Looking to the future
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CONSIDERATIONS IN DEVELOPING A NEW FISSILE TRANSPORT PACKAGE

Tim Gleed-Owen, C Eng, MIMechE
Senior Engineer, RAM Containers
Rolls-Royce Power Engineering Plc, PO Box
2000, Derby, DE21 7XX, Great Britain

ABSTRACT

This paper identifies and illustrates the typical activities and skills involved in the design and development of a new package. The activities described are modelled on those undertaken by Rolls-Royce Power Engineering in designing, developing and licensing the NMTSP package for carrying fresh fuel. It illustrates the wide range of skills required and the need for a flexible approach in deriving the final design. Topics considered are:

- Details of the payload to be carried, which includes assessments of containment boundary, fragility, thermal durability and means of criticality suppression;
- Space and weight constraints for the final package design;
- User requirements, eg stacking, ease of use, maintainability;
- Lifetime and whether used for transport only, or storage and transport;
- Permeation and humidity control;
- Material choices, future-proofing, and the trade off between initial and through-life costs;
- Transport modes and the effects on design;
- Design ambient temperature range;
- Pressurisation;
- Testing for material characterisation;
- Structural testing on design features;
- Thermal testing of barrier materials and sections;
- Scoping calculations for impact;
- Lifting and tie-down features;
- Lid joint development, including bolting sizing;
- Lid bolt testing;
- Adverse material property combinations;
- Detailed impact analysis and predictions for drop testing;
- Criticality modelling and confinement boundary for normal and accident conditions;
- Modifications through manufacture;
- Test programme, including cumulative damage for normal and accident conditions;
- Development of drop target;
- Drop and stacking test results;
- Correlation and validation between test and impact analyses;

- Ancillary equipment, eg lifting and transport;
- Licensing.

This list is not exhaustive, and not every step will be required for all package designs, but the intent is to illustrate a typical process.

DESIGN BOUNDARY

Payload

The radioactive payload is clearly the nub of the matter. All considerations of package categorisation, containment and dose-rate control, and confinement and criticality suppression in the case of fissile material, revolve around the characteristics of the payload. In this case the *Mechanical Engineering and Physics* disciplines confirmed the payload to be of enriched uranium with no irradiation history, accordingly has minimal radiation dose-rate, and has an inert metallic sheathing of high integrity that provides one layer of containment boundary. High levels of quality assurance and testing determined it to be mechanically robust and able to accommodate high temperatures without damage. The fuel composition was categorised as LSA-II [IAEA[1] 226b], which together with its fissile nature, required an Industrial Type 2 Fissile package for carriage in the public domain [IAEA Table 4 and 671].

User Restrictions

The fuel factory concerned has built up considerable experience in packing, storing and consigning these fresh fuel components in individual transport containers [Fig.1]; accordingly this concept was not changed for the replacement package design, the NMTSP. Adopting a ‘minimum-change’ philosophy carries many benefits to those directly involved in activities such as operator training, packing, health physics, storage, loading, facility infrastructure, transport mode, receipt, unpacking, and finally turnaround maintenance. However, to overlook opportunities for improvement would be an opportunity wasted. Accordingly, the previous design was scrutinised within the *Design Authority, Mechanical Engineering, Metallurgy, Operator and Human Factors* disciplines, and potential improvements identified that would assist the through-life management of the packages:

- Health and Safety of operatives
- Crevice and surface area reduction to assist in maintaining cleanliness
- Material changes to reduce operational problems
- Parts count reduction
- Flange and seal design to improve gas-tightness
- Closure process simplification and enhancement of success rate
- Design for universal contents
- Maintenance scope reduction and reduction in routine item renewals
- Simpler and intuitive attachment of lifting equipment
- Located stacking and enhanced stack/de-stack process

Whilst not critically restrictive, size and weight considerations for each package were targeted on the previous design, such that space and craneage constraints in existing facilities were not violated. In addition, to maximise use of the current experience base, the manner of loading, via a full-length removable lid, would remain [Fig.2], as would the present transport mode.

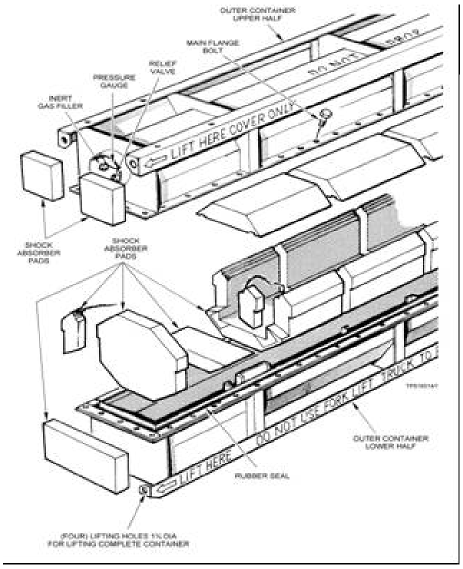

Figure 1. Previous Design

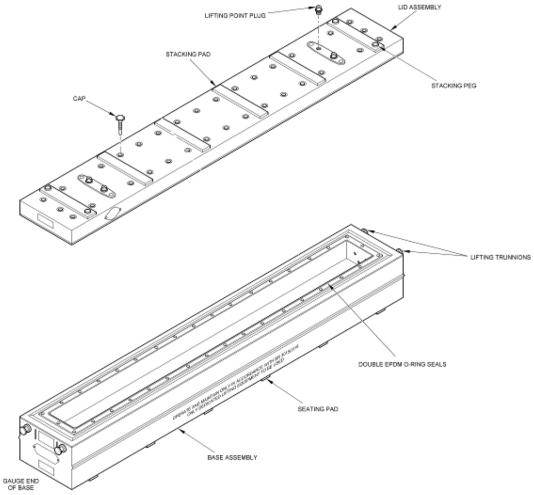

Figure 2. New Simpler Design

Human Factors

The opportunity was taken at an early stage in the design process to review all operations and the interaction of operators with features on the packaging, the lifting equipment and the transport tie-down equipment. The inclusion of *Human Factors* into design, specifically when considering safety, will focus on the strengths and weaknesses of operators under different working conditions (including both physical and psychological demands) and allow the design to support the operators throughout their interactions. The successful inclusion of human factors principles should result in a safer, intuitive, ergonomically sound workspace design. Accordingly, several iterations of design and HF assessment ensured that errors and unsafe practices would be minimised.

Lifetime Considerations

The lifetime brief included a considerable period in storage whilst containing a fuel component, followed by shipment, further storage, then unpacking. During this period an inert gas internal atmosphere was to be maintained whilst minimising operator involvement. Consequently, where elastomers were used for sealing and cushioning, materials must offer extended lifetimes with minimal compression set. Structural materials would need to accommodate long-term storage in conventional factory facilities, ie those without active humidity and temperature control. A further consequence of extended storage is that handling would be performed many years following intrusive maintenance periods. Involvement of *Design Authority, Mechanical Engineering, Metallurgy and Elastomer Consultancies* enabled materials and policy solutions to be determined.

UK Ambient Conditions

Initial design progressed assuming application of the UK-specific ambient conditions concession dispensed by the UK Competent Authority for surface modes, being a temperature range of minus 10 to plus 26 deg C. As the justification progressed, the *Design Authority* deemed it sensible to apply some margins, reflecting the withdrawal of BS 3895[2] in 2009, and the evidence of global warming, such as in the summer of 2009 in the UK when temperatures reached 33 deg C. Accordingly the *Design Authority* applied corrections to the specialist *Thermal Engineering* analysis to elevate the permissible upper temperature limit to plus 35 deg C.

INITIAL DESIGN

Concept Design

Hand calculations were adopted by *Mechanical Engineers* to formulate the overall package concept, including flange sizes that would be stiff enough to allow a reduced number of lid screws, skin and stiffener thicknesses, impact absorber thickness and density on the six faces of the design, together with overall size, shape and weight.

Materials of Construction

The relatively low weight and section thicknesses of this design, the intent to absorb impact energies by buckling of the outer skin and deformation of the contained foam, the use of sealed cavities, and the cleanliness requirements imposed by operations, have all encouraged the use of austenitic stainless steels for exposed surfaces [Fig.3]. For a long-life design, the extra costs incurred in manufacturing may often be offset by the simplified care requirements through life. These choices, determined through close co-operation by *Design Authority, Mechanical and Dynamic Stress Engineers,* were endorsed by *Metallurgists and Operators.* The many advantages emanating from this choice include ease of inspection of welds during maintenance periods, and avoidance of paint chips in clean-room facilities.

Figure 3. Illustrating Clean Flat Stainless Steel Surfaces

Figure 4. Body Under Construction, Showing Internal Stiffeners

Design for Manufacture

In common with the previous design, and partly driven by the payload shape, the packaging is of cuboidal form. However in the interests of presenting smooth surfaces to assist in clean-down, the previous single-skin construction with external stiffeners was replaced by sealed inner and outer skins, comprising mostly flat panels, separated by skeletal box-section internal rib structures [Fig.4].

Whilst welding on each packaging was necessarily considerable, the total length of weld was reduced by adopting extensive folding and rolling of sheet and plate, and stitch-welding of those internal structures that are not accessible to the payload cavity or external environment. Optimisation between designer and manufacturer at the detail design stage invoked extensive CNC machining in the lid to create a combined inner skin and flange structure, rather than separately welded flange sections, skin panel and stiffeners. Welds were generally of fillet type to simplify construction and minimise heat input. All of these techniques had the aim of minimising welding of the finished packaging, because of its potential for distortion of high-aspect-ratio austenitic structures.

The use of an impact-absorbing rigid foam was agreed at an early stage, through both commercial and technical considerations, to be confined within the double-skin structure. Consistency in behaviour of the foam impact absorbing material is crucial to package performance should a transport accident occur. Two potential means of inserting the foam during manufacture were identified. One is to pour the mixed constituent materials and allow reaction and expansion to occur in situ. The other is to machine blocks from a larger block of foam and insert these during build. Quality assurance considerations favoured the latter option, through the ability to test coupons cut from the larger block and document cast properties with a high level of confidence. It also permits test coupons to be stored for later analysis, as part of design life validation, and enabled the design to utilise several grades of foam, such as with higher density at the package ends where greater specific impact energies would be imposed. Build trials demonstrated that protection of these shaped foam blocks was necessary to avoid toxic fume from decomposition during welding of outer skins. Following extensive trials by the package manufacturer, in conjunction with the *Design Authority,* in which many thermal shield materials were deemed ineffective, the best solution identified was a brand of thin mineral fibre blanket overlaid on the foam, which would be justified as part of the thermal barrier [Fig.5]. The *Design Authority,* in conjunction with *Metallurgists,* analysed the blanket and imposed controls on humidity during all manufacturing and service operations, because of the potential for this best-performing blanket material to leach out species aggressive to the stainless steel structure.

Design features were planned such that the sequence of construction was working from inside to outside [Fig.4]. This assisted with control of clearances between metallic and foam structures, and provided the ‘cleanest’ weld-free surfaces on the payload cavity, where it is of greater importance that decontamination is readily achievable.

The involvement of *Design Authority, Mechanical, Dynamic Stress, Welding and Manufacturing Engineers, and Operators,* was crucial in these matters, as was close co-operation with the manufacturer.

Figure 5. Lid in Build, Showing Foam and Blanket Materials

Figure 6. Whole Package FEA Model

<u>Scoping of Impact Performance</u>

The concept design was numerically modelled within LS-DYNA by *Dynamic Stress Engineers* [Figs.6 & 7]. Early impact scoping work made modelling simplifications by ignoring many of the welds in the internal structures, typically those that hold the inner and outer skins together and enhance location of flanges. Early side-impact and corner-impact runs identified excessive and unrealistic rotations in the bolting flange, causing lid screw failures, and also identified the need for improvement in lid location spigotting. Early end-impact runs showed that impact protection onto the ends of the package required enhancement.

Under the guise of an Industrial Type 2 package, drop and stacking tests should be justified or demonstrated, representing Normal Conditions of Transport (NCT), with one of the limiting acceptance criteria being the 20% increase in maximum surface dose-rate [IAEA 622b]. Essentially, surface dose-rate for a design of this type, with an unshielded, solid, distributed source term, is principally governed by proximity of the outer surface to the source. Any reduction in the distance, caused by denting or ‘knock-back’ of the outer surface under impact, or shifting of the source within, raises the surface dose-rate, and the greatest increase for a given impact needs to be identified. Accordingly *Mechanical and Dynamic Stress Engineers* identified potential candidate attitudes, then conducted preliminary Finite Element Analysis (FEA), to identify the external face or feature that would ‘knock-back’ the greatest distance, as a proportion of the distance to the source. *Physicists*, in parallel, determined the limiting ‘knock-back’ for all faces and edges to meet the IAEA dose-rate increase criterion.

Fissile package designs must also assess the cumulative affect of Accident Conditions of Transport (ACT) as well as NCT, as part of the criticality safety justification [IAEA 682b]. Accordingly any given feature of the package may have to withstand firstly a ‘Normal’ drop from 1.2m followed by the ‘Accident’ drop from 9m. Taking these requirements literally, a drop test demonstration could present both of these scenarios in sequence, impacting onto the same location of the same specimen. However in the interests of minimising analysis and test house time, a realistic shortcut was proposed by the *Design Authority*, and endorsed by *Dynamic Stress Engineers*. This combined the NCT and ACT drops into a single 10.2m drop test, offering a cumulative impact energy equal to the sum of the two separate drops, and also cumulative ‘knock-back’ damage. All subsequent impact analyses adopted this 10.2m equivalent drop height, as did the subsequent drop tests.

A set of acceptance criteria was generated by the *Design Authority and Mechanical* discipline, for performance under impact. The maximum permitted knock-back for NCT dose-rate increase was a mandatory figure, as was retention of the fuel component within the package. Other criteria were set as targets, such as non-failure of any lid attachment screws, restrictions on the relative movements between fuel and absorber rods, and bending and acceleration limits on the fuel component.

Lessons-learned in this impact scoping stage were implemented by the *Design Authority, Mechanical and Dynamic Stress Engineers*, in both the package design and improved modelling. This included a study of lid screw size, involving the impact upon manufacturing costs, which resulted in a reduction in thread diameter and simplification of the profile. A rigorous system of model version control was instigated, to ensure traceability of all analyses to design and modelling modifications. Once simple impact behaviour was predictable and within mandatory and target criteria, a detailed phase of impact assessment was entered. Programme expediency required this detailed phase of impact analysis to be condensed, so an external organisation was contracted to perform particular aspects of the impact analyses in parallel with Rolls-Royce studies. As the model and software were to be used on two platforms in parallel, a suitable impact test case was commissioned and the results shown by *Dynamic Stress Engineers* to be identical across the two platforms.

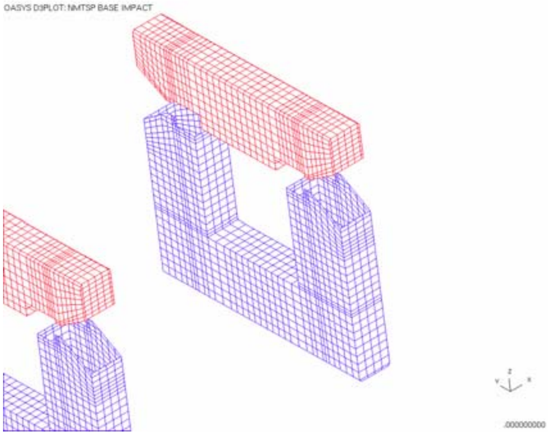

Figure 7. Mesh for Internal Structures

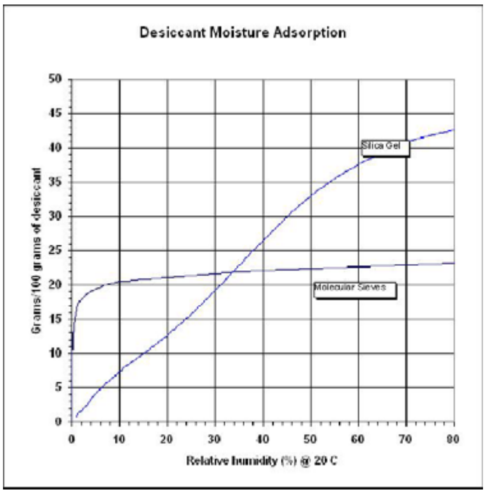

Figure 8. Desiccant Moisture Adsorption

Sealing and Humidity Control

Whilst high-integrity sealing of the package lid to base joint was not identified as a containment requirement, *Operators and Metallurgists* identified that it was important in maintaining a low pressure, dry, inert gas purge for preservation of the fuel component. Because of the extended storage period, a high degree of leak-tightness was required, which needed to be achieved without conflicting with other requirements such as rapid and successful lid sealing by the operator.

The solution agreed between the *Design Authority and Elastomer Consultants* was the conventional one of double O-ring face seals, using EPDM rubber for long life, absence of compression set and low permeability. Inward permeation of water vapour was also investigated, as this was perceived to be an issue, requiring calculations of dew-point change and desiccant types and capacity. A molecular sieve was selected, having advantages over the traditional silica-gel, [Fig.8], on the basis of the low humidity levels required, and of a mass suitable for the entire storage period.

SUPPORTING TEST WORK

Foam Characterising

Although basic characteristics of the foam under impact were available through the manufacturer, a need for more specific data on strain-rate and temperature variabilities, and effects of orientation and confinement, was identified by *Mechanical and Dynamic Stress Engineers*. This testing programme was commissioned at an accredited test house. Manufacturing tolerances on parameters such as density and specific energy absorption were also quantified by *Quality and Mechanical Engineers*, through initial batches and agreements reached with the foam manufacturer. The spectrum of results from all of this data were built into a material model by *Dynamic Stress Engineers*, used for bounding impact assessments using combinations of adverse parameters.

Lid Screw Tensile Tests

Production lid screw samples were subjected to destructive pull tests. These were specified by *Mechanical and Dynamic Stress Engineers*, and were designed to establish the relevance of failure with strain-rate, assist the impact modelling by characterising the failure modes, and to confirm that British Standard properties were realised.

Accident Impacts to Flat Faces

Analysis by the *Design Authority* and *Dynamic Stress Engineers* was unable to accurately predict whether the regulatory punch impact [IAEA 727b] onto the thin outer skins would cause penetration, either before or after the cumulative drops from 10.2m. Accordingly a series of tests were specified and commissioned on specimen panels [Fig. 9] that represented the full size wall construction. These tests imposed the energies from both a simulated punch and a flat-faced platen, in several permutations of sequence and foam density. The platen test was devised to simulate the package being dropped onto one flat face from 10.2m, either as a precursor, or subsequent, to punch impact. Inspection of these specimens showed that partial penetration of the punch was possible under some circumstances.

Figure 9. Specimen Panel, Following One Punch Impact

Figure 10. Panel Opened Following Impacts & Thermal Test to Show Burnt Foam

Thermal Test Simulation

Whilst heat transfer properties for the foam impact medium were well documented under laboratory conditions, considerable uncertainty existed in its behaviour when exposed to radiant heat, flame, confinement, pre-densification resulting from impacts, and variable oxygen ingress. The foam would intumesce when exposed to high temperatures, char on the surface, emit considerable quantities of gas and vapours, and slowly decompose. The *Design Authority* specified that empirical thermal tests [IAEA 728] should be conducted on the accident impact specimens described above [Fig. 10], these being most representative of a package wall section containing foam, and having severe accident damage superimposed. Testing was commissioned to instrument the specimens, using thermocouples at various depths and a hot-surface radiometer, and to apply essentially one-dimensional heat transfer by flame impingement to the outer face, with insulated edges and the inner face exposed to ambient. Results were assessed by *Mechanical* and *Thermal Engineers* and applied to an accident-damaged mathematical model of the full size package.

Static crushing

An unused sample of the through-wall specimen, described above for the impact and thermal testing, was used to characterise the crush resistance of the design under situations such as stacking [IAEA 723]. This provided early validation of the features in the NMTSP design that resist stacking and tie-down forces. This testing involved the services of *Mechanical and Dynamic Stress Engineers*, and a *Test House* to generate a load-deflection curve. This was then used to provide confidence before commissioning a practical Stacking Test [IAEA 723] on a full-sized package.

DETAIL DESIGN

Detail design followed immediately after the earlier described activities, and consolidated all of the stacking, lifting, handling, marking, pressure fittings, location and operator-aids into the design [Figs. 11 & 12]. It also accommodated all design changes agreed as a result of development problems or cost-reduction requirements encountered during early manufacture. This was an on-going phase involving the *Design Authority, Mechanical, Dynamic Stress, Manufacturing, Human Factors and Quality Assurance engineers*, *Operators* and the consultancy used for *Seal Technology.*

This resulting design was the basis for the testing, final justification work and licensing application to the Competent Authority.

Figure 11 Stacking & Lifting Features

Figure 12 Pressure Fittings & Locating Features

DETAILED ANALYSIS

Bounding Impact Studies

Armed with material property variations, particularly with the foam, a bounding set of property combinations for analysis was generated through close co-operation of *Mechanical and Dynamic Stress Engineers*. This principally recognised the temperature-dependence of foam properties, and the inherent variability in producing this material. Bounding studies adopted both ‘hard’ and ‘soft’ extremes for the foam, according to whether the target of interest was related to acceleration-related damage, such as of the fuel component, or whether to excessive deformation of the packaging, which could enhance close stacking and neutronic interaction. Other extreme combinations related to whether the lid screws were inadvertently left untightened, or that clearances were biased in an adverse manner. Sub-models were created as necessary to interrogate impact consequences upon the intricacies of the fuel component, or those mechanisms that hold the neutron absorbers in place. The net result was a set of bounding justifications, representing plausible extremes of circumstances for the packages in a real transport situation. For these bounding studies, all acceptance criteria were shown to be met. By contrast, the probability of a transport accident occurring with such extreme adverse circumstances is extremely small.

Thermal Justification

Consideration of inward heat transfer paths, into the fuel component during an accidental fire, led to the selection of an adversely damaged post-impact mathematical model as the starting point for thermal analysis. Combined with the empirical results obtained from the thermal test simulation specimens, this data was compiled by *Mechanical and Dynamic Stress Engineers* and provided to a *Thermal Engineering Consultancy* for a transient thermal analysis dictated by the regulations [IAEA 728]. This provided temperature peaks for key components that were part of either a pressure boundary or containment boundary, for feeding into structural and containment justifications of the design.

Criticality

Early scoping calculations, involving the *Design Authority* and *Physicists*, using array sizes based on the planned number of packages in a consignment, produced eigenvalues that were compared with project targets. Target values for K_{eff} had been set conservatively low, firstly to assist the CA in their review process, and secondly to provide room for degradations, such as from impact damage, as the design developed. On this early evidence the initially-chosen cross-sectional size of the package was increased, solely to reduce neutronic interactions.

Modelling for criticality assessment required a simplified model compared with the controlled and optimised one used for impact assessment. Accordingly a review was conducted of the features and their tolerances that would be significant to the criticality safety justification, and a simpler, conservative mathematical model was specified. This activity involved *Mechanical and Dynamic Stress Engineers and Physicists*, and ensured that an auditable trail existed for the basis of the criticality model. This model was also variable in some external dimensions to reflect the external damage caused by NCT or ACT. Parameter studies were conducted, with the purpose of identifying the worst case for each variable in isolation, including array shapes, foam combustion or survival, close-packing versus interstitial water, water densities within the various compartments, fuel component type, tolerances on the fuel components, etc. A second stage of the detailed criticality justification then combined these worst cases to create adverse scenarios for a package in isolation, an array of NCT damaged packages, and finally the array of ACT damaged packages [IAEA 677–682].

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DROP TESTING AND VALIDATION

Testing of Package Prototypes

Detailed specification of the tests had been created by the *Design Authority and Dynamic Stress Engineers*, and this included requirements for instrumentation and pressurisation of the drop prototypes, post test measurements, acceptance criteria, and photography. In parallel, the intended drop target was assessed under the guidance of the *Design Authority* and a refurbishment plan agreed and implemented to renew the top plate and ensure a high degree of fastening integrity. The *Design Authority and Dynamic Stress Engineers* specified and conducted a FEA study of this refurbished target, to confirm its continuing integrity under the planned package drops. Instrumentation plans, build procedures, drop procedures, quality plan, tracking and data-gathering plan, and schedules, were generated by the *Test House* and assessed by the *Design Authority* with assistance from *Dynamic Stress and Quality Engineering.*

Drop prototypes were built up with a dummy payload, and key dimensions, weights and seal leak rates recorded, by the *Test House*, under the supervision of the *Design Authority and Dynamic Stress Engineers*. As each test was set up, key parameters, such as stacking weight, internal pressure, drop height and attitude [Fig.13] were again recorded and accepted by signature of the *Design Authority*. Post test, all key dimensions, leak rates [Fig.14] and damage were again quantified and recorded, supported by photographic evidence as deemed necessary by the *Design Authority*. Instrumentation output data was supplied to the *Design Authority and Dynamic Stress Engineers*. In the case of drop attitudes upon striking the target, where these departed from the design intent, such as where a small degree of rotation occurred 'in-flight', the high-speed video recordings were analysed by the *Test House*, under the guidance of the *Dynamic Stress Engineer*, to provide real data on the actual impact attitudes.

Figure 13. Setting-Up for Drop Test

Figure 14. Typical Leak Tester

Validation of Impact Predictions

Actual drop test data, including weights, drop heights, temperatures, impact attitudes and damage incurred, were reviewed in detail by *Dynamic Stress Engineers.* Together with foam properties for those particular specimens at the time of drop testing, the mathematical models and boundary parameters were adapted as necessary to allow a set of impact validation runs to be conducted. With overview by the *Design Authority*, the *Dynamic Stress Engineers* produced damage predictions [Fig. 15] that matched the actual damage [Fig. 16] very closely. This step is necessary for clear validation of the software and operating platform.

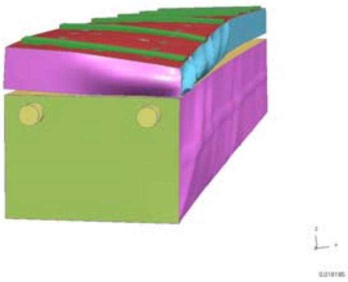

Figure 15. Result of Validation Modelling

Figure 16. Result of Real Drop for Comparison

CONCLUSIONS

Many skill groups are involved in the design of a fissile transport package. For the NMTSP, as example, they are listed with their typical activities below:

Table 1. Skill Groups and Their Involvement

Skill Group	Illustrative Involvement
Mechanical Engineering and Design Authority for the NMTSP	Acceptance criteria; Concept design; Scheme drawings; Prelim impact analysis; Prelim stacking analysis; Prelim pressure analysis; Interfaces with lifting and transport equipment; Co-ordination of detail design; Evaluation of manufacturing concessions; User requirements & liaison; Facility characterisation; Co-ordination of specialist disciplines; Technical co-ordination of test houses; Compilation of design approval documentation; Interactions with Competent Authority.
Dynamic Stress Engineering	Component & material test specifications; Materials characterisation from tests and research; FEA modelling; Specification and supervision of subcon FEA; Design feedback; Critical drop identification; Drop attitudes selection; Bounding parameter selection; Re-analysis of actual drops for validation.
Stress Engineering	FEA modelling, stacking, pressurisation & lifting analyses.
Metallurgy	Initial material choice; Payload preservation; Sanctioning controls for materials with leachable species.
Physics	Source term characterising; Dose-rates and increases due to impact; A_2 determination; Criticality evaluations for concept arrays; Detailed modelling; Predicted damage and actual damage; Final criticality safety justification.
Seal& Elastomer Engineering	Selection of rubber seal and pad materials; Permeation & leakage analyses; Liaison with mould designers & production facilities.
Noise & Vibration Engineering	Spectrum identification for transport mode; Analysis of control case; Analysis of support pad profiles & shock absorber options; Selection of final arrangement; Bump and vibration analyses.
Thermal Engineering	FEA impact model adaptation; Determination of worst-case impact damage; Application of empirical thermal test results; Temperature-time analysis of key parts of the model.
Plastic Moulding Engineering	Concept selection for screw retention and rain-shielding parts; Mould prototyping; Sample evaluation; Production components.
Human Factors Engineering	Reviews of design proposals; Process requirements and feedback into design & process control.
Test Houses	Arrhenius lifetime testing of rubbers; Foam material characterising; Development tests for impact, thermal & crushing environments; Drop test planning, procedure generation, safety supervision & test implementation; Selection of accelerometers, cable & umbilical routing; Data logging & interpretation; Test reporting.
Civil Eng Consultancy	Drop target assessment, refurbishment, and NDE re-assessment.

Skill Group	Illustrative Involvement
Quality Engineering	Review & monitoring of manufacturing and testing QA; Manufacturing and delivery documentation; Controlling technical queries and concessions.
Manufacturing Engineering	Design for manufacture; Review of fuel manufacturer's NDE & quality procedures; Monitoring of NMTSP manufacturer's progress and issues.
NDE Engineering	Review of NMTSP manufacturer's NDE procedures.
Welding Engineering	Design for manufacture; Review of NMTSP manufacturer's weld procedures & qualification process.
Operators	Initial design scoping; Attendance at design reviews; Demonstration of processes; Facility characterisation; Procedure writing; Spares policy.
Technical Authors	Writing of handbook with descriptions, specifications, illustrations, operating & maintenance instructions.

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2. BS 3895:1976 Guide to the design, testing and use of packaging for the safe transport of radioactive materials