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THE ASSESSMENT OF SMALL ARMS
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Development of a Ballistics Range for the Assessment of Small Arms Ammunition

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Abstract

As part of the Australian programme for the development and assessment of small arms ammunition a facility has been developed at the Materials Research Laboratory, Melbourne, in which the phenomena associated with the bullets in flight and during penetration through simulated targets can be studied.

This paper describes the development of the ballistics range and its specialized instrumentation.

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1. *Introduction*

For research and development work on the terminal ballistics aspects of small arms ammunition, an accurate knowledge of projectile positions and attitude in space and time is essential. This type of information may be obtained in a ballistics range which permits accurate radiographs and photographs of projectiles to be taken.

As part of the Australian programme of studies in wound ballistics, a facility has been developed at the Materials Research Laboratory, Melbourne, in which the phenomena associated with the penetration of small arms ammunition through tissue simulants can be investigated.

The object of the range instrumentation is to record the trajectory, yaw and velocity of a projectile prior to target impact and to study its behaviour while it is passing through and exiting simulated targets. Initially, work to assess the accuracy of the instrumentation used in the ballistics range was undertaken with firings of sabot launched steel spheres 6 mm in diameter.

The instrumentation in the ballistics range is a flash X-radiography system containing up to ten units, high speed cinephotography and instrumentation to measure entry and exit velocities of projectiles; with control, sequencing and recording systems operated from an instrument control room.

2. *The Range*

The MRL ballistics range is 150 m long and consists of a tunnel formed from sections of commercial drainage pipes. At one end is the instrumented stop butt with adjacent storage and preparation facilities, and at the other is the instrument control room (Fig. 1). Firing stations with separate access are let into the tunnel at

50, 100 and 150 m, and temporary firing positions can be set up within the tunnel if necessary.

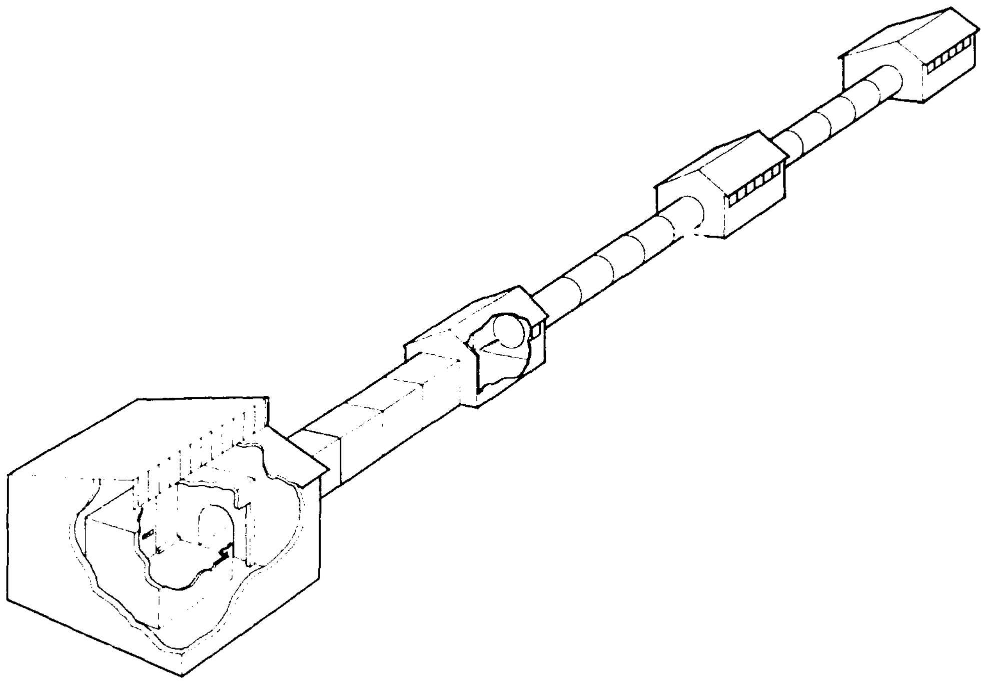

Figure 1: MRL ballistics range, from left the instrument and stop butt room, 50 m, 100 m, 150 m firing stations and the instrumentation control room.

The first 50 m of tunnel adjacent to the stop butt consists of square section culvert pipes of height 2.2 m and set on a solid concrete base suitable for fixing a gun mount at various distances from the target. The sections from the 50 to 150 m stations consists of 1.6 m diameter concrete pipe.

The instrumented stop butt is built with 800 mm reinforced concrete walls with horizontal and vertical port holes formed within the walls and ceiling to position the required instrumentation. Entrance to the stop butt is gained through steel doors. The rear concrete wall is protected by a 5 mm steel cladded cavity wall with its 150 mm cavity filled with sand.

Cabling is directed along the range with connections being made through specially designed patch panels situated in the control room, each of the firing stations, and in the instrumentation area of the stop-butt.

The projectile catcher is a wooden box (0.6 × 0.6 m deep) filled with sand. The front of the catcher consists of a 6 mm sheet of neoprene sandwiched between two sheets of commercial caneite. It was found that this type of catcher lasts for over a hundred shots before the front has to be replaced. The catcher is mounted on a trolley for easy positioning.

3. Instrumentation

3.1 Flash X-Radiography Instrumentation

The flash X-radiography (FXR) system consists of 300 kV Fexitron units with up to ten remote FXR tube heads being used at any one time. This system has four perpendicular and four horizontal remote heads to give eight orthogonal images and another pair of heads positioned within 45° holes drilled in the walls to view the target. The remote heads are located as shown in Figure 2. The x-ray beams are restricted by lead apertures to prevent "cross" exposures.

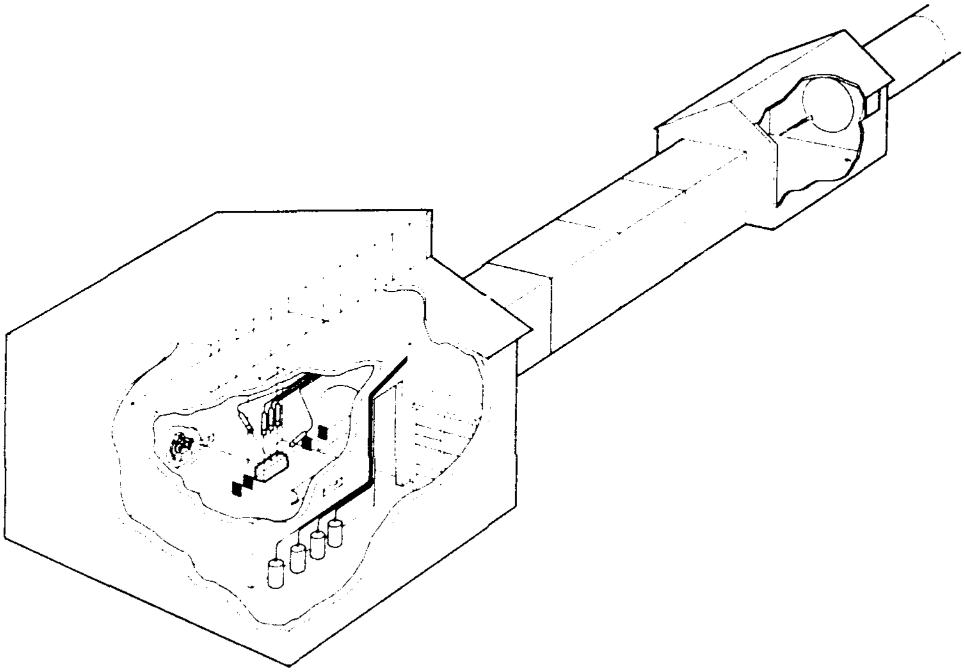

Figure 2: Flash x-ray system, high speed camera system, ballistics screens, sky screen and rifle position (50 m) used during experiments.

We use soft x-ray tubes type 5153 (dual head) for the study of the behaviour of various projectiles with soft target simulants. Best images are obtained when the tubes are positioned 1.6 m from the target and the film positioned 100 mm behind the target. Exposure time of the FXR is approximately 20 ns. The tubes are triggered at a predetermined time set by delay trigger amplifiers and initiated by the projectile penetrating a ballistics screen positioned close to the target within the stop butt.

Best results are obtained using Agfa-Gevart intensifying screens, type Curvix MR 800, and Kodak XO-MAT type XRP-5 film. These are enclosed in double light proof plastic envelopes and protected by a 10 mm thick sheet of lexan.

An automatic film processing machine was designed and installed to provide reproducible processing of exposed radiographs. The system is based on a dip-and-dunk principle commonly used in film photofinishing laboratories. It allows a wide range of processing conditions with independent control over time, temperature and agitation. The optimum processing conditions for flash radiographs which use Kodak XRP-5 film and Agfa MR 800 intensifying screens are 4 min at 24°C with nitrogen agitation for 5 s every 30 s. Films are processed to achieve an average contrast in the vicinity of 2.2. Kodak process control monitoring is used to monitor processing solution activity and provide a guide for maintaining consistent processing solution replenishment with an automated system.

Flash X-radiography may be used as the sole instrumentation or in a combination with high speed cinematography equipment (Fig. 3).

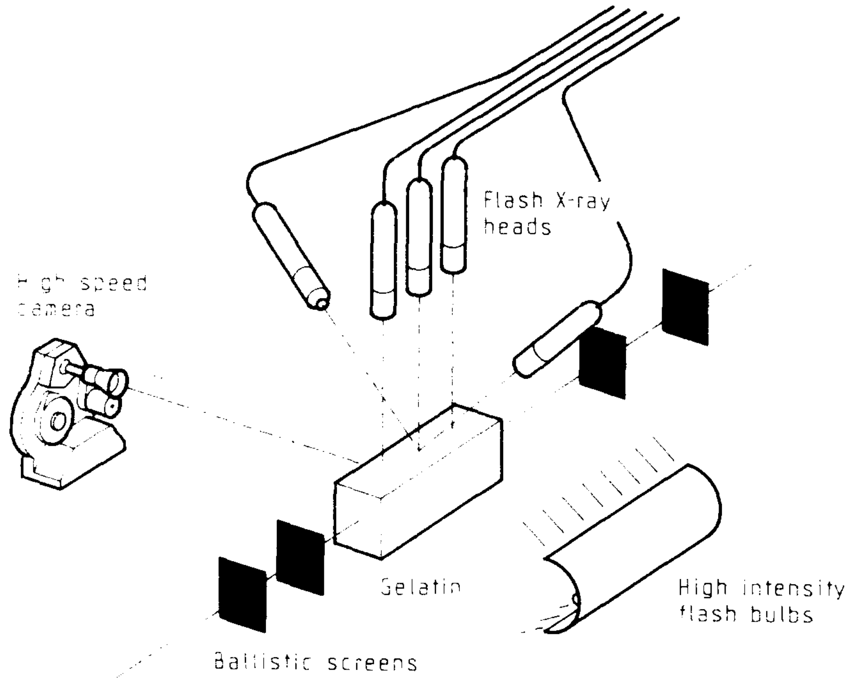

Figure 3: Flash x-ray system, high speed camera system and ballistics screen geometry.

3.2 *High Speed Cinematography Instrumentation*

The high speed camera used is a 16 mm half-frame Hycam, positioned to give a horizontal view of the target. The spatial orientation and position of the projectile are recorded when the camera is running at a framing rate of about 12 000 frames per second. The exposure time for each frame is approximately 1.6 ms. An accurate reference for the camera's framing rate is provided by a 1 kHz time base imaged onto the film edge. A time zero reference is provided by a marker pulse imaged onto the film record at the instant at which the first FXR unit fires.

Where the surface detail of the projectile is required, direct illumination is provided by flash bulbs positioned in front of the projectile. When it is required to study the projectile within the target (gelatin block) a bank of ten diffused flash bulbs positioned at the rear of the target is used to silhouette the projectile. Synchronization of the projectile's entry into the target with peak output of the flash bulbs is obtained using a ballistics screen to trigger the flash bulb firing unit at the flash bulb rise time, in our case 25 ms, prior to the projectile entering the target.

3.3 *Velocity Measurement Equipment*

The velocity of the projectile on entry to, or exit from, the target is measured using ballistics screens or a commercial optical velocity measuring system. Each system is mounted on mobile trolleys, with their detectors 1000 mm apart.

(a) Ballistics Screens

The ballistics screens are a simple, low cost but extremely accurate (better than 1%) means of measuring velocity. They were designed and constructed at MRL. Each screen consists of two sheets of aluminium foil separated and electrically insulated by a layer of commercial nylon mesh fly screen, one of the sheets of foil is raised to a potential of 150 V.

An electrical trigger pulse is generated as the metal projectile passes through the screen. The first screen pulse triggers the start circuit of a 1000 Hz time interval counter and the second screen pulse stops the counter on impact of the same round. From the measured time interval of the projectile travelling the 1000 mm separation distance between screens, we are able to calculate the velocity of the projectile. These screens are very suitable for measuring exit velocity as, in addition to velocity, the trajectory can be accurately calculated after passing through the target.

(b) Optical Velocity System

In addition to the aluminium screens the ballistics range has a Projectile Velocity Measuring System Type 758 constructed by M.S. Instruments Ltd.

This system contains two detectors each consisting of a 50 mm camera lens focusing on to an opto electronic device which translates a change of light intensity into an electrical signal (Fig. 4). As the projectile passes over each detector, it reduces the amount of light collected by the lens by a small fraction. The shadow so produced is translated into an electrical signal which is processed by a remote control unit and then used to start and stop an electronic timer.

The detectors are aligned so that their centre lines are parallel and positioned directly beneath a DC light source. The light sources are 450 mm strip lights powered by a 120 V DC source power supply. The mobile trolley holding the system may be positioned anywhere in the first 50 m section of the tunnel. The signals are transmitted along 12 core cable to the remote control unit and electronic timing equipment in the instrument control room.

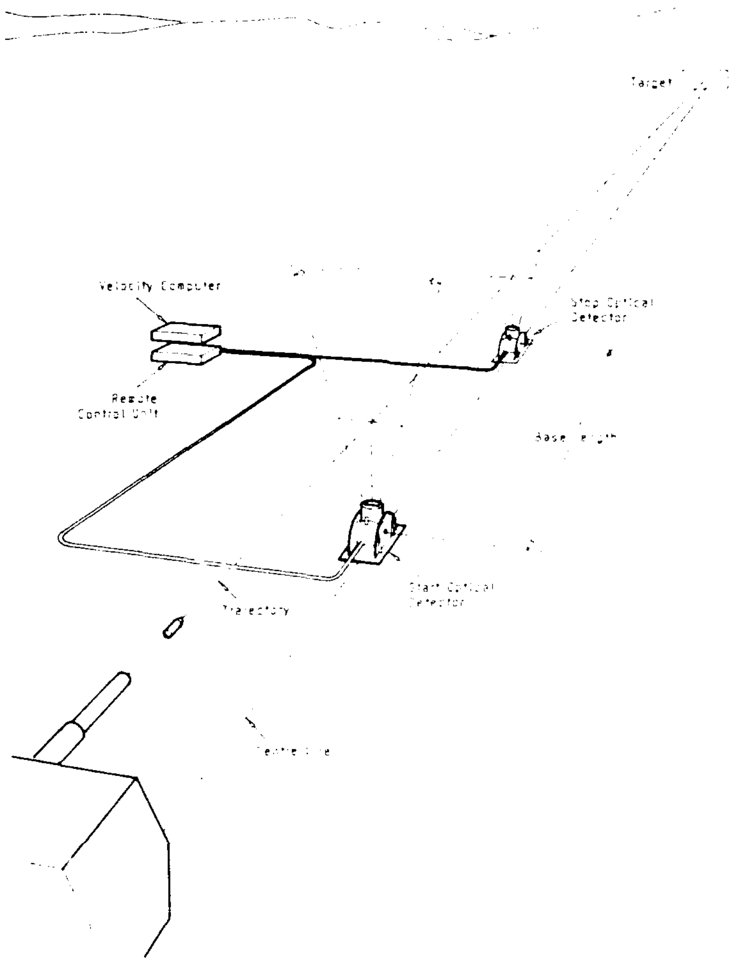

Figure 4: Projectile velocity measuring system.

The remote control unit provides the power supplies necessary for the operation of the optical detectors. It receives and processes the pulses generated by the detectors into a form suitable to operate a microsecond chronometer. Individual gain controls are provided to allow the sensitivity of each detector to be adjusted for maximum accuracy according to height and calibre of the projectile.

3.4 Operating Sequence

The firing sequence is started by remotely actuating the high speed camera. Once the required camera framing rate is reached this camera provides a signal for the firing unit to energize a solenoid which in turn triggers the rifle to fire the projectile down the range.

The projectile travels through a ballistics screen, producing an electrical pulse which triggers the high intensity flash bulb firing unit.

Further down range the projectile passes through the MSI Projectile Velocity Measuring System to record the entry velocity.

Just prior to entering the target area the projectile passes through the flash x-ray triggering screen which produces the pulse to commence the firing sequence of the FXR units. The flash x-ray heads are sequenced to record various stages of the projectile travel in the target.

On exiting the target the projectile triggers the exit velocity screens. The high-speed camera records the projectile behaviour within the gelatin block and cavity activity for some short time after the projectile leaves the target.

A diagrammatic representation of the firing sequence is given in Figure 5.

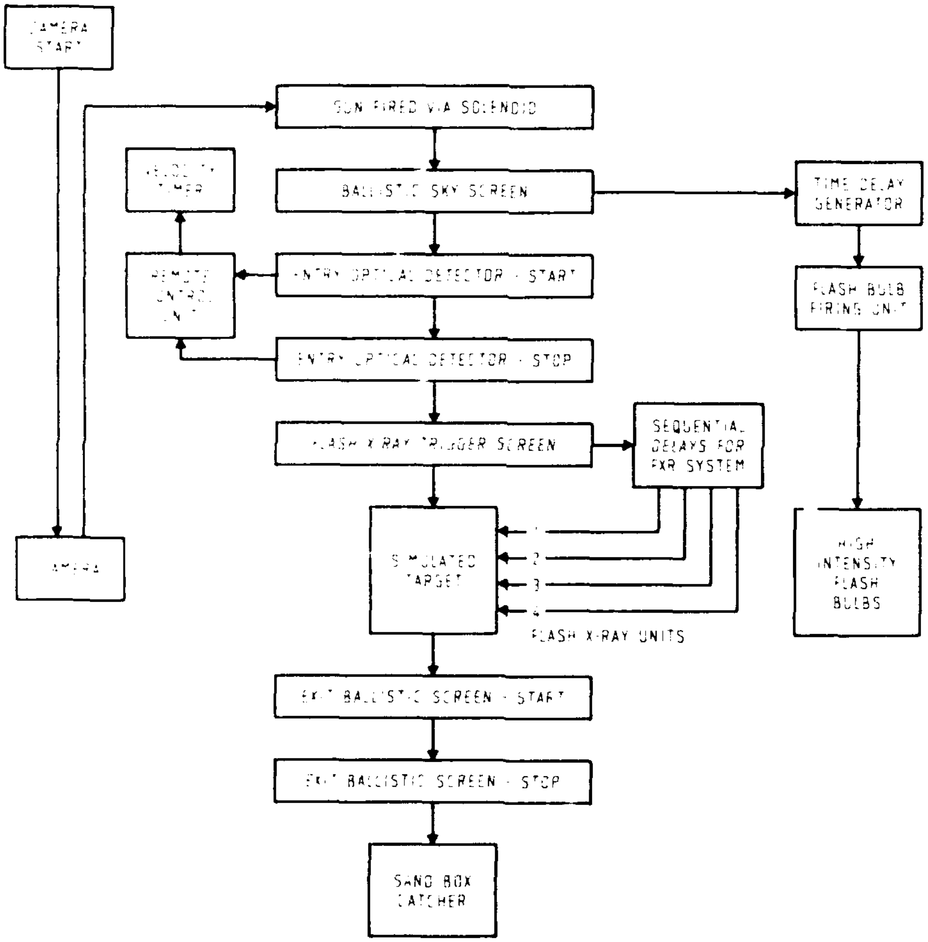

Figure 5: Instrumentation firing sequence.

4. Safety Features

The ballistics range has four entry points and with extremely high voltages and large doses of x-radiation in use, as well as hazards of firing projectiles, special safety features have been built into the range.

4.1 High Voltage Precautions

The high voltage power supply is housed inside an interlocked instrumentation console, this high voltage supply cannot be operated until the console door is locked. The high voltage control unit is situated up range in the instrumentation room, this unit cannot be operated until all flash x-radiography equipment interlocks are closed. A special earthing system, independent of the mains supply, is installed in the high voltage pulser area. The high voltage generating system earths are connected to these earth points and are checked on a regular basis. Standard high voltage safety practices are observed during all operations.

4.2 Radiation Exposure Precautions

A "Radiation About to be Produced" warning system is installed in the stop-butt. A flashing red light, buzzer and cut-out button are connected to the interlock jack of the high voltage control unit. This system warns personnel who may be inadvertently locked in the stop-butt that x-radiation is about to be generated and the cut out button can be operated to prevent generation of x-rays.

4.3 General Safety Precautions

Weapons are fired by a remotely operated electrical solenoid controlled by a firing unit in the instrumentation control room. All external doors of the range and the firing unit are fitted with the Castell interlock system. The four Castell door keys must be trapped in the key exchange box before the firing unit key can be released and removed. This ensures that no one can enter the range during firing operations.

There is a warning bell and a flashing red light outside each firing station to warn passers by that a firing is imminent.

5. Reference System

5.1 Instrumentation

To ensure that all instrumentation gave concordant results of projectile calculated velocity from direct timing or measurement of position a series of firings was undertaken. For these firings we used a 6 mm steel ball bearing held in a specially designed sabot (Fig. 6) and fired from a 7.62 mm rifle. The velocity profile of the ball was studied as it travelled along each section of instrumentation field of view.

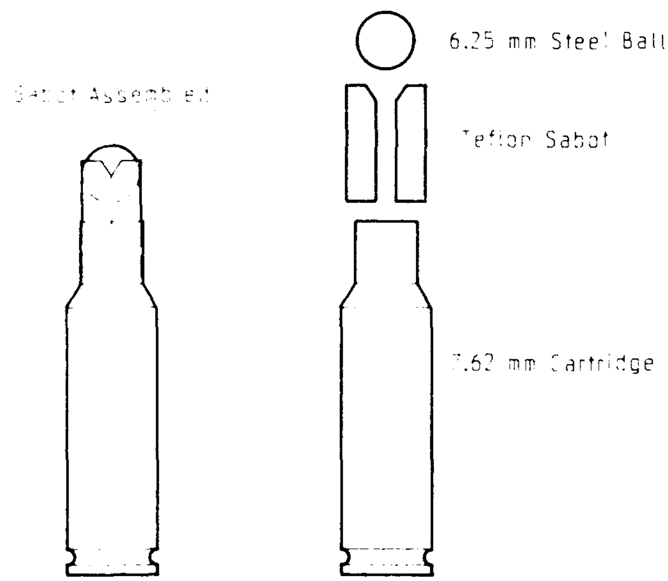

Figure 6: Sabot for firing 0.625 mm steel ball.

A reference bar with orthogonal points was placed on the target stand so that it was in the field of view of both the flash x-radiation system and the high speed cinematography. Copper reference wires were placed on the x-ray cassette directly beneath the centre point of each flash x-ray tube (Fig. 7). Markers set 100 mm apart were used as reference points for high speed cinematography.

5.2 Data Extraction

Velocities from the MSI system and exit screens were calculated directly from the time taken for the ball to pass through the start-stop screens for each system.

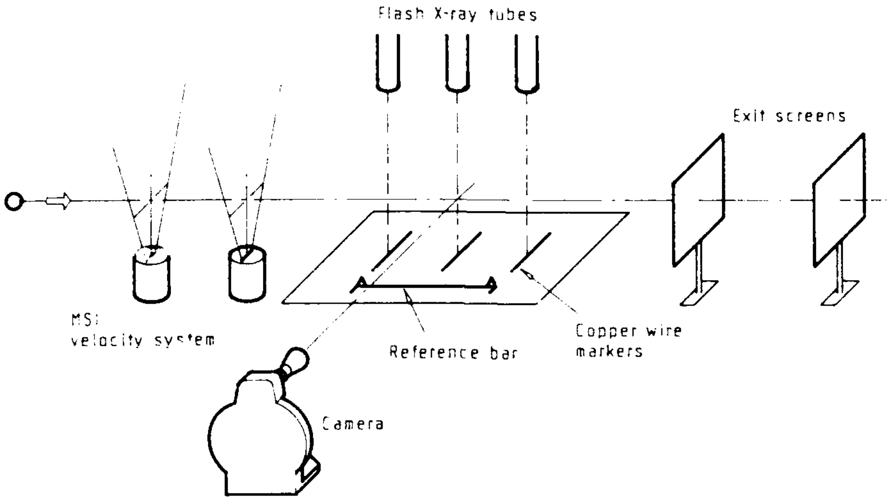

Figure 7: Instrumentation reference system.

The flash x-radiograph units were triggered with delay times set to the best estimate of the ball to be positioned precisely above the graduation wire. The small differences between images of the ball and wire were measured using an Opto-Rule with a graduated viewer. FXR measurements of velocity were calculated using corrected delay trigger amplifier times and the measured distance travelled by the ball.

The high speed cinematography data were extracted from the film records using a Vanguard Film Analyser. The camera was positioned at a fixed distance from the line of fire throughout the experiment. Camera framing rates were selected so that fourteen frames were exposed while the ball was in the field of view. A correction for parallax was applied when the ball did not pass directly over the reference markers. Using the 1 kHz time base imaged on the film edge as a standard, the time between film frames was calculated. From this time several measurements of the velocity of the ball could be determined as it travels across the field of view of the high speed camera.

A series of calibration shots were fired and velocities calculated using data obtained from the instrumentation. Velocities obtained from four of the firings are given in Table 1.

Results show that the different techniques of determining velocities gave the same result within experimental error.

Table 1:

Shot No.	Velocity m/s						
	Entry Screens	Flash X-Radiography			High Speed Camera		Exit Screens
		First Flash	Second Flash	Third Flash	Entry Section	Exit Section	
1	770	777	744	746	761	761	740
2	649	642	638	636	640	635	638
3	769	757	760	758	756	742	752
4	752	746	741	743	732	728	-

6. Applications

The ballistics range has been very successful in the study of scientific parameters of small arms firings. Some of these studies are recorded in the applications given below.

6.1 Wound Dynamics Studies

The primary aim of the study was to obtain an overview of the penetration dynamics of typical bullets (7.62 mm and 5.56 mm) at realistic ranges, and to evolve a methodology for the interpretation of penetration data.

Entry velocity of the bullet was measured using the M.S. Instruments projectile velocity measuring system Type 758. The bullet impacted the tissue simulant (20 percent gelatin block) and its motion within the block was monitored by a 16 mm half-frame Hycam cine camera operating at 12 000 exposures per second. Trans-illumination of the block was provided by a block of six photo-flash bulbs, GEC Type 2. A bank of four flash x-radiation heads above the block, triggered in sequence, produced a more precise record of the bullet position, attitude and integrity than was obtainable from the cine film. An additional pair of flash x-ray heads were located to produce an orthogonal view of the bullet at a point approximately 200 mm into the block.

The experimental data (impact velocities, cine records and flash radiographs) were processed to obtain estimates of the kinetic energy lost by the projectiles in penetrating to various depths in the gelatin block, and to obtain information on the characteristic deformation behaviour of the projectiles [1, 2].

6.2 *Comparative Measurement of Small Arms Muzzle Flash*

Weapons fired at night provide a visual cue to their position unless muzzle flash is effectively damped. During the preliminary assessment of the Steyr rifle MRL compared the muzzle flash of various small arms weapons, namely the Australian 'Steyr' rifle with M16, M60, L1A1 and a Minimi.

Two methods were used to compare the flash. Firstly, the standard method of photographically comparing the size of the flash, but this method is limited in its accuracy and is tedious to carry out.

We developed a new method for comparison between flash signatures, where the flash is focused through a camera onto a photomultiplier and the output recorded on a cathode ray oscilloscope and printed on a recorder. The detector equipment was set up six m down range from the weapon and offset 6° from the line of sight [3]. The ballistics range is ideally suited for simulated night firings as complete sections can be screened against light entering.

6.3 *Comparison of 5.56 Bullets*

A series of firings of several types of 5.56 mm ammunition was undertaken with the aim of comparing their integrity and stability when fired through a block of 20 percent gelatin specially selected for ordnance experiments. In this exercise firings were carried out in the ballistics range at 20, 50 and 100 m from the target.

Shots were first fired through the field of view of the flash x-radiography instrumentation without the gelatin block to assess the projectile yaw in air [4].

Bullets were then fired from the specified range into blocks of transparent gelatin monitoring the behaviour of the test bullet by means of flash x-radiography records, and subsequently visual inspection. The onset distance, defined as the distance along the track from bullet entry to the first appearance of yaw, was the most useful visual information.

6.4 *Measurement of Yaw Induced in Bullet Flight*

A spin-stabilized bullet flies with its long axis nearly coincident with its trajectory unless disturbed by some unbalancing force. If a bullet passes through a minor obstruction such as foliage or vegetation a series of minor but cumulative disturbing forces is experienced.

The ballistics range was used for experiments to establish a technique for measuring the yaw in bullet flight caused by passage through a light foliage obstruction, to evaluate the use of spaced caneite sheets as a foliage simulant, and to provide data on yaw behaviour of standard 7.62 mm and 5.56 mm bullets.

On emerging from the foliage the yawing bullet passed through the fields of view of two orthogonal banks of flash x-radiography (FXR) tubes with four tubes in each bank. The FXR triggering sequence was set to give the four pairs of images a convenient spacing on the x-ray film. The path length over which the FXR images were obtained was about 420 mm with an elapsed time of 550 ns [5].

It was found that as little as half a metre of foliage typical of forest density of 400 tonnes per hectare induced a yaw angle often exceeding 90°.

6.5 *Testing of Cladding Material for Telecom Repeater Stations*

Telecom have several repeater stations situated in outback Australia, some of which are vandalized by shooters with high powered rifles. The ballistics range was used to test several types of protective cladding against 7.62 mm ammunition. All the materials supplied by Telecom proved to be unsatisfactory, most failing after the second shot at the same target.

We recommended the system we used to protect the rear wall of the stop-butt, described earlier in this report. In brief the material is a sandwich of 5 mm mild steel cavity wall with the 100 mm cavity filled with bricklayers sand. This material withstood several shots hitting in the same area.

6.6 *Flash X-radiography of High Velocity Water Jets*

High velocity water jets are finding application in the demilitarization and disposal of explosives ordnance. Water jets, either continuous or discrete, can penetrate a thin case and disperse the explosives filling without initiating a reaction.

Using a propellant driven water cannon set up in the ballistics range with its nozzle just in the field of view of the flash x-radiography (FXR) system we were able to study the characteristics of the jets on FXR film. In this study a laser beam focused across the nozzle was used to trigger the FXR system. We set up "soft" x-ray tubes and used 180 kV pulse voltage to give us a very good water jet image. By sequential triggering of the tubes we could calculate the velocity of the jets.

7. *Summary*

The ballistics range described above has proved highly successful in the study of various military small arms ammunition both in flight and on impact. The flash x-radiography system is an accurate method for studying the quantitative behaviour of projectiles in gelatin.

The range has proved particularly useful in penetration-dynamics studies associated with wound ballistics.

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