	0.40	0.65	0.67	2.84	2.74	4.49	1.15	1.79	1.75	0.16	0.66	-1.68	0.13	0.21	-0.18
	140	3.47	1.39	0.99	0.44	0.79	0.58	9.03	4.76	2.89	1.11	1.98	1.49	-1.34	1.61	0.64	-0.01	-0.16	-0.10
	110	1.85	1.25	1.02	0.61	0.49	1.02	5.19	2.88	2.62	1.90	1.64	2.59	-0.92	0.08	-0.30	0.44	0.44	0.24
	80	3.07	1.53	0.97	1.02	1.09	0.76	6.88	4.11	2.47	2.94	2.55	2.31	0.06	-0.69	-0.22	-0.62	-0.06	-0.55
	50	4.15	1.33	1.30	1.68	0.86	1.42	9.68	3.52	3.24	4.30	2.61	3.56	0.39	0.54	-0.31	0.42	0.60	-0.38
		-40	-33	-13	21	52	63	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63
		Temperature °C						Temperature °C						Temperature °C					

MT43

		Reproducibility %						Uncertainty %						Bias %					
Pressure	650																		
MPa	600																		
	520	1.56	1.26	0.46	0.31	0.69	0.55	4.57	3.00	1.30	1.30	1.77	1.33	-0.82	0.13	0.16	-0.45	0.15	-0.01
	440	2.06	1.12	0.47	0.81	0.39	0.54	4.62	3.09	1.59	2.07	1.42	1.70	0.03	-0.55	0.43	-0.19	0.41	-0.40
	370	2.21	1.07	0.65	0.43	0.40	0.64	5.30	2.81	1.85	1.36	1.25	1.59	0.68	-0.52	0.35	-0.31	0.23	-0.10
	290	1.48	1.03	0.63	0.58	1.00	0.85	4.17	2.96	1.71	1.57	2.99	2.27	-1.03	0.74	-0.24	-0.20	0.78	-0.36
	220	1.59	0.54	0.57	0.61	0.79	0.63	4.32	2.77	2.03	1.80	2.44	2.26	-0.64	1.46	-0.68	-0.33	0.60	-0.78
	170	1.77	0.93	0.47	0.50	1.37	1.15	5.29	2.61	1.42	1.41	3.26	2.88	1.15	-0.46	0.25	0.18	-0.11	0.27
		-40	-33	-13	21	52	63	-40	-33	-13	21	52	63	-40	-33	-13	21	52	63
		Temperature °C						Temperature °C						Temperature °C					

UK98/US2002 Ranges and Limits - US Gauges

T19

Reproducibility %

Pressure MPa	-40	-33	-13	21	52	63
230	0.51	0.69	0.55	0.60	0.44	0.65
200	0.86	0.69	0.57	0.39	0.60	0.55
170	0.56	0.30	0.36	0.60	0.60	0.57
140	0.34	0.66	0.79	0.64	0.48	0.49
110	0.73	0.64	0.63	0.65	0.51	0.64
80	0.76	0.65	0.87	0.62	0.71	0.72
50	0.81	0.50	0.66	1.30	0.95	0.84

Temperature ^oC

Uncertainty %

Pressure MPa	-40	-33	-13	21	52	63
230	1.36	2.09	1.75	1.85	1.32	1.69
200	2.61	2.33	1.56	1.14	1.43	1.48
170	1.52	2.09	2.24	1.62	1.91	1.36
140	1.45	1.89	2.21	2.37	1.34	1.30
110	2.38	2.44	1.86	1.62	1.73	1.91
80	2.33	2.70	2.61	1.60	1.81	1.83
50	3.38	3.38	2.34	2.95	2.58	2.35

Temperature ^oC

Bias %

Pressure MPa	-40	-33	-13	21	52	63
230	0.13	-0.47	0.42	-0.44	0.22	-0.13
200	0.60	-0.70	0.20	-0.13	-0.02	-0.15
170	0.17	-1.25	1.27	-0.18	0.49	0.00
140	0.53	-0.33	0.37	-0.86	0.15	-0.11
110	0.69	-0.94	0.38	-0.10	0.49	-0.41
80	0.54	-1.17	0.61	-0.13	0.16	-0.15
50	1.49	-2.12	0.79	0.01	0.39	-0.38

Temperature ^oC

M11 Positive temperatures & M12 Negative temperatures

Reproducibility %

Pressure MPa	-40	-33	-13	21	52	63
650	0.73	0.75	0.47	0.33	0.56	0.74
600	0.91	0.67	0.46	0.66	0.35	0.30
520	0.90	0.64	0.57	0.73	0.63	0.59
440	0.65	0.40	0.64	0.54	0.63	0.46
370	0.72	0.53	0.48	0.52	0.71	0.56
290	0.45	0.44	0.41	0.49	0.59	0.53
220	0.71	0.68	0.32	0.27	0.60	0.37
170	0.52	0.49	0.38	0.50	0.42	0.44

Temperature ^oC

Uncertainty %

Pressure MPa	-40	-33	-13	21	52	63
650	2.02	2.17	1.57	2.86	2.54	1.75
600	2.67	2.28	1.90	3.10	1.88	1.49
520	2.63	2.18	1.69	2.71	1.54	1.63
440	1.86	1.12	1.54	1.92	1.82	1.47
370	1.69	1.94	1.19	1.70	2.18	1.53
290	1.40	1.62	1.35	1.67	1.97	1.58
220	1.96	1.98	0.91	0.92	1.72	1.35
170	2.34	2.81	1.64	1.69	1.19	1.43

Temperature ^oC

Bias %

Pressure MPa	-40	-33	-13	21	52	63
650	-0.36	0.31	0.40	-1.96	1.19	0.07
600	-0.33	0.66	0.75	-1.54	0.95	-0.58
520	-0.53	0.67	0.33	-1.01	0.06	-0.20
440	-0.32	0.09	-0.04	-0.61	0.32	0.31
370	-0.10	0.72	-0.05	-0.49	0.52	0.21
290	-0.33	0.58	-0.33	-0.49	0.61	-0.33
220	-0.31	0.39	-0.04	-0.13	0.30	-0.38
170	1.09	-1.61	0.66	0.44	0.12	-0.33

Temperature ^oC

UK98 Ranges and Limits - GE Gauges

38/3.5A

Reproducibility %

Pressure MPa	-40	-33	-13	21	52	63
850			0,75	0,98	0,43	0,51
800			0,98	0,50	0,45	0,54
750			0,62	0,46	0,29	0,80
690			0,86	0,54	0,49	0,74
650			0,82	0,43	0,44	0,52
630			0,86	0,40	0,28	0,62
600			0,56	0,20	0,22	0,24

Temperature ^{o}C

Uncertainty %

Pressure MPa	-40	-33	-13	21	52	63
850			2,27	2,51	1,48	1,44
800			2,80	1,66	1,51	1,57
750			1,82	1,60	1,40	2,68
690			2,25	1,53	1,62	2,07
650			2,33	1,38	1,58	1,36
630			2,11	1,47	1,10	1,78
600			1,44	1,33	1,32	1,02

Temperature ^{o}C

Bias %

Pressure MPa	-40	-33	-13	21	52	63
850			-0,51	0,13	-0,41	0,19
800			0,57	-0,35	-0,33	0,19
750			-0,35	0,36	0,37	0,19
690			-0,10	0,12	-0,35	0,24
650			0,26	0,25	0,43	0,03
630			0,01	-0,39	-0,26	-0,24
600			0,02	0,44	0,47	0,13

Temperature ^{o}C

NATO APPROVED CRUSHER GAUGES – BOURGES 1990

COUNTRY	CRUSHER GAUGE	CRUSHER	CRUSHER DIMENSIONS (mm)	TYPE
United States	T19 M11 M12	Sphere - Lot No 1-85 Sphere - Lot No 1-85 Sphere - Lot No 1-85	4.763 4.763 4.763	LP HP HP
United Kingdom	MK8 MK9	Sphere - Lot No. 8 Sphere - Lot No. 8	4.763 4.763	LP HP
Spain	MT 26 BP MT 26 AP	Cylinder - Lot No. 05-90-C1-MT26 Cylinder - Lot No. 05-90-C1-MT26	Ø 5.0 x 7.0 Ø 5.0 x 7.0	LP HP
Germany/ Netherlands	31/7.1 38/3.91	Sphere - Lot No. 90-91-01 Sphere - Lot No. 90-91-01	6.0 6.0	LP HP
France	FAN	Cylinder - Lot No. 1-90	Ø 3.0 x 4.9	LP and HP

Note: This Annex and the associated range and limits are based on the results of the 1990 NATO comparative firings in Bourges.

BOURGES 1990 RANGES AND LIMITS - US

STANDARD ACCEPTANCE CRITERIA
Indicators of precision (F) and accuracy
of the mean (J) of the gauge

Pressure (bars)	F/J	
6500	(1) 2/4	2/2
4000		
	2/2	1/2
500		

GAUGE: T 19
Indicators of precision of the gauge
F(%)

Pressure (bars)						
2300	.98	.61	1.2	.3	.76	.1
2000	.65	.40	8	8	.50	7
1700	.84	.49	.83	.6	.33	.7
			.38	4		8
				.5		.5
				1		9
1400	.70	.65	.66	.4	.68	.5
1100	.87	.91	.49	6	.59	4
800	1.0	.95	1.0	.8	.98	.6
500	2	1.2	8	5	1.0	6
	1.4	2	1.5	.5	8	.6
	0		5	9		0
				.7		.7
				7		7

GAUGES: M11 (positive temperatures)
and M12 (negative temperatures)
Indicators of precision of the gauge
F(%)

Pressure (bars)						
6500	1.48	1.0	.39	1.0	.57	.76
6000	1.02	1	.40	9	.69	.85
5200	1.04	.80	.58	.52	.55	.45
		.49		.38		
4400	1.03	.58	.73	.47	.58	.58
3700	.84	.65	.54	.48	.51	.51
2900	.48	.45	.51	.65	.44	.64
2200	.82	.83	.62	.44	.50	.65
1700	.87	.73	.47	.79	.72	.32

-40	-30	+63

Temperature (degrees Celsius)

-40	-33	-13	21	52	63

Temperature (degrees Celsius)

-40	-33	-13	21	52	63

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge J (%)

Pressure (bars)	-40	-33	-13	21	52	63
2300	1.03	.86	1.2	.43	.73	.33
2000	.69	.76	6	.61	.56	.82
1700	.93	.56	1.3	.72	.57	.59
1400	.69	.78	4	.50	1.1	.68
1100	1.69	1.2	.46	1.1	6	.69
800	1.29	7	.81	7	.82	.62
500	2.23	1.5	.73	.66	.93	.70
		1	1.6	.66	1.1	
		1.5	9		7	
		1	1.5			
			2			

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge J (%)

Pressure (bars)	-40	-33	-13	21	52	63
6500	2.9	1.5	.50	4.2	1.9	.96
6000	9	3	1.3	1	6	1.75
5200	2.9	1.0	8	1.9	2.0	1.50
4400	6	3	1.1	4	4	.82
3700	1.1	1.4	3	.54	.87	.57
2900	7	1	1.2	.64	.89	.70
2200	1.0	1.8	2	.57	.51	1.15
1700	9	2	.97	1.0	.41	.66
	.86	.83	1.2	8	.76	
	.65	.88	1	1.0	1.2	
	1.2	1.0	1.1	0	4	
	7	3	7	1.0		
	1.3	1.4	.83	5		
	1	8				

Temperature (degrees Celsius)

Note: Panel IV (SP/2) may authorise 4% for F for pressures above 4000 bars a temperatures below – 30^{o}C

BOURGES 1990 RANGES AND LIMITS - UK

STANDARD ACCEPTANCE CRITERIA

Indicators of precision (F) and accuracy of the mean (J) of the gauge F/J

Pressure (bars)	-40 to -30	-30 to +63
6500 – 4000	(1) 2/4	2/2
4000 – 500	2/2	1/2

Temperature (degrees Celsius)

GAUGE: MK 8

Indicators of precision of the gauge F(%)

Pressure (bars)	-40	-33	-13	21	52	63
2300	3.05	2.37	1.03	.52	.77	1.02
2000	2.48	2.18	.70	.83	.88	.58
1700	1.67	1.07	.63	.58	.71	.61
1400	1.37	.63	.51	.56	.36	.42
1100	.69	.59	.53	.50	.47	.45
800	.60	.62	.60	.62	.47	.63
500	.68	.61	.70	.49	.67	.45

Temperature (degrees Celsius)

GAUGE: MK 9

Indicators of precision of the gauge F(%)

Pressure (bars)	-40	-33	-13	21	52	63
6500		2.10	1.43	.70	.50	.56
6000		.89	1.03	.35	.39	.58
5200		1.00	.81	.58	.60	.56
4400		.71	.35	.62	.45	.54
3700		.60	.67	.24	.51	.42
2900		.50	.83	.60	.59	.66
2200		.61	.58	.52	.41	.82
1700		.56	.70	.49	.51	.52

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge
J (%)

Pressure (bars)	-40	-33	-13	21	52	63
2300	6.10	2.7	2.0	1.2	2.1	1.7
2000	3.48	8	8	3	2	9
1700	2.36	2.9	1.9	1.0	.95	.98
1400	1.79	1	5	5	.76	.95
1100	1.38	1.1	1.6	.61	1.1	1.1
800	.96	2	1	.63	8	1
500	2.77	1.4	1.4	.91	.47	.57
		4	8	1.3	1.0	1.0
		1.1	1.1	1	4	9
		7	1	.95	1.0	.73
		2.6	.70		4	
		1	.89			
		.96				

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge
J (%)

Pressure (bars)	-40	-33	-13	21	52	63
6500		6.7	2.2	.79	1.9	1.0
6000		3	5	.54	4	2
5200		5.1	3.4	.63	.87	.65
4400		8	6	.76	.76	1.3
3700		2.6	4.1	.46	.47	3
2900		0	3	.71	.55	1.3
2200		1.2	2.5	1.4	.62	7
1700		5	0	4	1.0	.97
		.96	1.9	.98	4	.72
		1.5	8		.73	1.0
		0	1.4			0
		1.6	3			.98
		5	1.7			
		1.7	0			
		1	1.2			
			0			

Temperature (degrees Celsius)

Note: Panel IV (SP/2) may authorise 4% for F for pressures above 4000 bars a temperatures below – 30°C

BOURGES 1990 RANGES AND LIMITS - SP

STANDARD ACCEPTANCE CRITERIA

Indicators of precision (F) and accuracy of the mean (J) of the gauge

Pressure (bars)	F/J	
6500	(1) 2/4	2/2
4000		
	2/2	1/2
500		
-40	-30	+6 3

Temperature (degrees Celsius)

GAUGE: MT 26 - BP

Indicators of precision of the gauge F(%)

Pressure (bars)						
2300	.50	.35	.65	.32	.25	.26
2000	.74	.62	1.0	.37	.48	.43
1700	.71	.55	6	.44	.48	.39
			.55			
1400	1.02	.55	.78	.47	.55	.55
1100	1.08	.57	1.1	.68	.84	.37
800	1.21	1.1	6	.79	.86	.60
500		1	1.1			
			2			
	-40	-33	-13	21	52	63

Temperature (degrees Celsius)

GAUGE: MT 26 - AP

Indicators of precision of the gauge F(%)

Pressure (bars)						
6500						
6000						
5200		.52	.24	.59	.26	.34
4400	.86	.56	.36	.30	.33	.26
3700	.51	.40	.40	.40	.27	.36
2900	.70	.61	.37	.38	.31	.34
2200	.78	.61	.32	.45	.51	.22
1700	1.20	.68	.21	.57	.51	.35
	-40	- 33	- 13	21	52	63

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge
J (%)

Pressure (bars)	-40	-33	-13	21	52	63
2300	.45	.56	1.2	.77	1.0	.88
2000	1.43	.83	9	.82	4	1.1
1700	3.11	.65	2.6	.59	.82	5
1400	1.90	.92	7	.46	.52	.73
1100	1.37	.64	1.8	.85	1.0	.76
800	1.75	1.2	2	.98	3	.47
500		4	2.1		1.4	.80
			9		0	
			3.5		.90	
			0			
			3.7			
			2			

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge
J (%)

Pressure (bars)	-40	-33	-13	21	52	63
6500						
6000						
5200		.95	.40	.67	1.2	.88
4400	1.66	1.0	.86	.38	6	.75
3700	1.39	3	.79	.39	.79	.78
2900	2.59	.67	1.7	.52	.42	.63
2200	5.04	1.4	7	.63	.62	.91
1700	5.55	5	1.4	1.0	1.0	.65
		1.3	8	1	5	
		0	.81		.85	
		.86				

Temperature (degrees Celsius)

Note: Panel IV (SP/2) may authorise 4% for F for pressures above 4000 bars a temperatures below – 30°C

BOURGES 1990 RANGES AND LIMITS - GE/NL

STANDARD ACCEPTANCE CRITERIA

Indicators of precision (F) and accuracy of the mean (J) of the gauge

Pressure (bars)	F/J (-30)	F/J (+63)
6500 – 4000	(1) 2/4	2/2
4000 – 500	2/2	1/2

Temperature (degrees Celsius): -40, -30, +63

GAUGE: 31/7.1

Indicators of precision of the gauge F(%)

Pressure (bars)	-40	-33	-13	21	52	63
2300	.44	.61	.50	.32	.27	.66
2000	.64	.41	.38	.50	.49	.30
1700	.63	.59	.40	.47	.48	.52
1400	.43	.49	.42	.28	.23	.39
1100	.31	.54	.60	.55	.87	.54
800	.67	.55	1.0	.46	.80	.43
500	.74	.75	1	.53	.86	.72
			1.0 0			

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge J (%)

GAUGE: 38/3.91

Indicators of precision of the gauge F(%)

Pressure (bars)	-40	-33	-13	21	52	63
6500		.79	.65	.55	.24	.48
6000		.55	.46	.58	.39	.37
5200	.72	.50	.47	.41	.53	.37
4400	.47	.70	.70	.48	.62	.53
3700	.74	.68	.72	.54	.47	.75
2900	.61	.33	.47	.64	.57	.53
2200	.76	.68	.74	.70	.57	.54
1700	.53	.61	.91	.52	.47	.81

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge J (%)

Pressure (bars)						
2300	.39	.65	.55	.45	.32	.64
2000	.78	.45	.49	.85	.91	.38
1700	.79	.65	.49	.85	.58	.52
1400	.45	.52	.44	.75	.29	.94
1100	.82	1.0	.59	.60	1.0	.67
800	1.09	7	.97	.55	5	.72
500	1.47	1.4	.96	1.0	1.6	1.2
		2		6	7	0
		2.1			1.3	
		4			9	
	-40	-33	-13	21	52	63

Temperature (degrees Celsius)

Pressure (bars)						
6500		1.6	1.3	2.4	.86	.92
6000		9	6	1	.55	.49
5200	1.59	.61	1.7	1.2	.85	1.3
4400	1.46	1.1	7	0	.74	4
3700	1.76	6	1.6	1.0	.46	.89
2900	.69	2.0	8	0	.60	.77
2200	.99	8	1.4	.57	.65	.57
1700	.76	.98	1	.52	.77	.84
		.39	.85	.74		.87
		.98	.62	.65		
		.75	.74	.72		
			1.9			
			3			
	-40	-33	-13	21	52	63

Temperature (degrees Celsius)

Note: Panel IV (SP/2) may authorise 4% for F for pressures above 4000 bars a temperatures below – 30°C

BOURGES 1990 RANGES AND LIMITS - FR

STANDARD ACCEPTANCE CRITERIA

Indicators of precision (F) and accuracy of the mean (J) of the gauge

Pressure (bars)	F/J	
6500	(1) 2/4	2/2
4000		
	2/2	1/2
500		
-40	-30	+6 3

Temperature (degrees Celsius)

GAUGE: FAN

Indicators of precision of the gauge F(%)

Pressure (bars)						
2300	.45	.59	.60	.57	.52	.58
2000	.74	.34	.70	.54	.66	.58
1700	.75	.63	.69	.55	.55	.66
1400	.53	1.2	.47	.33	.49	.69
1100	.71	2	.56	.70	.76	.65
800	.75	.95	.96	1.08	.97	1.2
500		.67				6
	-40	-33	-13	21	52	63

Temperature (degrees Celsius)

GAUGE: FAN

Indicators of precision of the gauge F(%)

Pressure (bars)						
6500			1.8	.30	.21	.26
6000			5	.21	.19	.14
5200			1.7	.49	.18	.20
			1			
			1.2			
			4			
4400			.22	.37	.25	.31
3700			.49	.31	.32	.26
2900			.55	.22	.37	.29
2200			.44	.28	.40	.17
1700			.75	.38	.54	.44
	-40	-33	-13	21	52	63

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge
J (%)

Pressure (bars)	-40	-33	-13	21	52	63
2300	.45	.81	.58	.83	.50	.56
2000	.72	.54	.84	1.0	.88	.61
1700	.92	.57	.76	5	.69	.68
1400	.61	1.2	.80	.66	.87	.69
1100	1.00	4	.70	.54	.81	1.0
800	1.28	1.4	1.0	.95	.92	9
500		7	8	1.2		1.2
		1.4		3		4
		3				

Temperature (degrees Celsius)

Indicators of accuracy of the mean of the gauge
J (%)

Pressure (bars)	-40	-33	-13	21	52	63
6500			2.99	.84	1.6	1.1
6000			2.02	.47	1	5
5200			1.20	.67	.66	.23
4400			.76	.97	1.2	2.0
3700			1.01	.43	6	1
2900			.83	.97	.80	.95
2200			.72	.91	.50	.49
1700			.79	.75	.48	.43
					.69	1.1
					1.2	2
					4	1.6
						3

Temperature (degrees Celsius)

Note: Panel IV (SP/2) may authorize 4% for F for pressures above 4000 bars a temperatures below – 30^{o}C

Word Definitions

Bias: Is the systematic error, which has not been removed by the taraging process. The systematic error of the mean is labelled **E** in the analysis of results.

Crusher: This component, usually a ball or cylinder, which is subjected to the crushing force and the resulting deformation measured.

Error: The error of a crusher gauge is the corrected measurement minus the true value of maximum pressure. The error comprises bias, which has not been removed by the taraging process and the lack of reproducibility. In the analysis of results the combined bias and random error is labelled **I.**

Gauge: The assembly, which provides the means of applying the crushing force to a ball or cylinder in the breech during the gun firing cycle.

Mastercurves: Pressure values for specific crush values determined for NATO crusher gauges at stated temperatures using a mathematical fit of pressure and remaining length.

Measurand: The maximum value of the gun chamber pressure is the measurand of the measuring system. The true maximum pressure in the chamber is taken to be the mean value of the measurements obtained by a pair of piezo-electric transducers mounted at the same distance from the breech face of the gun. The piezo-electric transducers are traceable to an international standard of hydrostatic pressure.

Measuring System: The crusher gauge when assembled with the crusher element (copper sphere or cylinder) form a pressure Sensor**.** When combined with a suitable dial gauge to measure the remaining length of the crusher element a maximum pressure measuring transducer results. The maximum pressure measuring system comprises: a crusher gauge from an approved manufacturing lot, a crusher element from a taraged lot, a procedure for assembly, loading in the gun and reading the remaining length, a dial gauge and an algorithm relating remaining length of the crusher to pressure and sensor temperature.

NATO Approved Crusher Gauge: Defined as the combination of gauge components and a crusher, for neither the gauge components nor the crusher can be used alone. The Working Group would have approved the crusher gauge and its tarage table or powercurve.

Piezo Electric Transducer: The means of providing an electrical signal which, when interpreted, will provide a pressure/time curve. Its use requires barrels to be drilled in a specified manner.

Pulse width: This is defined as the width of the pulse measured at half the maximum height of the pulse (Figure 2). It is given the symbol **τ** (Tau).

Quality plan. This is a deliverable setting out the specific quality practices/resources and sequence of activities relevant to a particular product/project/contract and must be supplied by the trials authority.

Reliability: The reliability of the crusher gauge is an important indicator of the working range. The reliability is determined by taking the ratio of the number of correct measurements obtained by a type of crusher gauge, to the number of planned measurements that achieved a reliable value for the measurand.

Reproducibility: The reproducibility of a crusher gauge is the closeness of the agreement between the results of corrected measurements of the same measurand carried out under changed conditions. The repeatability of the crusher gauge cannot be determined because the crusher element is plastically deformed during measurement. In the analysis of results the experimental standard deviation labelled **F** is a measure of reproducibility.

Standard Operating Procedures are defined as set of instruction for the use of the gauge to which they refer.

Tarage Tables: Pressure tables relating the remaining length of a deformed crusher to the pressure experienced in the gun breech. There is a series of tables for a set of predetermined gauge temperatures.

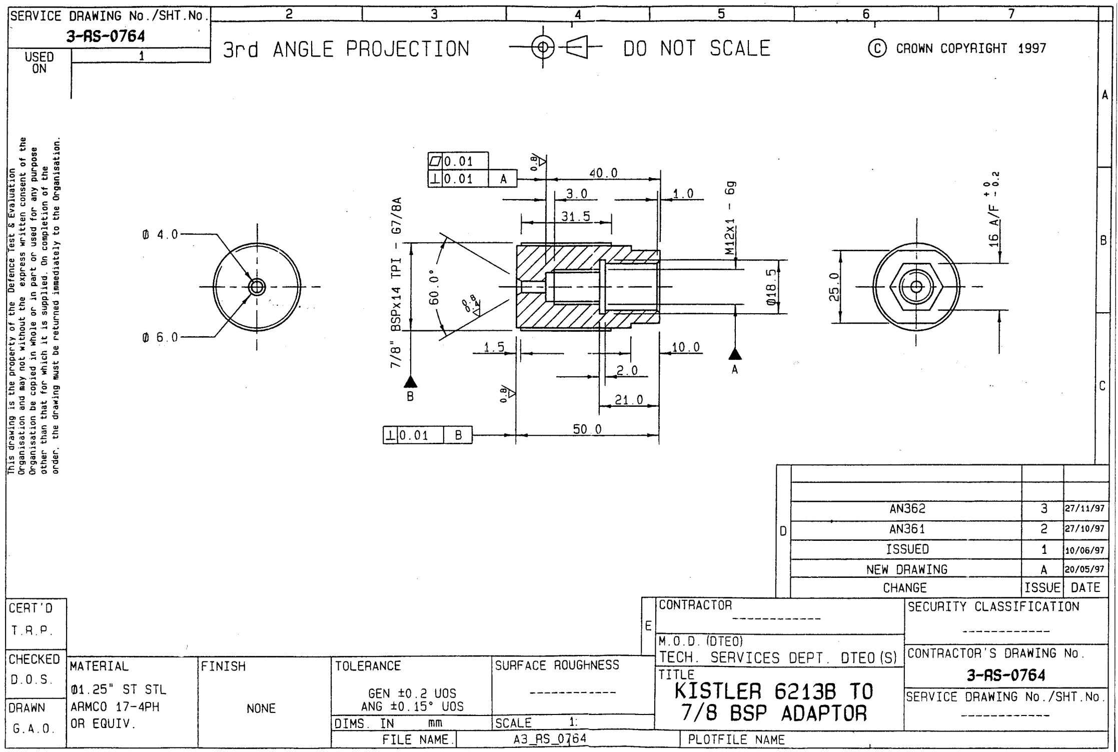
Taraging Trial: The test wherein the Crusher gauges and Crushers are functioned together in a series of gun firings and simulations. Resulting from this a related set of Tarage tables or Mastercurves which are issued and authorized

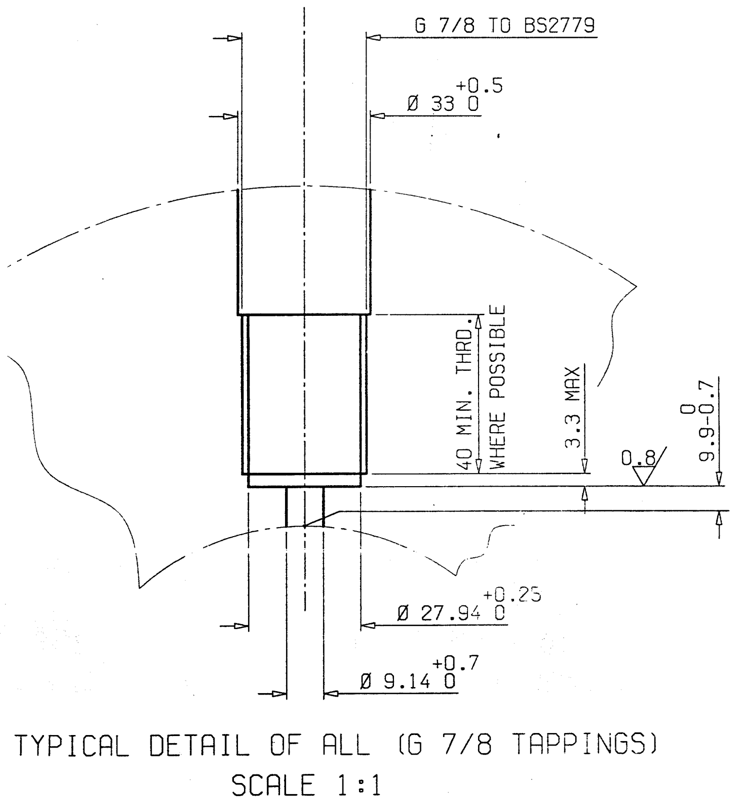
Uncertainty: The closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement (see reference below). For the UK1998/US2002 data (ANNEX A4 - A8) the uncertainty in the analysis is labelled **I.** For the Bourges 1990 data (ANNEX B2 – B6) refer to AEP 23 edition 1 (September 1991).

Working Group (WG). This WG works to Land Group 4 (LG4). It has Terms of Reference sanctioned by Sub Panel 2 (SP2) and controls the content of this AEP. Its main responsibility is to conduct the comparison trial and agree a method of computing the NATO comparative pressures. The Chairman of the WG is normally a Government official from the nation carrying out the trial. The members of the WG are detailed at Annex C.

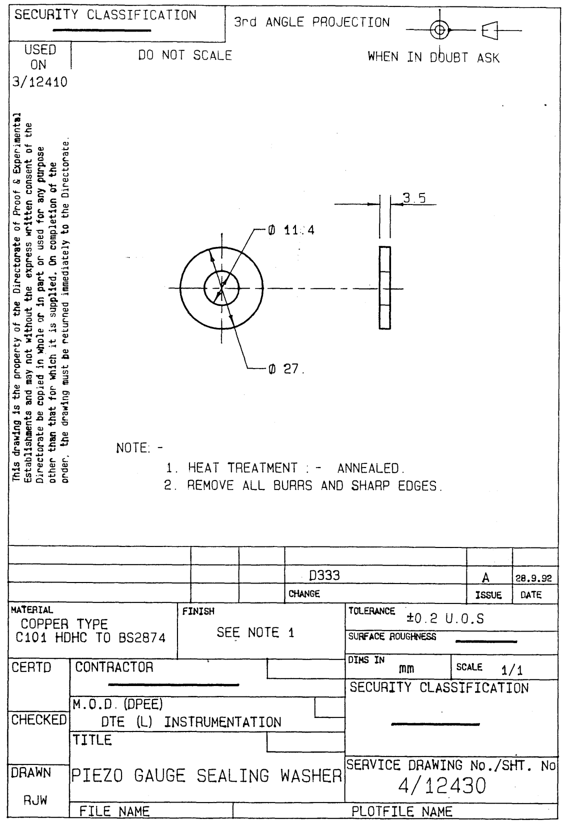
REFERENCE: ISO International Vocabulary of Basic and General Terms in Metrology 1993.

Kistler adaptor used in UK98 trials (Kistler torque 40Nm, Adapter torque 220Nm)





Kistler adaptor hole



Kistler adaptor sealing washer

US 2002 155-MM Gun Firing Matrix

Pressure Level (Mpa) & Round Count

Temperature		50	80	110	140	170	200	230	290	370	Total Rounds
-40		2	2	2	2	2	2	2	2	2	18
-33		0	0	0	0	0	0	0	0	0	0
-13		2	2	2	2	2	2	2	2	2	18
21		4	4	4	4	4	4	4	4	4	36
52		0	0	0	0	0	0	0	0	0	0
63		2	2	2	2	2	2	2	2	2	18

US 2002 120-MM Gun Firing Matrix

Pressure Level (Mpa) & Round Count

Temperature		200	230	290	370	440	520	600	650	690	Total Rounds
-40		2	2	2	2	2	2	2	2	2	18
-33		0	0	0	0	0	0	0	0	0	0
-13		2	2	2	2	2	2	2	2	2	18
21		4	4	4	4	4	4	4	4	4	36
52		0	0	0	0	0	0	0	0	0	0
63		2	2	2	2	2	2	2	2	2	18

Note: Total rounds for 155mm & 120mm equals 90 each.

Taraging Matrix

UK 1997 - Firings				
	Low Pressure	Medium Pressure	Medium Pressure	High Pressure
Gun Firings				
Pressure Range	500 - 2300 bar	1700 - 3700 bar	2900 - 6500 bar	5200 - 8500 bar
Pressure Levels	500, 800, 1100, 1400,	1700, 2300, 3000, 3700	2900, 3600, 4300, 5000,	5200, 5800. 6300. 6900
	1700, 2000, 2300		5800, 6500	7500, 8000, 8500
Gun	155mm	155mm	140mm	140mm
Temperature °C	-40, -33, -13, 21, 52, 63			
Tests	6 Temps	6 Temps	6 Temps	6 Temps
	7 Pressure Levels	4 Pressure Levels	6 Pressure Levels	7 Pressure Levels
	1 Round -40, -33, -13, 21,	1 Round -40, -33, -13, 21,	1 Round -40, -33, -13, 21,	1 Round -40, -33, -13, 21,
	52, 63	52, 63	52, 63	52, 63
	2 Round -40, -33	2 Round -40, -33	2 Round -40, -33	2 Round -40, -33
Rounds per Series	70	40	60	70
Oil Vessel				
Pressure Range	500 - 2300 bar	1700 - 3700 bar		5200 - 8500 bar
Pressure Levels	500, 800, 1100, 1400,	1700, 2300, 3000, 3700, 4300, 5000, 5800, 6500		5200, 5800, 6300, 6900
	1700, 2000, 2300			7500, 8000, 8500
Oil Vessel	LP	LP		LP & HP
Temperature °C	-13, 21, 52, 63			
Tests	4 Temps	4 Temps		4 Temps
	7 Pressure Levels	8 Pressure Levels		7 Pressure levels
	5 Rounds	5 Rounds		2 Rnds (LP) 4 Rnds (HP)
Rounds per Series	140	160		88

Working Group 1 on measurement of internal pressures in large calibre weapons systems

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