Headquarters Australian Defence Force

Environmental Testing of Explosive Ordnance to Determine Safety and Suitability for Service

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SUMMARY

Prior to procuring new or modified explosives or explosive ordnance, the Australian Defence Force requires information on their safety and suitability for service (S^3). This information is provided from the analysis of results from a program of tests designed to replicate the manufacture-to-target sequence of the explosive ordnance being procured. This paper discusses the development of such a test program, including the derivation of the life cycle environmental profile for the item.

1 INTRODUCTION

The men and women of the Australian Defence Force (ADF) must maintain themselves and their equipment in a state of readiness to protect Australia's national interests. Readiness for equipment such as weapons, ammunition, missiles and other explosive ordnance, involves spending long periods in storage interspersed with short periods of transportation and culminating in a requirement to work in the manner intended; for ammunition and missiles, this is a once only requirement.

Explosive ordnance is intrinsically lethal. And yet, we have to hang on to it for most of its service life if it is not used in training or combat. This presents a management problem as well as a safety problem: How do l know these explosives will remain safe while I have custody of them while at the same time l can be confident that they will function in the intended manner when required?

The answer lies in the test and evaluation programme, developed and used by the Australian Ordnance Council (AOC), prior to the introduction of the explosive ordnance to ADF service.

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2 THE AUSTRALIAN ORDNANCE COUNCIL

2.1 Status and Function

The AOC is an independent Defence body whose function is to advise on safety and suitability for service in the fields of design, development, test and evaluation, production, storage, transport and use of those parts of weapons systems and stores in which explosives are used.

As an independent organisation, the AOC is able to evaluate objectively the safety related characteristics of explosive ordnance to avoid the unnecessary exposure of Service and civilian personnel to hazards during the storage, transport, handling and use of explosives.

A number of specialist committees made up of the available explosive safety expertise advise Council in specific areas. These committees are:

- Explosives Storage and Transport Committee
- Electrical Explosive Hazards Committee
- Ballistics Coordination Committee
- Fuze Committee
- Explosives Environmental and Service Life Advisory Committee

2.2 Role

The main role of the AOC is to provide advice on the safety and suitability for service of weapons and stores containing explosives intended for use by the ADF.

3. AOC ASSESSMENT OF SAFETY AND SUITABILITY FOR SERVICE

3.1 Safety Assessment

The assessment of safety normally involves an appraisal of the inherent safety of the design and an evaluation of the risk attendant on deploying the store in the prescribed environment throughout its agreed service life, followed by consideration of the acceptability of this risk in the circumstances prevailing.

3.2 Suitability for Service

The explosive and associated components of a weapon system or store are to be capable of functioning technically as designed and without unacceptable degradation of either performance or safety by the service environment throughout the agreed service life. This definition excludes operational effectiveness and lethality but may include accuracy and probability of hit if these aspects are deemed to be part of the store's designed function.

3.3 Information Required for Assessment

To adequately conduct an assessment of safety and suitability for service (53), all relevant information must be obtained and verified. The information required includes:

- A definition of the total environment to which the store will be exposed and for what duration; this is the natural environment of temperature, humidity, wind, rain, weather etc as described in DEF (AUST) 5168(l) as well as the man-made environment such as vibration, mechanical shock, electromagnetic radiation etc, tests for which are described in DEF STAN 07-55(2).

- Details of the design of the store including drawings, specifications and operational requirements.

- Copies of any hazard analyses performed on the store.

- Full details, including the raw data, of any tests that the store has undergone in both developmental and production phases.

- If applicable, details of the previous service history of the store, particularly the number fired, the number of failures and results of investigations into the failures.

Under some circumstances an assessment can be conducted by analogy with a similar store. However, the relevance of the information concerning the donor store must be very carefully established.

Of all the information used for the assessment, the most fundamental comes from a thorough understanding of the environment the store will be exposed to. For this, the AOC needs an accurate life cycle environmental profile (LCEP).

4 LIFE CYCLE ENVIRONMENTAL PROFILE

4.1 Environmental Questionnaire

The first step in development of an LCEP is to complete an Environmental Questionnaire (3), with inputs from the task sponsor, users and operational authority.

The questionnaire is divided into six sections as follows:

- Section 1. Describes the store, its packaging and the user requirements for service life.

- Section 2. Covers what is broadly described as the "storage" phase of the store's life.

This phase will typically include all occurrences and environments up to and including storage in an armament depot. Storage by the manufacturer, modes of transport from the manufacturer and details of the storehouse in the destination armament depot are all included.

- Sections 3-5. These address particular requirements for stores subjected to the maritime, land and air service environments respectively in what is regarded as the "operational" phase. It covers transport from the armament depot to the ship, aircraft, combat vehicle or soldier and includes modes of transport, types of terrain and expected climatic conditions.

- Section 6. Covers those hostile environments and events which are not part of the normal manufacture-to-target sequence, but which will influence the safety assessment. Examples include fire, electromagnetic radiation and impact/shock such as bullet or fragment attack.

A risk and hazard analysis should now be performed in order to identify aspects of the design requiring special attention. Using responses from the questionnaire in conjunction with the hazard analysis, an environmental engineering analysis is performed to identify and delineate all probable single and combined environments that could affect the functioning, reliability or operational capability of the store.

The results of the analysis then become the basis for determining test procedures and parameters for the Environmental Test Plan (ETP).

4.2 Life Cycle Events

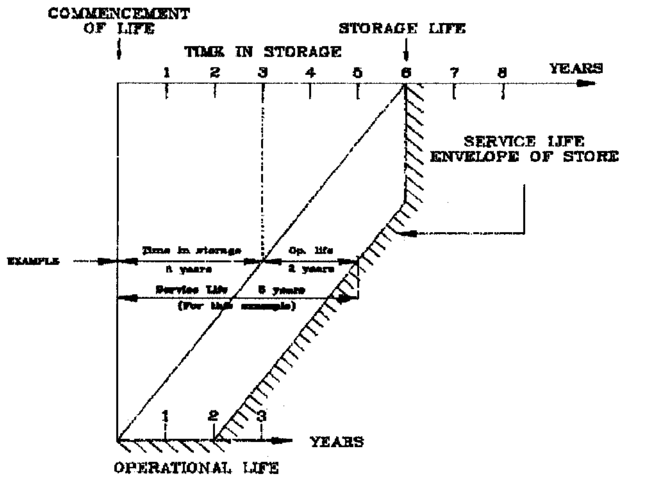
The environments described in the Environmental Questionnaire are best arranged into a manufacture-to-target sequence. This sequence excludes events occurring during manufacture and only commences immediately after manufacture. Generally, the service life of a store may be divided into two phases as shown at Figure l, storage and operational.

The storage phase consists of the explosive ordnance, either in its packaging or in bulk, being stored with the manufacturer or with the user at a storage depot. It includes transport between storage sites by all feasible transport modes.

The operational phase commences at delivery to the point where it is assembled or prepared for operational use. This stage may encompass transportation by a variety of modes, exposure to the natural environment in an unpackaged state, possible exposure to environments significantly harsher than in storage and even may undergo a firing sequence. Some explosives, such as missiles, spend all or most of their lives in one phase or the other. Other explosives may cycle repeatedly between the two.

Storage Life is defined as the time for which an explosive item, in specified storage conditions, may be expected to remain safe and suitable for service.

Operational Life is the time for which an explosive item may be expected to remain safe and suitable for service when used under its operational or training conditions, where these are different from its storage condition, but which is within the envelope of its Storage Life.



DIAGRAMMATIC EXPLANATION OF 'SERVICE LIFE'
OF AN EXPLOSIVE ITEM

Figure 1: Service Life

Service Life is defined as the time for which an explosive item, in specified storage conditions and when subsequently used under its operational and/or training conditions, may be expected to remain safe and suitable for service. Service Life will never be longer than Storage Life.

4.3 Storage Phase

Account must be taken of the modes of transportation occurring during this phase. The explosives could be subjected to surface, air or naval transportation and may experience rough handling or prolonged vibration. The packaging may offer some protection against the various environments such as sand, dust, rain, solar radiation and to a lesser extent vibration and shock. In developing tests for this phase, the expected climatic extremes and duration of exposure must be determined.

The length of time the item may remain in storage will be defined in the Environmental Questionnaire. If possible, temperature and humidity records from the storehouse should be obtained and applied. The extent of the effect of temperature and humidity may be initially gauged from a hazard analysis but the store should, where possible, be subjected to some form of diurnal cycling.

4.4 Operational Phase

Transportation. The extent and mode of transport experienced by the store varies depending on the weapon system and/or the role in which it is employed.

Storage. The store may be held in ship storage or the relatively harsher field storage for lengthy periods. When analysing the effect of such storage on the life cycle of the store, the credible maximum length of time the store may be exposed to such conditions and whether it is packaged are prime considerations.

Ready-Use. When ammunition is held in ready-use, that is carried on the soldier, held by a gun crew or on upper deck lockers near a gun, the environmental conditions could be approaching the extremes of the climatic category, as defined in DEF (AUST) 5168(l).

Standby in Weapon Systems. There are four main considerations which apply:

- The period and the environment which a round may experience in an exposed feed system, such as the belt feed system for 20 mm ammunition used in the Phalanx, Close In Weapon System (CIWS).
- The time taken to cook-off a round chambered in a hot gun.
- The shock loading experienced by the round in its feed system.
- Any unusual environments experienced because of the particular role of the store, such as a buried mine might experience.

Operation. Weapon system operation exposes the store to a variety of dynamic and climatic environments, often applied simultaneously.

5 CLIMATIC CATEGORIES

The DEF (AUST) 5168(1) uses 12 climatic categories to describe the distinctive types of climate to be found throughout the world, excluding Antarctica. Eight of these (termed Al, A2, C0, C0(A), Cl, C2, C3 and C4 respectively) are defined with temperature as the principal consideration while the remaining four (termed Bl, Bl(A), B2 and B3 respectively) represent climates in which high humidity accompanied by a relatively high temperature is the outstanding characteristic. The general characteristics of these regions, as described in DEF (AUST) 5168(1), are given in Table 1.

6 HAZARD ANALYSIS

The AOC has adopted MlL-STD-882(5) as its guide for hazard analysis. A detailed discussion of risk and hazard assessment is not appropriate here, although the process is important in the overall assessment of explosive ordnance for determining a test programme which gives assurance of the safety and suitability for service of the particular store.

Essentially, the analysis must identify all the hazards, be they hazards to personnel, equipment or mission effectiveness. The outcomes or consequences of each hazard must be ascertained and a judgement as to whether it is catastrophic, critical or some lesser measure of effect on mission effectiveness or safety, whichever has been deemed more important for the case in question.

When the severity of the consequence has been agreed by all the principals, the probability of occurrence of that particular event is assessed. From such a process, the AOC can focus the trials efforts on areas which are mission critical or which present special safety problems.

Reductions in degree of risk claimed for redundant or diverse sub-systems must be carefully analysed for common mode failures.

The assessment must consider whether agreed safety principles and design criteria have been observed and suitably implemented.

However carefully the design is assessed, the assessment relies on human judgement and is therefore liable to result in error. It is therefore essential that designs are tested.

7 PUTTING IT ALL TOGETHER

The results of the Hazard Analysis together with the Environmental Questionnaire are used to perform an environmental engineering analysis from which the Environmental Test Plan is produced.

7.1 Environmental Test Plan (ETP)

The ETP specifies a series of tests developed to establish the response of the store at the extremes of its simulated environment. The plan may be modified by deleting those test requirements where the results are already available from developmental testing or production testing. However, the tests should be based on the credible worst case environmental conditions identified from the LCEP and chosen from recognised standards such as DEF STAN 07-55(2) or MIL-STD-8l0(6); the tests may be tailored to levels appropriate to the environmental conditions.

The test plan is divided into two distinct phases: Sequential Tests and Non Sequential Tests. Sequential tests are more severe than comparable tests done separately. Results cannot be compared directly with those achieved on stores which were submitted as fresh items (unstressed) to each test. which follow the worst case manufacture-to-target sequence. Non Sequential Tests represent abnormal events in the manufacture-to-target sequence, such as bullet attack or a fire.

7.1.2 An Example: 20 mm Ammunition

The development of a Test Programme is seen from the example of the 20 mm ammunition used in Naval Phalanx guns, the high rate of fire CIWS. The tests are largely taken from DEF STAN

07-55(2).

7.1.2.1 Manufacture-to-Target

From analysis of the results of the Environmental Questionnaire, the Manufacture-to-Target sequence is drawn up. As shown in Table 2, the sequence has identified the various environments the ammunition will experience from the time it is delivered from the manufacturer to the time it is fired and includes estimates of the time exposed to each environment and whether it will be packaged or not.

7.1.2.2 The Hazards

Using Table l, a Hazard Analysis along the lines given in MIL-STD-882(5) and as outlined in section 6 above is performed. The ammunition has an electrically initiated primer and so the worst credible incident is an inadvertent firing of a round by stray electromagnetic radiation (radars, radio,) or static discharge during handling and loading or cook-off as a result of a fire. Since the magazines in this case are above the water line, the response to a bullet or fragment attack will also have to be considered. Tests for these hazards are not fully defined in the DEF STAN and tests certified by the UK Ordnance Board in its OB Proceeding 42242(7) must also be included.

7.1.2.3 Special Tests for Explosives

Electro explosive hazards. Stores such as this 20 mm ammunition which contain electrical circuits may present a hazard in that accidental application of electrical energy may cause faulty functioning, inadvertent operation or a dud. Special tests, such as irradiation of an instrumented round are used to determine levels of rf energy actually picked up; field strengths representative of those encountered in the service environment are used in the test.

Fire. The reaction of ammunition involved in a fire is determined by special testing techniques. In this case, a liquid fuel fire test is called for and requires the construction of a hearth and observations made of fragmentation, time taken to reach 550^{0}C (from thermocouples), whether detonation or deflagration occurs and the nature and distribution of debris.

Vulnerability. Enemy munitions, battle damage or other action which causes an item to function will have an effect on neighbouring stores which must be determined. This is especially so these days when ship designers are ignoring the lessons of history and siting magazines above the water line in major surface combatants. Not all types of enemy munitions can realistically be tested against and so a standard test using .5 inch armour piercing (AP) ammunition is used.

7.1.2.4 The Test Programme

Following consideration of the hazards and the expected environments, a test programme can be developed as shown in Figure 2. In this case, sequential tests, Tests l to 6 of Figure 2, are then prescribed which reflect the sequence of Table 2 and non-sequential tests such as Tests 7 to 2l of Figure 2, address the abnormal events in the life cycle.

8 CONCLUSIONS

Schedules of tests for armament stores should be developed from the manufacture-to-target sequence for the stores concerned. This sequence will usually involve logistic transportation (vibration and bounce), storage (hot and cold diurnal cycling), tactical transportation in, for example, tracked vehicles, warships, fixed and rotary wing aircraft (vibration), handling (drop and shock), packaged and unpackaged stores and functioning tests.

In the interests of realism, a trial should explore the probable effects of all the significant environmental conditions which a store will encounter in service.

Maximum confidence in the suitability of a store is derived from satisfactory results from functioning tests carried out at temperature extremes on a large proportion of the stores after completion of the trial sequence. As breakdown or sectioning of some stores may also be required, a balance must be struck between these requirements (functioning versus sectioning/breakdown) in deciding the number of stores involved at different stages of the trial.

The number of stores to be tested is determined primarily by economic and time considerations, and by the degree of confidence remaining to be established after design assessment and consideration by analogy with similar stores; the number will differ for each type of store. Except where small and cheap stores are involved, large numbers of items will not normally be available for test. However, care must be taken that sufficient numbers are available to ensure that results of trials do not depend upon single events.

In the end, even after careful assessment and suitable testing, explosive stores are continually monitored for possible degradation or unsafe performance throughout their life. This is achieved through an In Service Surveillance (155) programme which selects stores from the population and subjects them to breakdown, analysis and functioning.

9 REFERENCES

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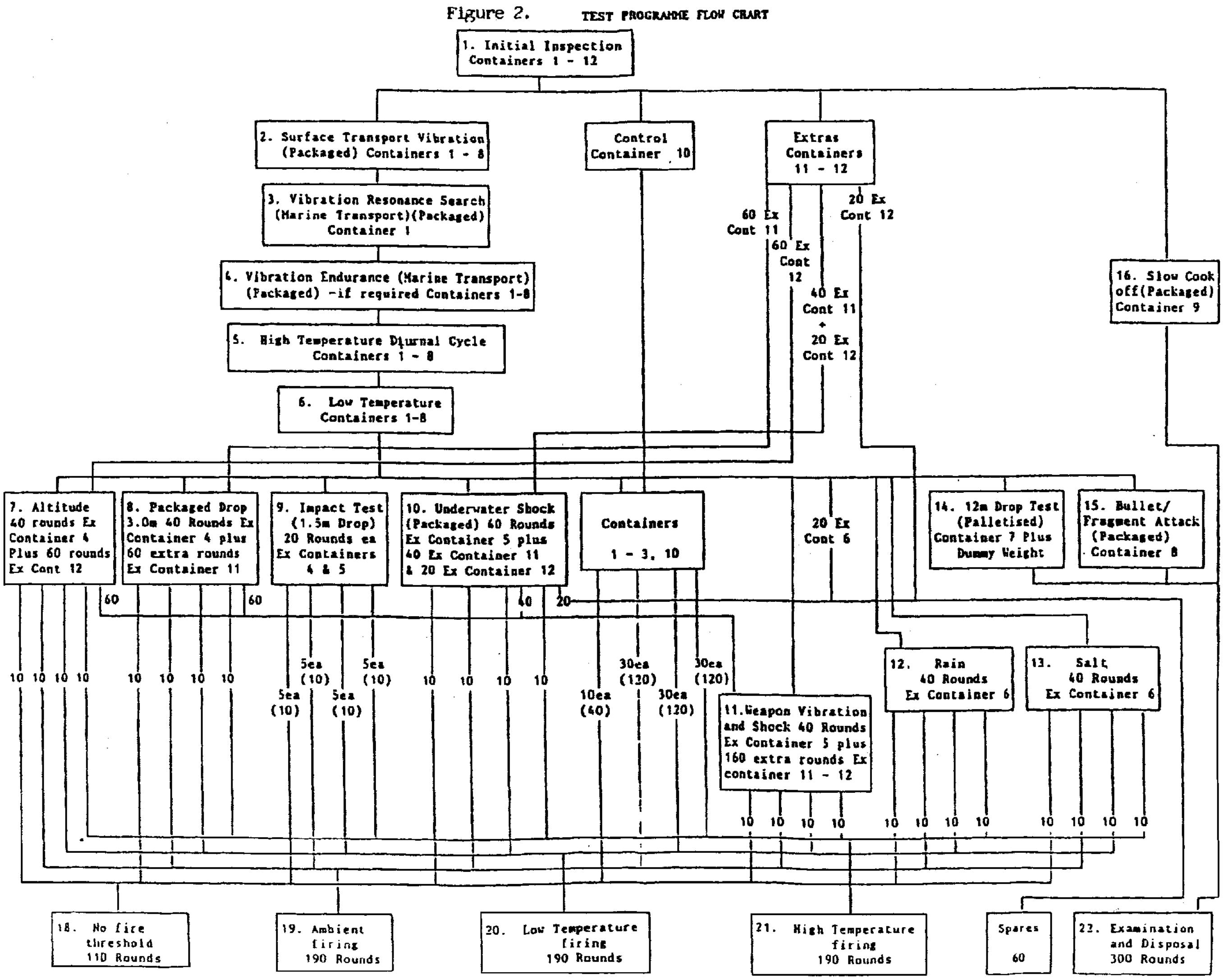

Figure 2. TEST PROGRM FLOW CHART

Table 1. DEF (AUST) 5168 Climatic Categories

CATEGORY	TYPE	DESCRIPTION	LOCATION	OPERATIONAL TEMP (^oC) and RH	STORAGE TEMP (^oC) and RH
A1	Hot/Dry	Very high temperatures accompanied by high levels of solar radiation.	Hot dry deserts of north Africa, parts of the Middle East, northern India and SW USA.	32 to 49 3 to 12 mb	33 to 70
A2	Intermediate Hot/Dry	High temperature accompanied by high levels of solar radiation and moderately low relative humididty	The Australian continent, southern Europe, south central Asia, northern and eastern Africa, coastal regions of north Africa, high plains of North America and most of Mexico	30 to 44 5 to 15 mb	30 to 63 5 to 15 mb
B1	Wet/Warm	Moderately high temperatures accompanied by continous very high relative humidity.	Rain forests and other tropical regions during periods of continuous cloud cover when direct solar radiation is not significant. Areas include the Congo and Amazon basins, soth east Asia including East Indies, the east coast of Madagascar and the Caribbean Islands.	Nearly constant at 24 throughout the 24 hour cycle. 95 to 100%	Nearly constant at 24 throughout the 24 hour cycle. 95 to 100%
B1(A)	Wet/Warm Australia	Moderately high temperatures accompanied by continuousvery high relative humidity.	Rain forests, tropical regions during periods of continuous cloud cover, where direct solar radiation is not a significant factor. Includes the northern coast of Australia.	24 to 28 95 to 100%	24 to 28 95 to 100%
B2	Wet Hot	Moderately high temperatures accompanied by high humidity and high direct solar radiation.	These conditions occur in exposed areas of the wet tropical regions named in B1.	26 to 34 74 to 100%	31 to 63 19 to 75%
B3	Humid Hot Coastal desert	Moderately high temperatures accompanied by high water vapour content of the air near the ground and high levels of solar radiation.	Hot areas near large expanses of water such as the Arabian Gulf and the Red Sea.	31 to 40 60 to 88%	33 to 71 14 to 75%
C0	Mild Cold	Mildly low temperatures.	Coastal areas of western Europe and parts of New Zealand.	-19 to -6 Tending to saturation	-21 to -10 Tending to saturation
C0(A)	Australian Cold	Mild cold conditions with clear skies; solar radiation not negligible between 0800 and 1600 hours.	Isolated areas above 1500 m and prevalent from Moe through Armidale. Isolated areas of Tasmania above 400 m.	1% diurnal cycle with ranges from -6 at 0600 hours (local) to 11 at 1500 hours (local).	Not known, but expected to be higher than Operational Temperatures for some part of the diurnal cycle.
C1	Intermediate Cold	Moderately low temperatures.	Central Europe including south Scandanavia, Japan and south eastern Canada.	-31 to -21 Tending to saturation	-33 to -25 Tending to saturation
C2	Cold		Northern Norway, prairie provinces of Canada, Tibet, and parts of Siberia but excluding areas detailed in C3 and C4.	-46 to -37 Tending to saturation	-46 to -37 Tending to saturation
C3	Severe Cold		The coldest areas of the North American continent.	Nearly constant at -51 throughout the 24 hours. Tending to saturation	Nearly constant at -51 throughout the 24 hours. Tending to saturation
C4	Extreme Cold		The coldest areas of Greenland and Siberia	Nearly constant at -57 throughout the 24 hours. Tending to saturation	Nearly constant at -57 throughout the 24 hours. Tending to saturation

Table 1. DEF (AUST) 5168 Climatic Categories

Table 2. Manufacture - to - Target Sequence for 20 mm

20MM PHALANX AMMUNITION

MANUFACTURE TO TARGET SEQUENCE

SERIAL	STAGE	DURATION	STORE STATE	SIGNIFICANT ENVIRONMENTAL CONDITIONS
1	SURFACE TRANSPORTATION	16 DAYS 8 HOURS/DAY	PALLETISED CONTAINERS	VIBRATION, TEMPERATURE EXTREMES. SHOCK, ROUGH HANDLING. CLIMATIC CATEGORY A2 STORAGE TEMPERATURES AND COLD DOWN TO -6°C.
2	AIR TRANSPORT	72 HOURS (10 FLIGHTS)	PALLETISED CONTAINERS	VIBRATION ALTITUDE (LOW PRESSURE) TO 3,050 M (10,000 FT).
3	SHIP TRANSPORT	6 WEEKS	PALLETISED CONTAINERS	AS FOR SUPPLY SHIP, BUT LESSER DURATION.
4	DEPOT STORAGE	12 YEARS	CONTAINERS, USUALLY PALLETISED	CLIMATIC CATEGORIES A2, B1(A), B2, CO(A).
5	WHARF TRANSFER	INCLUDED IN SERIAL 1	PALLETISED CONTAINERS	INCLUDED IN SERIAL 1
6	SUPPLY SHIP TRANSFER	FEW HOURS	CONTAINERS, USUALLY PALLETISED,MAY BE LOOSE IN CARGO NETS.	OPEN EXPOSURE OF CONTAINERS TO HOT WET, HOT DRY OR COLD CONDITIONS. RISK OF 18 M DROP, OR OTHER ROUGH HANDLING OF CONTAINER.
7	STORAGE IN SUPPLY SHIP	3 YEARS	CONTAINERS, USUALLY PALLETISED	SHIPBOARD VIBRATION, UNDERWATER SHOCK. TEMPERATURES WILL BE AS FOR LIMITED AMBIENT AIR CIRCULATION IN LARGE HOLD. HUMIDITIES MAY BE HIGH.
8	COMBAT SHIP TRANSFER	FEW HOURS	PALLETISED CONTAINERS	AS FOR SERIAL 6, BUT POSSIBLE SEA WATER IMMERSION.
9	STORAGE IN COMBAT SHIP	6 YEARS	CONTAINERS	TEMPERATURE CONTROLLED MAGAZINE (20 - 25°C) POSSIBLE HIGH HUMIDITY. VIBRATION. POSSIBLE HIGH TEMPERATURE DUE TO FIRE. UNDERWATER SHOCK.
10	READY USE LOCKER TRANSFER	SHORT	CONTAINERS	ROUGH HANDLING, INCLUDING POSSIBLE 3 M DROP. POSSIBLE ELECTROMAGNETIC RADIATION EXPOSURE (EMRE).
11	STORAGE IN READY USE LOCKER	12 WEEKS	CONTAINERS	MARINE HOT WET (M2), AND COLD (M3) "OPERATIONAL" CONDITIONS. VIBRATION. EMRE.
12	WEAPON SYSTEM TRANSFER	20 MINUTES	UNPACKAGED	POSSIBLE 1.5 M DROP, OTHERWISE AS FOR SERIAL 13.
13	STANDBY IN WEAPON SYSTEM	12 WEEKS	UNPACKAGED	MARINE COLD AND A2 STORAGE CONDITIONS. RAIN, SALT SPRAY, SOLAR RADIATION. SHIPBOARD VIBRATION, POSSIBLE HIGH TEMPERATURE DUE TO FIRE. EMRE.
14	OPERATION OF WEAPON	SHORT	UNPACKAGED	HIGH ACCELERATIONS, VIBRATION, SHOCK.
15	REMOVAL OF UNFIRED ROUNDS	SHORT	UNPACKAGED	AS FOR SERIAL 12.

Table 2. Manufacture - to - Target Sequence for 20 mm Ammunition