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Nuclear energy — Fuel technology — Trunnion systems for packages used to transport radioactive material

Énergie nucléaire — Technologie du combustible — Systèmes de tourillons pour colis de transport de matières radioactives

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 5, *Nuclear installations, processes and technologies*..

This second edition cancels and replaces the first edition (ISO 10276:2010), which has been technically revised. The main changes compared to the previous edition are as follows:

— The scope is extended to trunnion attachment components (trunnion systems are defined as being the trunnions and their attachment components);

— The normative references have been updated (IAEA TS-R-1 replaced by IAEA SSR-6) and enlarged to the IAEA SSG-26 (Appendix IV-1 - Package stowage and retention during transport);

— Quality Assurance is replaced by Management Systems;

— The load cases are to be defined by use of the minimum acceleration factors given in table IV-1 of the Appendix IV of IAEA SSG-26;

— The calculation methods (analytical and finite element analysis) and the minimum associated criteria are more precisely detailed;

— The bibliography has been updated and enlarged to the most recent recommendations, guidance and standards as acceptable by most of the Competent Authorities;

— The structure of the document has been slightly modified to enhance its legibility and understanding.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document has been produced to enable package owners, designers, users and regulatory organizations to have at their disposal a comprehensive document covering all aspects of trunnion systems. Experience has been drawn from the extensive knowledge of owners, designers, users and competent authorities. This document contains the minimum requirements and makes recommendations covering various aspects of trunnion systems.

Intermediate devices (sometimes referred to as transport frames, supports or cradles) can be used between the packaging trunnions and the transport conveyance to support and secure the package during transport; however, the energy-absorbing effects that may be provided by these intermediate devices are not taken into consideration in this document.

Nuclear energy — Fuel technology — Trunnion systems for packages used to transport radioactive material

1 Scope

This document covers trunnion systems used for tie-down, tilting and/or lifting of a package of radioactive material during transport operations.

Aspects included are the design, manufacture, maintenance, inspection and management system. Regulations which can apply during handling operation in nuclear facilities are not addressed in document.

This document does not supersede any of the requirements of international or national regulations, concerning trunnions used for lifting and tie-down.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IAEA SSR-6, *International Atomic Energy Agency (IAEA) Safety Standard No. SSR-6, Regulations for the Safe Transport of Radioactive Material*

IAEA SSG-26, *International Atomic Energy Agency (IAEA) No. SSG-26, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material*

3 Terms, abbreviated terms, symbols and definitions

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IAEA SSR-6 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
bending stress
variable component of *normal stress* (3.1.10), which might not be linear across the thickness

3.1.2
bolts
fasteners including bolts, screws and studs

3.1.3
designer
organization responsible for the design of the package

3.1.4
independent expert organization
organization administratively and managerially separate from the designers, manufacturers or owners of the subject package, constituted of specialized experts, or an insurance organization used to verify, oversee, witness or check

3.1.5
linearized stress
sum of the *membrane stress* (3.1.9) and of the linear component of the *bending stress* (3.1.1)

3.1.6
load case
specific configuration of transport or lifting associated to a total mass (transport or lifting), specified value and direction of acceleration, a given number of acting trunnions, and a given point/area of application of the load on the trunnion

3.1.7
maintenance schedule
document drawn up by the designer that gives, in appropriate detail, the applicable frequency/periodicity of maintenance items and details of methods to be employed; applied by the owner/operator

3.1.8
maximum service load
greater of *total mass (lifting)* (3.1.19) and *total mass (transport)* (3.1.20), subjected to gravity (1 g)

3.1.9
membrane stress
component of *normal stress* (3.1.10) that is uniformly distributed and equal to the average stress across the thickness of the section under consideration

3.1.10
normal stress
component of stress normal to the plane of reference

3.1.11
owner
operator
organization responsible for maintaining the condition of the packaging for transport

Note 1 to entry: The condition of packaging shall be in accordance with IAEA SSR-6.

3.1.12
peak stress
maximum stress that occurs in a component by reason of geometry, local discontinuities or local thermal stress, including the effects, if any, of stress concentration

3.1.13
periodic inspection
inspection of the trunnion system during the in-service life of the packaging at predetermined periodicities defined in the *maintenance schedules* (3.1.7)

3.1.14
primary trunnion system
trunnion system provided as a primary means for lifting and/or tilting, tie-down and supporting of the package

3.1.15
quality plan
document, or several documents, that together specify quality standards, practices, resources, specifications, and the sequence of activities relevant for manufacture

3.1.16
removable trunnion
trunnion, on a package secured by non-permanent methods, e.g. bolting

3.1.17
secondary trunnion system
trunnion system provided as an additional or alternative means for lifting and/or tilting, tie-down and supporting of the package

3.1.18
tie-down
securing of the package to the conveyance

3.1.19
total mass (lifting)
maximum mass of a package as supported by the trunnion systems during lifting, fitted with all necessary ancillaries and equipment, and including the radioactive material and water as appropriate

3.1.20
total mass (transport)
maximum mass of a package fitted with all ancillaries (shock absorbers, neutron shields, covers, transport frame as appropriate, etc.), as presented for transport and as supported by the trunnion systems

3.1.21
transport cycle
complete round-trip journey of a package between two complete loadings

3.1.22
trunnion
projection, typically cylindrical in shape, attached on a packaging by various means and used for lifting, tilting and/or *tie-down* (3.1.18) of the package; parts permanently attached to the trunnion are considered as being part of the trunnion

Note 1 to entry: A trunnion is an example of an attachment point as defined in IAEA SSG-26, Appendix IV.

3.1.23
trunnion attachment method
method of attaching the trunnion (e.g. welding, bolting, threaded attachment, interference fitting and bolting, or any combination of these methods) to the packaging body

3.1.24
trunnion attachment components
attachment components, e.g. welding to the packaging body, bolts, removable shear discs, female threads or housing in the packaging body, removable baseplates, etc., used to secure the trunnion to the packaging body

3.1.25
trunnion system
assembly of *trunnion* (3.1.22) and *trunnion attachment components* (3.1.24)

3.1.26
welded trunnion
trunnion directly secured to the packaging by welding

3.2 Symbols

K_{Ic} plane strain fracture toughness

$R_e(T)$ guaranteed yield strength or guaranteed 0,2 % proof strength at the operating temperature, T

$R_m(T)$ guaranteed minimum tensile strength at the operating temperature, T

T operating temperature

3.3 Abbreviations

FEA Finite Element Analysis

MT Magnetic particle test

NDE Non-destructive examination

PT Liquid penetrant test

SCC Stress corrosion cracking

UT Ultrasonic test

VT Visual inspection test

4 Regulatory requirements

4.1 General

In this document, the word “shall” denotes a requirement; the word “should” denotes a recommendation; and the word “may” denotes permission, i.e. neither a requirement nor a recommendation. Imperative statements also denote requirements. To conform to this document, all operations shall be performed in accordance with its requirements, but not necessarily with its recommendations.

The word “can” denotes possibility rather than permission.

4.2 Relevant regulations

The main applicable document is IAEA SSR-6. Other relevant national or international transport regulations should also be considered to ensure that any differences with the IAEA Transport Regulations are taken into account.

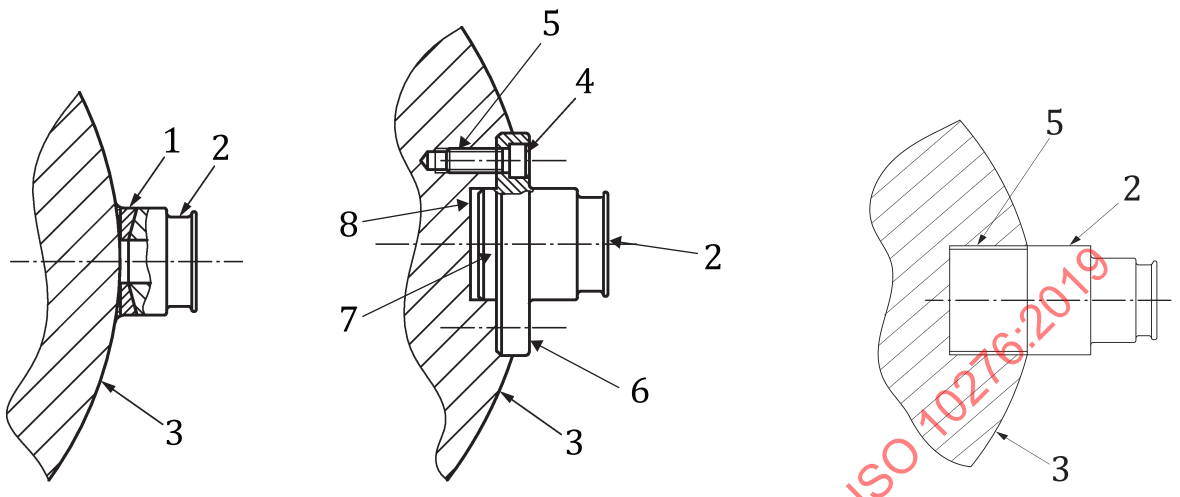
This document does not relieve the relevant parties of the responsibility for compliance with any requirement of the regulations applicable within the nuclear power plants (e.g. KTA 3905[3] or ANSI N 14.6[4]).

5 Design

5.1 General

5.1.1 Trunnion systems as part of a package design shall be designed in accordance with IAEA SSR-6 with consideration of IAEA SSG-26, and in particular its Appendix IV.

5.1.2 Trunnion attachment to a packaging may be carried out by welding, bolting, threaded attachment, interference fitting and bolting, or any combination of these methods. This document applies to these methods of trunnion attachment; see Figure 1 a), b) and c).



a) Welded trunnion **b) Removable trunnion (bolted)** **c) Removable trunnion (threaded)**

Key

1	weld	5	body thread
2	trunnion	6	removable baseplate
3	packaging body	7	removable shear disc
4	attachment bolt	8	body housing

Figure 1 — Examples of trunnions

5.1.3 Trunnions are fitted to the packaging to provide the following:

— a means of tie-down of the package during transport; and/or

— a means of providing lifting, or lifting and tilting, the package (with particular designs of package, the trunnions are used in tilting the package from horizontal to vertical position and vice-versa).

5.1.4 The designer shall consider how the package is supported during transport and lifting and/or tilting with respect to the trunnions. For these situations the load distribution for the trunnion system shall be derived. The designer shall consider the number of trunnions on the package required to fulfil a particular function (e.g. lifting, tilting, supporting) and the value, the direction of forces that are imposed on the trunnions and the way they are applied (point of application, width, angle of repartition...). See 5.4 for more details.

The load transferred by the trunnion system to the packaging body needs to be considered but is not part of this document.

5.1.5 The design of the trunnion system shall be capable of performing for a temperature range as defined in the IAEA Transport Regulations. In particular, minimum and maximum operating temperatures due to design heat load and worst case ambient conditions shall be considered. Differential thermal expansion between the conveyance means and the packaging may add stresses to the trunnion system unless specific design arrangements are made to avoid those effects.

5.1.6 The designer should ensure that the combination of environment, component materials, bolt coatings, bolt strength, grade, and tensile stress do not render the trunnion system vulnerable to the effects of stress corrosion cracking (SCC). Where the effects of SCC are not avoided by design, the designer shall specify a regime of inspection to detect the early effects of SCC and to allow for bolt replacement before there is damage.

5.1.7 Any trunnion systems shall be so designed that, under normal and accident conditions of transport, the forces in those trunnion systems shall not impair the ability of the package to meet the requirements of the IAEA Transport Regulations.

5.1.8 Specific surface finish limits shall be specified by the designer. Smooth surfaces and gradual changes of section aid decontamination and are also beneficial for fatigue properties. Liquid traps shall be avoided. Applying sealant or using gaskets can prevent the ingress of liquids.

5.1.9 As far as practicable, ease of decontamination shall be considered in the design of trunnion systems, particularly with regard to the bolted attachments.

5.2 Design methodology

Structural analysis of trunnion systems shall include a strength analysis and a fatigue analysis. If necessary, issues such as brittle fracture and structural stability should be considered.

This analysis can generally be performed by the following methods:

— analytical methods,

— finite element analysis (FEA), or

— a combination thereof.

The applicability of the chosen method shall be checked and justified by the designer.

In the case of trunnion systems with complex geometry and load situation, FEA is preferred as it leads to more detailed stress and strain results for complex structures.

Clarification on method and criteria are given in 5.5.

5.3 Materials

5.3.1 Material selection

Materials used for the trunnion systems shall be selected or treated to avoid corrosion, including SCC effects, as appropriate, during the life of the packaging. This includes, but is not limited to, the following considerations:

— the environment conditions in loading operation (borated water, moisture, protection or decontamination agents which might include demineralized water, oxalic acid, steam, nitric acid, caustic solution, NaOH-tartaric acid, lubricants, or other proprietary products),

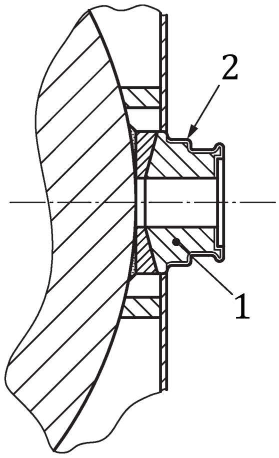
— ambient conditions (maritime, rain, snow,...) during transport or storage period,

— bolt grease, sealant (used in the packaging design),

— galvanic interaction (materials shall be chosen to ensure that the electro-potential sensitivity between components is minimal).

It is recommended that trunnions are made from corrosion-resistant steel. For the trunnions, the use of stainless steel cladding of a carbon-alloy-steel substrate can be justified (example of a clad trunnion is in Figure 2), provided the designer has carefully considered all aspects of inspection and maintenance that are likely to be most challenging. For the trunnion attachment system, the use of adapted specific coating, sealants or leaktight additional devices may be sufficient.

For duplex-steel welded trunnions, care shall be taken to prevent risk of brittle intermetallic phases that can reduce toughness and corrosion resistance.



Key

1 base material

2 stainless steel cladding

Figure 2 — Example of a clad trunnion

5.3.2 Mechanical properties

For the selected materials the minimum mechanical strengths $R_e(T)$ and $R_m(T)$ shall be specified.

In case where ferritic steels are used for trunnions, to ensure that the material is sufficiently ductile and tough, it shall be capable of achieving the following:

— Charpy impact test energy of 27 J minimum at the minimum temperature according to the IAEA Transport Regulations (see 5.1.5),

— Tensile test elongation to failure of 14 % minimum at 20 °C.

Where trunnions are not wholly stainless steel, but are stainless-steel covered, the mechanical properties used in calculations, for both the base and cladding materials, shall be those of the base material.

Consideration shall be given to the hardness of the trunnion and attachment component materials to minimize any surface incompatibility that can arise due to the material hardness of interface equipment.

Fracture toughness properties, such as K_{Ic}, of the materials shall be specified if needed to enable a fracture mechanics analysis of the trunnion system.

The designer shall specify the requirement of intercrystalline corrosion tests where this is relevant.

5.4 Design loads

5.4.1 Assembly state

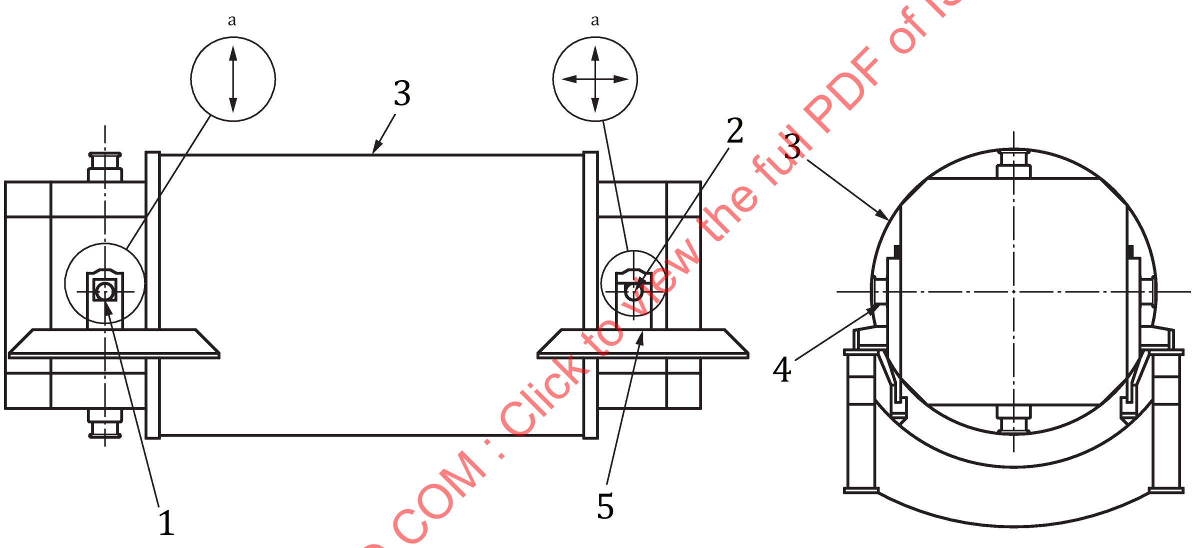
Where the trunnion attachment includes bolts, the bolt minimal ensured preload shall be appropriate to avoid any loosening of the bolts and sliding of the trunnion under the bolt heads during operation, including the effects of vibrations during transport. The bolt minimal ensured preload shall be determined considering uncertainties (tightening techniques and friction coefficients).

Depending on the assembling method, the bolt preload can vary due to the friction values between the bolts and their contact surfaces and also due to the uncertainties of tightening techniques. This assembly state is also applicable to the threaded trunnion type attachment. The bolt preload can also be affected by differential thermal expansion due to temperature change between assembly and design conditions. See References [7] to [10] for further details.

5.4.2 Tie-down

Designers may consider using different numbers of trunnions on packages to suit different operational or transport requirements. Where trunnions are used for tie-down, the total number of trunnions in any one plane may be restrained unequally. Consideration should be given to alignment on both the package and the tie-down equipment when four (or more) trunnions share a load. Local positioning imperfections or variations in tolerances can lead to high variations in the loads acting on each trunnion. Therefore, in the absence of justification, it shall be considered that the load is supported by only two trunnions. Example of trunnion restraints is in Figure 3.

The designer shall consider the different modes of transport the package is intended for. It is possible that the directional orientation of a package can differ between different modes of transport, e.g. the orientation of a package during sea transport may be at right angles to the orientation of the same package during rail transport. The designers shall consider all reasonably foreseeable package orientation during transport to determine the highest load case combination.



Key

1 vertical restraint by four trunnions

2 vertical and longitudinal restraints by two trunnions

3 packaging

4 trunnion

5 packaging support

a Restraint directions.

Figure 3 — Example of trunnion restraints

The designer shall identify all the possible allowed tie-down configurations and shall define for each the load case. Each load case shall be associated to:

— maximal load,

— load direction,

— bearing area of trunnion with transport means,

— number of acting trunnions.

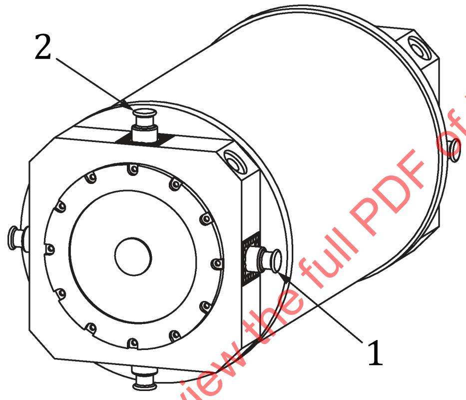
The maximal load applied shall generally be the total mass (transport) multiplied by the “acceleration” factor shown in Table IV.1 and in associated paragraphs of IAEA SSG-26, Appendix IV. Other values may be used subject to appropriate justification.

5.4.3 Lifting and/or tilting

Depending upon the design for operation, the package may have the capability of being lifted and/or tilted on the same trunnions. In some cases, packages might not be designed to be tilted. Whichever case applies, the total mass (lifting) that applies at any time to the minimum justified number of trunnions shall be taken into account.

In some cases, the designer may include packages fitted with secondary trunnion systems; see Figure 4. The primary and secondary trunnion systems shall be designed to act independently of each other.

Where trunnions are used for lifting and/or tilting, the total number of trunnions in any one plane may be restrained unequally. Consideration should be given to alignment on both the package and the lifting and/or tilting equipment when four (or more) trunnions share a load. Local positioning imperfections or variations in tolerance can lead to high variations in the loads acting on each trunnion. Therefore, in the absence of justification, when four (or more) trunnions share a load, the load shall only be supported by the two diagonally opposite trunnions.



Key

1 primary trunnion

2 secondary trunnion

Figure 4 — Packaging with primary and secondary trunnions

The designer shall identify all the possible allowed lifting or tilting configurations and shall define for each the load case. Each load case shall be associated to:

— maximal load,

— load direction,

— bearing area of trunnion with lifting or tilting means,

— number of acting trunnions.

The maximal load applying for a given load case shall be the corresponding lifting mass multiplied by a snatch factor of 1,8 g by Reference to [3]. Other values may be used subject to appropriate justification e.g. References [3], [4] or [11].

5.4.4 Load cycles for fatigue analysis

The designer shall take into account the fact that the in-service life can be reduced due to the effects of fatigue caused by cyclic stresses during transport, lifting or a combination of both. Fatigue analysis shall consider the whole lifetime of the trunnion system with load combinations from transport and lifting and/or tilting operations.

It is not possible to define universally valid load cycles for a transport on public routes therefore these must be specified both on the basis of the requested modes of transport (road, rail, sea or air) and on the basis of the length and number of anticipated transport cycles.

In addition to experimental determination of the transport load cycles, reference may also be made to published measurements. The transfer to other packages or transport routes may necessitate the use of correction factors before being considered in the fatigue strength analysis.

See IAEA SSG-26, Appendix IV for further details.

5.5 Methods of analysis and design criteria

5.5.1 General

For all the components of the trunnion system, the maximal equivalent stress (local or if allowable linearized stress) shall not exceed the predetermined limit value. This limit value is generally derived from correspondent $R_e(T)$ taking into account a safety factor depending on analysis method (see 5.5.2 or 5.5.3).

Specific considerations shall be evaluated for bolted trunnions to ensure the safe assembly is justified as specified in 5.4.1.

An additional safety factor shall be included for welded joints/interfaces. To justify the value of the safety factors to be used, due consideration should be given to the method of welding, NDE, and management system.

Strength analysis due to the load transferred by the trunnion system to the packaging body shall be justified but is not part of this document. In case of bolted trunnions, the required length of engagement in the packaging body shall be ensured.

More stringent safety factors may be added according some specific applicable national requirements, for instance in References [3] or [4].

Examples of approaches for strength analysis method and design criteria for trunnion systems are given in References [5] and [11].

5.5.2 Strength analysis using analytical methods

An analytical approach for strength analysis may be as presented in this section and can be based on References [4], [11] and [12].

This method can be used for simple cases such as full cylindrical continuous section of trunnion. Justification shall be provided for this method as the load application is idealized and the stress distribution averaged across the section.

For fatigue analysis (see 5.5.5) complementary strength evaluations are required to take account of stress concentration.

The equivalent stress shall be evaluated as follows:

— The maximum shear and tensile stress of the trunnion is calculated for most severely stressed cross section.

— The shear stress shall be taken as an average value over the cross section.

— The tensile stress may be due to direct or bending loads.

— The tensile stress due to the direct load shall be assumed to be uniformly distributed and equal to the average value of stress over the cross section.

— The bending stress varies linearly over the cross section.

— The tensile stresses due to direct and bending loads are additive.

— For combined shear and tensile stress states the effective stress is determined by using the Tresca criterion (max. shear stress theory) or Von Mises criterion (max distortion energy theory).

The following criteria shall be used for the lifting or tie-down situations or all the loading cases defined in 5.4.2 (based on References [4], [11] and [12]):

— Each load case defined in 5.4 shall be considered.

— For the trunnion the equivalent stress shall not exceed $R_e(T)/1{,}5$ and $R_m(T)/2$.

— When materials that have yield strengths $R_e(T)$ above 80 % of their ultimate strength $R_m(T)$ are used, each case requires special consideration, and the foregoing safety factors are insufficient. In such cases, the designer shall establish and justify criteria to assure adequate material fracture toughness.

For trunnion attachment components:

— the maximal equivalent stresses shall be less than $R_e(T)$. Concerning stresses in the shear disk housing, other justified criteria may be used for the limiting surface pressure, see for instance Reference [7] or [9].

For the trunnion bolts:

— the analysis and evaluation of bolts shall be performed according to appropriate standards, such as References [7] and [8], [9] and, [10] or [11].

— the maximal equivalent stresses shall be less than $R_e(T)$.

— the maximal stress in the trunnion under the bolt head shall not exceed $R_e(T)$. Other justified criteria may be used for the limiting surface pressure, see for instance Reference [7] or [9].

For welded joints/interfaces: in addition of the safety factor required in 5.5.1, an additional safety factor linked to the uncertainty of the method used shall be also included and justified.

5.5.3 Strength analysis using FEA methods

In the case of trunnion systems with complex geometry and asymmetric loading situation, FEA should be preferred. FEA leads to more detailed stress and strain results for complex structures. The use of FEA is recommended for strength analysis to calculate the spatial stress state at the most severely stressed points.

An approach using FEA methods for strength analysis is as follows:

— Each load case defined in 5.4 shall be considered.

— The stress evaluation for all components (incl. bolts) shall be based on the equivalent stress according to the Tresca criterion (max. shear stress theory) or Von Mises criterion (max distortion energy theory).

— Where the linearization of the stresses is justified, then the linearized equivalent stress at the most severely stressed point of the trunnion shall not exceed the value $R_e(T)/1{,}5$.

— The maximal equivalent local stress in the trunnion shall not exceed $R_e(T)$. Additional considerations may be necessary to show the safety margins against plastic collapse of the trunnion's cross section relevant for the load-bearing capacity, see Reference [5] for instance.

For trunnion attachment components:

— the maximal stresses shall be less than $R_e(T)$. Concerning stresses in the shear disk housing, other justified criteria may be used for the limiting surface pressure, see References [7] or [9] for instance.

For the trunnion bolts:

— the analysis and evaluation of bolts shall be performed according to national or international recognized standard, for instance References [5], [7] and [8], [9] and [10] or [11].

— the local stresses of FEA shall be transformed into nominal ones, as recommended in guideline Reference [5]. The maximal linearized equivalent stresses shall be less than $R_e(T)$.

— the maximal stress in the trunnion under the bolt heads shall not exceed $R_e(T)$. Other justified criteria may be used for the limiting surface pressure, see Reference [7] or [9] for instance.

For welded joints/interfaces: In addition of the safety factor required in 5.5.1, an additional safety factor linked to the uncertainty of the method used shall be also included and justified.

In case of complex interface between the trunnion system, the packaging body and the equipment where the physical phenomena shall be sufficiently detailed, a consideration of trunnion system instead of an isolated analysis of single structural components (trunnion, bolts, etc.) shall be done to properly include interactions between components. More detailed guidance for modelling trunnion system can be found in References [5] and [6] for instance.

5.5.4 Brittle fracture evaluation

Some materials are more susceptible to brittle failure at low temperatures and/or under lifting and routine transport conditions. In such cases, the designer shall apply an appropriate approach to avoid brittle fracture at the minimum service temperature. Guidance to prevent brittle fracture is given in IAEA SSG-26, Appendix V.

For welded trunnions, specific requirement to ensure the absence of brittle fracture shall be taken into account for the weld and the heat affected zone.

5.5.5 Fatigue analysis

Fatigue analysis shall consider peak stresses, and any weakening due to welds and features that can induce stress concentrations, and appropriate fatigue curves for the material that is used.

The safety factor depends on the material properties, the calculation method and the applied load-cycle behaviour. It may also vary depending on the applicable national requirements and the consequences of failure.

For example, approaches for fatigue evaluation can be found in Reference [11] for general aspect or in Reference [5] for lifting/tilting operations.

5.6 Other requirements and recommendations

5.6.1 The designer should aim to achieve simplicity and repeatability in determining the requirements for inspection, testing and assembly.

5.6.2 Due consideration should be given to the methods of periodic inspection, testing, and maintenance that is employed during the in-service life of the trunnion systems. Insufficient thought given to design with respect to these factors can cause difficulties in carrying out maintenance.

5.6.3 The design of the trunnion systems should, where possible, be integrated with the design of interfacing lifting equipment or, otherwise, the trunnion systems and interfacing equipment proposed should be assessed for mutual compatibility of geometry and material.

5.6.4 Operating aspects, such as safety, relationships to interface equipment (e.g. lifting equipment and package supports), radiation shielding, and ease of decontamination should be taken into account.

5.6.5 The designer should consider the inclusion of an in-service "wear allowance" in calculations to facilitate the re-machining of the trunnions, in accordance with the design safety assessment.

5.6.6 Consideration should be given to the trunnion surface finish with regards to decontaminability, tilting and fatigue analysis.

5.6.7 To facilitate comparison between manufacture and maintenance tests results, the designer should specify testing methods during manufacture that can be repeated during in-service life. The designer should ensure that there are no physical features on packaging that can inhibit repeatable tests.

5.6.8 The areas requiring regular inspection are surfaces subject to damage as well as bolts and threaded holes. These areas should be easily accessible and designed to facilitate inspection. The life of a trunnion system can be increased if repair is possible to recover non-conforming trunnions, or attachments components. Consideration should be given to the inclusion of an allowance within the design criteria to enable the recovery of non-conforming items.

5.6.9 As-built dimensional records of each trunnion, which are part of the manufacturing record/lifetime record, should-be retained as a basis for comparison during inspection.

5.6.10 The designer should ensure that the removable components of the trunnion system can be replaced as simply as possible and in accordance with 7.5.

5.6.11 To facilitate the evaluation of surface cracks and damage, the designer should specify that the inspection criteria incorporate a fracture mechanics-based approach.

5.6.12 Materials chosen for cleaning in operation shall be compatible with the materials of the trunnion system (including bolts, gaskets, sealants, etc.) and of the body of the packaging.

5.6.13 For bolted trunnions the designer should consider the bolt strength grade and any requirement for the trunnion attachment components to withstand the effects of the operational environment, for example reactor-pond water.

5.6.14 In order to avoid SCC, bolts can be suitably coated, ingress of moisture in void spaces between components can be prevented by suitable sealing solutions.

5.6.15 Trunnions are likely to wear due to frequent use. Because welded trunnions cannot be "easily" changed or repaired during the life of the packaging, it is recommended to use removable trunnion systems on packagings subjected to frequent transport cycles. In case of welded trunnions, consideration should be given to the availability of enabling tools and techniques for the required inspection and maintenance and to enable repair.

5.6.16 Where welding is considered a feasible repair solution, the designer should ensure that the materials chosen for the design can be welded satisfactorily without unacceptable detrimental effect upon the original material properties.

6 Manufacture

6.1 General

6.1.1 Manufacture of trunnion systems, assembly and attachment to the packaging, shall be carried out by suitable qualified and experienced organizations, qualified to carry out specific aspects of manufacture, materials testing, NDE, assembly and attachment.

6.1.2 In the specification of the material by the purchaser, the purchaser shall refer to material standards wherever possible, including any relevant additional information. When a requirement is indicated as "shall be specified" in Clause 5, it means that this requirement shall be specified to the supplier and shall be verified during manufacturing.

6.1.3 Manufacture shall be carried out in all cases to a predetermined quality plan. In practice, the quality plans may detail the status of the referenced documents and have provisions for material traceability and for controlling signatories responsible for the verification of quality. The quality plans shall be agreed and approved by the manufacturer/designer/purchaser and/or independent expert organization/competent authorities as appropriate, prior to manufacture commencing.

6.1.4 The manufacturing methods and processes including special manufacturing processes, i.e. forging, stress relieving, etc., shall be agreed between the designer, purchaser and the manufacturer.

6.1.5 Manufacture shall include assembly, inspection and testing. Examples for extent of final inspection and extent of acceptance testing are described in Reference [3].

6.1.6 Suitable NDE methods shall be used: examples are given in 6.3.2.

6.2 Assembly

Depending on the design and sizes of the trunnion components, positioning or location fixtures may be used to assist assembly. Assembly shall be carried out and reported in accordance with the procedures and standards as specified on the quality plans.

For bolted trunnions, it can be necessary to specify a sequence and range of torque application for the bolts, leading up to the application of the final torque; the application of bolt pretension can also be ensured by other techniques.

For welded trunnions, all root and filler runs shall be adequately specified. Where dissimilar materials are being welded, the types of welding materials being used shall be suitable. Qualification of welding procedures, welders, and welding operators is required before welding of the trunnions. Welders shall be qualified to a recognized national or international standard. It can be deemed necessary to carry out NDE at various steps of the welding process.

6.3 Inspection during manufacture and assembly

6.3.1 Dimensional and visual inspection

Dimensional inspection shall be carried out on the trunnion system. Each item shall be fully inspected to ensure conformity with design drawings, including but not limited to the following:

— feature dimensions and tolerance

— surface finish

— thread gauging for both bolts and threaded holes

Dimensional and visual inspection shall be carried out and reported in accordance with the procedures and standards as specified in the quality plans. Reporting shall compare dimensional inspection results with the acceptance criteria stated on the approved design drawings.

6.3.2 Non-destructive examination

Non-destructive examination, NDE, shall be carried out during specified steps of the manufacture to verify the material condition. NDE shall be carried out and reported in accordance with the procedures and standards as specified in the quality plans. Reporting shall compare test results with the specified acceptance criteria. Other NDE methods may be used as an alternative to those recommended hereafter, if considered more appropriate.

It is advised that all material (except plate and pipe) should be scanned for internal indications using UT methods before any significant fabrication is commenced.

If heat treatment is carried out during the manufacturing process, NDE shall be done after that.

If considered necessary by the purchaser, further NDE should be carried out on trunnions and trunnion components after final machining.

In the case of trunnions attached by welding, the welds and the heat-affected zones should be UT-scanned after completion of welding and any subsequent treatment steps involving heat, i.e. stress relieving, lead pouring, etc. Depending on the shape of the packaging body, the trunnion and the weld, various angles and types of transducers shall be used to assist in obtaining a three-dimensional picture. Test blocks shall be used to assist in calibrating. Ideally, one test block, manufactured from material similar to the trunnion and welded to the packaging, shall simulate the shape of the trunnion. This test block shall also contain a series of holes to simulate various flaws. Other NDE methods may be used as an alternative to those recommended above if considered more appropriate.

In addition to scanning by UT methods, all trunnions, trunnion attachment welds and trunnion attachment components should be surface-crack-inspected by PT or MT methods. This should be carried out on completion of manufacture, i.e. after final machining of components, final welding run, stress relieving, lead pouring, etc.

NDE may need to be repeated during the in-service life of the packaging. For trunnions attached by bolts, trunnions and bolts should be inspected by NDE separately. The same NDE technique used during manufacture should be used during in-service life. The same procedures should be used to facilitate the comparison of the results. In this respect, adequate records of surface or internal indications, including reference data, orientation of indications, trunnion serial number and trunnion attachment component serial numbers, as appropriate, should be retained for comparison purposes. In the case of UT scanning, adequate records of the observed results and equipment used should be retained for comparison purposes.

6.4 Testing during manufacture and assembly

6.4.1 Scope of testing

Testing during manufacture and assembly shall include, but not be limited to the following:

— chemical analysis

— mechanical testing of material properties

— static testing

6.4.2 Chemical analysis

Chemical analysis shall be performed before any fabrication work is carried out. The analysis shall be carried out to determine whether or not the material contains the constituents specified by the purchaser, and whether or not those constituents are within the tolerances specified. One analysis per batch or cast of material shall be carried out. Analysis and reporting shall be carried out in accordance with the procedure or standard as specified in the quality plans. Reporting shall compare the analytical results with the acceptance criteria quoted.

6.4.3 Mechanical testing of material properties

Testing to verify the material properties shall be carried out during specified steps of the manufacture to verify the finished condition of the material, where no further treatment, fabrication or manufacturing steps can alter the material properties. Test samples are normally used to verify material properties.

Test samples shall be representative of the materials being used and the tests shall be carried out per batch or cast of material. Any test samples that the purchaser requests to be archived shall be suitably identified.

The testing mode shall take account of the geometry and orientation of trunnions and trunnion attachments on the packaging to ensure that representative data are obtained. Testing and reporting shall be carried out in accordance with the procedure or standard as specified in the quality plans. Reporting shall compare test results with the specified acceptance criteria. Consideration shall be given to the number of tests to be carried out per test type to ensure a meaningful data set.

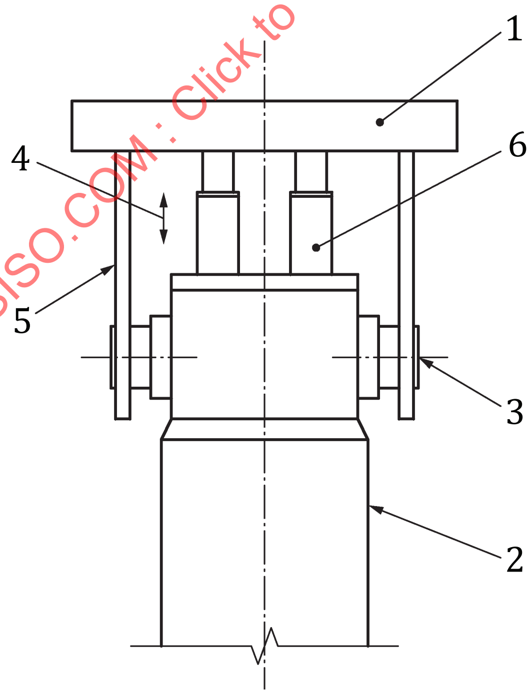
6.4.4 Static testing

Static testing of trunnion systems shall be carried out to verify the assembled condition. Testing shall be carried out on the pairs of trunnions that are used together. Testing shall be carried out by lifting, using weights attached to a packaging, or by using a pair of hydraulic jacks connected together between a yoke and a pair of trunnions positioned on a packaging to exert an equivalent load; see Figure 5. Testing, where possible, should simulate the mode in which the trunnions normally operate.

Trunnion systems shall be tested with a minimum factor of 1,5 times the maximum service load applied for a period of at least 5 min. It should be recognized that longer durations and higher load factors may be demanded according to local or national regulations, or the requirements of the competent authorities. The designer shall take adequate steps to address these requirements.

Trunnions and weld attachments shall be surface-crack-inspected using PT (stainless steel) or MT (carbon steel) or other suitable methods after static testing. Static testing shall be carried out in accordance with the procedures and standards specified in the quality plan.

With welded trunnions, the weld and the heat-affected zone shall be inspected by NDE after static testing as a comparison against the NDE after welding.



Key

1	yoke	4	load
2	packaging	5	yoke arms
3	trunnion	6	hydraulic jack

Figure 5 — Example of trunnion static testing using hydraulic jacks connected together

With bolted trunnions, the pretension of the bolts shall be rechecked after static testing (by checking the torques or other techniques). The designer should identify the most highly stressed bolt, either on the appropriate drawing or in the testing specification. If identified, the most highly stressed bolt can also be removed for dimensional analysis to ensure that the trunnion system has not been overstressed during static testing according with Reference [3].

Reporting shall compare static test results with acceptance criteria specified in terms of residual deformation, VT, PT or UT indications, and bolt torques, as appropriate.

7 Maintenance

7.1 General

7.1.1 Maintenance shall be carried out by suitable qualified and experienced persons, qualified to carry out the methods of the maintenance recommended by the designer, or qualified to carry out the maintenance required to meet the designer's recommendations.

7.1.2 Maintenance shall be comprised of one or more combinations of periodic inspection, periodic testing, component replacement or repairs. The scope of the maintenance shall be dependent upon its frequency and the feature being maintained.

7.1.3 Maintenance shall be carried out in accordance with a maintenance schedule; see 7.2.

7.1.4 Regular periodic inspection at predetermined frequencies shall be carried out to ascertain if the in-service limits have been approached or an unacceptable rate of wear or damage has taken place.

7.1.5 Periodic testing shall be defined to ensure that the system is in accordance with the in-service limits.

7.1.6 Repair of trunnion systems can be considered necessary if loss of material due to wear, corrosion or damage has resulted in the in-service limits being exceeded.

7.1.7 Maintenance shall comply with the predetermined quality plans. The quality plans, maintenance methods and routes shall be approved by the designer, owner/operator, maintenance organization, and/or independent expert organization/competent authorities, as appropriate, prior to any maintenance commencing. Repair plans shall be required for each unique type of repair.

7.1.8 Particular care shall be taken when solvents/chemicals are used during the cleaning or during NDE of trunnions and components during maintenance. The solvents/chemicals shall be checked to ensure that they are compatible with the trunnions and trunnion components, including bolts, gaskets, sealants, etc. and to prevent the onset of corrosion mechanisms.

7.1.9 Particular care shall be taken to prevent water intrusion into the space between the trunnion system and the body of the packaging, in due consideration of the sensitivity of the materials to corrosion mechanisms e.g. high-tensile bolts susceptible to SCC.

Where trunnion systems are designed to include sealed areas, those areas shall be examined to ensure the integrity of the sealed area. A functional test of the seals should be considered, if appropriate.

7.2 Maintenance schedule

The designer shall prepare a maintenance schedule, taking into account the requirements of 7.1 to 7.6.

The content and frequency of maintenance shall be agreed between the designer, owner/operator, maintenance organization, and/or independent expert organization/competent authorities, as appropriate, and provided in the maintenance schedule document. Examples for extent of final inspection and extent of acceptance testing are described in Reference [3].

7.3 Periodic inspection

7.3.1 General

The features for periodic inspection and the types of periodic inspection shall depend on the type of trunnion system and the periodicity at which it is being carried out. The following features shall be inspected in accordance with a maintenance schedule; see 7.2.

7.3.2 Removable trunnions

The following features for removable trunnions shall be inspected:

— accessible trunnion surfaces;

— attachment threads in the packaging body;

— attachment bolts (this applies only to attachment bolts that are not being discarded);

— trunnion assembly (bolt torque, etc.);

— sealing areas;

— feature dimensions.

7.3.3 Welded trunnions

The following features for welded trunnions shall be inspected:

— accessible trunnion surfaces;

— weld areas;

— sealing areas;

— feature dimensions.

7.3.4 Trunnion surfaces

The surfaces of the trunnions shall be checked to ensure they are in a condition that is not detrimental to any interface equipment in connection with which the trunnions are used, or to the design strength, e.g. by having damage or corrosion that can lead to collapse or fatigue failure of the trunnion system.

Trunnion surfaces shall be examined by VT and PT or other NDE methods. VT shall be complemented by any measuring techniques necessary to determine the height, depth, length and width of any surface damage present on the trunnions.

7.3.5 Attachment threads in packaging body

The attachment threads in the packaging body, used in conjunction with retaining bolts, shall be checked to ensure they are capable of carrying out their design function of retaining the trunnion in its position on the packaging body under all envisaged design stresses (shear, bending and tensile, as appropriate).

Attachment threads in packaging bodies shall be examined visually and by using thread-plug gauges.

