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Storage and Handling of Solid Ammonium Nitrate

Utilising a Risk Based approach

by

Australasian Explosives Industry Safety Group Inc. (AEISG)

CONTENTS

1. INTRODUCTION

The Australasian Explosives Industry Safety Group Inc. (AEISG) is an industry association with a mandate to promote and enhance safety and security in the commercial explosives sector in Australasia.

AEISG adopts various strategies in this regard, including the identification, development, drafting and publication of relevant Codes of Practice for the benefit of its members, their employees, their customers and the community. Generally, the need for such codes arises for explosives areas or activities which are not covered, or are inadequately covered, by existing legislations, codes or standards.

Such was the case in Australia, where the storage of ammonium nitrate (AN) is regulated at State / Territory jurisdictional level by eight (8) distinct explosives regulators. It should be noted that there is no Australian Federal Government regulatory oversight of explosives and their precursors, and hence no nationally harmonised / consistent approach to AN storage and handling.

AEISG had identified that the requirements for the safe and secure storage of AN in each of the state / territory jurisdictions ranged from non-existent, through inadequate to overly conservative. Only three of the eight jurisdictions identified separation distances for the location of AN storages, each using explosives quantity distance (QD) tables based on TNT and each applying different TNT equivalencies to the quantity of AN stored. This regulatory inconsistency created unnecessary confusion and significant administrative burdens on an explosives industry working nationally and was the impetus for the development of the AEISG Code of Practice - Storage and Handling of Solid Ammonium Nitrate (the Code).

Work commenced in 2016 with the aim of developing a transparent, technical and competent guide, specifically for the safe and secure storage and handling of AN and tailored to the explosives industry in Australasia. Initially AEISG undertook a review of relevant globally available standards or guides, adopting those common elements which had a clear safety and / or security outcome and questioning some traditional requirements which provided no identified benefit. Input was also sought from local environmental regulators to ensure best practice environmental practices were included.

The most significant point of difference in existing standards or guides concerned the site location for AN storages and what, if any, separation distances should be in place around such storages to minimise risk to neighbouring land uses. The likelihood of an explosion of stored AN is generally so low that in the majority of jurisdictions globally, no particular distances are prescribed to separate AN storages from other land uses. Larger storages, however, are likely to be subject to quantitative risk assessment (QRA). While the likelihood of explosion of an store might be considered to be negligible, catastrophic AN explosions have continued to occur around the world, typically because a store has not been well-managed.

Hence, AEISG decided that it would be a requirement of its Code that AN storages would not be located where the risk posed to surrounding land uses exceeded acceptable risk criteria detailed by government agencies for hazardous industries. In Australasia, the generally accepted risk criteria have been established by the New South Wales Department of Planning.

Rather than assessing risk at every site individually, AEISG used this accepted risk criteria to determine if separation distances were needed as a risk control measure and, if so, what those distances might be for a variety of types of AN storages. The outcomes would be considered for inclusion in its code to provide additional guidance to its members. This task involved significant time, and cost, to ensure any distances developed were soundly based and sufficiently conservative to meet the acceptable levels of safety to neighbouring land uses.

AEISG ensured that regulators were kept abreast of this project and the principles upon which the proposed AN Code was to be based. As the project progressed and some policy and technical decisions were required, all relevant jurisdictional regulators were invited to participate in a working group, with some regulators agreeing to work with AEISG in developing the initial draft of the Code.

As with all AEISG Code development, once finalised, the draft Code - Storage and Handling of Solid Ammonium Nitrate was forwarded to all regulatory authorities in Australasia for comments prior to completing a first edition. Any responses received were considered in detail by AEISG prior to finalising the first edition of the AEISG Code which was issued in June 2022.

The Code

- Has specified scope – AN storage and handling for the explosives industry;
- Outlines necessary precautions or risk control measures against fire, contamination and shock which might lead to explosion, while at the same time addresses environmental and security needs;
- Builds on the risk-based approach for AN storage location outlined in the SAFEX International AN Good Practice Guide: Storage of Solid Technical Grade Ammonium Nitrate - SAFEX Good Explosives Practice Series GPG 02, 2014) [SAFEX GPG];
- Specifies a methodology for assessing the acceptability of a proposed AN storage site location using:
    - Different AN storage types and adjacent land uses that reflect typical AN storage scenarios in Australasia, which might impact changing risk levels;
    - Risk targets (individual fatality risk) considered acceptable at each land use;
    - Defined (conservative) explosion frequencies (likelihoods) for 3 explosion scenarios (fire, contamination and shock) at each AN store;
    - IMESAFR (AN Module) as a means of consequence assessment and risk calculations;
- Includes Tables of Distance (ToD) for up to 1,000 tonnes of AN, developed using the specified methodology, which are considered conservative and may be used in lieu of site-specific QRA;
- Addresses situations where AN storages might be in proximity to Class 1 Explosives or ammonium nitrate emulsions (ANEs) (UN3375);
- Does not require AN to be treated as an 'equivalent' amount of TNT;
- Is transparent, with all parameters used in risk calculations fully defined such that appropriate separation distances outlined in its ToD are fully reproducible by 'anyone'; and
- Delivers community safety consistently and efficiently for AN storages in line with all hazardous industries in Australasia.

Purpose

This paper describes the development, the process and the final outcomes of the recently published AEISG Code, including:

- the AN landscape in Australasia and the factors driving AEISG to develop a new code for the storage and handling of solid AN;
- the initial approach adopted by AEISG and key findings;
- policy decisions needed to progress the Code;
- considerations around AN storage site locations including the need, if any, for separation distances to neighbouring land uses;
- the methodology used to ensure AN storage sites were located such that neighbouring land uses were not subjected to unacceptable risk levels;
- the results and outcomes of this significant research and analyses;
- other significant issues; and
- future intentions for the Code.

2. BACKGROUND

The Australasian Explosives Industry Safety Group Inc. (AEISG) is an industry association with a mandate to promote and enhance safety and security in the commercial explosives sector in Australasia.

AEISG utilises various mechanisms, including the development, drafting and publication of Codes of Practice, to collect and disseminate best practices to its members, other organisations involved in the Australasian explosives industry, regulatory authorities and the general public.

AEISG represents all the significant manufacturers and suppliers of blasting explosives, essential to the mining and construction industries and so vital to the economic well-being of Australia.

The explosives industry itself is a multibillion-dollar industry, supplying over 3 million tonnes of explosives per annum across Australia. It consists of national explosives companies manufacturing, importing, selling, transporting, storing, using and handling explosives with a need to safely, securely and efficiently move products, people and equipment seamlessly across borders and around Australasia to service their clients.

Explosives have long been subject to tight legislative controls for community safety and security reasons. These are acknowledged, understood and supported by our industry. However, in Australia there has been continued increase and divergence of Commonwealth / State / Territory legislation in this area over the years to the point where industry is now constrained by multiple sets of inconsistent and unnecessary requirements with little to no mutual recognition or acknowledgement of jurisdictional licences, permits, authorisations or security checks issued. The direct impacts are felt not only by the explosives industry itself but also by its multiple sets of contractors and suppliers of services, e.g., transport, engineering, construction industries who need to work to varying standards, codes and specifications to comply with differing jurisdictional requirements.

One example of this legislative environment is where the storage of ammonium nitrate (AN) is regulated at State / Territory jurisdictional level by eight (8) distinct explosives regulators. It should be noted that there is no Australian Federal Government regulatory oversight of explosives and their precursors and hence no nationally harmonised / consistent approach to AN storage and handling.

In 2007, under the auspices of AEISG, representatives of Australian based AN Major Hazards Facilities (MHFs) (i.e., global scale manufacturers of AN) commenced discussion on the merits of developing a risk-based Australian Good Practice Guide for the storage of AN. This was largely driven by the inconsistent and unsubstantiated safety and technical requirements of some regulators and the inadequacy of an Australian Standard 4326:2008 The storage and handling of oxidizing agents (AS 4326) as applied to MHF quantities of AN. The workings of this group were subsequently incorporated into similar work being undertaken by a global AN working group, eventually leading to the publishing of the SAFEX International AN Good Practice Guide: Storage of Solid Technical Grade Ammonium Nitrate - SAFEX Good Explosives Practice Series GPG 02, 2009 (since revised in 2014) [SAFEX GPG].

AN is not an explosive – it is classified, both locally in Australasia and internationally, as an 'Oxidising solid' and a Class 5 dangerous good for transport purposes. The UN Model Regulations and the associated Manual of Tests and Criteria provide specific provisions for classifying AN to ensure consistency and facilitate international and intermodal trade.

In Australasia, the estimated demand for AN is almost 3 million tonnes per annum (MTPA), with the vast majority (greater than 95%) used in the explosives sector. Approximately 2.4 MTPA of AN (UN 1942) is manufactured locally (New South Wales, Queensland and Western Australia), with the remainder being sourced from overseas.

AN is the primary ingredient in the downstream manufacture of most commercial explosives and is commonly stored at mining operation (mines and quarries) sites, ANE and explosives manufacturing sites or AN stores operated by transport contractors' depots as holding locations or distribution centres to address large scale imports and meet upcoming customer demand. Stores generally range in size from a few tens of tonnes up to hundreds and, less commonly, thousands of tonnes.

Australia is one of very few countries where some explosives regulators stipulate conservative safety separation distances (based only upon the potential consequence of a worst-case event) from AN storages. Three (3) of its eight (8) jurisdictions apply a TNT equivalency to AN and then resort to Quantity-Distance (QD) tables historically developed for explosives (TNT). However, each of these three (3) jurisdictions applies a different TNT equivalency (25%, 32% and 50%). The basis for these separation distances is consequence based with no consideration given to risk, which incorporates both the probability, or likelihood, of an event occurring and the potential consequences of that event. The remaining jurisdictions are silent on their requirements in this regard but still assess AN storages for licensing purposes.

The global explosives Industry has moved in the direction of increased safety by, for the most part, transporting and storing Class 5 raw materials (explosive precursors) which are only processed into explosives at (or close to) the point of use, rather than centrally pre-manufactured Class 1 explosives. This means that the global supply chain to deliver explosives to their point of use is predominantly handling less hazardous materials. Therefore, the imposition of mandatory QDs around AN (Class 5) storage and treating it as Class 1 undermines the UN classification system and reduces the incentive for the industry to continue to pursue this safer direction.

Conversely, for each of Australia's six (6) major AN manufacturing facilities, the relevant (jurisdictional) MHF regulators utilise a quantitative risk-based assessment approach which is applied to AN manufacturing sites and large storages (>2,500 tonnes). In Australasia, AEISG members are focused upon significantly smaller quantities of AN (< 1,000 tonnes) at approximately 200 national sites with most storages being at mine sites, which are usually very remote from the public. It needs to be noted that in most jurisdictions the explosives regulator and the MHF regulator are units within the same agency but puzzlingly apply different approaches.

Given that many Australian explosives companies operate nationally, the inconsistent, confusing and sometimes lacking regulatory approach by some jurisdictions to the storage of AN was a concern for AEISG members whose aim is to move seamlessly around Australasia and operate to best practice management systems at all their locations.

Work commenced in 2016 with the aim of developing a transparent, technical and competent guide, specifically for the safe and secure storage and handling of AN, tailored to the explosives industry in Australasia.

Note: Appendix A of this paper provides an overview of the AEISG association.

3. INIITIAL APPROACH

In developing the Code, AEISG utilised a thorough and inclusive phased approach, initially dependent on subject matter experts and drew on the knowledge and experience of its member companies.

This included a review and evaluation of all the existing globally available standards, codes and guides covering AN (referenced in Appendix B) to which members had access. This review and evaluation included not only "what" the guides said but also "why" they said it. Some 'accepted wisdom' was challenged and discarded if not justified, e.g., arbitrary maximum stack heights, separation to walls within a packaged store.

The numerous points of similarity across these guides generally included precautions against fire, precautions against contamination or accidental mixing, avoidance of potential shock (e.g., do not break up AN using explosives) and the need for considering security aspects. The significant point of difference concerned site location and what (if any) separation distances should be in place around AN storages. This divergence in approach ranged from "no separation required, but consider toxic fumes if there's a fire", through to "mandatory QDs as if AN is Class 1 explosives". In the vast majority of jurisdictions globally AN is treated as a Class 5 oxidising substance for the purpose of storage, with no pre-defined separation distance requirements to on-site or off-site populations. However, almost all such jurisdictions have a system similar to the Australasian Major Hazard Facility (MHF) approach, i.e., any proposal to establish a large AN store would almost certainly have the location and associated risk to offsite land uses assessed as part of those authorising processes.

AEISG also reviewed the risk-based approach utilised by MHF regulators and government land planning agencies when addressing hazardous industry siting and approvals. In such cases it was normal practice to require a thorough risk analysis and soundly based QRA demonstrating acceptable risk levels which met established criteria for any neighbouring facilities which could be exposed to adverse impacts from that hazardous industry. While this approach was common in assessing hazardous industries generally, it is not viewed favourably by many explosives regulators, wedded to the consequence based QD approach, who view QRA with some degree of scepticism (" … you can always get the answer you want by massaging the inputs … ").

Interestingly, while explosives regulators favoured the QD approach for determining separation distances for AN storages, it was readily apparent that the majority of those same regulators also placed significant confidence in the quality and competence of the SAFEX GPG, despite its promotion of a risk-based approach in determining the suitability of an AN storage location. Perhaps some comfort was taken in the fact that no separation distances were specifically quoted in the SAFEX GPG, which left it open to individual jurisdictional regulatory interpretation?

AEISG had initially believed that its only option in progressing this issue in the code was to accept the QD approach in siting AN storages to satisfy regulators and to at least attain some national consistency. However, as research progressed on both approaches (risk-based and QD) it became increasingly obvious that the QD option would not deliver the desired outcomes sought by AEISG.

AEISG is of the view that a conventional QD approach for AN storages has several flaws:

- A QD approach sets separation distances based on calculated overpressure (typically via a formula which calculates the peak incident side-on overpressure). However, the manner that a structure at an exposed site (ES) responds to overpressure can vary significantly depending on its construction;
- Since most QD tables are based on TNT, using a QD approach for AN requires the AN to be treated as "equivalent" TNT. While TNT is routinely chosen as a reference explosive because the blast waveform from TNT explosions has been well characterised by experiments, there is still much debate, and little consensus, about the appropriate conversion factor or factors for AN;
- A QD approach does not explicitly consider debris (projections or shrapnel), and so required distances are the same for storage in a tent on a sandy floor (zero significant debris) as they are for an unreinforced brick building (very high debris);
- A QD approach does not consider directionality, but recent large-scale testing shows debris distribution from rectangular structures is significantly directional, and that very little debris is projected directly away from corners;
- A QD approach is consequence based and hence does not reflect risks or allow risks to be minimised or better managed; and
- Preliminary analyses of several AN storages indicated that the separation distances determined by QD did not necessarily provide acceptable risk levels to neighbouring land uses, particularly at

lower quantity storages. At the same time, the risk levels at QD based separation distances from larger storages were so low as to be considered negligible, leading to the unnecessary sterilisation of neighbouring lands.

AEISG understood and appreciated the fact that if a risk-based approach to the siting of AN storages was to gain any acceptance by regulators in Australasia, it would need to be clearly defined, transparent, consistent, understandable and with all inputs to risk calculations identified, soundly based and tending to the conservative side of any range. Further, there would need to be clarity as to what risk levels, once determined, would be considered acceptable given the variety of potential AN storage types which would present the risk and the variety of neighbouring land uses exposed to that risk. AEISG was under no misapprehension as to the extent of this task, nor was it clear at an early stage as to what the eventual outcome would be and how it might impact its members.

In analysing the risks posed by AN storages, AEISG employed the IMESAFR modelling software referenced in the SAFEX GPG. It is a risk analysis software tool developed by the specialist explosives research company APT-Research as part of a joint effort with the Institute of Makers of Explosives (IME) and North American regulators. It was developed in the USA and derived from extensive earlier work done to create blast modelling software for the US military. The civil and military versions have each benefitted from ongoing collaboration, including shared access to many large-scale test programs, which have been used to refine the models.

It analyses the risk to people at an Exposed Site (ES), from an explosion at a Potential Explosion Site (PES). In doing so the software takes account of the physical construction details of both the PES and the ES. In AEISG's opinion, it is the most detailed risk calculator and is believed to be the most firmly anchored to actual test data gained from multiple test programs, including at a large scale (multiple tonnes). IMESAFR has many variables that can be adjusted to better represent a real-world situation, (such as building type, percentage glass, etc) and it is believed to generate the most accurate estimate of the likely effects of an explosion. Further, IMESAFR has a module specifically for AN explosions.

Historically, explosions of AN (like other materials) have been modelled as an "equivalent" amount of TNT (which is a very well-characterised explosive). When the IMESAFR AN module was developed in 2016, it became possible to move away from the historical method of treating AN as some equivalent percentage of TNT and instead model the explosion directly as an AN explosion. As standard, the tool adopts the SAFEX GPG structure of recognising three different mechanisms through which AN can explode (fire, contamination and shock) and also adopts the SAFEX GPG amounts of AN involved in any explosion for those mechanisms (10%, 50% and 100% respectively).

One of the key factors in AEISG choosing IMESAFR to underpin the Code is that IMESAFR allows simple, real-time analysis of composite risk at each ES (e.g., a house, office building, hospital, etc.) from a PES (i.e., an AN store) with three different explosion scenarios, each with its own quantity of AN, and its own explosion likelihood. AEISG is not aware of any other approach where these scenarios can be simply modelled in real-time. In AEISG's view the IMESAFR AN module is the most appropriate AN modelling tool, as it:

- Does NOT use a TNT equivalence – it models blast effects from AN explosions directly;
- Adopts the SAFEX GPG structure (i.e., 3 initiation mechanisms with different yields), with some modification of the event frequencies:
  - Shock - 100% of the AN present contributes, with event frequency 1.17E-6
  - Contamination - 50% of the AN present contributes, with event frequency 1.17E-6
  - Fire - 10% of the AN present contributes, with event frequency 2.34E-6

<u>Note</u>: **AEISG later adopted much more conservative values than these IMESAFR default frequencies, i.e., higher event frequencies representing (artificially) high rates at which explosions were assumed to occur**.

- Allows the user to adjust the event frequencies;
- Consistently utilises a 26-step series of calculations to determine consequence and risk;
- Uses many factors, some of which are entered by the user to describe a specific scenario, and some of which can either be an embedded default value or a user-defined value;
- Models differences in risk due to the nature / construction of the PES; and
- Other than user-defined inputs, whenever there is a choice IMESAFR defaults to the conservative.

It is in AEISG's view the most sophisticated, detailed and accurate blast assessment tool available to the commercial explosives and related industries. For this reason AEISG reached a critical decision that IMESAFR, specifically the AN module, would be used in its Code as the calculation basis for separation distances for AN stores. Further, this tool had already been used in successfully carrying out site specific QRA in Australasia and was gaining acceptance by regulators.

Note: Appendix B lists a range of standards, codes, guides and tools that have been considered in preparing the AEISG AN Code and summarises the way in which AN site location and separation distances are dealt with globally.

4. RESULTS OF INITIAL APPROACH

From all the current AN standards, codes and guides available to AEISG at this phase of code development, AEISG accepted all the similar and soundly based risk control measures (design, engineering, administrative, etc.) for inclusion into its code. It was accepted that most of these control measures influence the ‘likelihood’ side of the risk equation and that apart from AN stack sizes and their separations, little more was included to influence the ‘consequence’ of any potential AN explosion.

The close cooperation with environmental regulators identified a suite of control measures necessary to ensure any adverse environmental impacts from the siting, design and operation of AN storages would be minimised.

Acceptable risk targets have been established in Australasia for the siting and operation of hazardous industries. The NSW Hazardous Industry Planning Advisory Papers (HIPAPs) published by the NSW Department of Planning detail various aspects of the management of risk from a land-use planning perspective, and the *NSW Hazardous Industry Planning Advisory Paper No 4: Risk Criteria for Land Use Safety Planning* (HIPAP 4) details quantitative risk criteria that are deemed tolerable when used as the target for assessments at the planning stages of intended developments. These individual fatality risk (IFR) criteria are generally consistent with similar criteria adopted in other developed economies such as the UK, and other European and US jurisdictions. As these criteria are generally considered acceptable by Australasian regulatory jurisdictions for assessing IFR from hazardous industries, including MHF quantities of AN (>2,500t), AEISG decided that these criteria would also be appropriate for those smaller AN storages (<1,000t) associated with the commercial (non-military) explosives sector.

Hence, the framework of land uses neighbouring AN storages and the associated IFR criteria AEISG decided to use in its AN Code are drawn from HIPAP 4 as outlined in Table 1.

HIPAP 4 Land Use (summary)	**HIPAP 4 Risk Criteria Targets (individual fatality per year)**
Hospitals, schools, child-care facilities, old age housing	0.5 E-6
Residential, hotels, motels, tourist resorts	1 E-6
Commercial developments including retail centres, offices and entertainment centres	5 E-6
Sporting complexes and active open space	10 E-6
Industrial	50 E-6

Table 1: HIPAP 4 Risk Criteria Targets

Preliminary risk calculations on typical AN storages using IMESAFR at its default settings indicated, amongst other things, that:

- Stating the obvious, risk reduces as distance increases;
- Risk varied significantly, dependent upon the type of AN storage (silo, shed, open, etc.);
- Perhaps counter intuitively, risks posed by AN storages in the open to neighbouring land uses were higher, at larger quantities;
- Risk varied, but less significantly, with the type of exposed facility at a neighbouring land use (masonry, wood frame, metal shed, open, etc.);
- The application of QD distances to AN storages may not result in acceptable risk levels, particularly at lower quantity storages;
- The application of QD distances for large AN storages results in risk levels many multiples below those considered acceptable and hence could be considered excessive; and
- Given an identified target risk level, IMESAFR could be used to determine separation distances at which that risk level would be achieved.

5. FUTURE WORK

The above preliminary results provided added confidence to AEISG that a risk-based approach to separation distances for AN storages was the preferred option. Further, rather than simply specifying in the AEISG Code that site-specific risk assessments should be conducted for each AN storage site, AEISG was of the view that risk-based separation distance tables could be developed for different AN storages, which could be included in its code and applied generally to assist members in both reviewing existing AN storages and planning future AN storages. It was acknowledged and accepted that any separation distances tables generated for inclusion in its code would need to be clearly defined, transparent, consistent, understandable and with all inputs to risk calculations identified, soundly based and tending to the conservative side of any range.

It was evident that more work would be required to clearly define parameters that accurately reflected the Australasian AN environment and would be the bases for further analyses using the IMESAFR AN module, including:

- AN storage types which would be considered as PES;
- Types of facilities at neighbouring land uses which would be considered as ES;
- Typical AN storage quantity levels, to enable a relevant table of quantity versus separation distances to be developed;
- Establishment of potential consequences of an AN explosion at a PES;
- Establishment of conservative AN explosion event frequencies at any PES; and
- Reviewing and acceptance, or otherwise, of other settings / parameters to be included in the IMESAFR AN module.

6. METHODOLOGY

6.1 AN Storage Types (PES)

AEISG surveyed its member companies to identify the range of AN storage types currently being used within Australasia and determined that the bulk of the range could be satisfactorily allocated into five (5) distinct categories:

(i) Overhead Silo(s);
(ii) Metal Shed (shed with metal cladding over a steel frame);
(iii) Open (AN stored in the open);
(iv) Shipping Container(s) (one or more 20 foot shipping containers - assuming a capacity of 20 tonnes per container); and
(v) Concrete Shed.

Note: Appendix C provides guidance on which storage category should be used according to the identified construction of the AN store. Most AN stores were reasonably similar to one of the five types listed, but if the construction of a particular AN store is substantially different to any of the five identified categories then AEISG was of the view that either the most conservative separation distance for that AN quantity should be used (i.e., that quantity in any type of AN Store) or a site specific risk assessment should be conducted. The tabulated information within Appendix C provides guidance - AEISG included photos in its Code to assist with categorising typical AN storage types.

Because of the significance of the AN storage type upon risk posed to neighbouring land uses, AEISG determined that each AN storage type would be assessed separately.

6.2 Neighbouring Land Uses (ES)

Likewise, five (5) different types of facilities at risk (ES) were defined, again aiming to represent the range of types of buildings or exposures commonly found at sites neighbouring AN stores. Again AEISG could effectively allocate these different types of facilities into 5 categories to facilitate risk calculations:

(i) Large unreinforced masonry;
(ii) Small unreinforced masonry;
(iii) Small wood frame;
(iv) Large metal shed; and
(v) Open (people in the open).

AEISG determined that there would be one (1) table of separation distances for each type of AN store, so five (5) tables in total. Each table would detail the minimum separation distances required between that type of AN store and each of the five neighbouring land uses, as outlined in Section 4 of this paper, and for which acceptable risk criteria were established, with the distances based on meeting the risk target applicable to that land use. Note that the tables were to be based on land uses, not ES types.

With one exception, the land uses in themselves generally do not describe or necessarily relate to the type of construction of the ES. For instance, if the land use is "hospital, school, child-care facility or old age housing" a risk target of 0.5E-6 applies. But the physical construction of the ES being used for that land use could be any of "large unreinforced masonry", "small unreinforced masonry", "small wood frame", or even in some cases "large metal shed". The same type of ES could also be used for a residential or commercial or industrial land use, in which case the risk target would be different.

Analyses had shown that while the type of ES at the neighbouring land use had some impact on risk levels, the difference was not sufficient to present any significant difference to separation distances. **To err on the conservative side, AEISG decided that the distances tabulated for any neighbouring land use would be the biggest distance at which the applicable risk target for that land use is met for ANY of the types of ES construction that might be used for that land use.**

6.3 Typical AN Storage Quantity Levels

After considering typical AN storage quantity levels in Australasia, AEISG adopted a range of AN quantity levels to include in its risk-based separation tables. This range included 18 levels extending from 10 tonnes to 1,000 tonnes, of which ten (10) levels would be assessed using the IMESAFR AN Module. The remaining eight (8) quantities, which sat within those modelled, would be interpolated on a straight-line basis between the nearest modelled values.

AEISG adopted the stack separation distances outlined in the SAFEX GPG and hence the quantity levels quoted in the tables dictate the total quantity of AN stored in the biggest stack / pile within a store, provided those stack separation distances are applied. Where they are not, the AN quantity level represents the maximum capacity of the storage.

For specific quantities of stored AN which are not tabulated, interpolation would be used to calculate the required separation distance.

6.4 Establishment of Potential Consequences of an AN Explosion at an AN Storage site (PES)

The consequences to be avoided are primarily fatalities and injuries. For a given explosion scenario, irrespective of how unlikely it may be, it is possible to estimate the probability of fatalities and injuries occurring if that scenario occurred. This can be done semi-quantitatively using the descriptions in several publications, including the SAFEX GPG and HIPAP 4. These descriptions, similar to QD tables, are based on expected overpressure and provide relatively coarse estimates. More precise, numerical estimates can be obtained by using a blast assessment tool or calculator.

In AEISG's opinion, the best and most comprehensive of these tools is IMESAFR. It is the most detailed and is believed to be the most firmly anchored to actual test data gained from multiple test programs, including at a large scale (multiple tonnes). IMESAFR overcomes many of the flaws inherent in a QD approach as it has many variables that can be adjusted to better represent a real-world situation, (such as building type, percentage glass, etc) and it is believed to generate the most accurate estimate of the likely effects of an explosion.

It was, and remains, AEISG's view that the "consequence" part of the risk equation can be estimated to a high degree of accuracy and with a well-defined degree of conservatism by using the AN module of the IMESAFR blast assessment tool.

6.5 Establishment of Explosion Event Frequencies at an AN Storage site (PES)

AEISG considered four sources which could offer conservative but reasonable estimates of the likelihood of an AN explosion occurring:

1. Typical estimates that have already been used in QRA's / site assessments to support MHF or similar licensing purposes;
2. The baseline event frequencies and allowable reductions detailed in the SAFEX GPG;
3. The frequencies determined by the IMESAFR Technical Panel, and which appear as the IMESAFR defaults; and
4. AEISG's own "ground up" estimates based on AN event history.

The ranges of estimated explosion frequency and (where relevant) the split across mechanisms is summarised in Table 2, along with the values decided and used by AEISG in developing the minimum separation distances. The values used by AEISG are believed to be significantly conservative.

Total explosions per million store-years					
Origin of Estimate	**Total / Range**		**Split by initiation Mechanism**		
	Low	**High**	**High Energy Impact**	**Contamination**	**Fire**
			100% of AN	**50% of AN**	**10% of AN**
Typical estimates that have been used in QRAs	0.1	10	n/a		
SAFEX GPG: 'Raw'	55	80	5 to 10	10 to 25	25 to 50
SAFEX GPG: with reductions and exclusions per AEISG Code scope and SAFEX GPG best practices	10	20	0	0	10 to 20
IMESAFR defaults	4.68		1.17	1.17	2.34
AEISG estimate based on history (zero actual explosions at ~1000 in-scope stores over 50 years, so if an explosion occurred "today" the rate would be 1 per 50,000 store-years.)	20		n/a		
Frequency/split adopted by AEISG	20		2	6	12

Table 2: Total explosions per million store-years

The event frequency AEISG has decided to adopt for the purpose of calculation is deliberately conservative, both in light of the other estimates that have been used more widely, and also given that:

- The scope of this Code excludes manufacturing, transport, and any processing or mixing operation;
- This Code incorporates the significant "best practice" control measures (design, engineering, administrative) which reduce the SAFEX GPG baseline event frequency; and
- Due to the nature of operations at in-scope stores, the risk of shock or contamination as a source of initiation is likely to be negligible.

Note that the frequencies adopted by AEISG for the purpose of developing risk-based distances are nominally split across the three initiation mechanisms identified in the SAFEX GPG, but AEISG prefers to view the total (per million store-years) as representing:

- 2 explosions that involve 100% of the AN present, irrespective of how the explosion is initiated, plus
- 6 explosions that involve 50% of the AN present, irrespective of how the explosion is initiated, plus
- 12 explosions that involve 10% of the AN present, irrespective of how the explosion is initiated.

In AEISG's view, this approach is conservative and allows for some variability in the level of AN contribution. For instance, in some large fires it is likely the AN becomes contaminated as a result of the fire, so it is then more likely to explode, and more of the AN may be involved. Even though High Energy Impact is not credible at in-scope sites, and the SAFEX GPG specifies that this mechanism can be discounted, it is deliberately conservative to allow for some level of 100% AN contribution explosions.

6.6 Settings to be Included in the IMESAFR AN Module

In setting up and running the calculations within the IMESAFR AN Module, a number of conservative assumptions were made by AEISG to ensure that the specified distances would meet the targeted risk levels, even for "worst case" situations. Table 3 details the conservative assumptions used in this modelling.

Conservative Assumption	Comments
Increased Explosion Event Frequency	It could be argued that AN is generally robust against all but extreme sets of conditions, and for in-scope AN stores, no separation distances are required. However, in the interest of conservatism, it is assumed that even though an explosion has never happened at an in-scope store, it could be imminent. AEISG adopted higher event frequencies than the default frequencies in IMESAFR.
Every Exposed Site is continuously occupied	This is particularly conservative for non-residential land uses (commercial and sporting/open).
No reliance on evacuation	The modelling assumed all exposed sites are occupied continuously and risk targets are met on that basis. In practice, not all ES's are continuously occupied, and it is likely that in most situations there would be at least some attempt to evacuate, and any success in this would further reduce risk.
Any AN store is always filled to full licence capacity	In practice, the amount of AN present at most stores varies between near-zero and 100%, with a time-based average of about 60%. IMESAFR is able to take this into account and two values (MAXIMUM and EXPECTED) can be defined for the amount present and also the amount which contributes to the explosion. IMESAFR routinely calculates all 4 combinations of these, but AEISG has adopted the MAX/MAX combination (i.e., worst case) in its calculations.
AN store always operating	Assumed operating hours were 24 hours every day.
The type (construction) of the Exposed Site is the worst, i.e., requiring the largest separation distance from the AN Store	Hence, for other types of Exposed Sites the risk would be less.
Every Exposed Site is in the most hazardous orientation in relation to the PES	The modelling in IMESAFR can allow for variations in the direction that most debris will scatter to align with real-world testing. This variation was selected and the ES was always placed normal to the front wall, where the debris hazard is usually highest, i.e., worst case.
The modelling calculates distances on a centre-to-centre basis (centre of PES to centre of ES)	When the distances are applied in practice they will follow the convention of being measured edge to edge, so the actual centre-to-centre distances will be bigger than the modelling requires.
IMESAFR high-level choices or switches were set to what is normally the more conservative choice, including:	
Uncertainty is ON	Uncertainty is a factor which increases the calculated results to ensure estimates of risk are safe-sided.
Used default velocity scaling factor	When using the AN module of IMESAFR the initial velocity of debris fragments is calculated as a % of the value that would be used for TNT. There is an option to select a lower velocity scaling factor which may be more realistic. In this exercise the more conservative default scaling was used.
Unreacted AN was not considered	IMESAFR can take account of unreacted AN, so that when the % that contributes to the explosion is set to 10%, for example, the other 90% is entrained in the blast wave. The effect of making this choice is sometimes conservative, but sometimes is not conservative. For this exercise it was not selected.
No frangible walls at PES	Frangible walls at a PES can help relieve and direct the blast effects. They are occasionally used in explosives manufacturing plants but not common elsewhere and were not used in this exercise.
No credit / allowance for barricades or terrain (hills, trees)	Worst case is that there is no barricade (mound) or other features that may intercept or reduce debris (including other buildings).
Activity is always AN Storage with no "environmental factors" set	IMESAFR takes account of the type of activity at a PES, and also whether the risk is influenced by environmental factors (which can increase or reduce risk). No environmental factors were set.
All initiation mechanisms included in the modelling	Each of the three initiation mechanisms (fire, contamination, shock) were used in the calculations, each with a defined explosion event frequency.

Table 3: Conservative Assumptions / Settings to be Included in the IMESAFR AN Module

Table 4 summarises the event frequencies per mechanism (as detailed in Table 2) and this data was used in developing Tables 5.1 – 5.5. As an example, Table 5.1 addresses an “Open” PES, and superimposes 3 replications of that PES at the same physical location, with each replication representing one of the columns within Table 4, i.e., each column specifies an initiation mechanism, using a default % AN involved per mechanism but with AEISG’s conservative default event frequency.

PES	**1**	**2**	**3**
Mechanism	Shock/projectile	Contamination	Fire
% AN involved	100	50	10
Event Frequency	2.00E-06	6.00E-06	1.20E-05

Table 4: Event frequencies per mechanism

AEISG believes that the additional layers of conservatism built into its calculations when using IMESAFR provide confidence that the separations distances developed will ensure IFR targets, as specified in HIPAP 4, are comfortably met.

7. RESULTS

Tables 5.1 to 5.5 list all of the separation distances obtained by following the abovementioned methodology.

Scenario A	PES->	3 x Open (i.e., this represents one PES at 100% plus one at 50% plus one at 10% all superimposed on the same physical location)												
	ES->	Open	Large Masonry			Small Masonry			Small Wood Frame			PEMB		
	Risk target->	1.0 E-5	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6
	Tonnes	Distance (m) where Risk Target is just met												
	10	69	147	117	87	172	153	108	172	150	104	171	150	103
	20	92	202	159	117	228	202	143	228	200	138	227	200	138
	40	121	272	220	154	301	266	189	300	265	183	302	266	184
	60	143	323	263	180	352	311	221	351	311	216	355	314	217
	100	174	390	326	217	422	380	269	423	380	264	430	383	267
	140	199	432	369	246	470	428	306	470	427	301	481	434	306
	200	229	473	415	282	521	481	350	521	480	346	537	492	352
	300	269	509	460	326	583	544	407	582	543	402	608	561	410
	500	328	567	517	389	654	611	481	653	610	477	699	637	487
	1000	422	661	630	496	751	708	579	736	698	569	855	750	582

Table 5.1: ‘Open’ Storage – initial tabulated distances to neighbouring land uses

Scenario B	PES->	3 x Metal Shed (i.e., this represents one PES at 100% plus one at 50% plus one at 10% all superimposed on the same physical location)												
	ES->	Open	Large Masonry			Small Masonry			Small Wood Frame			PEMB		
	Risk target->	1.0 E-5	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6
	Tonnes	Distance (m) where Risk Target is just met												
	10	76	299	247	111	286	231	119	302	250	125	301	249	108
	20	90	324	264	132	319	258	142	324	267	139	323	266	130
	40	96	346	284	153	344	282	173	347	285	157	347	287	147
	60	110	359	295	170	361	299	192	361	296	170	364	304	159
	100	121	376	319	192	380	330	221	378	314	195	399	338	182
	140	128	392	343	211	404	356	242	393	328	213	431	368	197
	200	142	419	368	238	436	396	266	409	348	239	476	406	218
	300	159	461	400	267	479	436	297	432	378	265	539	451	253
	500	185	525	462	310	548	501	341	473	434	303	640	528	302
	1000	222	623	577	385	695	619	416	569	520	369	844	665	392

Table 5.2: 'Metal Shed' Storage – initial tabulated distances to neighbouring land uses

Scenario C	PES->		3 x (Groups of) Shipping Containers (i.e., this represents one PES at 100% plus one at 50% plus one at 10% all superimposed on the same physical location)												
	ES->		Open	Large Masonry			Small Masonry			Small Wood Frame			PEMB		
	Risk target->		1.0 E-5	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6	5.0 E-7	1.0 E-6	5.0 E-6
	Tonnes	No. of Containers	Distance (m) where Risk Target is just met												
	10	1	100	288	242	121	284	238	124	289	247	137	288	241	122
	20	1	126	318	275	157	316	273	161	319	280	177	317	274	160
	40	2	173	400	342	215	400	343	217	401	344	230	400	342	219
	60	3	205	450	387	250	451	391	252	452	391	265	451	390	254
	100	5	247	508	444	295	513	450	299	512	451	308	512	450	300
	140	7	278	539	482	319	545	489	335	545	489	338	545	488	331
	200	10	309	568	517	344	577	527	368	577	527	366	575	526	366
	300	15	349	598	551	376	610	565	419	610	565	416	609	565	417
	500	25	413	626	587	437	637	601	478	637	602	476	639	605	477
	1000	50	496	652	627	505	679	654	543	679	654	543	696	660	548

Table 5.3: 'Shipping Containers' Storage – initial tabulated distances to neighbouring land uses

	PES->		3 x (Groups of) Overhead Silos ((i.e., this represents one PES at 100% plus one at 50% plus one at 10% all superimposed on the same physical location)												
	ES->		Open	Large Masonry			Small Masonry			Small Wood Frame			PEMB		
	Risk target->		1.0E-5	5.0E-7	1.0E-6	5.0E-6	5.0E-7	1.0E-6	5.0E-6	5.0E-7	1.0E-6	5.0E-6	5.0E-7	1.0E-6	5.0E-6
	Tonnes	No. of Silos	Distance (m) where Risk Target is just met												
Scenario D	10	1	19	114	77	36	119	100	54	131	91	38	106	71	33
	20	1	25	151	113	48	154	135	74	166	122	56	145	109	44
	40	1	33	191	155	70	194	178	98	209	161	79	190	150	61
	60	2	38	212	176	85	221	204	115	233	185	96	215	175	73
	100	2	47	267	224	113	270	249	146	285	228	125	275	226	98
	140	3	63	295	254	136	301	284	169	320	263	148	314	265	118
	200	4	78	330	290	161	338	313	195	357	296	172	352	303	143
	300	5	98	363	320	190	371	354	227	368	322	203	387	338	172
	500	9	122	405	368	232	442	394	270	388	367	242	479	394	213
	1000	17	170	508	448	306	560	493	343	474	429	309	631	515	295

Table 5.4: **'Overhead Silos' Storage – initial tabulated distances to neighbouring land uses**

	PES->	3 x Concrete Shed ((i.e., this represents one PES at 100% plus one at 50% plus one at 10% all superimposed on the same physical location)												
	ES->	Open	Large Masonry			Small Masonry			Small Wood Frame			PEMB		
	Risk target->	1.0E-5	5.0E-7	1.0E-6	5.0E-6	5.0E-7	1.0E-6	5.0E-6	5.0E-7	1.0E-6	5.0E-6	5.0E-7	1.0E-6	5.0E-6
	Tonnes	Distance (m) where Risk Target is just met												
Scenario E	10	274	428	403	317	427	401	305	428	403	318	428	402	316
	20	304	476	446	352	475	444	341	476	447	352	475	446	352
	40	336	528	495	389	527	493	387	529	495	390	527	494	388
	60	357	561	524	413	560	523	411	561	525	413	560	524	412
	100	384	605	563	446	605	561	443	605	563	446	603	562	445
	140	403	632	586	468	632	586	464	633	587	469	631	586	468
	200	423	657	607	491	656	606	490	657	608	492	657	607	492
	300	447	665	629	519	664	629	512	666	630	518	668	634	519
	500	476	686	655	546	687	655	540	688	657	546	695	668	550
	1000	500	696	672	572	699	675	578	697	672	568	767	699	580

Table 5.5: **'Concrete Shed' Storage – initial tabulated distances to neighbouring land uses**

However as indicated earlier, **AEISG decided that the distances tabulated for any neighbouring land use would be the largest distance at which the applicable risk target for that land use is met for ANY of the types of ES construction that might be used for that land use**. Hence, Tables 5.1 to 5.5 were further refined as indicated in Tables 6.1 to 6.5.

AEISG Short Name	Vulnerable	Residential	Commercial	Open	Industrial
HIPAP 4 Risk Criterion	**5.0E-7**	**1.0E-6**	**5.0E-6**	**1.0E-5**	**5.0E-5**
Quantity of AN stored (tonnes)	**Minimum Distance Required (metres)**				
10	170	155	110	70	70
20	230	200	145	90	90
30*	265	235	165	105	105
40	300	265	190	120	120
50*	330	290	205	130	130
60	355	315	220	145	145
80*	395	350	245	160	160
100	430	385	270	175	175
120*	455	410	290	185	185
140	480	435	305	200	200
160*	500	455	320	210	210
180*	520	475	335	220	220
200	535	490	350	230	230
300	610	560	410	270	270
400*	655	600	450	300	300
500	700	635	485	330	330
750*	775	695	535	375	375
1000	855	750	580	420	420

Table 6.1: Separation from AN stored in the Open

AEISG Short Name	Vulnerable	Residential	Commercial	Open	Industrial
HIPAP 4 Risk Criterion	**5.0E-7**	**1.0E-6**	**5.0E-6**	**1.0E-5**	**5.0E-5**
Quantity of AN stored (tonnes)	**Minimum Distance Required (metres)**				
10	300	250	125	75	75
20	325	265	140	90	90
30*	335	275	160	95	95
40	345	285	175	95	95
50*	355	295	185	105	105
60	365	305	190	110	110
80*	380	320	205	115	115
100	400	340	220	120	120
120*	415	355	230	125	125
140	430	370	240	130	130
160*	445	380	250	135	135
180*	460	395	260	135	135
200	475	405	265	140	140
300	540	450	295	160	160
400*	590	490	320	170	170
500	640	530	340	185	185
750*	Distances not modelled; tonnage not feasible in building modelled.				
1000					

Table 6.2: Separation from AN stored in a Metal Shed

AEISG Short Name	Vulnerable	Residential	Commercial	Open	Industrial
HIPAP 4 Risk Criterion	**5.0E-7**	**1.0E-6**	**5.0E-6**	**1.0E-5**	**5.0E-5**
Quantity of AN stored (tonnes)	**Minimum Distance Required (metres)**				
10	290	245	135	100	100
20	320	280	175	125	125
30*	360	310	205	150	150
40	400	345	230	175	175
50*	425	370	250	190	190
60	450	390	265	205	205
80*	485	420	285	225	225
100	515	450	310	245	245
120*	530	470	325	265	265
140	545	490	340	280	280
160*	555	500	350	290	290
180*	565	515	360	300	300
200	575	525	370	310	310
300	610	565	420	350	350
400*	625	585	450	380	380
500	640	605	480	415	415
750*	670	635	515	455	455
1000	695	660	550	495	495

Table 6.3: Separation from AN stored in Shipping Container(s)

AEISG Short Name	Vulnerable	Residential	Commercial	Open	Industrial
HIPAP 4 Risk Criterion	**5.0E-7**	**1.0E-6**	**5.0E-6**	**1.0E-5**	**5.0E-5**
Quantity of AN stored (tonnes)	**Minimum Distance Required (metres)**				
10	130	100	55	20	20
20	165	135	75	25	25
30*	190	155	85	30	30
40	210	180	100	35	35
50*	220	190	105	35	35
60	235	205	115	40	40
80*	260	225	130	45	45
100	285	250	145	45	45
120*	305	265	160	55	55
140	320	285	170	65	65
160*	330	295	180	70	70
180*	345	305	185	75	75
200	355	315	195	80	80
300	385	355	225	100	100
400*	435	375	250	110	110
500	480	395	270	120	120
750*	555	455	305	145	145
1000	630	515	345	170	170

Table 6.4: Separation from AN stored in Overhead Silo(s)

AEISG Short Name	Vulnerable	Residential	Commercial	Open	Industrial
HIPAP 4 Risk Criterion	**5.0E-7**	**1.0E-6**	**5.0E-6**	**1.0E-5**	**5.0E-5**
Quantity of AN stored (tonnes)	**Minimum Distance Required (metres)**				
10	430	405	320	275	275
20	475	445	350	305	305
30*	505	470	370	320	320
40	530	495	390	335	335
50*	545	510	400	345	345
60	560	525	415	355	355
80*	585	545	430	370	370
100	605	565	445	385	385
120*	620	575	460	395	395
140	635	585	470	405	405
160*	640	595	475	410	410
180*	650	600	485	415	415
200	655	610	490	425	425
300	670	635	520	445	445
400*	680	650	535	460	460
500	695	670	550	475	475
750*	730	685	565	490	490
1000	765	700	580	500	500

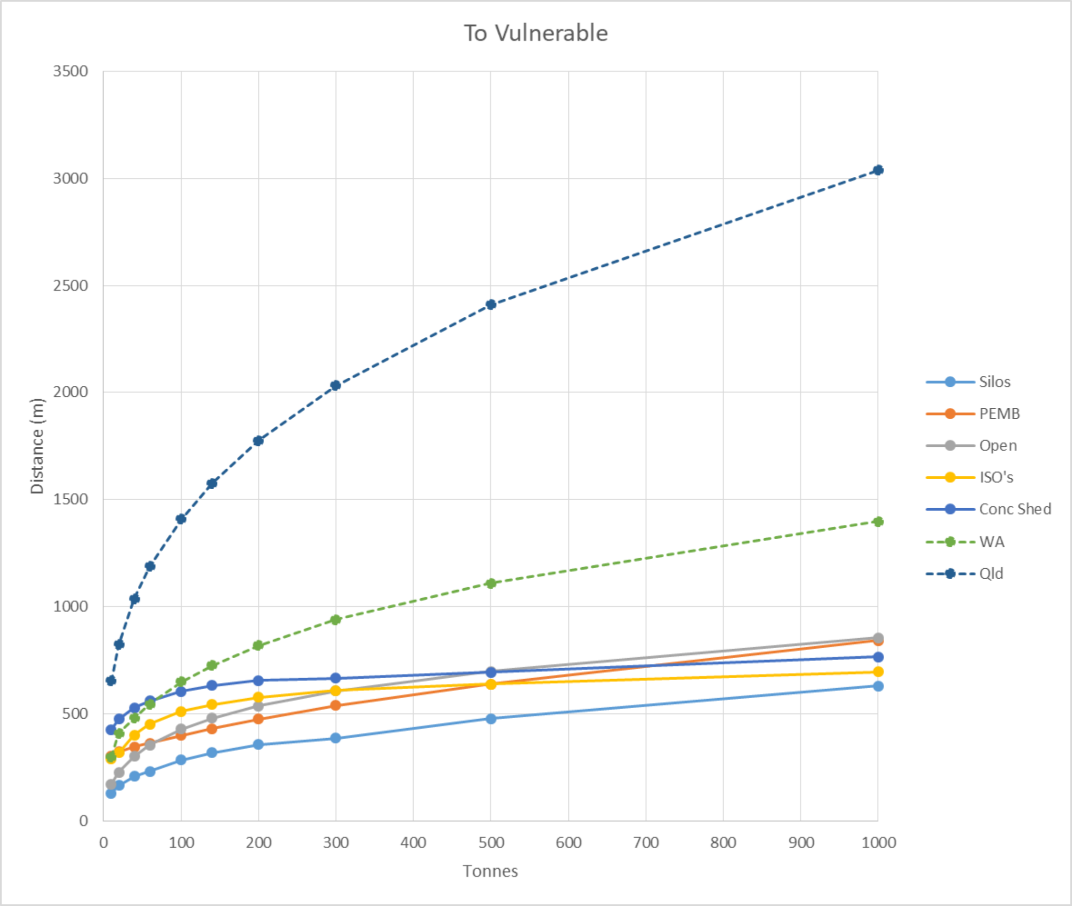
Table 6.5: Separation from AN stored in a Concrete Shed

AEISG is of the view that the above risk-based Tables (5.1 to 5.5) of Separation Distances provide conservative guidance on the use of separation as a risk control measure in ensuring AN storages are located such that they pose no unacceptable risks to neighbouring land uses.

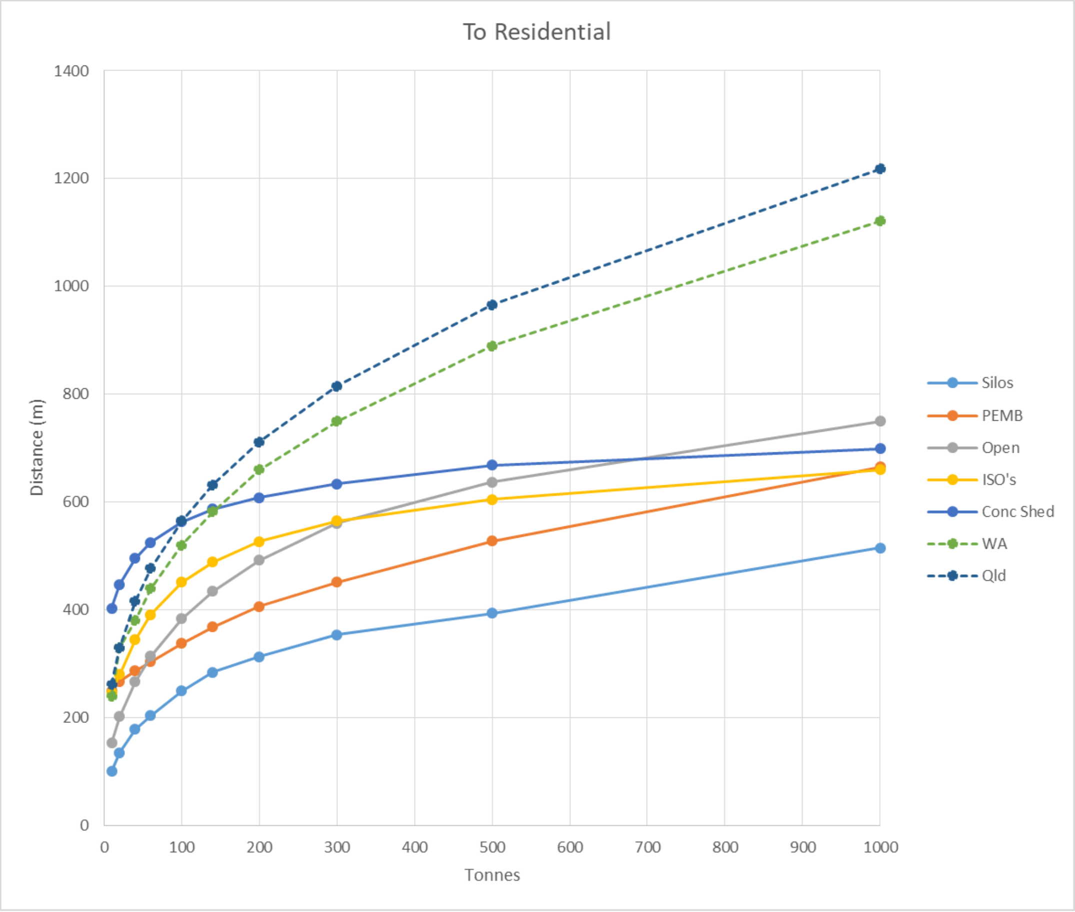
Comparison of these risk-based separation distances with existing QD based distances applied by two jurisdictions in Australasia can be seen in the following graphs. In the graphs the solid lines show the AEISG distances for the 5 types of AN Store (i.e., PES). The blue dashed line shows distances AEISG believes would be required under the Queensland code (QLD IB53) and the green dashed line shows the Western Australia (WA code) equivalent. Neither of these codes use the exact same definitions of surrounding land uses as AEISG – the WA code is only slightly different to the AEISG definitions (which essentially adopt the HIPAP 4 structure) whereas QLD IB53 uses a “Protected Works” approach adopted from Explosives requirements.

Of particular note:

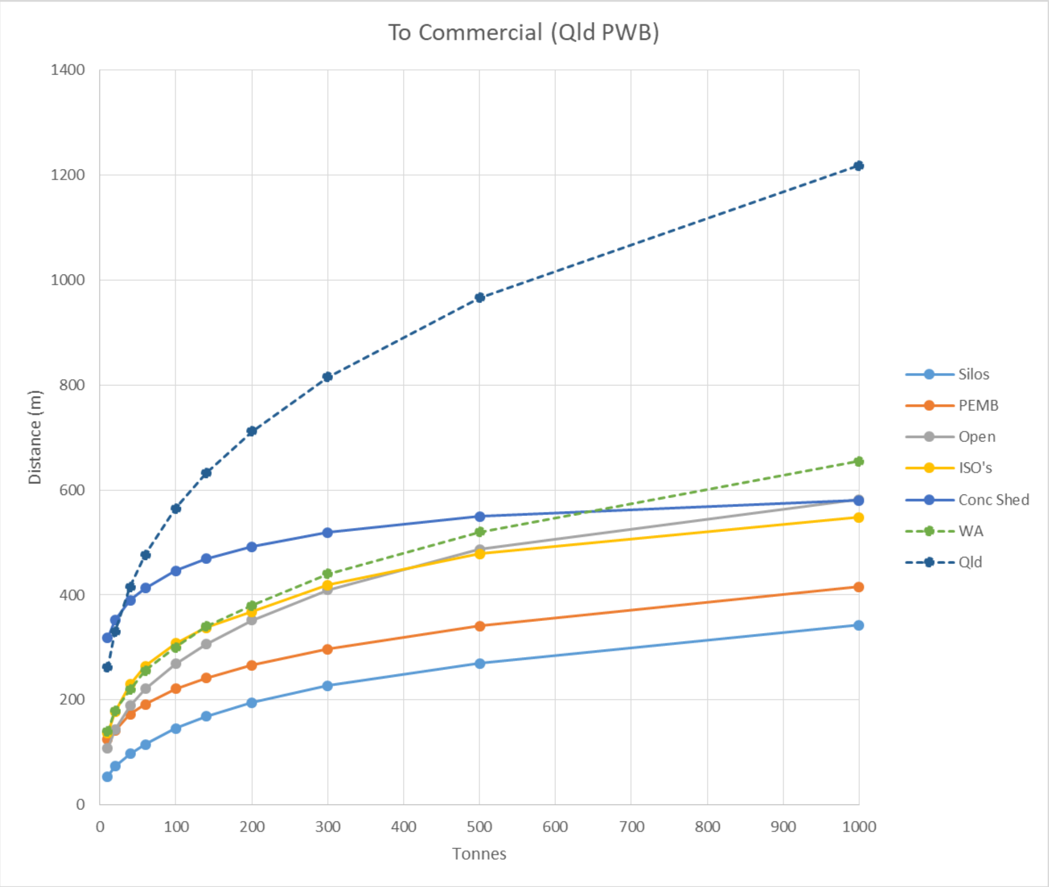
- Not surprisingly, risk-based separation distances are generally, **but not always**, less than QD based (consequence) distances;
- Application of QD derived distances does not always provide acceptable risk levels; and
- Continued application of QD based distances at larger AN quantities results in unnecessary sterilisation of land around AN storages.



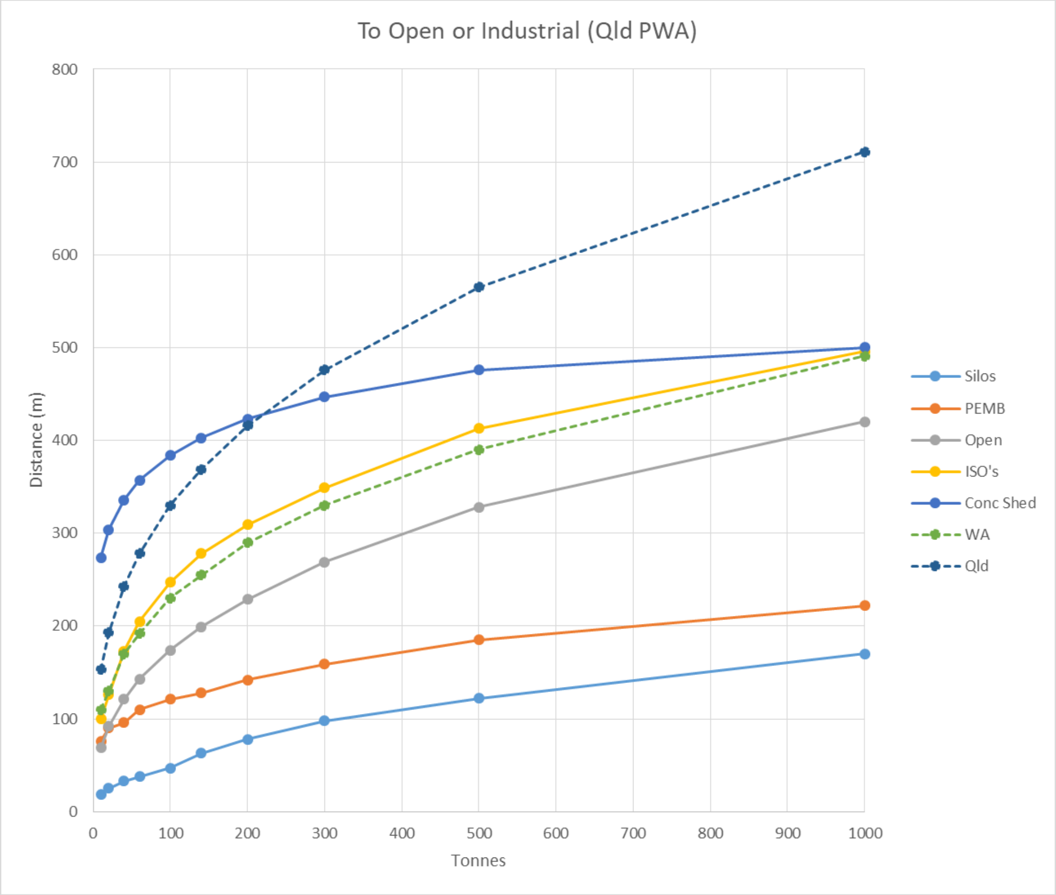
Graph 1: 'Vulnerable' locations – charting of separation distances, AEISG risk-based v QD (WA and QLD)



Graph 2: 'Residential' locations – charting of separation distances, AEISG risk-based v QD (WA and QLD)



Graph 3: 'Commercial' locations – charting of separation distances, AEISG risk-based v QD (WA and QLD)



Graph 4: 'Open' or 'Industrial' locations – charting of separation distances, AEISG risk-based v QD (WA and QLD)

8. CONCLUSION

Rare events such as the Beirut tragedy (2020) have resulted in some Australasian regulatory jurisdictions continuing to take an ultra-conservative approach to the storage of AN, akin to explosives. AEISG acknowledges that AN was stored in large quantities in Beirut, however the virtually non-existent safety management systems and practices that allowed the co-storage of fireworks and combustible products within the same warehouse, are in no way comparable to the levels of operational safety that have been established, and continue to apply within Australasia.

The Beirut tragedy, although relevant to the topic of this Paper, gives rise to no new "technical" learning. This tragic explosion does, however, give added point to the need for appropriate and uniform standards for safe and secure AN storage and handling, and AEISG is confident that the AEISG Code, if implemented, could have prevented the Beirut (and many similar) tragedies.

To manage the risk arising from a potential explosion of AN, the Code has adopted the hierarchy:

i. Ensure the likelihood of any explosion is reduced to as low as reasonably practicable through the application of all known and soundly based risk control measures (design, engineering and administrative);
ii. Ensure that any AN storage is appropriately located so that it poses no unacceptable risk to neighbouring land uses through the application of appropriate separation distance to achieve targeted and acceptable risk levels (HIPAP 4 criteria); and
iii. Ensure that in the event of conditions which potentially could lead to an explosion, a well-thought-out emergency response plan, including evacuation, is established, tested and ready to be carried out.

The methodology developed, and the resulting tables of risk-based separation distances, make it possible for AEISG members and others involved in the explosives sector to establish AN storage sites without the need for a site-specific QRA. Through assessing hazards and risks in a conservative manner, the Code delivers community safety in a consistent and efficient way for most proposed AN stores, with very few exceptions, e.g., those above MHF thresholds or those not reasonably fitting within the limits detailed in the Code. Such exceptions need site-specific risk assessment, and the Code recommends a methodology for the conduct of any such assessment.

The completed AEISG Code for the Storage and Handling of Solid Ammonium Nitrate:

- Has specified scope – solid AN storage and handling for the explosives industry;
- Outlines necessary precautions or risk control measures against fire, contamination and shock which might lead to explosion, and at the same time addresses environmental and security needs;
- Builds on the risk-based approach for AN storage location outlined in the SAFEX GPG;
- Specifies a methodology for assessing the acceptability of a proposed AN storage site location using:
    - Different AN storage types and adjacent land uses that reflect typical AN storage scenarios in Australasia which might impact changing risk levels;
    - Risk targets (individual fatality risk) considered acceptable at each land use;
    - Defined (conservative) explosion frequencies (likelihoods) for 3 explosion scenarios (fire, contamination and shock) at each AN store;
    - IMESAFR (AN Module) as a means of consequence assessment and risk calculations;
- Includes Tables of Distance (ToD) for up to 1,000 tonnes of AN, developed using the specified methodology which are considered conservative and may be used in lieu of site-specific QRA;
- Addresses situations where AN storages might be in proximity to Class 1 Explosives or ANEs (UN3375);
- Does not require AN to be treated as an ‘equivalent’ amount of TNT;

- Is transparent, with all parameters used in risk calculations fully defined such that appropriate separation distances outlined in its tables are fully reproducible by ‘anyone’, or can be used in the competent risk assessment of AN storage sites differing from those in the AEISG code;
- Provides guidance on application at mine sites;
- Includes relevant security requirements established nationally (Australia) for AN in 2004;
- Includes an extensive history of incidents involving AN;
- Includes an audit checklist for both internal and external audits of AN storage sites; and
- Delivers community safety consistently and efficiently for AN storages in line with all hazardous industries in Australasia.

This project was completed in 2022 and ratified by AEISG Member Companies enabling the publishing of the AEISG Code of Practice – Storage and Handling of Solid Ammonium Nitrate, June 2022, Edition 1. The Code adopts risk-based principles for the storage of solid AN and **requires mandatory compliance by all AEISG member companies in addition to any jurisdictional (local) legislative requirements**. AEISG is of the view that as with all other AEISG Codes of Practice, many of which have been referenced in existing legislations and / or accepted by regulators as ‘Approved codes’, the AEISG AN Code will have significant flow-on benefits to relevant government agencies (State, Territory and Commonwealth) and the communities that they seek to protect.

It is not completely clear at this stage how the new AEISG AN Code will interact in practice with the various regulatory authorities in Australasia into the future, however AEISG will continue to promote its application. Further, AEISG Members will undoubtedly uncover complexities and issues as the implementation of the Code proceeds. It is possible there will be a further update within 12 months to (hopefully) accommodate and resolve whatever issues arise.

It should be noted that stakeholder comments that are received post publication of the Code will be retained by AEISG for consideration as part of future Code revision, and this process is anticipated to commence in mid-2023.

AEISG is always receptive to constructive comments on its codes and encourages interested parties to provide such comments and suggestions for improvement directly to AEISG.

9. REFERENCES

No	Short form	Full Title
1	SAFEX GPG	Good Practice Guide: Storage of Solid Technical Grade Ammonium Nitrate (GPG 02 rev02, March 2014); published by SAFEX International
2	AEISG AN Code	AEISG Code of Practice – Storage and Handling of Solid Ammonium Nitrate, June 2002, Edition 1; published by the Australasian Explosives Industry Safety Group
3	AS 2187	Australian Standard 2187:1998 Explosives - storage, transport and use; Published by Standards Australia (Note: this standard is published in 4 parts; references when used in this Code are to the relevant part according to the context.);
4	AS 4326	Australian Standard 4326:2008 The storage and handling of oxidizing agents; Published by Standards Australia
6	UN Model Regulations	Recommendations on the Transport of Dangerous Goods: Model Regulations, 22nd Revised Edition, 2021; Published by the United Nations
7	Manual of Tests and Criteria	Manual of Tests and Criteria - Seventh Revised Edition Series: Recommendations on the Transport of Dangerous Goods: Tests and Criteria, 12 December 2019; Published by UNECE
8	HIPAP 4	NSW Hazardous Industry Planning Advisory Paper No 4: Risk Criteria for Land Use Safety Planning, 2011 (HIPAP 4); Published by New South Wales Dept. of Planning
9	WA code	Safe Storage of Solid Ammonium Nitrate (Fourth Edition, 2021): Published by Department of Mines, Industry Regulation and Safety, Western Australia
10	QLD IB53	Information Bulletin No 53 (Version 5, 31 Oct 2017): Published by Explosives Inspectorate, Department of Mines and Energy (subsequently Department of Natural Resources and Mines, then Resources Safety & Health Queensland), Queensland Government

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APPENDIX A - AEISG OVERVIEW

Origin of the Australasian Explosives Industry Safety Group Inc. (AEISG)

The Australasian Explosives Industry Safety Group Inc. (AEISG) is a not for profit Industry Association, who's catalyst for formation was the tragic accident that occurred on 2 August 1994 at Porgera (Papua New Guinea), which resulted in 11 employee fatalities.

Following the regulatory investigation, by several Australasian regulatory jurisdictions, into the Porgera plant explosion, the commercial explosives sector was asked to form an industry group to enhance the level of inter-industry communications on safety and technical issues towards consistent safety goals in the face of new technology. This approach was seen as critical by regulatory jurisdictions given the considerable growth of mining operations in the 1980s and early 1990s, which was supported by new explosive products and processes. The formation of this industry group was anticipated to assist not only industry in the sharing of best-practice safety but importantly would allow regulatory jurisdictions to liaise with a single point of contact representing safety best-practice, rather than with each manufacturer of explosives.

The Australian Explosives Manufacturing Safety Committee (AEMSC) was formed in circa 1995, initially as an informal association of explosives companies with the majority of Australian explosives manufacturers at the time joining this group under the leadership of ICI Explosives and Dyno Nobel.

Subsequently, the Australian Explosives Industry Safety Group Inc. (AEISG) was formally incorporated and registered as a non-profit organisation in 2005, and further, in 2020 the mandate for AEISG was extended to encompass Australasia.

What is AEISG

AEISG is an industry association representing all the significant manufacturers and suppliers of explosives and explosive precursors – products and services which are essential to the mining and construction industries, so vital to the economic well-being of Australia.

According to its Constitution, the primary role of the AEISG Association is to:

- continuously improve the level of safety and security throughout the entire life-cycle of explosives and associated precursors, as well as their use and handling in Australasia; and
- to improve the legislative controls on explosives and their associated precursors, and their effective administration throughout Australasia.

Therefore, AEISG's primary role, in its current and prior forms, has always been to promote the safe and responsible management of commercial explosives and precursors for explosives, be that in import, manufacture, supply, storage, transport, handling and / or use. It is important to note that AEISG is non-commercial.

As an effective explosives industry association in Australasia, AEISG focuses on ensuring the collection and dissemination of best safety practices to our members, other organisations involved in the Australasian explosives industry, Regulators and the Public.
This is achieved by:

- Providing a forum for Members to raise and resolve industry safety issues
- Exchanging ideas and incidents amongst Members
- Developing Codes of Practice (CoP) and Policy
- Keeping our Members advised and aware of relevant issues, amendments, forums, etc.
- Representing industry with issues involving jurisdictional regulators
- Liaising with similar industry associations (SAFEX, IME, FEEM, etc.) nationally and internationally
- Promoting AEISG issues at relevant forums (AFER, IGUS/CIE, UN sub-committees / working groups, etc.)

Continuous improvement for the safe and responsible management of explosives, throughout the life cycle, has always been, and always will be the goal of AEISG.

AEISG is currently comprised of nineteen (19) member companies, many of whom operate throughout Australasia and either directly or indirectly, via parent companies, operate internationally. Diagram 1 illustrates the region of Australasia and AEISG member companies.

Diagram 1: Map of Australasia and current AEISG member companies (October 2022)

AEISG Codes of Practice

AEISG's published Codes of Practice are freely available at www.aeisg.org.au and currently include:

- Storage and Handling of Solid Ammonium Nitrate
- Electronic Initiation Systems
- Import of Explosives
- Storage and Handling of UN3375
- Mobile Processing Units
- Elevated Temperature and Reactive Ground
- On-Bench Practices for Open Cut Mines and Quarries
- Segregation Barriers for Transporting Mixed Loads of Detonators and High Explosives
- Blast Guarding in an Open Cut Mining Environment
- Prevention and Management of Blast Generated NOx Gases

AEISG's practice in the development of its Codes of Practice, is to consult with and key stakeholders, including regulatory jurisdictions. Feedback considered as 'material' is welcomed and addressed wherever relevant in finalising the document to ensure best practice is captured. In addition, AEISG Codes are reviewed after initial publication, utilising the abovementioned consultation approach, and subsequently at 5-yearly intervals or as required.

APPENDIX B – OTHER AN STANDARDS, CODES, GUIDES AND TOOLS

Document Title	Publisher	Published	Observations - Site Location and Separation Distances
Storing and Handling Ammonium Nitrate, INDG230	Health and Safety Executive (HSE) United Kingdom	2004	• Produced to assist duty holders to ensure the safe storage and handling of AN at, for example, harbours, merchant stores and manufacturers' premises. • Notes that the main use of AN is as a fertiliser, marketed either as prills (small spheres) or granules. Distinguishes between AN containing more than or less than 28% nitrogen. (Higher nitrogen more hazardous). • The precautions described are primarily designed to minimise the risk of explosion but can also reduce the risks associated with oxidising properties and the release of toxic fumes in a fire. • Does not require any separation distances. Guidance on location is limited to *"… in some circumstances, such as where the stores are located near to densely populated areas, it may be better to store ammonium nitrate outside …."*

Australian and NZ Standard AS 4326—2008 The storage and handling of oxidizing agents	Standards Australia	2008	• This Australian Standard applies to most oxidisers.
			• The 2008 edition introduced a specific section for AN, with the requirements primarily aimed at reducing the risk of fire or the risk of accidental mixing with incompatibles.
			• Previously:
			  • The 2005 edition includes a requirement to consult regulations / regulators about store location and separation distances.
			  • The 1995 edition had no "explosion based" distances - it typically required 8m or 15 m to the premise's boundary.

Hazardous Industry Planning Advisory Paper No 4 - Risk Criteria for Land Use Safety Planning (HIPAP 4)	Department of Planning and Infrastructure of New South Wales (NSW)	2011	• One of a set of 12 guidelines published to assist stakeholders understand and manage the hazards and risks associated with planned development (of land in NSW).
			• HIPAP 4 accounts for:
			  • The orderly development of industry and the protection of community safety, necessitating the assessment of hazards and risks.
			  • Formulated and implemented risk assessment and land use safety planning processes that account for both the technical and the broader locational safety aspects of potentially hazardous industry.

			• The identification of hazards and the quantification of risks outside the boundaries of a potentially hazardous development, and the assessment of that risk in terms of the nature of land uses in the vicinity provide the basis for compatible land use safety planning. • Since publication this has become a de-facto reference guideline in Australia for numerical risk targets.
Western Australia Code of Practice – CODE OF PRACTICE Safe storage of solid ammonium nitrate Fourth edition	Western Australian Department of Mines and Petroleum	2021	• Adopts several (but not all) parts of the SAFEX GPG. In particular it deviates from SAFEX by assigning a uniform 25% TNT equivalence, irrespective of initiation method and abandons any consideration of likelihood. • It abandons AS 2187 definitions of sites potentially affected by an explosion, and instead adopts definitions similar to HIPAP 4. • It tabulates recommended separation distances and comments that these are consistent with HIPAP 4 risk criteria but does not clarify specifically which HIPAP 4 criteria were chosen or how they were translated into distances. • It recognises the distinction between new and existing sites. • It permits relaxation of distances based on risk assessment.
FM Global Property Loss Prevention Data Sheet 7-89	FM Global	2013	• This data sheet covers all types of ammonium nitrate storage. • It "provides guidance for minimizing the potential for explosion by effective use of Process Safety Management Systems which include ensuring adequate process design, process control, process hazard knowledge, operating procedures, and management of change." • It does not specify site location / separation distances for off-site occupancies.
Good Practice Guide: Storage of Solid Technical Grade Ammonium Nitrate - SAFEX Good Explosives Practice Series GPG 02	SAFEX International	2014	• SAFEX is an international body of explosives experts and organisations / companies, aiming to capture and disseminate expertise and best practice relating to the safety of explosives and some associated materials. AN is a major ingredient in most modern commercial explosives, so is of interest. • The SAFEX GPG is explicitly risk-based.
Storage requirements for security sensitive ammonium nitrate (SSAN) Explosives information Bulletin no. 53	Queensland Department of Mines and Energy	2017	• This Information Bulletin uses AS 2187 definitions of sites potentially affected by an explosion, and some AS 2187 formulae for separation distances. • It assigns a uniform 32% TNT equivalence to stored AN, irrespective of initiation method. • It draws specifically and <u>selectively</u> from AS 4326. • It recognises the distinction between new and existing sites.

			• It permits relaxation of distances based on risk assessment.
IMESAFR: blast modelling, consequence and risk assessment tool Version 2.1	Institute of Makers of Explosives and APT-Research Inc.	2019	• IMESAFR is not a Standard - it is a software tool which incorporates a specific methodology for the estimation of blast consequences, the likelihood of accidental explosions, and the likelihood that such explosions may cause injury or fatality. AS 2187 and similar standards, as well as the SAFEX GPG, WA and Qld Codes all base separation distances on "overpressure". They also "convert" AN into an "equivalent" quantity of TNT (TNT is routinely chosen as a "reference" explosive because the blast waveform from TNT explosions has been well characterised by experiments). There is much debate but little unanimity about the appropriate conversion factor for AN. • IMESAFR does not use overpressure as an analogue for risk (or consequence). And the AN module does not rely on converting AN to an equivalent amount of TNT. • It is in AEISG's view the most sophisticated and detailed blast assessment tool available to the commercial explosives and related industries. • It includes a specific module to address potential explosions from AN.

APPENDIX C – AN STORAGE TYPE CATEGORIES

AN Store Construction (representative photo)	**Notes / Details**	**Which AN Storage Type to Use**
Overhead silo (60 tonnes) (Photo 5)	Fabricated metal silo with all AN > 3m above ground level, and capacity 60 tonnes.	Overhead Silos
Overhead Silo (capacity other than 60 tonnes) (Photo 5)	Fabricated metal silo with all AN > 3m above ground level, and capacity other than 60 tonnes. Although the modelling was based on 60 tonnes fabricated steel overhead silos, different sizes should make only a minor difference, since the available mass of steel (and therefore the debris hazard) should be similar – e.g., 4 x 30 tonnes silos would have a similar mass of steel to 2 x 60 tonnes silos. For silos made of a lighter metal (e.g., aluminium) or other lighter material (e.g., fibreglass) the debris hazard will be less so the table will be conservative and can be used.	Overhead Silos
Concrete or masonry silo or bin	Any silo (whether overhead or low level) or bin made of concrete or masonry.	Concrete Shed
Non-concrete/masonry silo or bin (Photo 6)	Silo (other than an overhead silo) or bin made of fabricated metal or other non-concrete / non-masonry material.	Shipping Containers
Metal Shed (Up to ~ 250 sq. m area by 3.7m high) (Photo 12, in background)	Shed with metal cladding over a steel frame, with floor area up to 250 sq. m. and walls 3.7m high.	Metal Shed
Big Metal Shed (significantly bigger than 250sq.m. floor area by 3.7m high). (Photo 12, in background)	Modelling for Table 5.4 (AN stored in Metal Shed) was based on a shed of dimensions (L x W x H) 22 x 11 x 3.7m. A shed bigger than the one modelled will have a greater mass of steel available as debris. The shipping container table is based on one container for every 20T of stored AN, so the mass of steel increases with tonnage, and although this table will be conservative for metal sheds it should be used for metal sheds significantly bigger than the one modelled.	Shipping Containers
Open (Photo 10)	AN stored in the open or under lightweight cover, e.g., tarpaulin.	Open
Igloo without shipping container walls. (Photo 8)	Igloo without shipping container walls. Floor may be hardstand (rock / clay) or concrete.	Open
Shipping Containers	AN stored in shipping containers.	Shipping Containers
Igloo with shipping container walls. (Photo 7)	Igloo with shipping container walls. (Irrespective of the presence or absence of any airgap between stored AN and the	Shipping Containers

	shipping containers.) Floor may be hardstand (rock / clay) or concrete.	
Concrete Shed (up to 900 sqm. by 12m high)	AN stored in a concrete shed.	Concrete Shed
Very large concrete building (significantly bigger than 900sq.m. floor area by 12m high).	Modelling was based on a shed with dimensions (L x W x H) 30 x 30 x 12m, with 100mm reinforced concrete walls and a steel panel roof. A significantly bigger shed would have a greater mass of concrete available as debris, which is generally more hazardous (although this is not a given). The issue of significance is the mass of debris available - so a shed with double the perimeter but half the height would have similar mass, and table 5.7 would apply. And a shed with walls of lower density than poured concrete (e.g., "breeze blocks") would have lower mass for the same dimensions. So some judgement is required in deciding whether table 5.7 may be applied.	Concrete Shed OR Site-specific assessment required.
Building with masonry walls (bricks / blocks).	With any type of roof.	Concrete Shed
Composite construction. (Photo 9)	With significant masonry or concrete, e.g., masonry or concrete lower walls with portal frame/metal cladding above.	Concrete Shed