Legal name of applicant(s): Roxel (UK Rocket Motors) Ltd

Submitted by: Roxel (UK Rocket Motors) Ltd

Substance: Bis(2-ethylhexyl) phthalate (DEHP)
Dibutyl phthalate (DBP)

Use title: Industrial use in manufacture of solid propellants and motor charges for rocket and tactical missiles

Use number: 1 & 2
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APPENDIX A: Overview of Supply Chain and Responsibility in Supply Chain
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1. SUMMARY

Roxel (UK Rocket Motors) Ltd (Roxel) designs, develops, manufactures and sells solid propulsion systems and related equipment for all types of rockets and tactical and cruise missiles for air, sea and ground forces.

Roxel manufactures cast double-base (CDB) propellants as propulsion systems for various missiles. DEHP and DBP were specified as components of certain propellant formulations in the 1960’s and continue to be used for this purpose in several current missile systems. These propellant formulations have been developed over many years based on progressive optimisation of numerous parameters that combine to provide the overall performance characteristics of the propellant.

Roxel uses very modest quantities of DEHP (< 300 kg/year) and DBP (< 10 kg/year) in propellant.

It is expected that both DEHP and DBP have multiple functions within the propellant (e.g. plasticiser, extrusion/flow aid, propellant coolant, ballistic catalyst), which makes the process of substitution more complicated.

Roxel has identified four potential candidates for replacement of DEHP/DBP in propellant. The candidates have been selected based on consolidated knowledge within Roxel regarding substances that are stable in mixtures with nitrocellulose and nitroglycerine and that, based on available information, are likely to have similar chemistry and functionality to the DEHP/DBP.

An extensive replacement programme for DEHP and DBP is required to confirm technical feasibility and qualify alternative propellant formulations, in accordance with strict requirements to ensure the safety and performance of the missile and sub-components; the details of this programme have been agreed in principle with the Design Authority and Roxel's customer, and the programme is expected to be approved shortly. The potential alternatives will be comprehensively tested within this replacement programme; this involves testing of the propellant powder, the cast charge and the rocket motor under various environmental conditions and accelerated ageing scenarios, within the programme. The programme to replace DEHP / DBP in the propellant is scheduled to take approximately 2.5 years to complete. After a successful replacement programme, an extended period is also required to manufacture replacement powder & convert this to a production batch of charges.

Alternatives to DEHP/DBP cannot be considered available until the replacement programme, including re-qualification of the propellant formulations by the Design Authority and relevant customers in the supply chain, is successfully completed and the new propellant and motor charge has been manufactured. On this basis, an alternative for DEHP/DBP in the propellant application is not expected to be commercially available until mid-2017. This projected timeframe assumes one of the four candidates that are included in the replacement programme successfully meets the criteria for replacement and that no obstacles are encountered during testing or manufacture.
Thus, Roxel will not be able to continue to supply several charges to the market after the Sunset date unless it can continue to use DEHP/DBP in the propellant formulations.

The candidates for the replacement programme have been carefully selected as part of a ‘down-selection’ or screening programme to identify the most promising potential alternatives before progressing into qualification. Roxel is optimistic that a suitable alternative will be identified and qualified through the replacement programme; however, there is no certainty that the replacement programme will be successful.

The supply chain for the rocket motors is described in Figure 1 in Appendix A.

Additional confidential information on the potential candidates is presented in Box 1, Section 1: Summary, page 2, of the Confidential Report
2. ANALYSIS OF SUBSTANCE FUNCTION

2.1 Overview of Manufacture of Propellant and Charges by Roxel

Roxel designs, develops, manufactures and sells solid propulsion systems and related equipment for all types of rockets and tactical and cruise missiles for air, sea and ground forces.

Roxel specialises in the chemistry of energetic materials and mechanical fields; it designs and manufactures all the elements of bespoke propulsion systems (i.e. the structures, energetic and inert materials) to meet the most advanced of requirements in terms of performance, quality and safety.

Roxel has globally recognised expertise in insensitive munitions (IM/Murat) technology for ‘Minimum Smoke’ rocket motors. Such rocket motors are used across all missile and rocket segments: air-to-air, ground-to-air, artillery, anti-ship, anti-tank air-to ground, cruise missiles and guided bombs. Roxel is responsible for propulsion systems used in, for example, the EXOCET family, ASTER family, RAPIER, MAGIC, MICA, MILAN, ASRAAM and RBS15.

Roxel (UK Rocket Motors) Ltd has particular expertise in the design and manufacture of Cast Double Base (CDB) propellants used as propulsion systems for anti-tank and other missiles. Roxel has developed the propellant formulations based on progressive optimisation of the numerous parameters that combine to provide the overall performance characteristics of the propellant over a 40 to 50 year period. The propellant has been subject to extensive laboratory and field testing over that time.

The particular types of CDB propellants/charges manufactured by Roxel are distinct in the marketplace. Roxel’s propellant charges and motors have a high degree of Insensitive Munitions safety performance and are formulated to provide Minimum Smoke exhaust. The exhaust signature is important to enable the missile to be guided and to prevent disclosure of the firing position, so protecting the crew at the firing post. The charges in this application are used in systems that are already in service or are in the final phase of development for systems that have high performance requirements for safety, smoke and thrust, such that alternative types of propellants are not feasible.

Roxel UK casts the CDB propellants into charges. An overview of a typical propellant and charge manufacturing process is provided in Appendix 1. The charges may be cast directly into an engineered motor casing, cast into a beaker, or cast as a cylinder then machined and an inhibition subsequently cast around the outside diameter (and other surfaces) of the charge. The particular CDB propellant-based charges that contain DEHP (and may also contain DBP) and are the subject of this AfA are supplied to Roxel UK’s customer. The customer then incorporates the charge into the final rocket or missile motor assembly. Thereafter, finished rocket motors are shipped to the missile prime contractor for final assembly within the missile.
2.2 Background to Propellant Chemistry and Composition

A rocket propellant is a substance stored on board of a rocket that at some point in time is used as the propulsive mass that is ejected/expelled from a rocket engine in the form of an exhaust jet to produce thrust. Rocket propellant is used in the same way to produce thrust in missiles (i.e. guided weapons). This Application for Authorisation (AfA) relates to use of propellant in rockets and missiles; the term ‘rocket’ is generally used in reference to the propellant function, since this is well-established terminology within the industry.

Solid rocket propellants offer the advantage over liquid propellants of minimum maintenance and instant readiness. Once ignited, solid propellant motors cannot be shut down; they will burn until all the propellant is exhausted. Liquid propellants are not used for tactical missile applications. The particular rocket propellants that form part of this AfA are part of the Cast Double Base (CDB) family. CDB propellants were first developed in the 1940s, with the particular formulations that are included in this AfA having been first developed in the 1960s; much of the technical research and insight underpinning these materials dates from then\(^1\).

Double Base propellants consist of nitrocellulose and energetic nitrate esters such as nitroglycerine, plus smaller quantities of stabilisers and other additives. They are commonly used in small arms, cannons, mortars and rockets and lend themselves well to smaller rocket motors. They do not produce traceable fumes and are, therefore, commonly used in tactical weapons.

In CDB propellants, the nitrocellulose serves as a polymeric binder and the nitrate ester acts as a plasticiser, to create a rigid gel network of plasticised nitrocellulose and a propellant with a homogenous physical structure. Various additives are added to the composition to improve the function of the propellant, for example, its mechanical properties, shock sensitivity and chemical stability. The main additives are described below.

- **Plasticisers and shock stabilisers**
  Increasing the fraction of nitroglycerine in the propellant increases the performance of the composition. However, as nitroglycerine is an oily, shock sensitive liquid explosive, plasticisers and stabilisers must be mixed with nitroglycerine to formulate practical CDB propellants.

\(^1\) The treatise by Davenas (Solid Rocket Propulsion Technology, ISBN-13: 978-0080409993) includes a description of the development of these propellants. Further detailed information is provided in the paper by Steinberger published in “Propellants Manufacture, Hazards, and Testing” (Editor(s): Carl Boyars, Karl Klager, Volume 88, Publication Date (Print): June 01, 1969, American Chemical Society).
• **Chemical stabilisers**  
The chemical stability of nitrocellulose and nitroglycerine is inherently poor due to breakage of –O-NO$_2$ bonds. Therefore chemical stabilisers (e.g. ethyl centralite (EC), diethyl diphenyl (DED)) are added to the propellant formulation to limit chemical degradation and enhance the storage lifetime.

• **Other additives**  
Other additives in the composition may include flash suppressors (e.g. potassium sulphate, potassium nitrate) to reduce visible flame emission, burn-rate modifier/catalysts (e.g. salicylates, stearates) to increase the regression rate, and opacifiers (e.g. carbon black, graphite) to increase absorption of flame radiation (increase regression rate, reduce casing/insulator temperature).

Propellant compositions have been carefully developed over many years of research and development, building on operational experience, in order to achieve the multiple, very specific, often inter-dependent performance characteristics that are required for individual rocket and missile systems. These performance characteristics include:

• Energetics (Specific Impulse, $I_{sp}$)  
• Density (motor size, density impulse)  
• Regression / burn rate characteristics  
• Temperature sensitivity (i.e. how the thrust generated changes over the operating temperature)  
• Reliability of ignition and ignition rise time  
• Mechanical properties (stiffness, modulus, thermal expansion)  
• Ageing (sag, temperature cycling, cracking, debonding, moisture)  
• Shock sensitivity  
• Emissions (observable smoke), toxicity

Solid propellant formulations are therefore complex mixtures. It is possible that each individual constituent of the formulation has more than one critical or non-critical functions; the extent to which an individual constituent of a propellant formulation directly contributes to one or more performance characteristics of the overall propellant may not be well characterised or understood, reflecting the complexity of the mixture, as further described below. Changes to composition can result in substantial effects on performance which are not foreseen or predictable, demonstrating the sensitive and complex behaviour of energetic mixtures in general.

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2 This sensitivity to minor change is demonstrated by an example provided by the UK MOD (http://www.cranfield.ac.uk/cds/departments/deas/pdfs/02%20(sloan)%20nitrocellulose%20dosg%20propellant%20qualification%20requirements.pdf) where a change in source of nitrocellulose is considered to have resulted in catastrophic failure of a rocket motor. This failure occurred, despite the fact that the nitrocellulose had been found to meet specification and the rocket motors had passed initial testing, due to unpredicted behaviour resulting from ageing of the material.
Failure of propellant performance will adversely affect the performance of the overall missile, with potentially important implications for safety and security. Therefore organisations responsible for defence have put in place strict procurement procedures in order to protect against the possible consequences of unevaluated changes. This process is referred to as “qualification”. The requirements for qualification of rocket propellant affect the timeframe for availability of alternatives to DEHP within this application, and are therefore critical to the AoA.

To provide further context, typically 5 to 10 years is required for development and qualification of a new rocket motor design, while production (including activity by the missile prime contractor) has an additional start up time requirement of 1 to 2 years. The missile may be used for 10 to 20 years. The cost to develop and qualify a new propellant charge alone (i.e. excluding the rest of the rocket motor, structure or other sub-components) is typically of the order of £5million. These figures provide an indicative illustration of the investment involved in bringing a rocket charge to the marketplace.

2.3 Use of DEHP and DBP by Roxel in Propellant and Charges

Roxel first specified DEHP and DBP as components of certain solid propellant formulations in the 1960s. These substances are still specified within the same propellant formulations. In particular, DEHP and DBP are used by Roxel in a number of missile propulsion systems. Such phthalates are also common ingredients in some gun propellants. While not all propellants formulated by Roxel contain DEHP, the use of these substances have been qualified and proven in missile systems that have been in service for more than 40 years. The particular formulations that are included in this AfA relate to propellants that have used essentially the same formulation for more than 30 years. Due to the lengthy time-scale and the high cost to manufacture CDB propellant in small batches, large powder production runs are employed.

The propulsion systems for four missiles utilise low quantities of DEHP.

The propulsion systems for two of the four missiles utilise trace quantities of DBP.

The manufacturing process for the charges can combine a number of individual CDB powders with different formulations, only some of which include DEHP/DBP. Up to 5 different propellant powders may be utilised in an individual charge.

The amount of DEHP used is less than 0.3 tonnes per annum. The concentration in the propellant & charges is an average of < 2.9% & < 2.0% respectively.

Roxel uses <0.01 tonnes per annum of DBP in propellant. DBP is present in a concentration of < 0.14% in the powder and < 0.03% in the finished charge.

DEHP and DBP are widely used as plasticisers. However the specific function of DEHP and DBP within the propellant is not well elaborated or characterised. It is likely that they have more than one function within the propellant. In particular, available and received knowledge indicates that any or all of the following functions may make a significant contribution to performance of the propellant:
• Plasticiser – DEHP/DB is often included in mechanically stiff, high solids formulations which typically operate in temperature ranges between -40°C and +60°C. The content of DEHP in the propellant does not exceed 5%. This is in the range typical of plasticiser type applications.

• Extrusion/Flow Aid – DEHP/DBP may improve flow and surface finish properties of the propellant extrudate. The outer surface of the propellant granules can affect the cut quality, but primarily it is the quality of the surface finish that provides the correct bulk density when the powder granules are cast.

• Propellant Coolant – DEHP/DBP may reduce the overall energy of the motor system. This can be required for a number of reasons relating to the desired ballistic performance of the system. It is sometimes necessary to reduce system energy to increase the effectiveness of catalysis for improved plateau characteristics.

• Ballistic Catalyst – There is reason to believe that DEHP/DBP acts as a ballistic catalyst in its own right. It contains the chemical species appropriate to absorbing UV radiation and is present in systems where it would be difficult to explain resultant catalysis without its presence.

It is quite feasible that DEHP / DBP could contribute to all of these individual functions. DEHP and DBP possess a high boiling point and decomposition temperature which allows for increased residence time at the flame front, and therefore more effective catalysis.

The lack of information and certainty regarding the specific function(s) of DEHP and DBP in the propellant, coupled with the need to qualify any changes to the propellant mixture means that replacing these substances within the propellant is not a simple or inexpensive procedure.

2.4 Background to requirement for Qualification of Alternatives

A carefully planned replacement programme is required by Roxel and by customers in the supply chain to identify and test possible alternatives to ensure a revised propellant formulation performs in an equivalent manner to the existing formulation over a range of endpoints across the short and long term. This includes qualification of the alternative formulation.

As described above, there are extensive requirements through the defence industry for qualification and, where minor changes to existing design are proposed, requalification of energetic materials (propellant), on its own, in charges and in rockets or missiles because the implications of failure to perform as intended present a clear and immediate risk to life and property. In this regard, the requirements for qualification of energetic materials can be considered akin to the requirements set out by the aerospace industry to guarantee performance. The requirements of such a programme are described in Section 3 below.

The importance of fulfilling these requirements to replace and qualify alternatives to DEHP and DBP in relevant propellants is reflected in Roxel’s decision to apply for an authorisation for continued use of very small quantities of these substances (<10 kg/year
of DBP and <300 kg/year of DEHP) while alternatives are tested and qualified as replacements. The cost to Roxel of the application for authorisation, coupled with the technical, administrative and cost implications of completing a replacement programme for DEHP and DBP serves only to emphasise the critical nature of these requirements, and the importance of the authorisation to the ongoing production of these missiles until the replacement programme is successfully delivered.
3. IDENTIFICATION OF POSSIBLE ALTERNATIVES

This section considers the process for identifying alternatives to DEHP and DBP in certain CDB propellant charges manufactured by Roxel. Since the requirements in the supply chain for changing the formulation of the energetic material are both particular and stringent, they are outlined here to provide context for the more detailed analysis of alternatives that follow.

3.1 Background to requirement for Qualification of Alternatives

In NATO, a Standardization Agreement (STANAG) defines processes, procedures, terms, and conditions for common military or technical procedures or equipment between the member countries of the alliance. Each NATO state ratifies a STANAG and implements it within its own military. The purpose is to provide common operational and administrative procedures and logistics, so one member nation's military may use the stores and support of another member's military. STANAGs also form the basis for technical interoperability between a wide variety of communication and information systems essential for NATO and Allied operations.

Energetic materials need to be assessed as safe and suitable for use in a specific application. The aim of qualification is to ensure that energetic materials are sufficiently characterised in order to be considered for use in their intended role. STANAG 4170 defines the principles and methodology for the qualification of explosive materials for military use.

The aims of STANAG 4170 are:

(a) to establish the concept and requirement for Qualification of explosive materials by a National Authority for military use by NATO nations;

(b) to ensure that only explosive materials sufficiently characterised and assessed as possessing properties making them safe and suitable for consideration for military use are Qualified for an intended role. A change of role (e.g. the use of a Qualified booster as a main charge explosive) will require a separate assessment on a case-by-case basis, to determine whether that explosive can be used in a new particular application not covered under the intended (original) role;

(c) to provide for NATO nations an acceptable and uniform basis to achieve Qualification status of explosive materials by the adoption of the principles and methodology described in this STANAG and related document AOP-7.

STANAG 4170 defines the clearance regime that should be followed (for NATO country end use) when there is a change in ingredient in an energetic material. Thus, for ratifying countries, the specifications for the propellant can only be modified in accordance with

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3 AOP-7 is a Manual of Data Requirements and Tests for Qualification
those terms and following a lengthy testing and approval process. The replacement
programme proposed by Roxel follows the principles of STANAG 4170 and has been
agreed in a technical proposal with Roxel’s customer.

The formulation of propellants used in missiles within national and international defence
programmes is defined in manufacturing specifications and the performance of the
charge/rocket motor is defined in technical requirement and acceptance specifications;
Roxel is required to agree with its customers any changes to processes and specifications
(before changes may be implemented). The specifications for rocket components are set
out in commercial agreements and can only be modified in accordance with the terms of
those agreements and following a lengthy testing and approval process. Roxel Group, as
the contractually identified Design Authority for the charge and rocket motor, is responsible
for all aspects of the design of these items, including derivation of the design solution,
design proving and certification, design safety, design producibility, and the compliance of
the design with the requirements specified.

Roxel is optimistic that it will be possible to substitute the very modest quantities of DEHP
and DBP used in propellant. However, as described above, and since it is not possible to
predict the performance of any new material via chemical analysis or theoretical
supposition, such modifications to the formulation can only be approved and accepted
following extensive testing and formal qualification involving manufacturing and testing trial
samples of a particular propellant. Such testing must be conducted with the prior approval
of the relevant Design Authority and downstream customers. Roxel, as the Design
Authority, has discussed with its customer the detail of the expected replacement
programme for DEHP and DBP. This is summarised below and described in more detail in
section 3.3.1.

There are several necessary elements to the testing programme. Each ‘alternative’
formulation must be tested at the powder, propellant and potentially at the rocket motor
level. Testing to prove long-term stability during the service life of the rocket motor may
need to be completed under numerous environmental conditions. This may also require
simulating long term storage prior to testing. The time to conduct a replacement
programme is expected to be approximately 30 months, including the final phase of
qualification, assuming no major obstacles are encountered and a successful outcome
from one of the identified potential alternatives.

Following successful qualification of the DEHP/DBP replacement, a 16 month period is
required to manufacture the first batch of the replacement propellant powder, cast charges
and finish a production batch of charges.

On this basis, the overall timeframe for commissioning and successfully completing a
research and testing programme to support the identification of an alternative to
DEHP/DBP and to deliver new charges is expected to be 46 months. A contingency is
necessary to allow for technical or production issues. Therefore, a minimum period of 48
months is foreseen. Thus, assuming success, charges manufactured from the alternative
propellant are expected to be available in 2017. Importantly, this schedule assumes that
Roxel can rely on accelerated ageing tests, where the charges are held at an elevated
temperature for a number of months in an attempt to simulate the natural ageing behaviour
that occurs in service, at lower temperatures, over many years. Since such accelerated
tests can be over-tests, resulting in failures that would not occur normally, there is a further
risk that the qualification programme may not be successful. As noted above, it also assumes a successful outcome from one of the identified potential alternatives in the replacement programme. The selection of the potential alternatives is described below.

Since Roxel will initially undertake a down selection/screening programme before progressing into qualification, if this replacement programme is unsuccessful then there would be little prospect of further successful research and qualification activity. Also as the replacement project is very expensive there would be limited opportunity for a further attempt at replacement activity with what appear to be less promising candidates. There could be the possibility of repeating the aging at a lower temperature, over a longer period of time, assuming only the accelerated ageing was unsuccessful.

The supply chain & the responsibilities of the different parties are illustrated in Figure 1 in Appendix A.

3.2 List of possible alternatives

Four possible alternatives have been identified by Roxel based on known propellant additives with similar properties and therefore implied functionality. The four alternatives are carboxylic acid esters.

Additional confidential information on the potential candidates is presented in Box 2, Section 3.2: List of possible Alternatives, page 11, of the Confidential Report

3.3 Description of efforts made to identify possible alternatives

3.3.1 Research and development

The list of potential alternatives has been compiled based on consolidated specialist knowledge and the outcome of various research and development programmes over the last 40 or 50 years.

The first criteria when assessing the suitability of materials for addition to CDB propellants is to ensure that there is no adverse reaction with the two base energetic ingredients present in these formulations, namely the nitrocellulose (NC) and nitroglycerine (NG). Stringent compatibility testing takes place on a laboratory scale to ascertain any reactivity between a new material and these energetic compounds. This factor alone significantly reduces the number of available alternatives and precludes the use of more active materials.

This leads Roxel to focus upon ‘tried and tested’ substances where there is already good knowledge of their behaviour in propellant systems. Therefore Roxel has developed the list of possible alternatives from substances whose stability and lack of reactivity with nitrate esters has already been proven. Targeting substances that are already used in similar applications immediately focuses the scope of the replacement programme.
Additionally, confirmation of one of these substances as a functional replacement for DEHP and DBP might allow reduced (re)qualification assessment for the finished propellant.

Based on this pre-selection, a more targeted list of potential alternatives to DEHP and DBP could be selected based on consideration of chemistry and known functionality of the individual substances.

From a logistical viewpoint, and subject to technological success, efforts will be concentrated on materials that are projected to have a long-term future (i.e. no to low hazard and commercially viable). Literature searches have been conducted to ensure that any materials considered will be commercially available for the foreseeable future.

No new research and development was completed to identify the initial list of alternative candidates but considerable Roxel Intellectual Property & effort was required to identify the replacement candidates most likely to succeed. However extensive new research and development will be required to further evaluate the suitability of these initial candidates as alternatives to DEHP and DBP, and then to qualify one of these.

A replacement programme has been designed and is in the process of being set up to investigate the use of the potential candidates that are already used in propellants within Roxel. Final approval of scope of and funding for the programme are expected in September 2013. Materials have been supplied to support this programme.

The DEHP replacement programme involves four main phases. These are also shown at a summary level in the GANNT chart below.

Phase I involves attempting to manufacture the base energetic casting powder with four new substances to replace DEHP/DBP and assessing the impact on both processing and finished powder properties. The mixes will be visually assessed and evaluated for extrusion (variations in the speed of extrusion may be necessary to achieve a suitable surface finish). The samples will undergo physical, chemical and safety tests. The physical tests will include mechanical and ballistic property assessment of the propellant, also over the range of temperatures. The majority of the ballistic and mechanical properties of the finished propellant are derived from the casting powder and it is therefore absolutely critical that the alternative formulation meets these basic specification requirements in order to proceed to Phase 2.

Phase 2 involves ballistic testing of the propellant powder (mixture). Since the DBP is added in very low quantities to the propellant powder and is present only at very low concentrations in the finished propellant (and is only used in the charges for 2 of the 4 missiles), the initial two phases will be conducted with the replacement for DEHP alone; DBP will be included in the formulation for Phase 1 and 2 as normal to avoid confounding the study results. Phase 3 and Phase 4 will then also include the selected alternative replacement for DEHP as the replacement for DBP (i.e. it is considered likely that DEHP and DBP can be replaced by the same alternative).

Phase 3 then involves fine tuning the ballistic properties of the propellant. This is achieved by varying small amounts of one of the critical ballistic modifiers. It is not known whether there will be a step shift in properties caused by changing to a new plasticiser and
therefore this tuning phase is again critical to the potential success of replacing DEHP and DBP. In addition there will be a parallel tuning phase with the powder.

Phase 4 involves qualification. The final phase is to manufacture sufficient powder of the chosen variant to proceed to rocket motor level trials. These trials include long-term storage for testing of stability of the final rocket motor. Each propellant mixture to be tested will require the manufacturing of numerous charges, machined to the final shape. The charges will then be stored for various periods of time at elevated temperatures in an attempt to accelerate the natural ageing process. The charges will then be assembled into representative motor hardware, conditioned at representative operational temperatures and then static tested (functioned), as indicated below. The pressure and thrust data for each firing will then be analysed.

- Various tests at a specified range of (including extreme) temperatures
- Age for specified period at (extreme) temperature then various tests, as described above
- Age for extended specified period at (extreme) temperature then various tests, as described above

The replacement programme will be completed for the primary potential candidates for replacing DEHP and DBP.

Two of the four missiles that use DEHP/DBP will have their charges qualified by this programme. The other two will require an equivalent Phase 4 activity if/when a new DEHP/DBP free propellant is required.

Following completion of the testing and write up of the experimental data, and assuming suitable safety/performance data, there will need to be final review with the customer.

Additional confidential information on the details of the replacement programme and candidates to be tested is presented in Box 3, Section 3.3.1: Research and Development, page 13 and 14, of the Confidential Report

### 3.3.2 Data searches

As described above, a primary requirement for any alternative is stability and lack of reactivity with nitrate esters. In addition, there is limited data in the public domain to support detailed data searches. This is further confounded since the specific function(s) of the DEHP and DBP in each propellant mixture is not well elaborated and characterised. Consequently, data searching has focused on substances already well known to Roxel.
3.3.3 Consultations

Consultations with other parts of Roxel, customers and others within the defence industry have been conducted to gauge best practice and the direction of investigation with regard to replacing DEHP and DBP.
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<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
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<tbody>
<tr>
<td>1</td>
<td>DEHP/DBP in Powder &amp; Charges</td>
</tr>
<tr>
<td>2</td>
<td>Sunset date</td>
</tr>
<tr>
<td>3</td>
<td>Replacement Programme</td>
</tr>
<tr>
<td>4</td>
<td>Order from customer</td>
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<tr>
<td>5</td>
<td>Production slot available to start replacement project</td>
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<td>6</td>
<td>Validation of new source</td>
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<td>7</td>
<td>Phase 1: Initial manufacture &amp; testing</td>
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<td>8</td>
<td>Phase 2: Confirmation</td>
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<td>9</td>
<td>Phase 3: Tuning</td>
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<td>10</td>
<td>Phase 4: Qualification - Powder manufacture for ageing trials &amp; ageing</td>
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<td>Consider approval to manufacture Powder without DEHP/DBP</td>
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<td>12</td>
<td>Reporting</td>
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<tr>
<td>13</td>
<td>If successful on replacing DEHP/DBP: manufacture Powder &amp; Charges</td>
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<tr>
<td>14</td>
<td>Manufacture Powder</td>
</tr>
<tr>
<td>15</td>
<td>Manufacture Charges</td>
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<tr>
<td>16</td>
<td>If replacement programme is successful - deliver 1st Production batch of DEHP/DBP free charges</td>
</tr>
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**Timeline Diagram:**

- **2014:**
  - Q1: 03/09
  - Q2: 23/02

- **2015:**
  - Q3: 11/11
  - Q4: 26/4

- **2016:**
  - Q1: 2015
  - Q2: 2016
  - Q3: 2017
  - Q4: 2018

- **2017:**
  - Q1: 2017
  - Q2: 2018
  - Q3: 2019
  - Q4: 2020

Use number: IU-1 & IU-2  
Legal name of applicant(s): Roxel (UK Rocket Motors) Ltd
4 SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES

Additional confidential information on the assessment of the alternatives is presented in Section 4 (see Box 4), Suitability and Availability of Possible Alternatives, page 15 to 25, of the Confidential Report.

The potential alternatives were initially screened and reviewed with regard to the criteria set out in Section 3.3.1. As a result, four substances emerged as preferred candidates for further technical evaluation (i.e. these will be tested in the replacement programme described in Section 3.3.1). Information about the preferred candidates for replacing DEHP and DBP is confidential. The substances are carboxylic acid esters, hereafter referred to in this document as Alternative 1, Alternative 2, Alternative 3 and Alternative 4.

There is already good knowledge regarding the stability and lack of reactivity with nitrate esters of each of these possible alternatives in rocket propellant systems. Furthermore, the preferred alternatives are already used in similar applications in propellant systems, increasing confidence that they will prove an adequate alternative for DEHP and DBP, and that a replacement programme based on these alternatives will be ultimately successful.

4.1 ALTERNATIVE 1

4.1.1 Substance ID and properties

Alternative 1 is a carboxylic acid ester. It is a liquid at room temperature and pressure. It is fairly soluble and has a moderate vapour pressure.

4.1.2 Technical feasibility

Alternative 1 is a known propellant ingredient with well characterised properties and effects. In other words, there is no known adverse reaction with the two base energetic ingredients, namely the nitrocellulose (NC) and nitroglycerine (NG), present in these formulations. Whether Alternative 1 can match DEHP and DBP in specific functional performance in terms of the characteristics outlined in Section 2.1 can only be determined as part of the formal testing and requalification programme.

The detailed replacement programme to assess the technical feasibility of this substance is outlined in section 3.3.1
4.1.3 Economic feasibility

Preliminary inquiries indicated that Alternative 1 is currently commercially available at an acceptable cost.

The need for and cost of process modifications associated with use of Alternative 1 as a replacement for DEHP have not been evaluated at this time. This will be assessed as part of the detailed replacement programme.

4.1.4 Reduction of overall risk due to transition to the alternative

DEHP is classified as Toxic to Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

DBP is classified as Toxic for Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

Alternative 1 is not classified for any hazard endpoint.

Therefore, based on current classification and subject to a formal review of the available toxicological evidence, a transition from DEHP/DBP to Alternative 1 in propellant could result in use of a less hazardous substance. However, since the CSR demonstrates exposure to workers is below the threshold at which reproductive effects occur, a reduction in adverse health effects to workers is not expected for this endpoint under conditions of normal use.

4.1.5 Availability

Alternative 1 is commercially available and suppliers have been identified although extensive discussions to confirm availability have not been held at this stage.

Importantly, Alternative 1 cannot be considered an available replacement for DEHP/DBP in the propellant formulation at this point. Specifically, requalification of the re-formulated propellant must be completed before it will be accepted by national defence authorities and/or other customers.

4.1.6 Conclusion on suitability and availability for Alternative 1

The replacement programme outlined in section 3.2.1 needs to be completed and evaluated before it is possible to conclude regarding the technical suitability of Alternative 1 as a replacement for DEHP/DBP.

Alternative 1 is currently commercially available in suitable quantities. However, the re-formulated product needs to be re-qualified before it will be accepted by national defence authorities / customers. Alternative 1 cannot be considered available as an alternative to DEHP/DBP until that qualification process is complete.
4.2 ALTERNATIVE 2

4.2.1 Substance ID and properties

Alternative 2 is a carboxylic acid ester. It is liquid at room temperature and pressure. It is slightly soluble and has a moderate vapour pressure.

4.2.2 Technical feasibility

Alternative 2 is used by Roxel in a number of propellant formulations. In other words, there is no known adverse reaction with the two base energetic ingredients, namely the nitrocellulose (NC) and nitroglycerine (NG), present in these formulations. Whether Alternative 2 can match DEHP and DBP in specific functional performance in terms of the characteristics outlined in Section 2.1 can only be determined as part of the formal testing and requalification programme.

The detailed replacement programme to assess the technical feasibility of this substance is outlined in section 3.2.1

4.2.3 Economic feasibility

Roxel has secured temporary supply, however it is in the process of defining supplier details for long-term supply. Therefore the economic implications of replacing DEHP/DBP with Alternative 2 are currently uncertain.

The need for and cost of process modifications associated with use of Alternative 2 as a replacement for DEHP have not been evaluated at this time. This will be assessed as part of the detailed replacement programme.

4.2.4 Reduction of overall risk due to transition to the alternative

DEHP is classified as Toxic to Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

DBP is classified as Toxic for Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

Alternative 2 is not classified for any hazard endpoint.

Therefore, based on current classification and subject to a formal review of the available toxicological evidence, a transition from DEHP/DBP to Alternative 2 in propellant could result in use of a less hazardous substance. However, since the CSR demonstrates exposure to workers is below the threshold at which reproductive effects occur, a reduction in adverse health effects to workers is not expected for this endpoint under conditions of normal use.
4.2.5 Availability

Roxel has secured temporary supply, however, is in the process of defining supplier details for long-term supply.

Importantly, Alternative 2 cannot be considered an available replacement for DEHP/DBP in the propellant formulation at this point. Specifically, requalification of the re-formulated propellant must be completed before it will be accepted by national defence authorities and/or other customers.

4.2.6 Conclusion on suitability and availability for Alternative 2

The replacement programme outlined in section 3.2.1 needs to be completed and evaluated before it is possible to conclude regarding the technical suitability of Alternative 2 as a replacement for DEHP/DBP. Based on available information, replacement of DEHP/DBP with Alternative 2 could result in use of a less hazardous substance, but would not result in a reduction in health effects since current use of DEHP/DBP is adequately controlled.

Further research is required to ascertain whether Alternative 2 is currently commercially available in suitable quantities and at commercially acceptable rates. A long-term supplier has not yet been identified. Furthermore, the re-formulated product needs to be re-qualified before it will be accepted by national defence authorities / customers. Alternative 2 cannot be considered available as an alternative to DEHP/DBP until that qualification process is complete.

4.3 ALTERNATIVE 3

4.3.1 Substance ID and properties

Alternative 3 is a carboxylic acid ester. It is liquid at room temperature and pressure. Limited information is available regarding its physico-chemical properties.

4.3.2 Technical feasibility

Alternative 3 is used as a propellant plasticiser. In other words, there is no known adverse reaction with the two base energetic ingredients, namely the nitrocellulose (NC) and nitroglycerine (NG), present in these formulations. Whether Alternative 3 can match DEHP and DBP in specific functional performance in terms of the characteristics outlined in Section 2.1 can only be determined as part of the formal testing and requalification programme.

The detailed programme to assess the technical feasibility of this substance is outlined in section 3.3.1

4.3.3 Economic feasibility
Roxel has secured temporary supply, however it is in the process of defining supplier details for long-term supply. Therefore the economic implications of replacing DEHP/DBP with Alternative 3 are currently uncertain.

The need for and cost of process modifications associated with use of Alternative 3 as a replacement for DEHP have not been evaluated at this time. This will be assessed as part of the detailed replacement programme.

4.3.4 Reduction of overall risk due to transition to the alternative

DEHP is classified as Toxic to Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

DBP is classified as Toxic for Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

Alternative 3 is not classified for any hazard endpoint.

Therefore, based on current classification and subject to a formal review of the available toxicological evidence, a transition from DEHP/DBP to Alternative 3 in propellant could result in use of a less hazardous substance. However, since the CSR demonstrates exposure to workers is below the threshold at which reproductive effects occur, a reduction in adverse health effects to workers is not expected under conditions of normal use.

4.3.5 Availability

Roxel has secured temporary supply, however it is in the process of defining supplier details for long-term supply.

Importantly, Alternative 3 cannot be considered an available replacement for DEHP/DBP in the propellant formulation at this point. Specifically, requalification of the re-formulated propellant must be completed before it will be accepted by national defence authorities and/or other customers.

4.3.6 Conclusion on suitability and availability for Alternative 3

The replacement programme outlined in section 3.2.1 needs to be completed and evaluated before it is possible to conclude regarding the technical suitability of Alternative 3 as a replacement for DEHP/DBP. Based on available information, replacement of DEHP/DBP with Alternative 3 could result in use of a less hazardous substance, but would not result in a reduction in health effects since current use of DEHP/DBP is adequately controlled.

Further research is required to ascertain whether Alternative 3 is currently commercially available in suitable quantities and at commercially acceptable rates. A long-term supplier has not yet been identified. Furthermore, the re-formulated product needs to be re-qualified before it will be accepted by national defence authorities / customers. Alternative 3 cannot be considered available as an alternative to DEHP/DBP until that qualification process is complete.
4.4 ALTERNATIVE 4

4.4.1 Substance ID and properties

Alternative 4 is a carboxylic acid ester. It is liquid at room temperature and pressure. It is fairly soluble and has a low vapour pressure.

4.4.2 Technical feasibility

Alternative 4 is an ingredient for inclusion in casting liquids. In other words, there is no known adverse reaction with the two base energetic ingredients, namely the nitrocellulose (NC) and nitroglycerine (NG), present in these formulations. Whether Alternative 4 can match DEHP and DBP in specific functional performance in terms of the characteristics outlined in Section 2.1 can only be determined as part of the formal testing and requalification programme.

The detailed programme to assess the technical feasibility of this substance is outlined in section 3.2.1

4.4.3 Economic feasibility

Preliminary inquiries indicated that Alternative 4 is currently commercially available at an acceptable cost.

The need for and cost of process modifications associated with use of Alternative 4 as a replacement for DEHP have not been evaluated at this time. This will be assessed as part of the detailed replacement programme.

4.4.4 Reduction of overall risk due to transition to the alternative

DEHP is classified as Toxic to Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

DBP is classified as Toxic for Reproduction (Category 1B) on the evidence of adverse effects on fertility and reproduction.

Alternative 4 is not classified for any hazard endpoint.

Therefore, based on current classification and subject to a formal review of the available toxicological evidence, a transition from DEHP/DBP to Alternative 4 in propellant could result in use of a less hazardous substance. However, since the CSR demonstrates exposure to workers is below the threshold at which reproductive effects occur, a reduction in adverse health effects to workers is not expected under conditions of normal use.

4.4.5 Availability
Inquiries indicate Alternative 4 is commercially available in the required quantities without undue delay.

Importantly, Alternative 4 cannot be considered an available replacement for DEHP/DBP in the propellant formulation at this point. Specifically, requalification of the re-formulated propellant must be completed before it will be accepted by national defence authorities and/or other customers.

4.4.6 Conclusion on suitability and availability for Alternative 4

The programme outlined in section 3.2.1 needs to be completed and evaluated before it is possible to conclude regarding the technical suitability of Alternative 4 as a replacement for DEHP/DBP. Based on available information, replacement of DEHP/DBP with Alternative 4 could result in use of a less hazardous substance, but would not result in a reduction in adverse health effects since current use of DEHP/DBP is adequately controlled.

Alternative 4 is currently commercially available in suitable quantities and at commercially acceptable rates. However, the re-formulated product needs to be re-qualified before it will be accepted by national defence authorities / customers. Alternative 4 cannot be considered available as an alternative to DEHP/DBP until that qualification process is complete.
5 OVERALL CONCLUSIONS ON SUITABILITY AND AVAILABILITY OF POSSIBLE ALTERNATIVES FOR USE 1

Roxel has identified four potential candidates for replacement of DEHP/DBP in propellant. The candidates have been selected based on consolidated knowledge within Roxel regarding substances that are stable in mixtures with nitrocellulose and nitroglycerine and that, based on available information, are likely to have similar chemistry and functionality to the DEHP/DBP.

At this point, it is not possible to draw any firm conclusions regarding the technical suitability of any of the possible alternatives. An extensive replacement programme for DEHP and DBP is required to confirm technical feasibility and qualify alternative propellant formulations; the details of this programme have been agreed in principle with the Design Authority and Roxel’s customer, and the programme is expected to be approved shortly. Four potential alternatives will be tested, including testing of the propellant powder, the cast charge and the rocket motor under various environmental conditions and accelerated ageing scenarios, within the programme. The programme to replace DEHP / DBP in the propellant is scheduled to take approximately 2.5 years to complete. After a successful replacement programme an extended period is also required to manufacture replacement powder & convert this to a production batch of charges. Alternatives to DEHP/DBP cannot be considered available until the replacement programme, including re-qualification of the propellant formulations by the Design Authority and relevant customers in the supply chain, are successfully completed and the new propellant and charges have been manufactured. On this basis, an alternative for DEHP/DBP in the propellant application is not expected to be commercially available until mid-2017. This projected timeframe assumes one of the four candidates that are included in the replacement programme successfully meets the criteria for replacement and that no obstacles are encountered during testing or manufacture.

The possibility that one of the replacement candidates may be identified as a SVHC cannot be discounted, introducing uncertainty regarding the long term feasibility of this substance as a replacement for DEHP/DBP.

Long term suppliers need to be identified for two of the potential candidates. It is likely that all of the possible alternatives would be economically feasible and commercially available in suitable quantities, particularly given the relatively low quantities of DEHP and DBP used.

While available information indicates all the possible alternatives, with the possible exception of one of the candidates, are less hazardous than DEHP/DBP, current use of DEHP/DBP is adequately controlled, such that substituting these substances would not result in a reduction in adverse health effects to workers or the public.

The candidates for the replacement programme have been carefully selected as part of a ‘down-selection’ or screening programme to identify the most promising potential alternatives before progressing into qualification. Roxel is optimistic that a suitable alternative will be identified and qualified through the replacement programme; however, there is no certainty that the replacement programme will be successful.
Additional confidential information on the assessment of the alternatives is presented in Box 5, Section 5, Overall Conclusions on Suitability and Availability of Possible Alternatives, page 27, of the Confidential Report.
APPENDIX A: Overview of Supply Chain and Responsibility in Supply Chain

<table>
<thead>
<tr>
<th>ACTOR IN SUPPLY CHAIN</th>
<th>ACTIVITY / TASK</th>
<th>RESPONSIBILITY &amp; QUALIFICATION OBLIGATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roxel UK</td>
<td></td>
<td>Roxel has the responsibility to meet the agreed specification. It is unable to introduce a change to the propellant formulation or manufacturing process without the agreement of the Design Authority, its customer (the missile prime contractor) and the Defense Authority.</td>
</tr>
<tr>
<td>DEHP/DBP Manufacturer/Importer</td>
<td></td>
<td>Either Roxel UK or Roxel France is specified as the Design Authority (DA) for the Charges subject to this AfA; Roxel France is the DA for the complete motor.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roxel is responsible to deliver finished rocket motors to the agreed schedule &amp; qualified build standard.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roxel, as the DA, defines the testing required to introduce a change &amp; agree this with the missile prime contractor.</td>
</tr>
<tr>
<td>Roxel Customer</td>
<td></td>
<td>Roxel’s customer is also the partner for the contract to deliver missiles. The customer specifies requirements for and agrees to the motor qualification.</td>
</tr>
<tr>
<td>End User/Commissioning User</td>
<td></td>
<td>The customer will originally have undertaken All Up Round (missile level) Qualification &amp; missile flight trials with the propellant formulation including DEHP/DBP. They must be satisfied the changes are adequately proven.</td>
</tr>
</tbody>
</table>

Use number: IU-1 & IU-2
Legal name of applicant(s): Roxel (UK Rocket Motors) Ltd
APPENDIX B: Overview of Propellant and Charge Production

Figure 1a: General CDB Powder Manufacturing Process (Steinberger, 1969)

Figure 1b: General CDB Casting Process (Steinberger, 1969)
Figure 1c: Examples of different Charges

4 The particular Charges that form part of the application are not included for reasons of confidentiality.