## Designing Tie-Down Systems For Heavy RAM Packages – Should Revised Design Criteria Apply?

**Author**
**Peter C Purcell**
International Nuclear Services Ltd,
Hinton House, Birchwood Park Avenue, Risley, Warrington, Cheshire UK WA3 6GR

## ABSTRACT

The safe transport of Radioactive Materials (RAM) is the top priority for all stakeholders and achieved through compliance with the IAEA Transport Regulations TS-R-1. These regulations cover all RAM transport package types, irrespective of the nature of their radioactive contents.

In practice, the majority of package types are relatively light in weight but there are many RAM package designs that weigh over 100 tonnes.

The object of this paper is to discuss issues that arise from the transport by road and rail of such packages, in particular the design and operation of the tie down systems acting between the RAM package and its conveyance.

The TS-G-1 regulations do not specify acceleration factors for RAM package tie downs but the supporting advisory material TS-G-1.1 gives indicative factors that are frequently applied by designers of tie down systems. However, the tie down designer may be permitted to use lower acceleration factors, subject to agreement with competent authorities and transport modal organisations.

This paper will demonstrate, in the case of heavy RAM packages, there can be issues arising from designing tie down systems, which may lead to over design without real increase in transport safety. Indeed, in some cases achieving compliance with certain transport loading conditions could potentially increase risks to operating personnel.

It will be demonstrated where the RAM package weighs more than the conveyance vehicle, it is the mass and geometry of that vehicle that can determine stresses in the tie down system and not the mass of the package itself.

This paper makes the case, when designing a tie down system for heavy RAM packages for routine movements by road and rail, the weight and geometry of the conveyance should be taken into account and demonstrates there will be no reduction in safety as a consequence.

## INTRODUCTION

All organisations responsible for the transport of Radioactive Materials (RAM) must comply with the IAEA Regulations (Ref 1) for the Safe Transport of Radioactive Material, this is a legal obligation which ensures safety to the public and operators. These regulations apply to all RAM transports irrespective of the nature of the radioactive contents. In most cases, the IAEA Regulations have been specifically developed around the varied and unique issues associated with RAM transport. However, in regard of the tie down of RAM packages, the IAEA Advisory material (Ref 2) recommends methods and parameters largely based on those established by recognised modal organisations for road, rail and sea. The following paper discusses issues that can arise from applying these methods to the tie down design of heavy packages, specifically those transported by road and rail.

## BACKGROUND

The IAEA regulations (Ref 1) require the package to be properly secured to the conveyance (Ref 1-para 606) A principle requirement being that any tie down attachments should be designed not to impair the ability of the package to meet the regulations (Ref 1 para 636). This is further emphasised in Appendix IV of the IAEA Advisory Material (Ref 2) where it states the package may be required to separate from the conveyance in order to preserve the package integrity. Also presented in Appendix IV are Tables IV-1 and IV-2, which give acceleration factors for routine transport which may be applied for package retention system design. Table IV-1 gives general guidance but Table IV-2 gives acceleration factors for specific packages and presented below in Table 1.

In practice, the factors stated in Table 1, although not mandatory, are frequently applied by default to most heavy RAM package tie down systems. The advisory material (Ref 2) also gives guidance on how these factors are to be applied, ie acting in combination through the centre of gravity (C of G) of the package. Again this advice is generally applied, irrespective of the weight of the package and its conveyance. In the majority of cases, advice given in Ref 2 is very satisfactory and usually complies with or bounds the statutory requirements of the modal organisations. However, INS has found where the package weighs significantly more than the conveyance vehicle this advice may lead to over design of the tie down system without any corresponding increase in safety.

### Designing A Tie Down System or Intermediate Frame

Over many years, International Nuclear Services (INS) has been involved in the design and procurement of different designs of tie-down frames for the road/rail transport of RAM packages. At the start of the design process INS will initially prepare a specification stating the parameters the design must achieve. A designer will then be selected through a tendering process based on the INS specification. In many cases, a contract will be issued to design and manufacture the tie down frame within a single organisation. This process has worked efficiently for INS but nevertheless has highlighted a number of issues specific to the design of tie down frames for heavy RAM packages, as described below;

### The INS Design Specification – General Principles

INS has typically specified acceleration factors as given in Table 1 and stress limits in accordance with BS 2573 (Ref 3, as recommended in Ref 4). These have been successfully applied in all cases, but for designs of tie down frames for heavy packages the following has been observed, as described in the following examples;

**Example 1 -** To ensure dimensional and weight parameters are achieved, the finished frame designs require high strength steel members with resulting cost and fabrication issues. However, an overall analysis of the system can reveal that the acceleration factors (taken from Table 1), cannot fully act in practice due to the limiting effects of the conveyance vehicle geometry and weight. Consider the simple example shown in Figure 1, here the package and rail wagon are subject to a lateral acceleration counteracted by the weight of the package and wagon acting down. When the resultant of these two forces falls outside the rail, overturning will commence.

**Table 1 - Taken From IAEA Advisory Material Ref 2**

TABLE IV.2. ACCELERATION FACTORS FOR PACKAGE RETENTION SYSTEM DESIGN FOR SPECIFIC PACKAGES

| Type of package | Acceleration factors[a] | | |
|---|---|---|---|
| | Longitudinal | Lateral | Vertical |
| Certified fissile and Type B(U) or Type B(M) packages in the USA [IV.7] | | | |
| All | 10g | 5g | 2g |
| Radioactive material packages in Europe by rail (UIC) [IV.8] | | | |
| Rail | 4g (1g[a]) | 0.5g[a] | 1g ± 0.3g[b] |
| Carriage of irradiated nuclear fuel, plutonium and high level radioactive wastes on vessels [IV.9] | | | |
| Sea | 1.5g | 1.5g | 1g up, 2g down |
| Domestic barge transport of radioactive material packages [IV.6] | | | |
| Sea/water | 1.5g | 1.6g | 2g |
| Uranium hexafluoride packages [IV.1] | | | |
| Road and rail | 2g | 1g | ±1g |
| Sea | 2g | 1g | ±2g |
| Air | 3g | 1.5g | ±3g |

[a] These values are required by the US for tie-down fixtures that are structural parts of Type B(U) and Type B(M) and fissile package designs.

[b] Lower acceleration factors are allowed if dedicated movements with special rail wagons are made. Additionally, higher acceleration factors are required if snatch lifting on the attachment points is likely to occur, or if the rail wagons are to be carried on certain roll-on/roll-off ferries [IV.8].

Here, this force corresponds to a lateral acceleration of 0.32g, hence overturning would occur before a 0.5g lateral acceleration force could act. In practice, overturning of a rail vehicle is virtually unheard of as a primary event, derailment usually happening first. Indeed, safe practice for rail vehicle stability design and operation require that the resultant force vector falls within the middle region (s on Figure 1) of the track which actually corresponds in this example to a lateral acceleration below 0.15g. Clearly the limiting acceleration against stability criteria will depend on the weight of the load and the overall geometry, but for heavy RAM packages must be well below 0.5g. In this example, a lateral acceleration of 0.15g would be generated by the rail vehicle traveling around a $22^o$ curve (80m radius) at about 11m/s (25mph). A $22^o$ curve being very tight and only found where strict speed restrictions apply, for example site movements. On the main line, where speeds are limited to 27m/s (60mph) for RAM transports in the UK, super-elevation (ie the outside rail being higher than the inner rail) and much gentler curves ensure vehicle stability, ie the resulting force vector acting within ‘s’ and well below 0.5g.

**Figure 1 – Heavy Package On Rail Wagon – Lateral Acceleration**

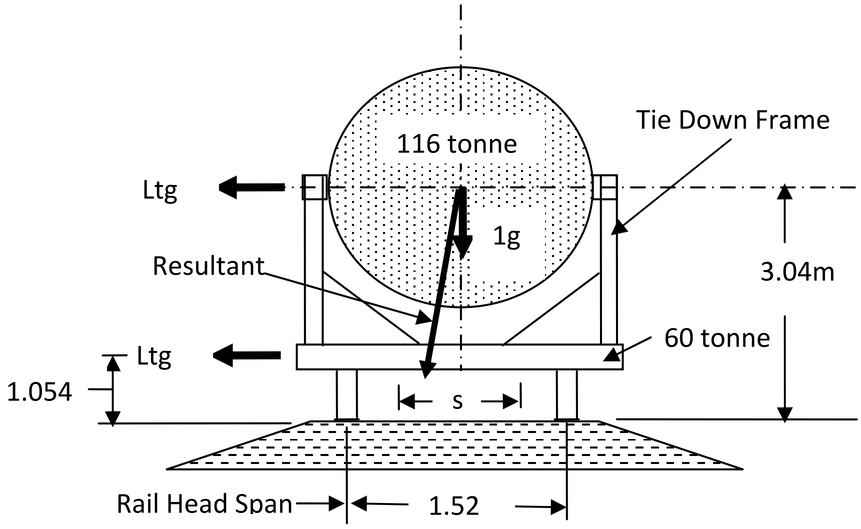
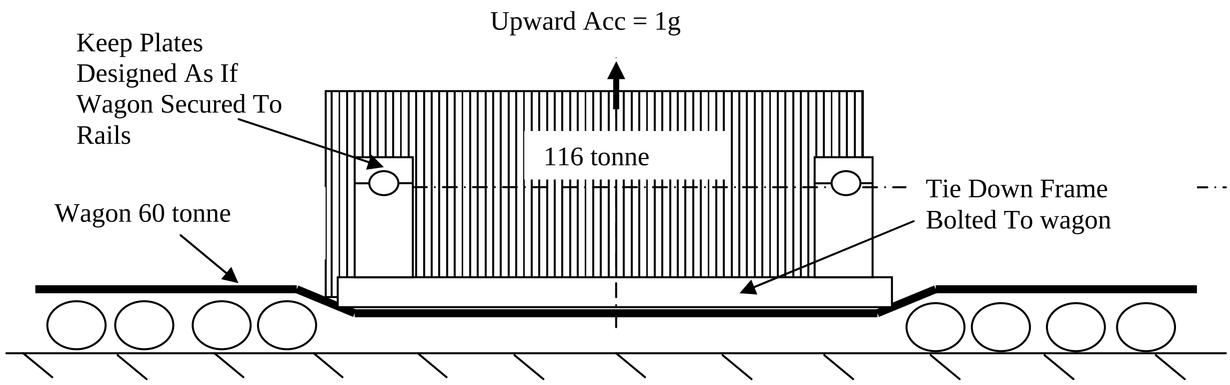
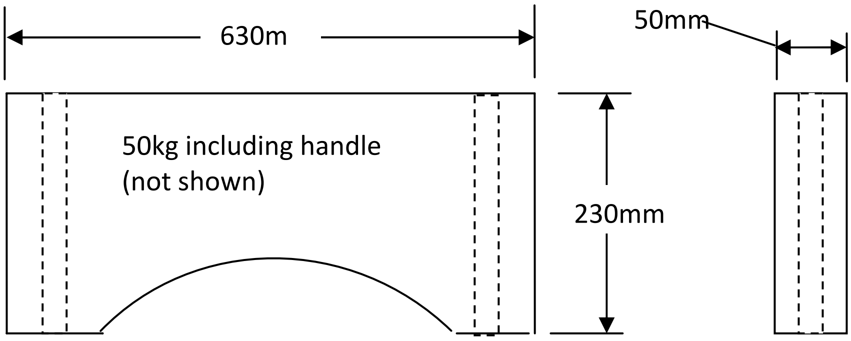



**Figure 2 – Heavy Package On Rail Wagon – Upward Acceleration**




**Example 2 -** Where a heavy package has four trunnions for lifting and support, journals on these trunnions are frequently used to connect the package to the rail wagon through an intermediate frame, see Figure 2 above. Here, the package is subject to a net upward acceleration of 1g, the potential upward flask movement being initially restrained by loads acting on the trunnion keep plates. However, when applying the design principles set out in Ref 2, INS has found the resulting keep plates weighed as much as 50kg each, see Figure 3. This being too heavy for solo manual handling and potentially exposes the operators to increased dose uptake. In reality, the stresses in these keep plates are limited by the weight of the wagon which would lift off the rails before the full package weight could act. Hence, the keep plates are of substantial size and weight with no real increase in safety resulting, potentially the opposite when considering their operation.

**Figure 3 Trunnion Keep Plate For Heavy Flask**




***Footnote*** **–** This is an actual example, but one of the reasons for the heavy trunnion keep plates here was the designer had conservatively assumed only two of the four keep plates were acting. The IAEA Advisory Material (Ref 2), does not specifically advise on this type of conservatism but TCSC 1006 (Ref 4) recommends all four are considered acting when designing for a heavy flask. When TCSC 1006 recommendations were applied the keep plate weight dropped by 20kg. Nonetheless, despite the reduced depth of keep plate, one of these alone could lift the full weight of the frame and wagon without exceeding yield!

**Example 3 -** When designing a tie down system for heavy RAM packages, there are frequent conflicts between the size of structure required and the space available. This is particularly the case for UK rail transport, where the loading gauge is more restrictive than in most of Continental Europe and the USA. Consequently, it is essential the design specification reflects, not only the requirements of the IAEA and modal organisations, but also site specific standards. In the experience of INS, this can become challenging because of differing acceleration factors and parameters that apply. For example, INS operated a tie down frame for a heavy RAM package compliant with Table 1 and UK rail regulations but later encountered a specific site requirement of 1.5g lateral acceleration factor. Such an unexpected occurrence can easily be accommodated for a light package but not always so for a heavy package. In this particular case, the INS tie down system was eventually accepted on the site, on the basis the stresses in the tie down system did not exceed yield from applying 1.5g lateral acceleration. In the process it was established that the site standard of 1.5g lateral acceleration had been chosen as 'all bounding' without any consideration of the actual acceleration limits that could apply

**Road Transport**
In the specific case of road transport a heavy package being transported can also weigh considerably more than the conveyance vehicle. Normally, this will be wider than a rail vehicle with the centre of gravity of the load acting at a lower height, hence a higher lateral acceleration force would be required to cause overturning. A positive consequence of the extra width on the conveyance vehicle is the additional space to accommodate a tie down system. Nevertheless, operating restrictions applying to heavy loads by road ensure lateral forces generated whilst

negotiating bends would be very low. In the UK, road regulations do not specify acceleration factors for the tie down design but give recommendations based on the weight of the load and the number/strength/angle of retention straps. The specific retention of a heavy load in a vertical upward direction is not detailed beyond the recommended strap angle, which may be an acknowledgement that it is virtually impossible for a heavy package to become 'weightless' under routine road transport conditions. Hence, based on advice given in Ref 2, a road transport tie down system for a heavy package could be far more substantial than actually required by the UK road transport regulations, particularly in regard of vertical restraint.

**Transport By Sea**

The focus of this paper has been the tie down frames of heavy packages by road and rail but it must be acknowledged the same frames are also sometimes used for sea transport. In fact INS, operate a number of packages that travel to a sea port by rail, where they are transferred with the frame from the rail vehicle directly to a ship for onward transport. Clearly here, any argument that the tie down load is limited by the weight of the conveyance cannot apply. Nevertheless, it remains appropriate to consider all upwards loading forces acting on all four trunnions, particularly where the limiting allowable stress is taken from a recognised standard, ie Ref 3.

**Longitudinal Acceleration Factors**

The case for considering the weight and geometry of the conveyance in the tie down design of heavy packages applies principally to road and rail transport under upward and lateral acceleration forces. Longitudinal acceleration factors are a different matter as these are not so dependant on the weight of the conveyance but more on its structural stiffness under longitudinal loads. Hence, there can be no argument but to apply the advice from Ref 2 or appropriate modal organisations where the full package weight is considered to act through its centre of gravity. Fortunately, in this loading direction there is usually more space to accommodate the structure required and little likelihood of safety implications to operators.

**Implications On Fatigue Design**

The usual practice within the UK for fatigue design of tie down systems is for acceleration factors to be in accordance with TCSC 1006 (Ref 4) – see Table 2 below.

**Table 2 Acceleration Factors For Fatigue Loading (g)**
**(Taken from Ref 4)**

| Mode of Transport | Direction of resultant force relative to motion of conveyance | | |
|---|---|---|---|
| | Longitudinal | Lateral | Vertical |
| Road | +/- 0.2 | +/- 0.2 | +/- 0.5 |
| Rail | +/- 0.2 | +/- 0.25 | +/- 0.6 |
| Sea | +/- 0.12 | +/- 0.55 | +0.65/1.35g abs |

Usually in the UK, the factors from this table are applied in conjunction with design fatigue life of $10^6$ cycles, as recommended in the (UK) Department Of Transport, Applicants Guide. These acceleration factors are lower than in Table 1 but it is interesting to note for road and rail transport the lateral acceleration factors are equal to or exceed those in the longitudinal direction. Acceleration factors presented in Table 2 are meant to apply to all tie down systems for RAM packages irrespective of their weight. However for the reasons outlined above, it is virtually impossible for these acceleration factors (lateral and upward) to apply to a heavy RAM package in a continuous cyclic manner. For example the lateral acceleration factor for rail given in Table 2 (0.25g) would be considerably higher than permitted by stability criteria for heavy packages in rail operation. Similarly, 0.6g vertical acceleration (upwards) could mean the rail wagon was virtually lifting off its rails, a situation that just could not arise in routine conditions of transport. There may be a strong case for rationalising the acceleration factors in Table 2 to take account of the conveyance weight, when/where this is applicable.

**Discussion**

Designing tie down systems for heavier RAM packages is often found to be a frustrating business. By comparison, lighter packages are easier to deal with, as a conservative approach is usually readily accommodated.

In practice, many designers make unnecessary challenges for themselves by applying these same conservatisms to tie downs for heavy RAM packages. For example, when preparing a design specification INS would invariably state that limiting stresses must be determined from BS2573 (Ref 3), indeed this standard in the UK is recommended by TS1006 (Ref 4). However, the IAEA Advisory Material (Ref 2), simply states the retention system should not be stressed beyond yield which is a position consistent with other modal standards. Yet, in order to ensure stress limits for heavy package tie down systems comply with BS2573, designers often meet considerable challenges, even when Finite Element Analysis methods are used. A similar situation arises with acceleration factors, where, INS would apply the ‘default option’ and specify these must comply with Table 1. In fact, these are only advisory and in some circumstances may exceed anything that could arise during routine transport, particularly where the package weighs more than the conveyance. In a similar vein, INS will specify the designer should apply good engineering practice, but without clear instructions in advance this can lead to unnecessary over design. The unwieldy trunnion keep plates, mentioned above, being an example, resulting in potentially increased hazards to operators without any safety benefit.

It would be correct to note these examples are largely self imposed and could be avoided through appropriate attention to the original design specification. Whilst conversely, to specify standards that deliberately limit conservatisms in the design process would run counter to the general principles of the RAM transport industry.

In practice, acceptable margins of compliance could still be maintained by applying lateral and vertical acceleration factors to the conveyance weight where the package weighs considerable more than the conveyance vehicle. Clearly, this could only apply to heavy RAM packages transported under Exclusive use, but from INS experience all heavy packages are transported under Exclusive use and can not accidentally encounter unforeseen transport modes.

**Summary**

When a RAM package weighs more than the conveyance the stresses induced in the tie down system during upward and lateral loadings can be limited by the weight and parameters of the conveyance vehicle.

The application of standards ie BS2573 to determine allowable stress limits, whilst good engineering practice, are not specifically recommended by either the IAEA or modal regulations (in the UK) which expect that members in the tie down structure do not exceed yield under the specified loading conditions.

In the specific case of restraining upward accelerations using bespoke frames for heavy RAM packages, it is unnecessarily penalising to assume only two members can act, in particular all four trunnion keep plates should be considered to act together.

**Recommendations**

1. The IAEA Advisory material could state that where a package weighs more than the road/rail vehicle on which it is transported, the weight of the vehicle **may** be taken into account when designing the intervening tie-down system. This would only apply to transports under Exclusive use and where it can be demonstrated stresses in the tie down loading system are limited by the conveyance weight.

2. To ensure safety with this proposal, the IAEA Advisory material could state that in such cases a recognised standard for establishing allowable stress limit should be applied. This proposal would need to be agreed by the modal transport organisations but this should not present a problem as they generally allow stresses up to yield for the tie down structure.

**References**

Ref 1 – IAEA Safety Standards – Regulations for the Safe Transport of Radioactive Material - 2005 Edition Safety Requirements No TS-R-1

Ref 2 - Advisory Material for the Regulations for the Safe Transport of Radioactive Material – IAEA Safety Standards series TS-G-1.1 Rev 1

Ref 3 – Rules for the Design of Cranes – BS2573-1:1983

Ref 4 – The Transport of Radioactive Material – Code of Practice - The Securing/Retention of Radioactive Material packages on Conveyances – TCSC 1006