FIRING RANGES:
PRINCIPLES AND TECHNOLOGIES LEADING TO ITS IMPROVEMENT

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ABSTRACT

The study of firing ranges involves the identification and assessment of the different phenomena regarding safety requirements, environmental issues and occupational safety and health hazards regarding noise and lead exposure. After describing the source, means of propagation and effects of those phenomena on firing ranges and on people, the different methods and technologies for optimization of outdoors and indoors firing ranges' are presented. Concerning safety, the need to include adequate bullet traps, safety baffles, side walls and steady covered firing lines on the range layout is pointed out. Regarding noise control, the need for surrounding firing lines with sound barriers and treating them acoustically, and implementing the use of hearing protection devices was identified. On indoors firing ranges the sound isolation requirements must be met. Regarding lead exposure, the main protection systems consist of lead management practices, on outdoor firing ranges, and of well-designed ventilation systems, on indoor firing ranges. The major relevance of implementing health, hygiene, and safety plans was showed both for indoor and outdoor firing ranges. The results presented showed the urgent need to deepen the paragon enhancements already felt on the planning and construction of the 20th century firing ranges. This new paragon will be applicable both on new firing range sites and on the improvement of older ones.

KEYWORDS

Firing range; Safety; Range layout; Noise control; Lead

INTRODUCTION

The Portuguese Army firing ranges are mostly still located according to the original regulations and manuals, which date back to the end of the 18th Century. The concept beneath its design was based on the proximity to the barracks, and on the displacement of a broad surface danger area. For the last centuries, the enlargement of the urban limits of cities and towns has been placing these lands under the pressure of the building industries, and political interest.

Simultaneously, the professionalization of the Army, which fully occurred in 2004, brought deep changes to the firing instruction charges. Moreover, the reorganization of the Army unit's staff which attributed the responsibility of managing firing infrastructures to departments without the necessary means to respond to that, led many of these to a degradation of the existing conditions.

These facts raised the urgent need to promote a reorganization of the territorial display of firing ranges, which demands a proper evaluation and assessment of the phenomena regarding firing practice, according to the actual pattern of needs in the matters of safety and security.

Nowadays, this pattern requests the economical sustainability of firing ranges, which regards especially what concerns occupational noise and lead exposure and the environmental aspects related both with noise and lead, besides the ballistic safety.

This research work gathers a broad amount of information, creating a handbook of methods and solutions, which are described and discussed, providing effective tools to plan, conceive, and design new firing ranges, or assess and improve existing ones.

THEORETICAL BACKGROUND

Concepts

The regulations applicable to the Army concerning firing ranges are the administrative regulation RAD-38-1 and the technical manual MT-38-2. These don't apply to firing ranges for civil use, which are regulated by RTFSCCT. Although the time lapse between their publication (the first two date back 1988 and 1989, and the last one dates 2007), their definition of firing range is quite similar, stating that firing ranges are permanent infrastructures destined to the practice of firing with portable weapons charged with single bullet, usually referred to as rifle firing ranges. According to the last one, firing ranges can be classified as indoors or outdoors, whenever they are enclosed between permanent walls and ceiling, providing full containment or just enclosed by earthen embankments or berms, which only provide partial containment (ETL-06-11).

According to RAD-38-1 and MT38-2, either outdoor or indoor firing ranges must physically comprehend three distinct areas: the service area, the firing area and a surface danger area. The service area should be right next to the firing area, and may include administrative structures, barracks, target and weapons storage, walkways, parking lots, toilets and other infrastructure that may be considered useful. The firing area is where shooting is executed, and must include the range floor, a firing line, a target line, safety baffles, water and power supply and other specific equipment. The surface danger area is an area surrounding the firing range, where there is the possibility of projectile impact, shot from the firing range presupposing certain firing conditions.

Ballistic safety

RAD-38-1 defines two kinds of projectile trajectories resulting from weapon shooting activity in firing ranges: direct fire and ricochets. The direct fire includes all the trajectories which start and end without any deflection, and includes fire shot wrong and accidentally. Ricochets are all the other fire that suffers any kind of deviation or deflection before being stopped.

Usually, the direct fire trajectories are grouped under a dispersion pattern, which can be defined by the group of shots made by the same shooter, under the same conditions, towards the same target. The present study admitted the dispersion pattern of the automatic rifle G3 7,62 mm, used broadly in the Portuguese Army, which is defined by MT-38-2 in the following terms:

- Accuracy practice: up to 8º elevation and up to 5º direction (horizontally);
- Instinct practice: up to 14º elevation and up to 9º direction (horizontally).

The most prominent feature of the ricochet trajectories are their random character, which depends on the angle of incidence, resistance and deformability of the materials that are hit, the tension of the direct trajectory, the speed of the projectile and its geometry and composition. It is known that the probability of ricochet is larger when the angle of incidence is near 0º, and that when this angle is near to 90º, the probability is smaller, an therefore the projectile penetration is more likely.

According to MT-38-2, under good conditions, the maximum ricochet angle is 20º to 30º in every direction (elevation and direction), reaching 45º under bad conditions.

The range layout is the set of all the safety structures the function of which is to stop the shots fired from direct and ricochet trajectories, vertically and horizontally, absorbing all of its kinetic energy.

Noise

By definition, noise is an unwanted sound, or a sound of random nature, the spectrum of which does not exhibit distinct frequency components (Harris, 1991). Virtually every problem in noise control involves a system composed of three basic elements: a source, a path, and a receiver (Beranek, 1971; Harris, 1991).

Besides its physical phenomena, sound has a strong subjective component influenced not only by the nature of the path and the spectrum of noise, but also by psychological factors (Beranek, 1971), as the acceptability degree of the source path, as shown by studies developed cited by the Army's Comissão Técnica da Carreiras de Tiro (CTCT) or by the US's National Rifle Association (NRA) (2004).

The primary sound source in firing ranges has its origins essentially on the detonation component of the sound produced when firing a gun. The detonation, or explosion, starts a spherical sound wave centered on the muzzle of the gun. According to CAPS (1985) the detonation produces an impulsive noise of high intensity, with short duration and broad frequency spectrum. Peak sound pressure levels may rise to 160 dB, at 20 cm from the muzzle (CAPS, 1985; ETL 06-11), and depends essentially on the kind of ammunition fired.

The analysis of the octave band frequency spectrum shows a large energy distribution, with energy from the lower frequencies, below 20 Hz, to the higher, near 20000 Hz. On the region of the low frequencies (from 20 Hz to 200 Hz), it is shown a predominance of energy below 50 Hz, reaching 10 Hz (region of the ultrasound).

The sound transmission path in firing ranges is aerial, and can be described by the laws of sound propagation in the open air and in enclosed spaces, respectively for outdoor and indoor firing ranges.

Concerning the receiver, whilst inside the firing area the occupational hazard of noise exposure must be considered, outside this area, the environmental impact of noise might become a source of noise pollution. Both aspects are regulated respectively by the Decreto-Regulamentar n. º 9/92 de 28 de Abril, and Regulamento Geral do Ruído (RGR), which define the criteria for occupational noise exposure and ambient noise. The Army ranges are also under the criteria defined by the North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 2899. All the criteria must be related to impulsive noise, which could mean being diminished 12 dB (A), corresponding to more incommodity produced by impulsive sound when compared to an equivalent continuum sound level. These criteria are summarized as showed below:

- permissible daily occupational noise exposure limit: 90 dB (A);
- permissible sound level peak limit: 140 dB;
- whenever these limits cannot be achieved, the use of individual hearing protection devices is mandatory;
- permissible equivalent continuum sound level limit of 53 dB (A) [65 dB (A) -12 dB (A)], during day time (from 7 to 22), and of 43 dB (A) [55 dB (A) – 12 dB (A)], during night time (from 22 to 7);
- noise levels can't exceed ambient noise level in more than 5 dB (A) during day time, and 3 dB (A) during night time, and being corrected in 3 dB due to his impulsive nature;
- all permanent noise activities should be submitted to environmental impact assessment.

Numerous studies document the hazardous effects noise has on human hearing and its physiological effects.

Lead

Lead is a naturally occurring element that can be found in many forms. In its metallic form, lead has very low reactivity. However, it can also be found in the form of various lead compounds, some of which can be readily absorbed into the bloodstream. Most lead used in ammunition is in the metallic form used on the bullet or projectile, and a small amount of lead compounds, as lead styphnate and lead azide, is in the primer [National Association of Shooting Ranges (NASR), 2005].

Although the lead source is ammunition, lead exposure in firing ranges results form the following processes:

- during firing, hot gases can vaporize lead in the bullet;
- as the bullet leaves the barrel, the hot expanding gases from the detonation will leave the muzzle in all directions. These expanding gases and the pressure shock can cause disturbances in the air around the breathing zone of the shooter;
- because of their density and the effect of gravity, lead particles will settle out of the air quickly, coating the surfaces immediately downrange from the shooter with a fine lead dust;

- all the layout elements, which stop, deflect or absorb the impacts of bullets are source of lead and lead dust [Navy Environmental Health Center Technical Manual (NEHC-TM6290.99-10); National Rifle Association (NRA), 2004; NASR, 2005].

Regarding the occupational hazards, lead exposure occurs by inhalation of dust and fume and ingestion of lead contaminants on surfaces (Barsan, 1996; NASR, 2005)[1]. These are regulated by Decreto-Lei n. º 274/89, de 21 de Agosto, and are summarized below:

- action level: 75 micrograms of lead per cubic meter of air (75 $\mu g/m^3$) as an eight-hour time-weighted average (8 hour corresponding to a full workday);
- permissible exposure limit: 50 $\mu g/m^3$ as an eight-hour time-weighted average;
- blood lead level: 70 micrograms of lead per deciliters of whole blood (70 $\mu g/dl$).

While the occupational hazard of lead exposure is usually related with indoor firing ranges, concerning the environmental impact, there is high probability of occurring lead contamination of soils and water resources in outdoor shooting ranges. The major factor that determines how lead interacts with the environment is the acidity of the soil and water the lead is exposed to. Lead is least active at very slightly acid to very slightly alkaline pH, or between pH 6,5 and 8,5. It might cause environmental problems only if it becomes active or mobile, which can happen if lead becomes:

- dissolved or associated with fine suspended sediment particles in ground water or surface water that people or wildlife drink;
- eaten accidentally by wildlife while feeding;
- associated with dust particles that may be inhaled, particularly during recovery/recycling operations.

OUTDOOR FIRING RANGES

Ballistic Safety

Traditionally, outdoor range's layout consisted of earthen backstops and berms and fewer overhead baffles, which demanded the existence of large danger areas. Today, outdoor ranges must be designed under the fundamental aspect of reducing danger areas to its minimum extent, when it isn't affordable or possible to eliminate them.

Earthen backstops and berms can be designed according to specific criteria found both on MT-38-2 and on NRA (2004). Their biggest advantage is their initial costs, because usually earthen elements take advantage of natural terrain features, and, in normal conditions, can be built with local soils. Another advantage is its high sound absorption rate, especially when covered with vegetation. On the other hand, their maintenance costs are much higher, requiring frequent soil removal and bullet recovery operations, as well as the environmental costs, because earthen elements become high sources of lead exposure and lead contamination. Instead of these,

[1] Usually 5 to 10% of the ingested lead may be found in blood and up to 80 to 90% is taken up bone, and small amounts can be found on soft tissues, specially kidneys and brain. The half-life of lead in blood and soft tissues is 24 to 40 days, and in bone, 104 days (Kasper, *et al*, 2004). Numerous studies have documented toxic effects of lead on the nervous system, reproductive system, kidneys, blood-forming system and digestive system (Barsan, M. *et al*, 1996).

commercial equipments conceived especially to stop, contain and recover projectiles, frequently used on indoor firing ranges, should be adopted.

As important as the backstop on the overall layout, safety baffles must be impenetrable and reduce the possibility of ricochet formation. There is a wide range of materials which can be used to build baffles, although the most common are concrete or steel, covered with wood or high density rubber layers. Overhead safety baffles must be set in place under a *no blue sky gap* rule, to interrupt or redirect higher trajectory lines (ETL 06-11), as schematically represented by figure 1.

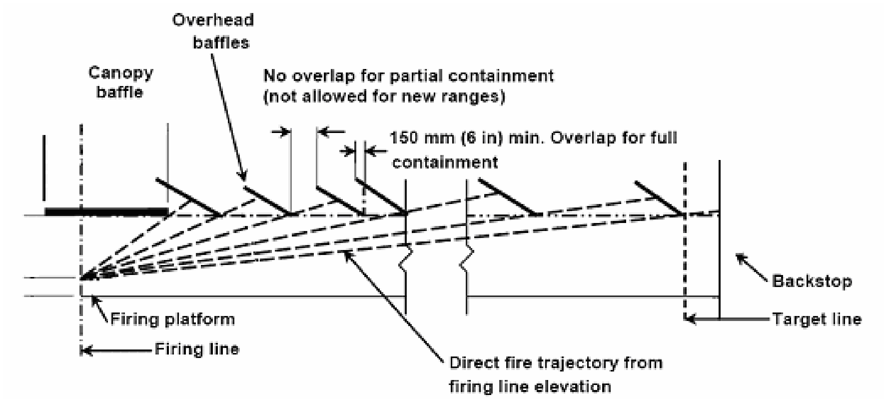

Figure 1 – Overhead safety baffles layout set at 25 degree angles with and without overlap. (Reference: ETL 06-11)

Ground baffles might be installed as well, set in place at 90 degree angles, under the same base concept of the *no blue sky gap* rule, this turn, applied to the floor. Usually their constitution may differ from overhead baffles, because advantage can be taken of the ground soil. Ground baffles can be made as a small earthen embankment (MT-38-2), hardly displaying the 90 degree angle suggested, or gathering the advantage of ground soil to a sandwich panel of plywood with wash gravel or crushed rock inside, set at a 90 degree angle, supported by an earthen embankment (NRA, 2004).

Side walls can replace side berms too, providing a laterally safe layout. These can be set longitudinally or crosswise, achieving 15 to 45 degrees angles with direct fire trajectories (ETL 06-11). The *no gap rule* base concept can be used equally, applied to the sides.

Other layout elements can be used to provide interception of bullets, anti-ricochet surfaces. Another major importance element is the canopy baffle. Its purpose is to eliminate the higher direct fire trajectories that can occur between the firing platform cover and the first overhead baffle, as shown on figure 1.

The range floor should be nearly level, sloping only enough to provide drainage (MT-38-2; NRA, 2004). Either it is totally protected by ground baffles, or it must have good bullet absorption conditions, and either way must present an anti-ricochet surface. All the projections above its plan must be covered with safety baffles, as stands as an example, the target lines or pits. Target pits or target butts are usually needed for firing distances longer than 100 meters.

The outdoor range should have only one fixed firing platform, and multiple target lines, when different firing distances are required.

Noise

Noise control techniques might be classified in three categories: noise control at the source, at the transmission path, and the use of protective measures at the receiver (Harris, 1991).

Regarding the sound source little can be done. On the other hand, concerning the transmission path measures are intended to reduce the energy transmitted to the receiver, whether he is inside or outside the firing area. These include the siting, setting sound barriers, and the use of acoustic absorption materials, which reduce sound reflection.

Siting must observe the distance to urban areas needed to provide enough attenuation and the proximity that grants economical viability. In between, there are all the technologies that permit rising sound attenuation and shortening of distances. Terrain features and natural barriers might be useful.

Sound barriers are most effective in the spectrum range of high frequencies and can be used as the layout elements, eliminating the line of sight between the sound source and the receiver, once they work almost as sound reflecting walls, creating shadow zones behind them. The use of sound absorbing materials on barriers surface might rise its effectiveness, especially when set near the sound source. Sound barriers set behind the firing platform might come as an example. The insertion loss attenuation of sound barriers must be evaluated for each frequency spectrum octave band.

The configuration of the firing platform's cover, and the materials used on the firing line also have a major impact on the sound abatement of the firing range, because there is where the noise source is located. The flat or shed roofs are best suited for firing line covers, and should be covered with sound absorbing materials or other acoustic materials. The firing platform's floor, as well as every other firing platform's surface, must be equally designed to reduce sound reflection, being generally used soil, or concrete covered with acoustic materials.

Concerning the inside receiver, all the references about this subject suggest that the implementation of individual hearing protection devices is mandatory and that should be implemented hearing conservation and education programs. Military firing ranges must submit to STANAG 2899 criteria. The outside receiver might be exposed to noise pollution, therefore all the legal criteria must be met.

Lead

The lead issues must be analyzed through the perspective of occupational lead exposure and natural resources contamination. At outdoor firing ranges the second one is most prominent regarding that usually the firing platforms are open, even when covered (when closed might need mechanical ventilation systems, as used at indoor ranges), what provides good ventilation rates, which severely reduces lead occupational exposure rates.

Management techniques used to control lead issues on outdoor firing ranges are usually referred as Best Management Practices (BMPs), as described by the Environmental Protection Act (EPA) (2005), and the National Shooting Sports Foundation (NSSF) (1997). These include bullet and shot containment techniques, prevention of lead migration to the subsurface and surrounding surface water bodies, and recovery and recycling of lead bullets or projectiles.

Backstops are the main bullet or projectile containment devices. The ideal concept of backstop would be one that trapped all the bullets intact, without fragmentation, providing easy recovery mechanisms, and physically separated from the natural resources, with low levels of lead dust, and low cost maintenance. The backstops used at indoor firing ranges are usually nearer to this conceptual idea, than the traditional earthen berms used at outdoor ranges.

Prevention of lead migration can be achieved by applying some of the following techniques:

- monitoring and adjusting soil pH, by lime addition
- immobilizing lead, by phosphate addition, organic matter addition, cultivation of lead accumulating vegetation, adding or using clay soils;
- controlling water runoff (and erosion), by cultivation of vegetation covers, organic matter addition, and engineered drainage (NSSF, 1997; EPA, 2005).

The bullet or projectile recovery processes is used whenever the backstops don't provide bullet recovery or removal mechanisms, usually the earthen backstops. It may request the removal of large portions of soil, screening and replacement of the backstop usual conditions. This process could be handmade or using lead reclamation equipments. These procedures have high risk of occupational lead poisoning (NSSF, 1997; EPA, 2005).

INDOOR FIRING RANGES

Ballistic Safety

Indoor ranges layout consist of two fundamental aspects: the backstop, which must guarantee interception and containment of direct fired projectiles, and safety baffles, which must provide impenetrable and antiricochet surfaces for protection of architectural and structural elements, as walls, ceilings and floors, and any other systems required, as ventilation, lightning, target retrieval, among others. It is important to underline that architectural and structural elements of the building where the range is installed, which might be totally dedicated or multifunctional, mustn't be considered as safety layout elements on its own.

There are several backstop models available commercially. Their selection criteria must be consonant with the lead issues presented above. Typical backstop materials, advantages and disadvantages are summarized below:

- backstop devices using sand boxes, usually have higher maintenance costs, because of their harder bullet recovery processes, and excessive fatigue caused to exhaustion systems. At the same time, lead dust levels are much higher. However, their initial costs are usually lower;
- backstop devices using steel, usually have lower maintenance costs than sand backstops, although fragmentation of projectiles usually rises lead dust levels, and hardens the recovery processes. Steel plates usually require higher initial costs. There are many models made of steel, each has specific advantages and disadvantages;

- backstop devices using water or fluids combined with steel plates usually have higher maintenance costs than steel backstops, as they cause excessive fatigue to exhaust systems and create humidity problems inside the firing area. They have the same disadvantages of steel backstops although they reduce very effectively lead dust levels. At the same time, the water or fluid used must be treated as toxic waste. These usually have initial costs as high as steel backstops;
- rubber backstops have nearly level maintenance costs as the steel made, although they have the great advantage of not producing fragmentation, catching bullets intact, almost without lead dust formation. They require more maintenance however, because bullets that don't fall intact might have to be removed manually from the rubber elements, and have the great disadvantage of high fire hazard.

Safety baffles are used on the ceiling and walls and might be used on floors as well. They represent the same layout elements referred for outdoor firing ranges, but usually are lighter and more versatile, once they should be able to be set whenever and wherever there is an equipment requiring cover from direct fire trajectories. Besides this other major difference from outdoor safety baffles, is that when used indoor it is of great importance that they provide good sound absorbing surfaces.

No roof gap, *side gap* or *floor gap* rules might be used, similar in concept to those applied outdoors. The range floor should slope from the firing line towards the backstop.

More recently the use of modular ballistic antiricochet rubber panels on the cover of safety baffles joined two of the most important aspects of indoor ranges layout: the impenetrable and antiricochet surfaces, with low maintenance costs, and high sound absorption levels. These commercially available products exists in a broad range of products, made from recycled rubber, for ceilings, floors, walls, indoors and outdoors. Their main disadvantage is their porosity which accumulate a great amount of lead dust, although they have good cleanability characteristics.

Noise

As defined above, sound transmission on indoor firing ranges can be described by the laws of propagation on enclosed spaces. Those state that the sound wave will reflect energy on all reflecting surfaces creating a diffuse sound field, rising sound pressure levels above the source sound pressure level, and only then slowly decreasing. To avoid this effect, sound absorbing surfaces must replace all sound reflective surfaces existing inside the firing area. This will reduce sound levels inside the firing range, which will help decrease the sound transmission rate through the boundary elements toward the outside. Once indoor firing ranges can be set up both on dedicated or multifunctional buildings, sound isolation shall be designed according to common buildings sound isolation principles.

The selection of acoustic absorbing materials must focus on the variation of sound absorption coefficients with frequency, once the detonation has a wide frequency spectrum, as well as their mounting conditions, which may alter severely the sound absorption coefficient for the same acoustic material (Harris, 1991). Other properties that must be considered are: flame spread and fire endurance, mechanical strength, light reflectance, maintenance and modularity, and cleanability.

The use of individual hearing protection devices is mandatory and hearing conservation and education programs should be implemented. Indoor firing ranges submit equally to STANAG 2899 military firing ranges criteria.

Lead

The indoor firing range enclosed layout provides a reasonable isolation from the natural resources. Therefore their prime consideration, concerning lead, is proper ventilation systems and lead medical and hygiene programs (Anania, 1975; NASR, 2005), as determined by Dec-Lei n.º 274/89 de 21 de Agosto.

Ventilation systems must be designed to provide even air flow across firing platform, sweeping the entire section’s air forward downrange, where it is exhausted. Such system will require the introduction of very large volumes of new air, at low velocities and controlled temperature, guaranteeing that re-circulation of air inside the firing area does not occur. To provide this, the inlet air distribution shall be made through a perforated rear wall working as a plenum, and set behind the firing line, occupying the whole rear wall. This device is usually called “air wall” or “laminar wall”. There are other inlet equipments that might be used, once they fulfill all the ventilation system requirements.

Air flow across the firing line should be approximately 0,38 meters per second (m/s), with a minimum acceptable of 0,25 m/s. Downrange a minimum air flow of 0,18 m/s should be maintained evenly (NEHC-TM6290.99-10).

To help the continuum even air flow, the firing area should be maintained at a slight negative pressure, what can be achieved by exhausting form 3 to 10 percent more air than it is supplied (Anania, 1975; NEHC-TM6290.99-10; NASR, 2005; ETL 06-11).

Air supply entering the range should be filtered and conditioned, and all air being exhausted from the range should be filtered using High Efficiency Particulate Filter (HEPA) or equivalent. Supply air intakes should be located upwind from the exhaust stacks, minimizing the possibility of re-introduction of contaminated air (Anania, 1975).

Indoor firing range’s ventilation systems can be direct or closed loop systems. The first ones have lower initial cost, although in extreme weather conditions might have higher energy costs, because of the need to heat or cool all the intake air. The second one have lighter energy costs over time although they are more expensive to install, and needs more equipment to assess the re-introduced air quality, which undoubtedly has more risks to users, than direct systems. The closed loop systems are equally used when a direct exhaust point can’t be isolated, which happens frequently in urban areas (NASR, 2005).

In both, the supply and exhaust systems must be electrically interlocked, and independent from other ventilation systems existing on the building.

CONCLUSIONS

This research work gathered a broad amount of information, creating a handbook of methods and solutions, which are described and discussed, providing effective tools to plan, conceive, and design new firing ranges, or assess and improve existing ones. The interpretation of this knowledge must correctly consider the definition of firing range presented, as many of the considerations made don't apply to other kinds of shooting facilities.

The compilation of all this data provides essential discussion basis, about the actual condition of the Army firing ranges, showing at the same time what subjects require deeper studies and evaluations.

Anyway, the gathering of information itself allowed to conclude, that the existing manuals and regulations over this subject, are behind the needs of today's Safety and Sustainability concepts. So, the discussion referred above must lead to new technical manuals, to the definition of the design required for new infrastructures and to the proper assessment and improvement of the existing ones.

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