REVISS SERVICES
Manufacturing and Technical Group

Test Plan for the R7021 Transport Container

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1. PURPOSE AND SCOPE

The purpose of this document is to detail the test plan for the REVISS R7021 radioactive material transport package.

The purpose of the test plan is to demonstrate the compliance of the R7021 with both the IAEA impact test requirements of TS-R-1 and the US impact test requirements of 10CFR71 for Type B package designs.

This document includes a description of the R7021, regulatory requirements, failure mode analysis, pass/fail criteria, test sequence and procedures.

2. DESIGN DESCRIPTION

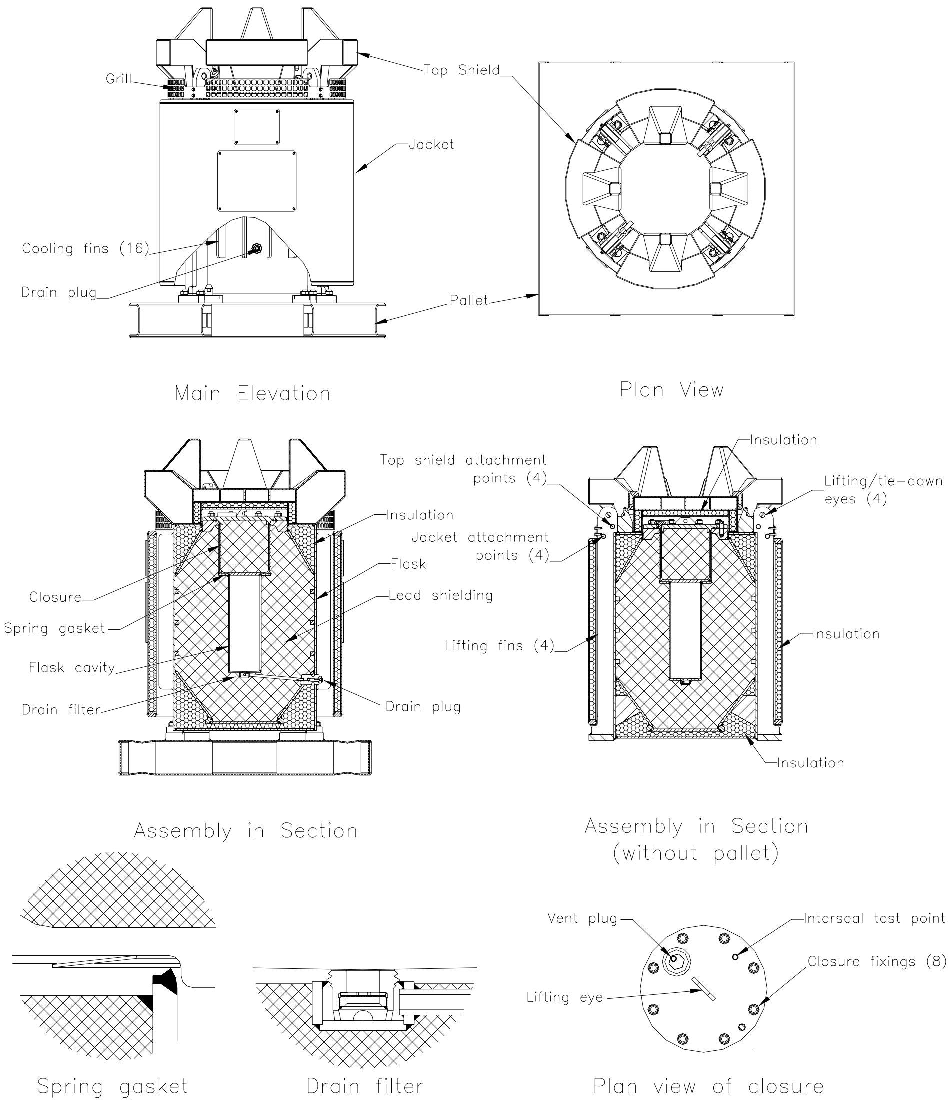


Figure 1: R7021 Constructional Details

The outer components of the R7021 are a cylindrical, insulated jacket, a top shield (with energy absorbing structures and insulation), and a pallet. These components are constructed predominantly from carbon steel and are fastened to a lead shielded, stainless steel flask. There is also a stainless steel grill around the top edge of the flask to restrict access to hot surfaces. The flask is an upright cylinder with a conventional plug type closure in the top. The closure has a vent point and the cavity has a drain tube to allow the flask to be operated in ponds as well as in cells. The cylindrical cavity accommodates encapsulated radioactive material (solid cobalt metal) in a basket. The flask has a containment system as it is also intended to carry such material as non-Special Form. The closure and the vent and drain plugs are therefore equipped with testable O-ring seals. In addition, to prevent the migration of coarse solids outside the shielded volume, the top of the drain tube is fitted with a fine meshed filter and a spring gasket is used to seal the gap under the closure around the top of the cavity. The flask has additional thermal insulation at the top and bottom corners. The maximum radioactive content is approximately 140kCi (5.1 PBq) of ^{60}Co giving a heat output of about 2.1 kW.

3. REGULATORY TEST REQUIREMENTS

3.1 Normal Conditions Tests

3.1.1 Water spray test (UK – para 721, US – part 71.71 (6)): Both regulations specify a water spray test before each test for normal conditions of transport. This may be ignored as none of the constructional materials suffer degradation from water.

3.1.2 Free drop test (UK – para 722 (a), US – part 71.71 (7)): Both regulations specify a drop from 1.2m for packages weighing less than 5,000kg. In this case the maximum gross weight of the package is 4,500kg.

3.1.3 Stacking test (UK – para 723, US – part 71.71 (9): Both regulations state that the specimen shall be subjected, for a period of 24 hours, to a compressive load equal to the greater of the following:

a) 5 times the weight of the package or:
b) 13kPa multiplied by the vertically projected area of the package.

This requirement shall be verified through calculation.

3.1.4 Penetration test (UK – para 724, US – part 71.71 (10)): The bar shall be dropped from a height of 1m and must be aimed at the containment system (UK) or perpendicular to the most vulnerable surface (US). The package is sufficiently robust that neither is likely to cause more than superficial marking.

3.2 Normal Conditions Requirements

Following normal conditions of transport testing the package shall:

- Prevent loss of shielding integrity that would result in:
  - more than a 20% increase in the radiation level at any external surface (UK – para 646(b)).
  - a significant increase in external surface radiation levels (US – part 71.51 (a) (1)).
- Restrict the loss of radioactive contents to not more than $10^{-6}A_2$ per hr (UK – para 646(a), US – part 71.51 (a) (1)).

3.3 Accident Conditions Tests

3.3.1 Drop I - Free drop test (UK – para 727 (a), US – part 71.73 (c) (1)): Both regulations specify dropping the package from 9m so as to suffer the maximum damage.

3.3.2 Drop II - Puncture test (UK – para 727 (b), US – part 71.73 (c) (3)): Both regulations specify dropping the package from 1m on to the upper end of a solid, vertical, cylindrical (15cm diameter), mild steel bar of sufficient length to cause the maximum damage.

3.3.3 Drop III - Crush test (UK – para 727 (c), US – part 71.73 (c) (2)): Both regulations specify a crush test only for packages weighing less than 500kg, therefore this test will not be performed.

3.4 Accident Conditions Requirements

Following accident conditions of transport testing the package shall (UK – para 656(b), US – part 71.51 (a) (2)):

- Retain sufficient shielding to ensure that the radiation level at 1m from the surface of the package would not exceed 10mSv/h with the maximum radioactive contents that the package is designed to contain; and
- Restrict the accumulated loss of radioactive contents in a period of one week to not more than A_2.

3.5 Regulatory Test Criteria

- The IAEA advisory material (TS-G-1.1 (ST-2) para. 656.12) suggests either developing appropriate criteria based on empirical data or using a helium leaktightness criteria of 10^{-6} Pa.m^3/s (10^{-5} atm.cc/s) for powdered solids. The UK Competent Authority accepts a helium leak-test criteria for finely powdered solids of 5 x 10^{-4} atm.cc/s based on empirical data. The US Competent Authority accepts a leaktightness criteria of 10^{-7} atm.cc/s based on dry air at 25ºC (ANSI N14.5). This converts to a value of 2.6 x 10^{-7} atm.cc/s for helium. The worst case will be considered, which is therefore a helium leak-rate of 2.6 x 10^{-7} atm.cc/s. This level of leaktightness is most readily measured using a helium mass spectrometer however, as silicon rubber seals allow helium to permeate at a rate which would represent a fail, it will be necessary to use fluorocarbon seals for the test programme in order to best demonstrate the leaktightness of the flask.
- The UK regulations require that the free drop and puncture tests be conducted in the most damaging order for the following thermal (fire) test. The US regulations specify a free drop followed by a puncture. Since the most damaging order is not always apparent, each free drop test will have a puncture test performed before and after it.
- The UK regulations make no stipulation as to the temperature of the test specimen. The US regulations require the most adverse ambient conditions between -29ºC and +38ºC to be used throughout any normal or accident conditions test sequence. The carbon and stainless steels are not susceptible to embrittlement nor are the O-ring seals to excessive shrinkage at -40°C. The flask is heated by its contents however, which will affect the strength of certain key structural and containment components and the pressure within the containment system. The test specimen will take account of these effects (see 5.3) and therefore the tests may be conducted at ambient temperature.

4. FAILURE MODES

4.1 Discussion

Containment:

Special Form material: The containment afforded by such material will not be lost or reduced by normal or accident conditions of transport. This may be verified by comparing IAEA Special Form drop test requirements against the environment inside the package under accident conditions of transport testing for Type B packages (normal conditions may be ignored as they are less demanding).

Test	Type B Package	Special Form Material
Drop I	9m drop onto an unyielding surface, any orientation.	9m drop onto an unyielding surface, any orientation.
Assessment	Although the requirements are essentially the same the contents benefit from any and all shock absorption afforded by the package. The R7021 jacket, top shield and pallet are deformable structures with external shock absorption components providing protection for the flask. Whilst it is difficult to accurately quantify the consequent reduction in impact forces it is evident that the unprotected impact demanded of Special Form material is far more demanding.	
Drop II	1m drop onto 15 cm diameter punch, any orientation.	25mm diameter, 1.4 kg bar dropped 1m, any orientation.
Assessment	As long as the punch does not penetrate to the flask cavity the contents are fully protected and the impact demanded of Special Form material is far more demanding.	

Non-Special Form material: Such material must contained be in welded, metallic, leaktight encapsulations which may be assumed to withstand the minor accelerations and vibrations associated with normal transport. However, although the package affords a significant degree of insulation from external mechanical events, it may not be assumed the encapsulation would survive accident conditions of transport without leakage or rupture. It is therefore necessary to demonstrate the containment system (the seals and containment boundary) remain leaktight:

- Each seal is provided with a secondary seal and an interseal test point in order its leaktightness may be directly measured. In order to avoid disturbing any of the seals when the cavity is filled with helium the closure must be provided with an additional penetration to the cavity space.
- Closure seal compression is maintained by the closure fixings. Pre- and post- drop test length measurements may be used to confirm the robustness of these fixings by verifying the lack of permanent strain.
- Plug seal compression is maintained by the plugs being torqued down. The security and condition of the vent and drain plugs may be readily verified by visual inspection.
- The containment boundary may be leak-tested by pressurising the shielding space with helium via a tapped hole in the outer wall and measuring the leak-rate into the cavity.
- The jacket and top shield prevent the seals overheating in the thermal test. Their condition and the security of their fixings may be readily verified by visual inspection.

Shielding:

Radiation levels could be affected by the following events:

(a) Loss or displacement of the flask closure (normal or accident conditions).

(b) Loss or compression of jacket, top shield or pallet leading to reduced measurement distance (normal conditions only).

(c) Loss or damage to jacket or top shield leading to lead melting (accident conditions

only).
(d) Displacement or damage to the drain filter leading to a small Special Form capsule migrating down the drain tube (normal or accident conditions).
(e) Displacement or damage to the drain filter or spring gasket leading to active material migrating down the drain tube or up around the closure (accident conditions only).

- The security of the closure fixings may be readily verified by visual inspection.
- The condition of the jacket, pallet or top shield and the security of their fixings may be readily verified by visual inspection.
- The condition and security of the drain filter and spring gasket may be readily verified by visual inspection.

4.2 Failure Mode Analysis

Tables 1 & 2 detail the various test scenarios that could lead to failure in normal and accident conditions of transport.

Table 1: Failure Mode Analysis, Normal Conditions of Transport, Mechanical Testing.				
Criteria	**Scenario**	**Cause**	**Remarks**	**Orientation**
1. Leakrate $>10^{-6}A_2$/hr.	1.1 Loss or displacement of flask closure.	Failure or elongation of closure fixings.	The fixings could fail under tensile loads exerted by the momentum of the closure and contents. Tensile loads in the fixings are at a maximum when the package is dropped vertically inverted.	VERTICAL INVERTED
			The fixings could fail under shear loads exerted by the momentum of the closure. Shear loads are at a maximum when the package is dropped on its side. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the closure fixings.	HORIZONTAL SIDE (SLAP-DOWN)
	1.2 Loss or displacement of vent plug.	Damage to vent plug.	The vent plug could fail under tensile loading. The tensile load in the vent plug is at a maximum when the package is dropped vertically inverted.	VERTICAL INVERTED
	1.3 Loss or displacement of drain plug.	Damage to drain plug	The drain plug could fail under tensile loading. The tensile load in the drain plug is at a maximum when the package is dropped on its side.	HORIZONTAL SIDE (SLAP-DOWN)
		Penetration of jacket and damage to drain plug.	The drain plug could fail due to damage inflicted by the penetration bar.	HORIZONTAL SIDE
2. Radiation increase >20%.	2.1 Loss or displacement of flask closure.	Failure of closure fixings.	The fixings could fail under tensile loads exerted by the momentum of the closure and contents. Tensile loads are at a maximum when the package is dropped vertically inverted.	VERTICAL INVERTED
			The fixings could fail under shear loads exerted by the momentum of the closure. Shear loads are at a maximum when the package is dropped on its side. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the closure fixings.	HORIZONTAL SIDE (SLAP-DOWN)
	2.2 Loss of jacket.	Failure of jacket fixings.	The fixings could fail under shear loads exerted by the momentum of the jacket. Shear loads are at a maximum when the package is dropped vertically inverted.	VERTICAL INVERTED
	2.3 Loss of pallet.	Failure of pallet fixings.	The fixings could fail under shear loads exerted by the momentum of the flask. Shear loads are at a maximum when the package is dropped on its side. The pallet should be orientated so that the ends of the channels impact the ground so that the maximum shear stress is applied to the studs holding it to the flask.	HORIZONTAL SIDE (SLAP-DOWN)

Table 1: Failure Mode Analysis, Normal Conditions of Transport, Mechanical Testing.				
Criteria	**Scenario**	**Cause**	**Remarks**	**Orientation**
2. Radiation increase >20% (cont).	2.4 Loss of top shield.	Failure of top shield fixings.	The fixings could fail under shear loads exerted by the momentum of the flask. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the top shield fixings.	HORIZONTAL SIDE (SLAP-DOWN)
	2.5 Distance from contents to surface of jacket reduced.	Crushing of jacket.	The closest point to the contents on the surface of the jacket is halfway up the side. It is not possible to drop the package in such a way that this would be the first point of impact. However, loss of the top shield and/or pallet would leave the jacket exposed to deformation. A side drop is the best way to achieve this.	HORIZONTAL SIDE (SLAP-DOWN)
	2.6 Distance from contents to surface of pallet reduced.	Crushing of pallet.	The closest point to the contents on the surface of the pallet is in the centre of the base. An upright vertical drop would cause the greatest deformation in this region.	VERTICAL UPRIGHT
	2.7 Distance from contents to surface of top shield reduced.	Crushing of top shield.	The closest point to the contents on the surface of the top shield is in the centre of the top surface. The impact limiters mean that it is not possible to drop the package in such a way that this would be the first point of impact. However, sufficient deformation of the impact limiters would expose the surface to deformation. A vertically inverted drop is the best way to achieve this.	VERTICAL INVERTED
	2.8 Loss of drain filter.	Failure of fixing thread.	The filter is screwed into the base of the cavity. The only direction the thread can be loaded is vertically upwards. A vertical inverted drop generates the maximum deceleration.	VERTICAL INVERTED

Table 2: Failure Mode Analysis, Accident Conditions of Transport, Mechanical Testing				
Criteria	**Scenario**	**Cause**	**Remarks**	**Orientation**
1. Leakrate $>A_2$/wk .	1.1 Loss or displacement of flask closure.	Failure or elongation of closure fixings.	Drop I: The closure fixings can be loaded in tension by the momentum of the closure and contents. A flat end drop will tend to realise the maximum benefit from the top shield shock absorption and will also support the closure. Angling the package to CoG over a top edge (33º from the vertical) will reduce the shock absorption benefit, reduce support and concentrate flask momentum onto one corner of the closure. The top shield top edge engages the least volume of shock absorption and also generates combined tensile and shear loads on the flask fixings. This therefore will generate the maximum deformation in the top shield and the maximum tensile loads in the closure fixings.	ANGLED INVERTED OVER CORNER
			Drop I: The fixings could fail under shear loads exerted by the momentum of the closure. Shear loads are at a maximum when the package is dropped on its side. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the closure fixings.	HORIZONTAL SIDE (SLAP-DOWN)
			Drop II: Angling the package with the CoG over the top corner (33º from the vertical) will ensure maximum damage to the top shock absorber before it is subjected to the angled inverted Drop I test above.	ANGLED INVERTED OVER CORNER (PUNCH)
	1.2 Loss, displacement or damage to closure vent plug.	Crushing of top shield.	Drop I: The closure vent plug is on the top of the closure near the outer edge. The only way it could be damaged would be if the top of the top shield was crushed down onto it. A flat end drop will tend to realise the maximum benefit from the top shield shock absorption. Angling the package to CoG over a top edge (33º from the vertical) will reduce the shock absorption benefit and concentrate flask momentum onto one corner of the closure.	ANGLED INVERTED OVER CORNER
		Penetration of top shield	Drop II: The punch will most threaten the vent plug by being aimed at it through the top of the top shield with the COG directly over the point of impact (13º from the vertical).	ANGLED INVERTED OVER VENT PLUG (PUNCH)
	1.3 Loss, displacement or damage to drain plug.	Crushing of jacket.	Drop I: There are no features inside the jacket that could damage the plug so the only conceivable orientation in which the plug could be damaged in the Drop I test would be in a side drop (upright or inverted drops would have no impact on a side feature) in which, if the pallet and/or top shield were crushed or lost, the jacket could be crushed onto the plug.	HORIZONTAL SIDE (SLAP-DOWN)

Table 2: Failure Mode Analysis, Accident Conditions of Transport, Mechanical Testing				
Criteria	**Scenario**	**Cause**	**Remarks**	**Orientation**
1. Leakrate $>A_2$/wk (cont).	1.3 Loss, displacement or damage to drain plug.	Penetration of jacket.	Drop II: The drain plug could be damaged if the punch penetrated the side of the jacket. The punch will most threaten the drain plug by being aimed through the side of the jacket at an angle of 35º upwards from the horizontal.	ANGLED SIDE OVER DRAIN PLUG (PUNCH)
	1.4 Seal over-heating	Failure of jacket fixings resulting in loss of fire protection.	Drop I: The fixings could fail under shear loads exerted by the momentum of the jacket. Shear loads are at a maximum when the package is dropped vertically inverted.	VERTICAL INVERTED
		Penetration of jacket resulting in partial loss of fire protection.	Drop II: An angled punch will penetrate the outer surface of the jacket easier than a flat one. Paragraph 727.14 of TS-G-1.1 states that the most damaging angle of impact is between 20º and 30º to the vertical, however, dropping with the centre of gravity over the drain plug will result in the greatest risk to the seals (angled 35º upwards from horizontal).	ANGLED SIDE OVER DRAIN PLUG (PUNCH)
		Failure of pallet fixings resulting in loss of fire protection.	Drop I: The fixings could fail under shear loads exerted by the momentum of the flask. Shear loads are at a maximum when the package is dropped on its side. To achieve a single impact on the side of the package, it needs to be angled at 8º down from the horizontal. The pallet should be orientated so that the ends of the channels impact the ground so that the maximum shear stress is applied to the studs holding it to the flask.	HORIZONTAL SIDE (SLAP-DOWN)
		Penetration of pallet resulting in partial loss of fire protection.	Drop II: An angled punch will penetrate the outer surface of the pallet easier than a flat one. Paragraph 727.14 of TS-G-1.1 states that the most damaging angle of impact is between 20º and 30º to the vertical, so an angle of 25º shall be used.	ANGLED UPRIGHT (PUNCH)
		Failure of top shield fixings resulting in loss of fire protection.	Drop I: The fixings could fail under shear loads exerted by the momentum of the flask. Shear loads are at a maximum when the package is dropped on its side. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the top shield.	HORIZONTAL SIDE (SLAP-DOWN)
		Penetration of top shield resulting in partial loss of fire protection.	Drop II: An angled punch will penetrate the outer surface of the top shield easier than a flat one. Paragraph 727.14 of TS-G-1.1 states that the most damaging angle of impact is between 20º and 30º to the vertical, however, dropping with the centre of gravity over the vent plug will result in the greatest risk to the seals (angled 13º from the vertical).	ANGLED INVERTED OVER VENT PLUG (PUNCH)

Table 2: Failure Mode Analysis, Accident Conditions of Transport, Mechanical Testing				
Criteria	**Scenario**	**Cause**	**Remarks**	**Orientation**
2. Radiation >10mSv/h @1m.	2.1 Loss of flask closure.	Failure of closure fixings.	Drop I: The closure the fixings can be loaded in tension by the momentum of the closure and contents. A flat end drop will tend to realise the maximum benefit from the top shield shock absorption and also support the closure. Angling the package to CoG over a top edge (33º from the vertical) will reduce the shock absorption benefit, reduce support and concentrate flask momentum onto one corner of the closure. The top shield top edge engages the least volume of shock absorption and also generates combined tensile and shear loads on the flask fixings. This therefore will generate the maximum deformation in the top shield and the maximum tensile loads in the closure fixings.	ANGLED INVERTED OVER CORNER
			Drop I: The fixings could fail under shear loads exerted by the momentum of the closure. Shear loads are at a maximum when the package is dropped on its side. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the closure fixings.	HORIZONTAL SIDE (SLAP-DOWN)
			Drop II: Angling the package with the CoG over the top corner (33º from the vertical) will ensure maximum damage to the top shock absorber before it is subjected to the angled inverted Drop I test above.	ANGLED INVERTED OVER CORNER (PUNCH)
	2.2 Lead melting.	Failure of jacket fixings resulting in loss of fire protection.	Drop I: The fixings could fail under shear loads exerted by the momentum of the jacket. Shear loads are at a maximum when the package is dropped vertically inverted.	VERTICAL INVERTED
		Penetration of jacket resulting in partial loss of fire protection.	Drop II: An angled punch will penetrate the outer surface of the jacket easier than a flat one. Paragraph 727.14 of TS-G-1.1 states that the most damaging angle of impact is between 20º and 30º to the vertical, so an angle of 25º shall be used.	ANGLED SIDE (PUNCH)
		Failure of pallet fixings resulting in loss of fire protection.	Drop I: The fixings could fail under shear loads exerted by the momentum of the flask. Shear loads are at a maximum when the package is dropped on its side. The pallet should be orientated so that the ends of the channels impact the ground so that the maximum shear stress is applied to the studs holding it to the flask.	HORIZONTAL SIDE (SLAP-DOWN)

Table 2: Failure Mode Analysis, Accident Conditions of Transport, Mechanical Testing				
Criteria	**Scenario**	**Cause**	**Remarks**	**Orientation**
2. Radiation >10mSv/h @1m (cont).	2.2 Lead melting (cont).	Penetration of pallet resulting in partial loss of fire protection.	Drop II: An angled punch will penetrate the outer surface of the pallet easier than a flat one. Paragraph 727.14 of TS-G-1.1 states that the most damaging angle of impact is between 20º and 30º to the vertical, so an angle of 25º shall be used.	ANGLED UPRIGHT (PUNCH)
		Failure of top shield fixings resulting in loss of fire protection.	Drop I: The fixings could fail under shear loads exerted by the momentum of the flask. Shear loads are at a maximum when the package is dropped on its side. Dropping the flask horizontally results in the pallet taking the primary impact, but the resulting angular acceleration (through 8º) of the package will result in maximum shear loads in the top shield.	HORIZONTAL SIDE (SLAP-DOWN)
		Penetration of top shield resulting in partial loss of fire protection.	Drop II: An angled punch will penetrate the outer surface of the top shield easier than a flat one. Paragraph 727.14 of TS-G-1.1 states that the most damaging angle of impact is between 20º and 30º to the vertical, however, dropping with the centre of gravity over the vent plug will present a greater risk to the fire protection (angled 13º from the vertical).	ANGLED INVERTED OVER VENT PLUG (PUNCH)
		Damage to flask insulation resulting in partial loss of fire protection (cont).	Drop II: A punch angled at 44º from the horizontal could potentially cause damage to the insulation in the top corner of the flask. The jacket provides some protection from the impact.	ANGLED INVERTED OVER JACKET CORNER (PUNCH)
	2.3 Movement of shielding	Failure of bottom cone weld.	Drop I: An upright vertical drop would cause the greatest shear loads in the bottom cone weld due to the momentum of the shielding.	UPRIGHT VERTICAL
	2.4 Displacement or damage to drain filter.	Failure of fixing thread.	Drop I: The grill is screwed into the base of the cavity. The grill is protected from impact from the contents by the base of the basket. The only direction the thread can be loaded is vertically upwards. A vertical inverted drop generates the maximum deceleration.	VERTICAL INVERTED
	2.5 Displacement or damage to spring gasket.	Impact from contents.	Drop I: The gasket is held in position by the closure. It cannot be struck by the flask contents however it could be displaced by a sideways force. A slap-down side drop generates the maximum deceleration at this end of the flask.	HORIZONTAL SIDE (SLAP-DOWN)

4.3 Pass/Fail Criteria

4.3.1 Purpose

The pass/fail criteria identified below are intended to determine whether the assembly is fit to continue being tested, in addition to what is necessary to demonstrate regulatory compliance.

4.3.2 Normal Conditions of Transport

- Shielding:
  1. Top shield: Shall remain securely attached.
  2. Jacket: Shall remain securely attached.
  3. Pallet: Shall remain securely attached.
  4. Flask closure: Shall remain securely attached.
  5. Drain filter: Shall remain securely attached and undamaged.
- Containment:
  1. Closure: Shall remain securely attached to the flask.
  2. Vent plug: Shall remain securely attached and undamaged.
  3. Drain plug: Shall remain securely attached and undamaged.
  4. All O-ring seals: Shall each be leak-tight to 2.6×10^{-7} atm.cc/s[1].
  5. Containment boundary: Shall be leak-tight to 2.6×10^{-7} atm.cc/s.

4.3.3 Accident Conditions of Transport

- Thermal:
  1. Top shield: Shall remain securely attached to the flask.
  2. Jacket: Shall remain securely attached to the flask.
  3. Pallet: Shall remain securely attached to the flask.
- Shielding:
  1. Flask closure: Shall remain securely attached.
  2. Drain filter: Shall remain in position and undamaged.
  3. Spring gasket: Shall remain in position and undamaged.
  4. Maximum radiation level: Shall not have risen by more than 100%.
- Containment:
  1. Closure fixings: Shall not be permanently stretched, i.e. by more than 0.2%, which is 0.17mm (length 85mm).
  2. Vent plug: Shall remain securely attached and undamaged.
  3. Drain plug: Shall remain securely attached and undamaged.
  4. All seals: Shall each be leak-tight to 2.6×10^{-7} atm.cc/s.
  5. Containment boundary: Shall be leak-tight to 2.6×10^{-7} atm.cc/s.

5. TEST PLAN

Drop	Description	Procedure
-	Shielding test.	OP 214.
-	Leak test seals and containment boundary.	See Appendix.
-	Inspection, weighing and assembly.	To this plan.
1	1.2m drop: Vertical upright.	OP 225.
2	1.2m drop: Side horizontal (slap-down).	
3	1.0m penetration: Side horizontal (at drain plug).	
4	1.2m drop: Vertical inverted.	
-	Leak test seals.	See Appendix.

[1] All leaktesting is performed with dry helium, at ambient temperature and at 1 atm pressure differential.

-	Inspection and re-assembly.	To this plan.
-	Leak test seals.	See Appendix.
5	1m punch: Angled upright.	OP 225.
6	9m drop: Vertical upright.	
7	1m punch: Angled upright.	
8	1m punch: Angled inverted at vent plug.	
9	9m drop: Vertical inverted.	
10	1m punch: Angled inverted opposite vent plug.	
11	1m punch: Angled inverted.	
12	9m drop: Angled inverted.	
13	1m punch: Angled inverted at jacket.	
14	1m punch: Angled side onto jacket.	
15	9m drop: Side horizontal (slap-down).	
16	1m punch: Angled side (at drain plug).	
17	1m punch (unspecified).	
-	Leak test seals and containment boundary.	See Appendix.
-	Inspection.	To this plan.
-	Shielding test.	OP 214.

Table 3: Test and Inspection Sequence

5.1 Target and Punch

- The drop test target surface shall be unyielding and horizontal. The target shall be approximately cuboid with a total mass not less than 45,000kg (TS-G-1.1, para 717.2). The target shall be surfaced with a securely bedded carbon steel plate not less than 40mm thick (TS-G-1.1, para 717.2).
- The punch shall be rigidly mounted perpendicular to the target and of sufficient length that the specimen comes to rest without contacting the target or any other object (excepting the secondary impact in the event of it falling from the punch).

5.2 Assembly Torque Values

Item	Torque (N.m)
Flask-to-pallet fixings	150
Closure-to-flask fixings	150
Vent and drain plugs	20
Top shield and jacket fixings	80

5.3 Closure Fixings Temperature and Pressure Compensation

Temperature: The closure is retained by eight M20, Grade 80, stainless steel studs. Thermal analysis performed on the R7021 (FTT Report R5108) shows that the heat load from the radioactive contents causes a temperature of 126ºC in the closure fixings in normal conditions of transport. This is sufficient for the strength to be reduced. As the fixings and their mating parts are both austenitic stainless steel the reduction may be calculated from the material properties given in Table 2.3 (c), Design Strength Values, BS 5500, for the weaker of the two, i.e. the housings which are 304L. The table shows that the design strength of 304L is reduced from 143 to 111 N/mm^2, i.e. by 22.4%, at 150ºC. The yield strength of the studs (600 N/mm^2, BS EN ISO 3506-1) may therefore be assumed to be reduced similarly, i.e. to 466 N/mm^2.

Pressure: Thermal analysis performed on the R7021 (FTT Report R5108) shows that, due to the heat load from the contents, the mid-height cavity wall temperature in normal conditions of transport is 166ºC. A mean gas temperature of three times this, i.e. 500ºC is assumed.

Cavity pressure (abs) = $P_{cv} = \left(\dfrac{273 + T_g}{273 + T_a} \right) \times P_a$

where
T_g = mean gas temperature = 500ºC
P_a = atmospheric pressure at time of closing = 0.101 MPa
T_a = ambient temperature at time of closing = 20ºC
thus

$$P_{cv} = \left(\frac{273 + 500}{273 + 20} \right) \times 0.101 = 0.266\,\text{MPa}$$

Subtracting minimum atmospheric pressure, 60kPa (TS-R-1 para. 643) gives the maximum pressure differential:

$$P_{cv}(gauge) = 0.206\,\text{MPa}$$

Stress in the closure fixings = $S_f = \dfrac{D^2 P_{cv}}{Nd^2}$

where
D = O-ring internal diameter = 279 mm
N = number of fixings = 8
d = fixings effective tensile diameter = 17.7 mm (M20, BS 3643)
thus

$$S_f = \frac{279^2 \times 0.206}{8 \times 17.7^2} = 6.40\,\text{N/mm}^2$$

Therefore the percentage reduction in strength = $\dfrac{6.40}{466} \times 100 = 1.4\%$

This shows that the strength of the closure fixings in normal conditions of transport, assuming the containment system is closed at room temperature, is effectively reduced by a maximum of 1.3% (taking into account internal pressure and reduced external pressure and assuming the mean gas temperature does not exceed 500ºC).

Conclusion: The total reduction in strength caused by elevated temperature and pressure differentials is 22.4 + 1.4 = 23.8%. Grade 70 stainless steel has a yield strength of 450 N/mm^2. Use of this material for the studs will reduce closure retention by 25% which is sufficient to compensate for the effects above.

5.4 Jacket and Top Shield Fixings Temperature Compensation

Temperature: The jacket and top shield are each retained by four Grade 10.9, carbon steel shoulder bolts. Thermal analysis performed on the R7021 (FTT Report R5108) shows that the heat load from the radioactive contents causes a maximum temperature of 93ºC in the jacket and top shield fixings in normal conditions of transport. This is sufficient to reduce their strength. The reduction may be calculated from the material properties given in Table 3.8.1.4, Design Strength Values, BS 5500. The table shows that the design strength of the nearest grade, 8.8, is reduced from 192 to 174 N/mm^2, i.e. by 9.4%, at 100ºC.

Conclusion: Grade 10.9 fixings have a yield strength of 900 N/mm^2 (BS 3692). Grade 8.8 has a yield of 640 N/mm^2. Use of this material for the bolts will reduce jacket/top shield retention by 29% which is sufficient to compensate for the effect of elevated temperature.

5.5 Contents Modelling

It is not possible to use radioactive contents in the test programme so the test contents need to be representative of the mass and form of the typical design contents (up to 15kg of R2089 capsules (Ø11.1 x 451 mm)). The contents therefore shall be stainless steel rods of the same dimensions in a typical basket. The R8062 basket holds up to 48 capsules and weighs 2.3 kg. Filling this with the rods would give a total mass of 19.1 kg, which would provide a 27% margin over the design capacity.

5.6 Weight Compensation

The maximum design weight of the package is 4,500kg, therefore the calculated design weight is slightly less. For the drop tests to represent the worst case the specimen needs to be dropped at its maximum design weight, or it must subjected to the same equivalent impact energy. To this end, the specimen (with contents) shall be weighed before testing and a factor (the ratio of the maximum to measured values) shall be applied to all drop test heights to account for the weight deviation.

5.7 Inspection and assembly prior to normal conditions testing

- All components shall be visually inspected and any defects or non-conformances recorded.
- The following deviations shall be applied:
  - The closure fixings shall be Grade 70 (to compensate for temperature).
  - The top shield and jacket fixings shall be Grade 8.8 (to compensate for temperature).
  - The contents shall be 48 solid stainless steel bars in an R8062 basket.
  - The O-ring seals shall be fluorocarbon.
  - The closure shall have an additional penetration into the cavity space to allow helium filling.
  - The flask wall shall have a penetration into the shielding space to allow leak testing of the containment boundary.
- The length of the closure studs shall be measured (for post-test comparison).
- The flask shielding shall be surveyed (for post-test comparison).
- The specimen shall be assembled in accordance with this plan.
- The containment boundary and seals shall be leak-tested (see Appendix).
- The assembly shall be weighed.

5.8 Drop Test Tolerances

Height : +20/-0mm.
Position: +5/-5mm.
Angle : ±2° (to ensure no more than 0.06% (1-cos2°) of the impact energy is diverted into a rotational force).

5.9 Replacement of Components

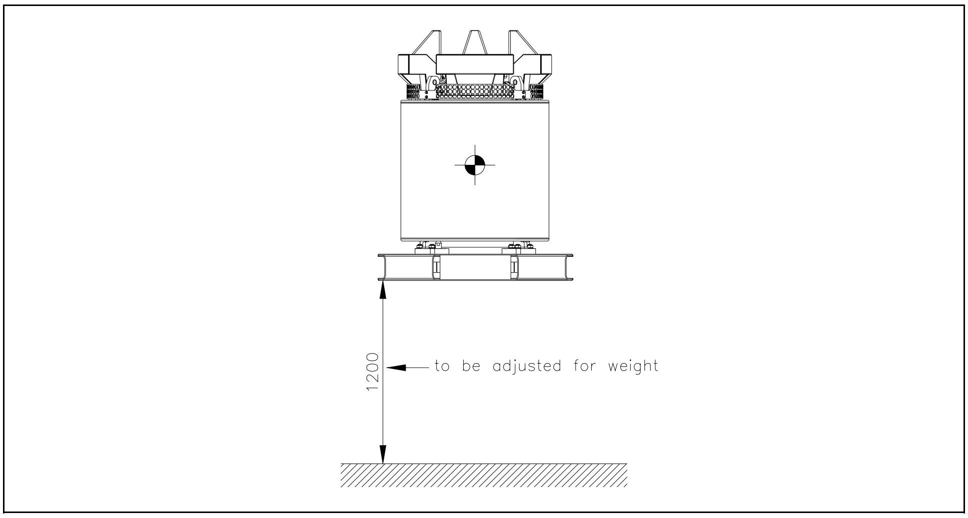
Components may be replaced during the test programme if the Design Authority considers that accumulated damage could invalidate subsequent tests.

5.10 Test Temperature

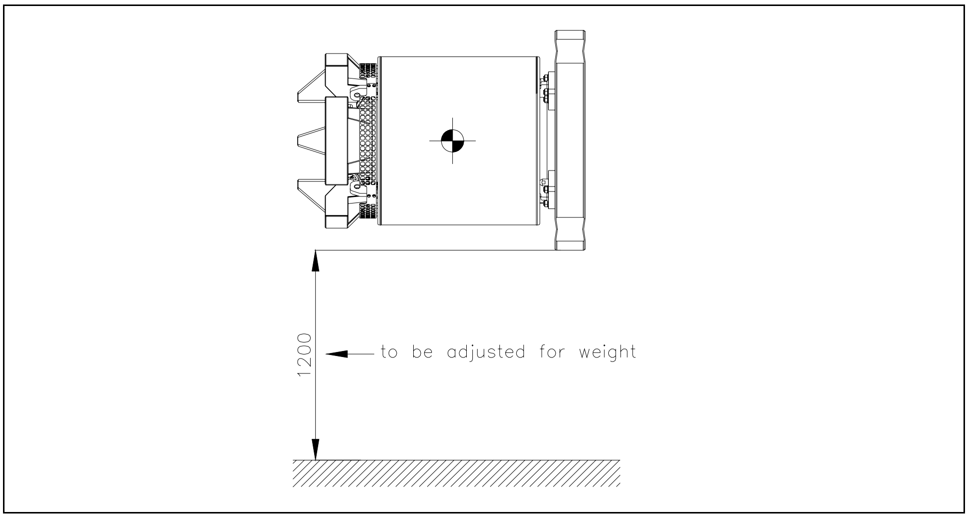
All tests will be performed at ambient temperature.

5.11 Normal Conditions Drop Testing

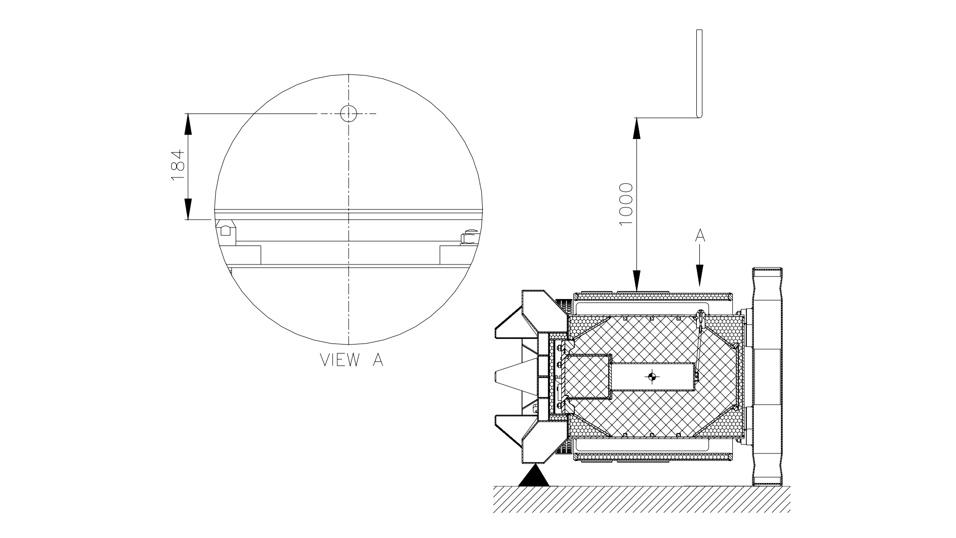
5.11.1 Drop 1 (1.2m: Vertical upright)



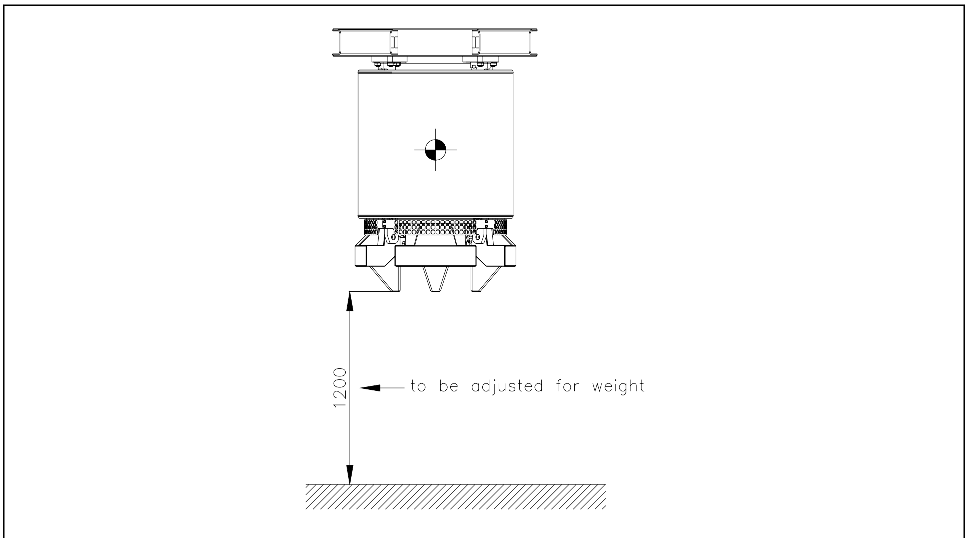
5.11.2 Drop 2 (1.2m: Horizontal)



5.11.3 Drop 3 (1.0m penetration: Onto jacket)



5.11.4 Drop 4 (1.2m: Vertical inverted)

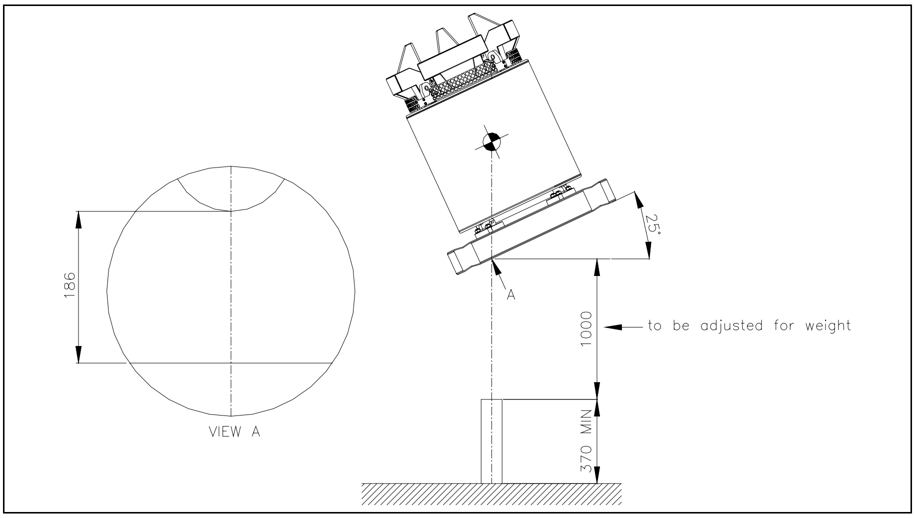


5.12 Inspection

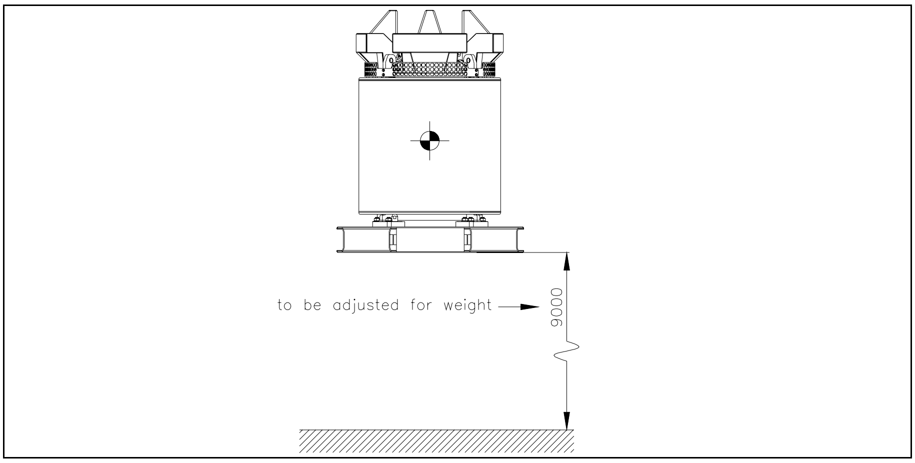
- The specimen shall be visually inspected and all damage recorded.
- Pass/fail Criteria:
  - Shielding:
  1. The top shield shall be securely attached to the flask.
  2. The jacket shall be securely attached to the flask.
  3. The pallet shall be securely attached to the flask.
  4. The closure shall be securely attached to the flask.
  5. The drain filter shall be securely attached and undamaged.
  - Containment:
  1. The closure shall be securely attached to the flask.
  2. The vent plug shall be securely attached to the closure.
  3. The drain plug shall be securely attached to the flask.
  4. The flask seals shall each be helium leak-tight to 2.6×10^{-7} atm.cc/s or better.

5.13 Accident Conditions Drop Testing

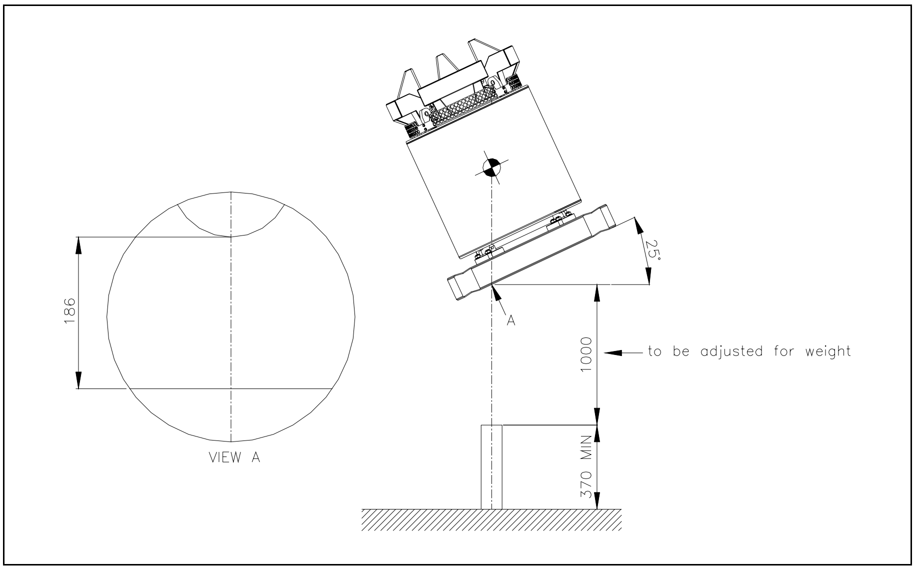
5.13.1 Drop 5 (1.0m punch: Onto pallet)



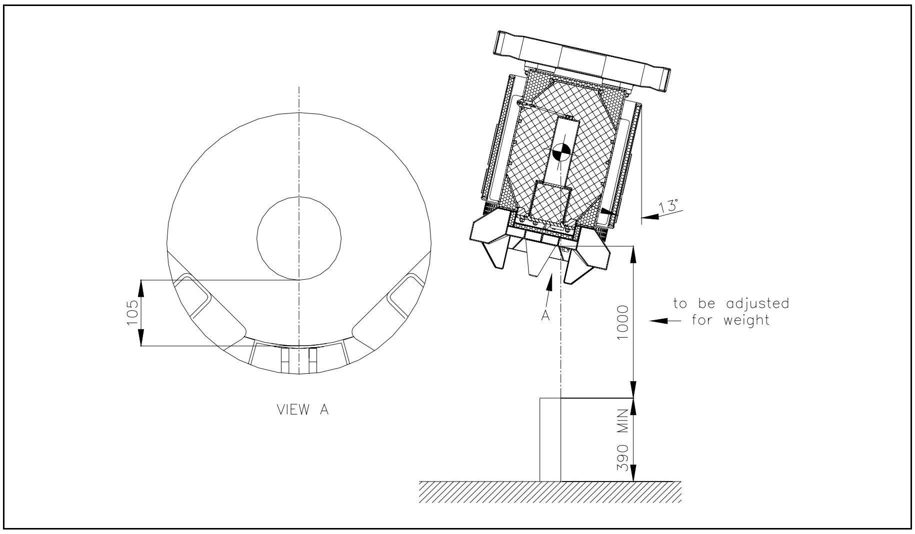
5.13.2 Drop 6 (9.0m: Vertical upright)



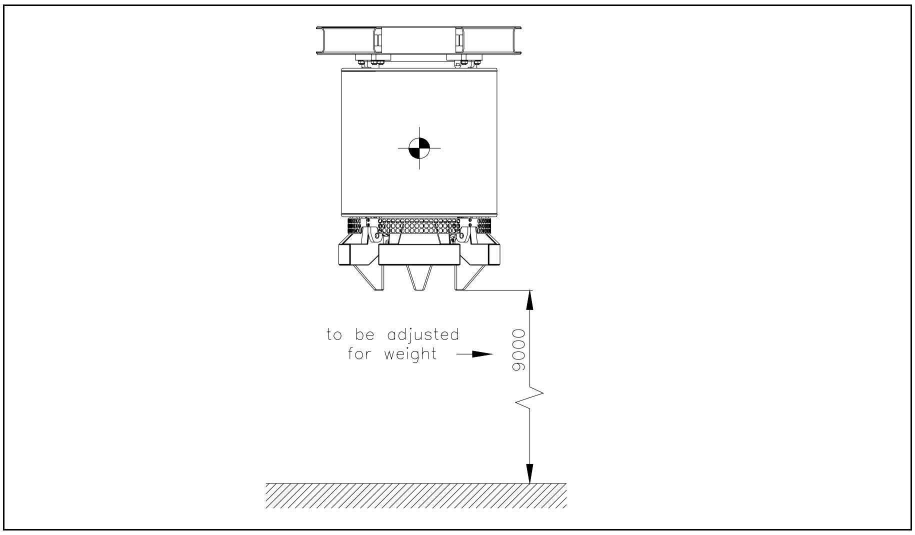
5.13.3 Drop 7 (1.0m punch: Onto pallet opposite Drop 5 position)



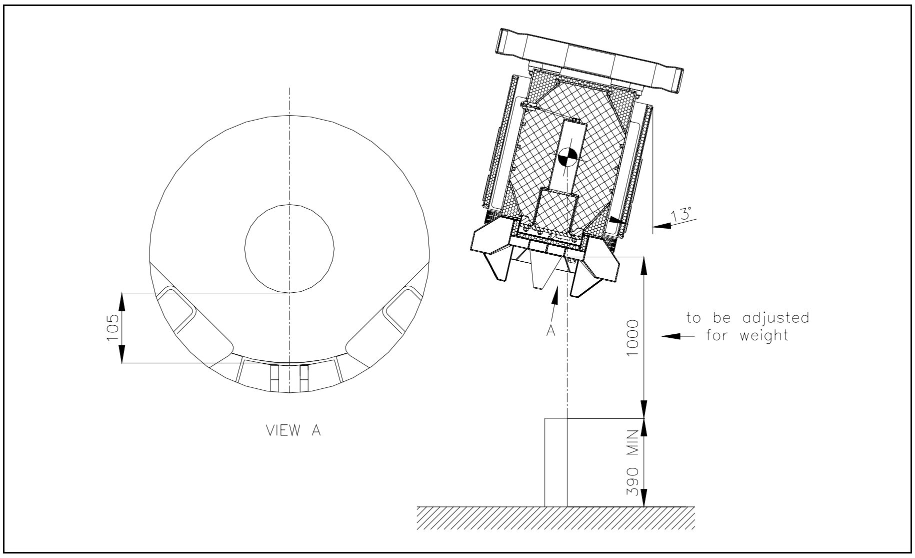
5.13.4 Drop 8 (1.0m punch: Onto top shield over vent plug)



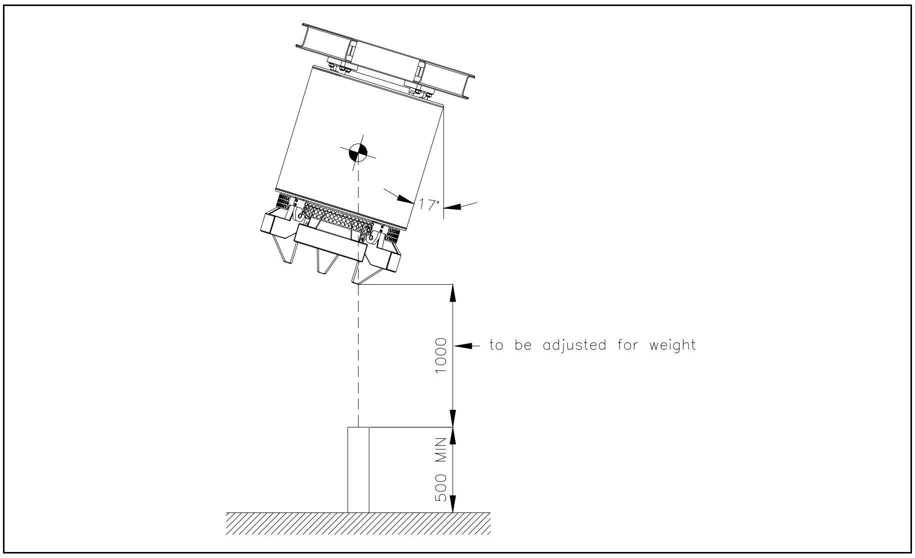
5.13.5 Drop 9 (9.0m: Vertical inverted)



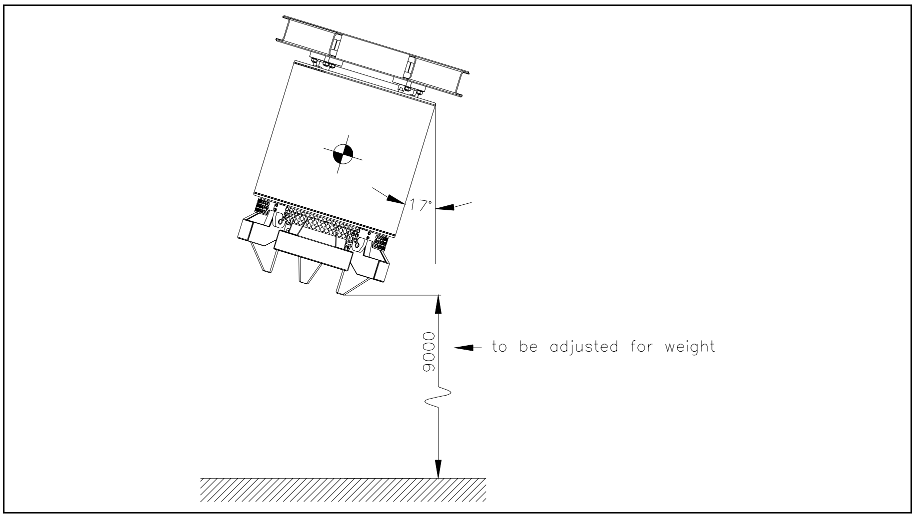
5.13.6 Drop 10 (1.0m punch: Onto top shield opposite vent plug)



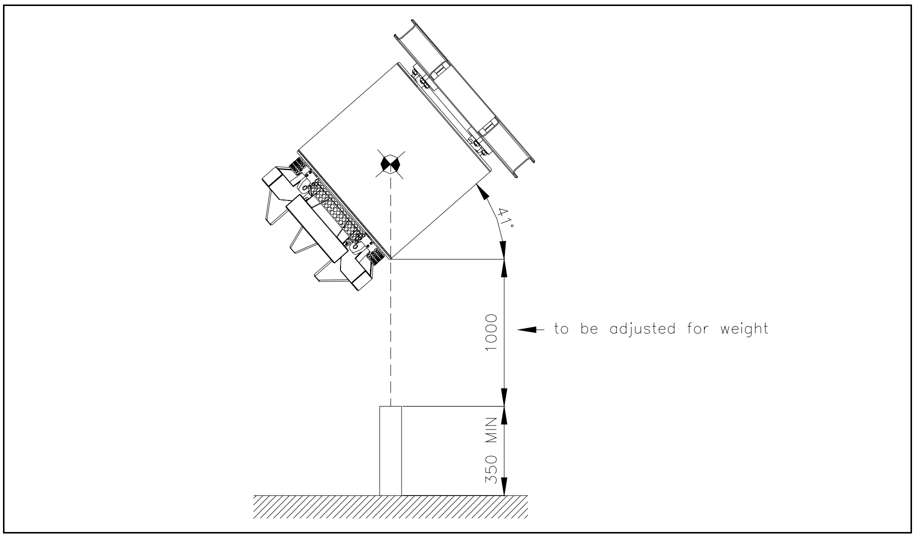
5.13.7 Drop 11 (1.0m: Angled inverted)



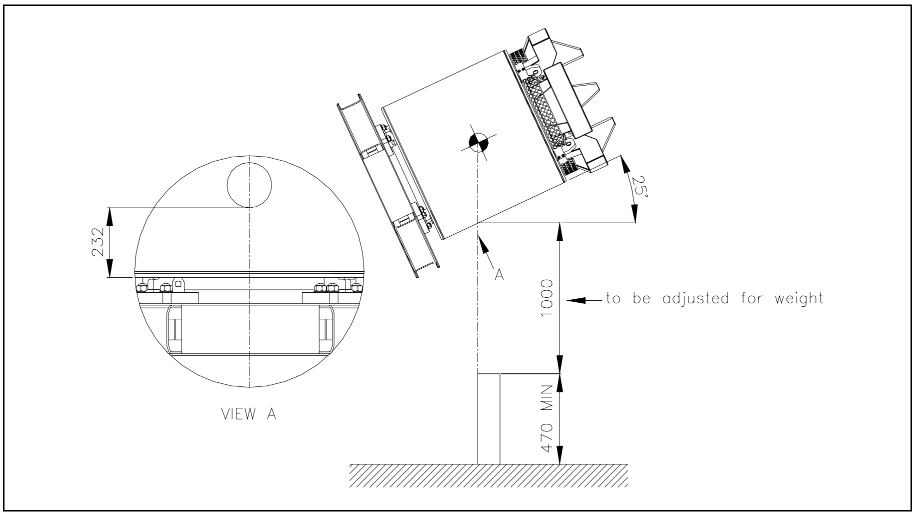
5.13.8 Drop 12 (9.0m: Angled inverted)



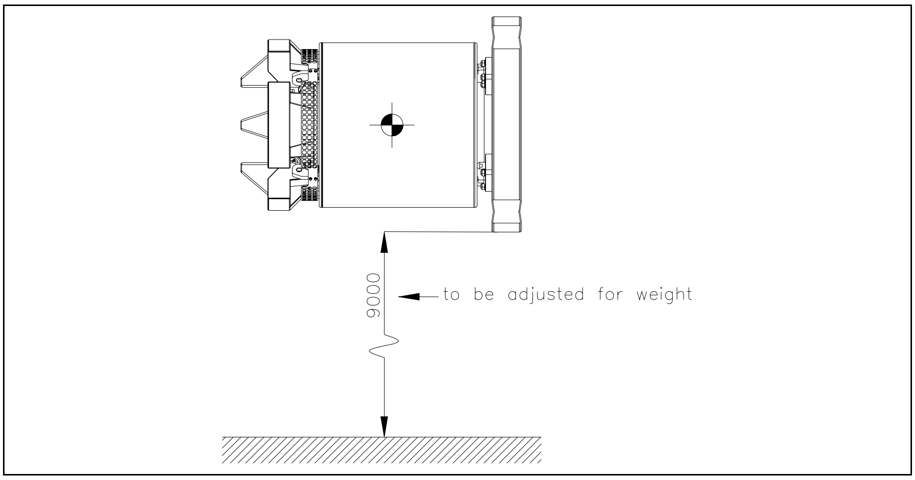
5.13.9 Drop 13 (1.0m punch: Angled inverted onto jacket corner)



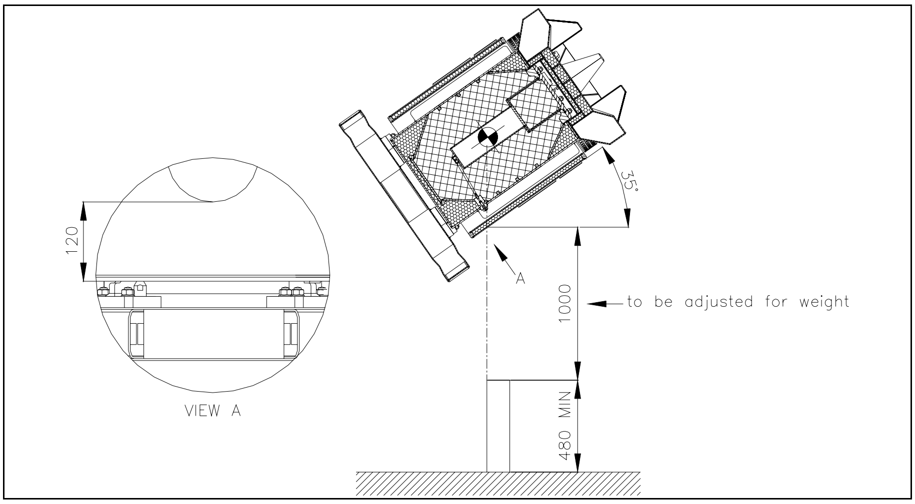
5.13.10 Drop 14 (1.0m punch: Onto jacket opposite drain plug)



5.13.11 Drop 15 (9.0m: Horizontal)



5.13.12 Drop 16 (1.0m punch: Onto jacket over drain plug)



5.13.13 Drop 17 (1.0m punch)

If considered necessary by the Design Authority in order to demonstrate the performance of the specimen in an orientation not previously tested.

5.14 Post-Test Inspection and Testing

- All components shall be visually inspected and all damage recorded.
- Pass/fail Criteria:
  - Thermal:
  1. The top shield shall be securely attached to the flask.
  2. The jacket shall be securely attached to the flask.
  3. The pallet shall be securely attached to the flask.
  - Shielding:
  1. The closure shall be securely attached to the flask.
  2. The drain filter and spring gasket shall remain in position and undamaged.
  3. The maximum flask surface radiation level shall not have increased by more than 100%.
  - Containment:
  1. The closure shall be securely attached to the flask.
  2. The vent plug shall be securely attached to the closure.
  3. The drain plug shall be securely attached to the flask.
  4. The containment boundary and flask seals shall each be helium leak-tight to 2.6×10^{-7} atm.cc/s or better.
  5. The closure studs shall not be stretched by more than 0.17mm.

6. QUALITY ASSURANCE, TEST DATA AND REPORTING

Equipment, data collection and reporting shall be as required by the test procedure.

7. VARIATIONS

- Equivalent procedures may only be used with the consent of the Design Authority.
- The test plan may only be modified with the consent of the Design Authority.

8. REFERENCES

- TS-R-1: IAEA Safety Standards Series, Regulations for the Safe Transport of Radioactive Material, 1996 Edition (As Amended 2003), IAEA, Vienna.
- TS-G-1.1 (ST-2): Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, IAEA, Vienna.
- Code of Federal Regulations (01-01-06 Edition), Title 10, Chapter 1, Subpart F.
- ANSI N14.5-1977: American National Standard for leakage tests on packages for shipment of radioactive materials.
- BS 3643-1, 2007: ISO metric screw threads. Principles and basic data.
- BS 3692, 2001: ISO metric precision hexagon bolts, screws and nuts. Specification.
- BS 5500, 1994: Unfired fusion welded pressure vessels.
- BS EN ISO 3506-1, 1998: Mechanical properties of corrosion-resistant stainless-steel fasteners. Bolts, screws and studs.
- OP 214: Shielding test procedure, REVISS Services (UK) Ltd.
- OP 225: Drop test procedure, REVISS Services (UK) Ltd.
- QS 7021: R7021 Drgs list and associated drgs, REVISS Services (UK) Ltd.
- FTT Report R5108: Thermal Analysis of the R7021 Radioactive Materials Transport Container.

9. Appendix – Leak-testing Procedure

This may be applied in full or in part at any time during the test programme.

1. Equipment:
    a. Vacuum pump and gauge (capability 1mbar (abs) or better).
    b. Mass spectrometer.
    c. Dry, oil free helium supply regulated to 1.0-1.1 bar (abs).
    d. 1/8” BSPP adaptor.
    e. Sundry vacuum valves, pipework, connectors and fittings.

2. Test containment boundary (cavity wall and drain tube):
    a. Assemble flask and closure with vent and drain plugs.
    b. Connect vacuum pump to tapped hole in flask wall and reduce pressure in shielding space to 1 mbar (abs) or less.
    c. Connect helium mass spectrometer to cavity test point on closure.
    d. Run spectrometer pump until base reading is less than 2.6×10^{-7} atm.cc/s.
    e. Backfill shielding space with helium to atmospheric pressure.
    f. Take spectrometer reading after one minute or when reading has settled (pass rate 2.6×10^{-7} atm.cc/s).

3. Test O-ring seals (closure, vent plug and drain plug).
    a. Connect vacuum pump to cavity test point and reduce cavity pressure to 1 mbar (abs) or less.
    b. Backfill with helium to atmospheric pressure.
    c. Attach spectrometer to closure interseal test point.
    d. Test seal (pass rate 2.6×10^{-7} atm.cc/s).
    e. Repeat c. & d. for vent and drain plugs in turn.

4. Purge cavity (if necessary):
    a. Connect vacuum pump to closure test point and reduce pressure to 1 mbar (abs) or less.
    b. Open to atmosphere so cavity refills with air.
    c. Repeat a. & b. twice more before refitting plug.