SAFETY ANALYSIS REPORT
GNS 11

- Summary -

GNS

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Section 3

1. Introduction

This Safety Analysis Report is a summary of the information provided for licensing of a GNS 11 cask as a Type B (U) package, Nuclear Safety Fissile Class I, for the transport of radioactive material (spent MTR-fuel or other radioactive material) in the Federal Republic of Germany.

This report summarizes the safety aspects for the transport of spent MTR fuel as well as other radioactive material in casks made of stainless steel/lead.

The GNS 11 cask represents the IAEA international specifications for Type B (U) packaging corresponding to Nuclear Safety Fissile Class I.

2. GNS 11 Design Concept

The GNS 11 cask is a package which can be utilized for the transport of:

a) irradiated fuel assemblies from material test reactors
b) high-level or intermediate-level radioactive materials in 55-gallon drums
c) radiation sources composed of different radionuclides

The main purpose of the GNS 11 is the shipment of spent MTR-fuel. The GNS 11 will accommodate up to 33 square or up to 28 tubular MTR-type fuel assemblies.

The GNS 11 cask body is built as a sandwich construction consisting of an inner and outer liner (SS 304) with lead shielding inbetween.

2.1 Principal Design Criteria

The principal design criteria of the GNS 11 cask are:

Shielding

Maximum dose rate at any point on the package surface less than 200 mrem/h. Maximum dose rate at a two meter distance from a single cask: 10 mrem/h.

Thermal

The max. temperature at the outer cask surface is 82 °C based on ambient air temperature at outer cask environment of 38 °C.

Structure

The cask structures are designed, fabricated, and tested to maintain the confinement of the fuel assemblies, both for normal operation and under accident conditions, based on the requirements of the IAEA for Type B (U) packages, Nuclear Safety Fissile Class I.

Criticality

The effective multiplication factor (k_{eff}), assuming optimal reflection and fresh fuel, is less than 0.95, including statistical uncertainties.

Containment

The cavity atmosphere consists of air at a pressure of 0.5 bar. The cavity is closed with one lid. The standard helium leak rate of the lid is less than 10^{-4} mbar l/sec.

2.2 Requirements for Type B (U) Packages

The design for the GNS 11 Type B (U) packaging is done in accordance with the:

- "Richtlinien für die Zulassung des Baumusters von Versandstücken zur Beförderung radioaktiver Stoffe" (Guidelines for Type Approval of Packages for the Shipment of Radioactive Materials) under the provisions for materials of Class 7, as applicable to the GNS 11 for transportation by road, rail, sea and air.

- The Regulations for the Safe Transport of Radioactive Materials and the Advisory Material for the Application of the IAEA Transport Regulations

were taken into account in the compilation of the following:

- "Internationale Ordnung für die Beförderung gefährlicher Güter mit der Eisenbahn (RID)" [International Regulations for the Shipment of Dangerous Goods by Rail]

- "Europäisches Übereinkommen über die internationale Beförderung gefährlicher Güter auf der Straße (ADR)" [European Agreement on International Shipment of Dangerous Goods by Road]

- "Verordnung über die Beförderung gefährlicher Güter mit Seeschiffen" [Regulations on the Shipment of Dangerous Goods by Ship]

- "Verordnung über die Beförderung gefährlicher Güter mit der Eisenbahn" [Regulations on the Shipment of Dangerous Goods by Rail]

- "Verordnung über die Beförderung gefährlicher Güter auf der Straße" [Regulations on the Shipment of Dangerous Goods by Road]

3 Description of the GNS 11

3.1 General

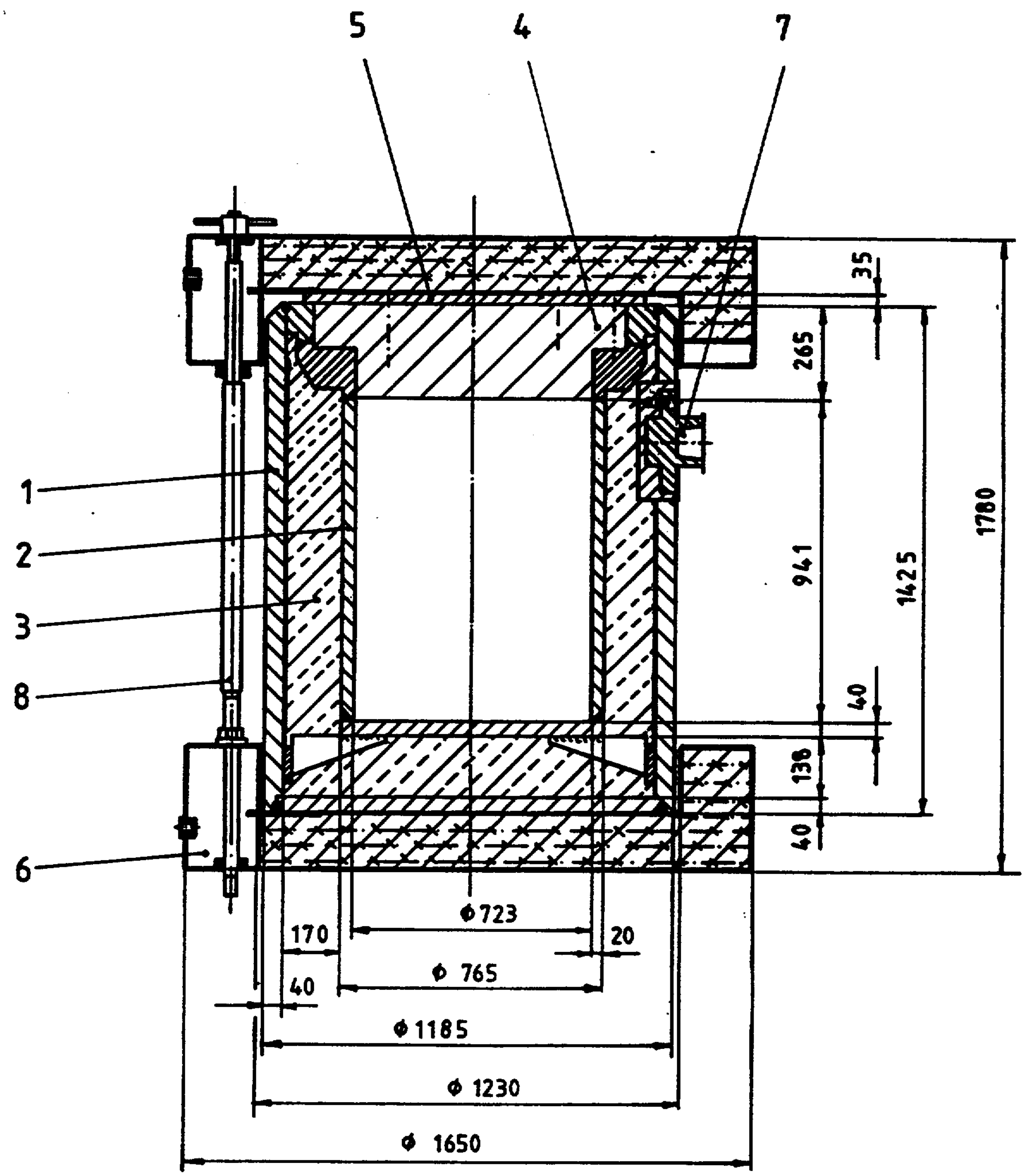
The GNS 11 cask is a sandwich construction made of steel/lead/steel. The cask is approximately 1.46 m (57.5 in) high, 118.5 m (46.7 in) in diameter, and weighs (empty) 11.1 metric tons (24,500 lbs). The cask has a cylindrical cask cavity which holds a fuel basket and is designed to accommodate either up to 28 tubular or up to 33 square MTR fuel assemblies as specified in Section 4.

The GNS 11 cask is sealed with one lid and one protective cover on top of each other, both made of stainless steel and bolted to the cask body. The lid and the protection cover are made of stainless steel and are bolted to the cask body. The lid is sealed with two seals consisting of elastomer O-rings. Two trunnions are bolted on the head end of the body.

The main components of the GNS 11 are

- cask body
- cask lid
- protective cover
- seals
- fuel basket
- impact limiters

In Fig. 3-1 the GNS 11 cask is shown. Additional cask drawings are provided in Appendix 1 of this report. The overall dimensions and design characteristics are summarized in Tab. 3-1.



Alle Abmessungen in mm
All Dimensions in mm

1 Außenliner
Outer Liner

2 Innenliner
Inner Liner

3 Bleiabschirmung
Lead Shielding

4 Deckel
Lid

5 Schutzplatte
Protective Plate

6 Stoßdämpfer
Shockabsorber

7 Tragzapfen
Trunnion

8 Verspannung
S.A. Fastning

Overall length (w/o impact limiters)	146.0 cm	57.5 in
Overall length (w/impact limiters)	178.0 cm	70.0 in
Cross section (w/o trunnions)	118.5 cm	46.7 in
Cross section (w/trunnions)	135.5 cm	53.3 in
Cavity diameter	72.3 cm	28.5 in
Cavity length	94.1 cm	37.0 in
Wall thickness		
- Inner liner	2.0 cm	0.79 in
- Lead shielding	16.5 cm	6.5 in
- Outer liner	4.0 cm	1.6 in
Bottom thickness		
- Inner liner	4.0 cm	1.6 in
- Lead shielding	13.8 cm	5.4 in
- Outer liner	4.0 cm	1.6 in
Lid thickness		
- Primary lid	26.5 cm	10.4 in
- Protective cover	3.5 cm	1.4 in
Cask capacity (F/A)	21 or 28 tubular F/A 26 or 33 square F/A or one 55-gal drum	
Weight		
- total weight of loaded cask w/impact limiters	13,300 kg	29,300 lbs
- empty cask w/o protective cover but with basket	11,100 kg	24,500 lbs
Material		
- Cask body	Sandwich: Steel/Lead/Steel	
- Lid, bolts, basket, trunnions	Stainless steel (ASTM A 240 Type 304)	
- Impact limiters	Wood boxed in carbon steel	

3.2 Cask Body

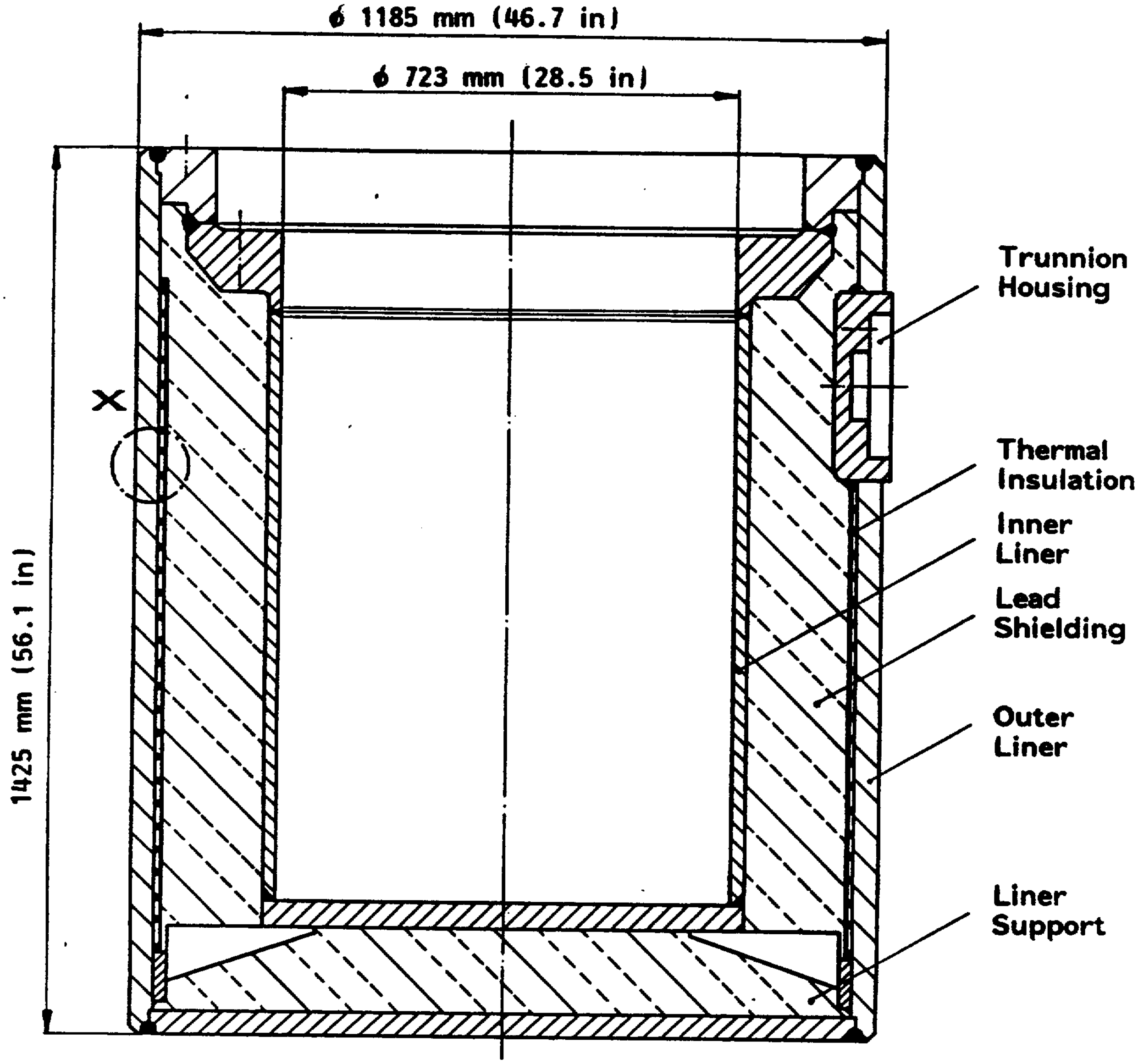
The cask body has a cylindrical shape and a cylindrical cavity. The cask body of the cask, consisting of welded stainless steel plates, is composed of an inner and outer wall with the accompanying bottom plates and the stainless steel parts for holding the lid. The spaces between the liners are filled in with lead. The total wall thickness of the cask body is 231 mm (9.1 in) and is subdivided into a 40 mm (1.6 in) outer liner, 20 mm (0.8 in) inner liner, 165 mm (6.5 in) layer of lead and 6 mm (0.2 in) thermal insulation. The mass of the cask body is about 10 Mg (22,000 lbs).

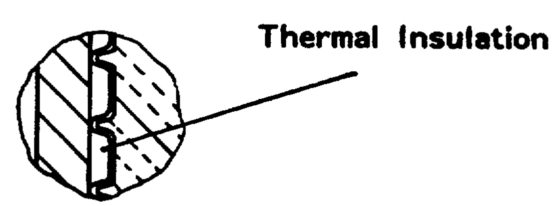
In Fig. 3-2 a cross-section of the cask body is shown. The main dimensions of the cask body are:

total height:	1,425 mm (56.1 in)
outer diameter:	1,185 mm (46.7 in)
cavity diameter:	723 mm (28.5 in)

The materials of construction for the cask body are:

outer liner inner liner and lid housing:	austenitic stainless steel No. 1.4541 DIN Standard No. 17440 U.S. equivalent: ASTM A 240 Type 304
lead shielding:	cast lead No. 2.3085 DIN Standard No. 1719 U.S. equivalent ASTM B 29
thermal insulation:	stainless steel, ASTM A 240 Type 304





Detail X

GNS	GNS 11 Cask Body	Fig. 3-2

A pair of trunnions at the top end are inserted into the outer liner of the cask body and bolted in place. Lifting tackle can be attached to the trunnions.

3.3 Cover and Seal System

The "tight containment" is formed by the cask body together with a lid. The containment consists of an inner vessel and an outer lead shielded secondary vessel. The inner vessel provides together with the primary lid bolts and seals pro vide the primary containment boundary.

Fig. 3-3 shows the GNS 11 lid system. The lid system consists of a primary lid and a secondary protection plate. Both lids are fabricated from Type 304 stainless steel. Twenty-four closure bolts with cap nuts secure the primary lid to the innervessel body. The primary lid is sealed with two elastomer seals.

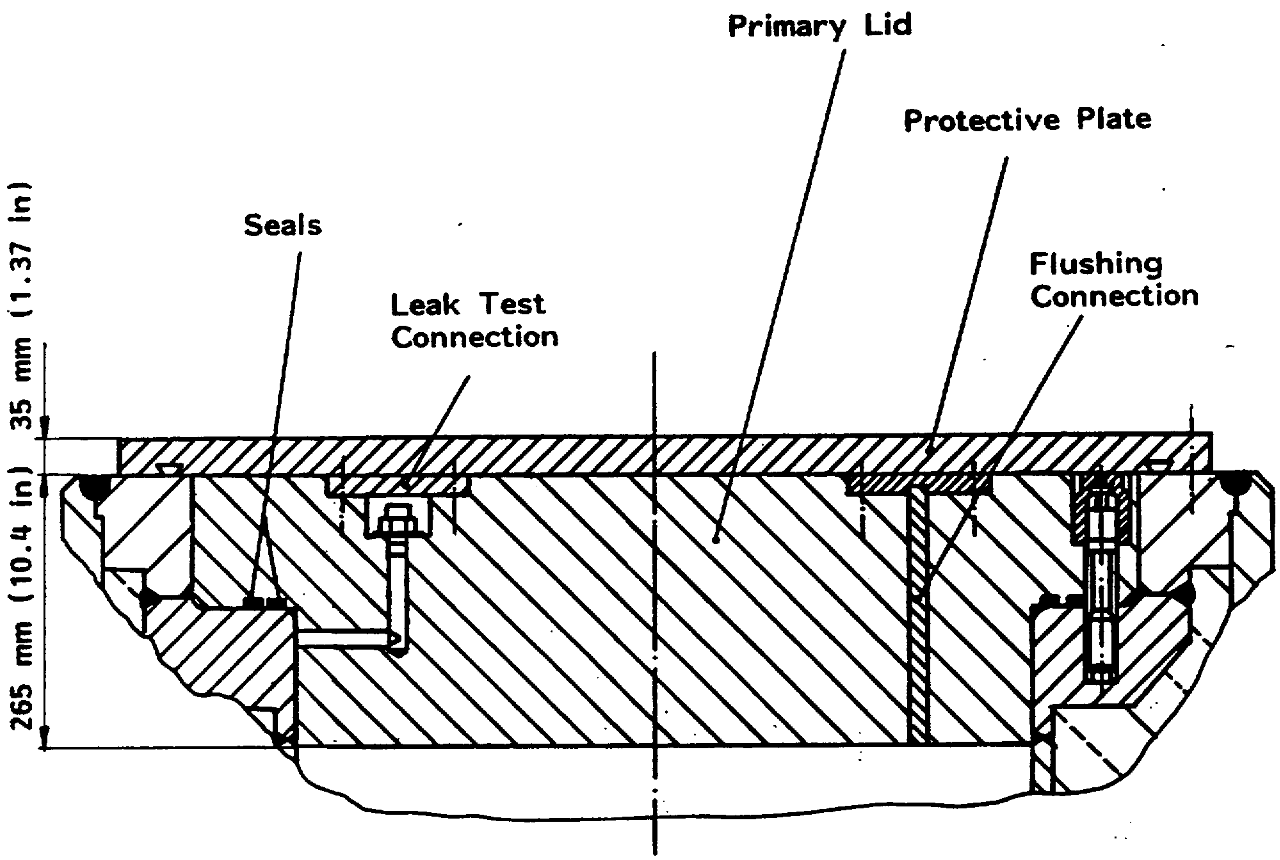
The lid has two penetrations for the performance of necessary handling operations during loading and unloading:

- one hole for flooding and draining the inside of the cask. After loading, the hole is closed with a seal plug sealed with elastomer gaskets

- one hole for evacuating or venting the inside of the cask through a vacuum valve inserted in the hole and sealed with an elastomer gasket.

Both these holes are covered with seal covers, each with an elastomer seal.

The protection plate is placed on top of the lid and also sealed with an elastomer gasket.



GNS

GNS 11
Lid and Seal System

Fig. 3-3

The main dimensions of the lid system are:

Primary lid thickness:	265 mm (10.4 in)
Protective cover:	35 mm (1.4 in)
Bolt size:	M 30 x 185

The materials of construction of the lid system are:

Primary lid, : Protection plate, Bolts	austenitic stainless steel, No. 1.4313 DIN Standard 17440 U.S. similar to AISI 414
Seals:	silicon rubber

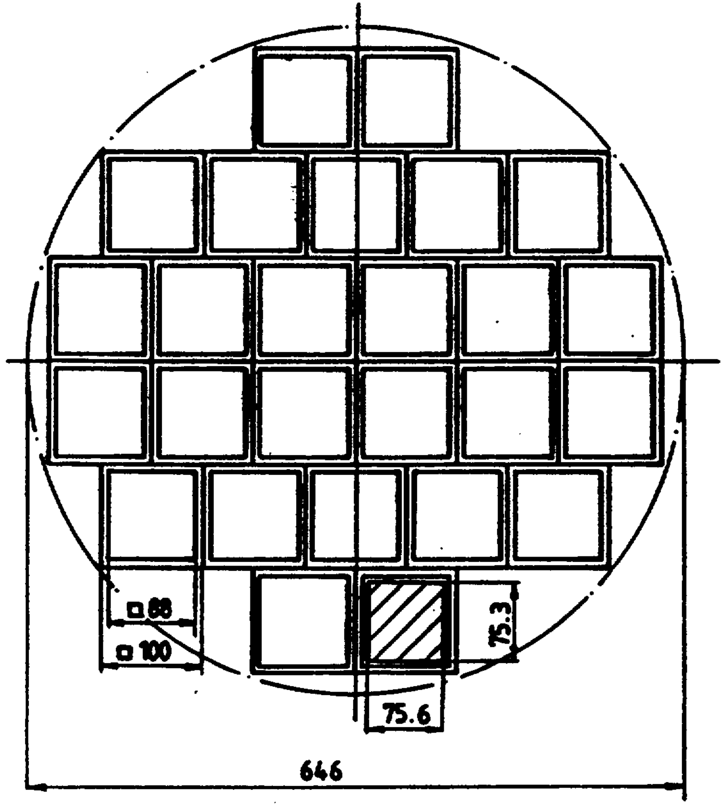
3.4 Fuel Baskets

The GNS 11 cask cavity can accept two different types of fuel baskets, each type with two different loading capacities. The following four basket versions can be used:

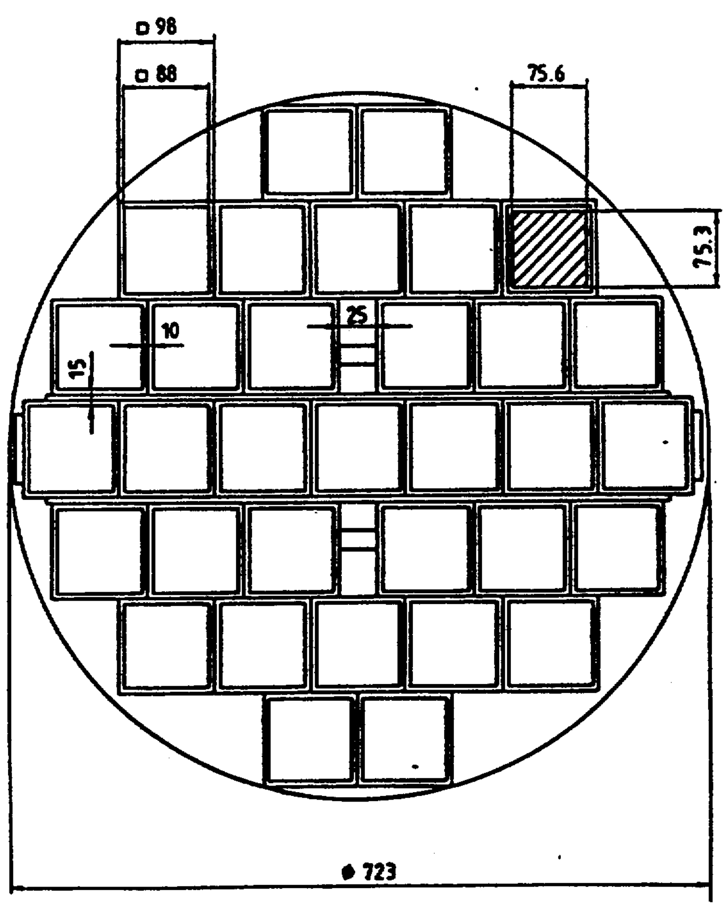
- basket for 21 tubular MTR F/A
- basket for 28 tubular MTR F/A
- basket for 26 square MTR F/A
- basket for 33 square MTR F/A

Cross sections of the four different fuel baskets are shown in Fig. 3-4 and Fig. 3-5.

The fuel basket inserted into the cask cavity is made of stainless steel (Type 304). The fuel baskets are welded structures with either a cylindrical-cross-section grid (tubular MTR F/A) or a square-cross-section grid (square MTR F/A) corresponding to the shape and number of fuel assemblies.

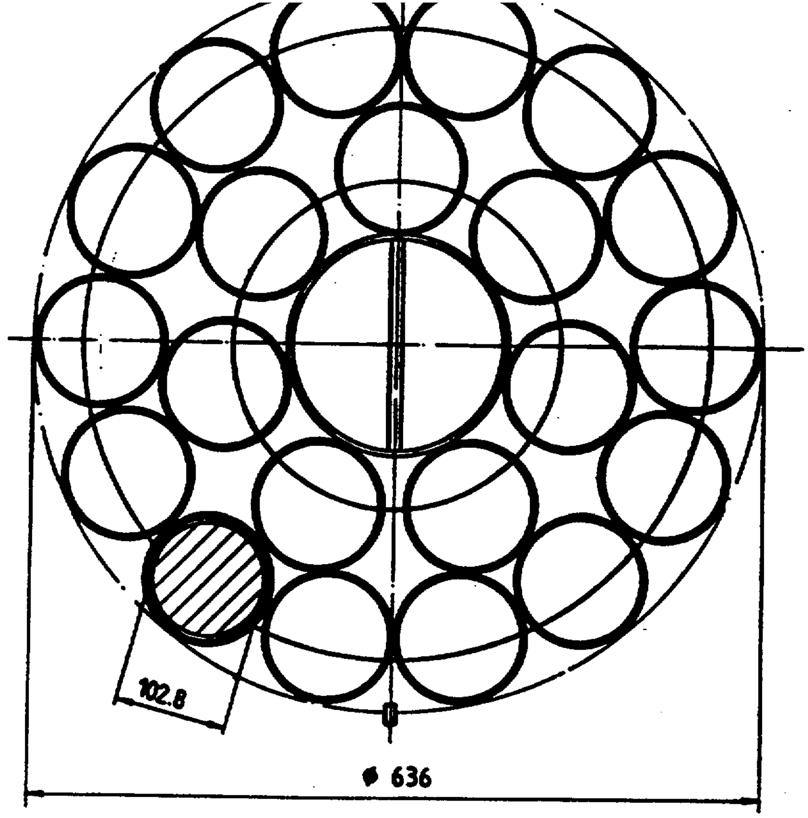


a) Basket for 26 F/A

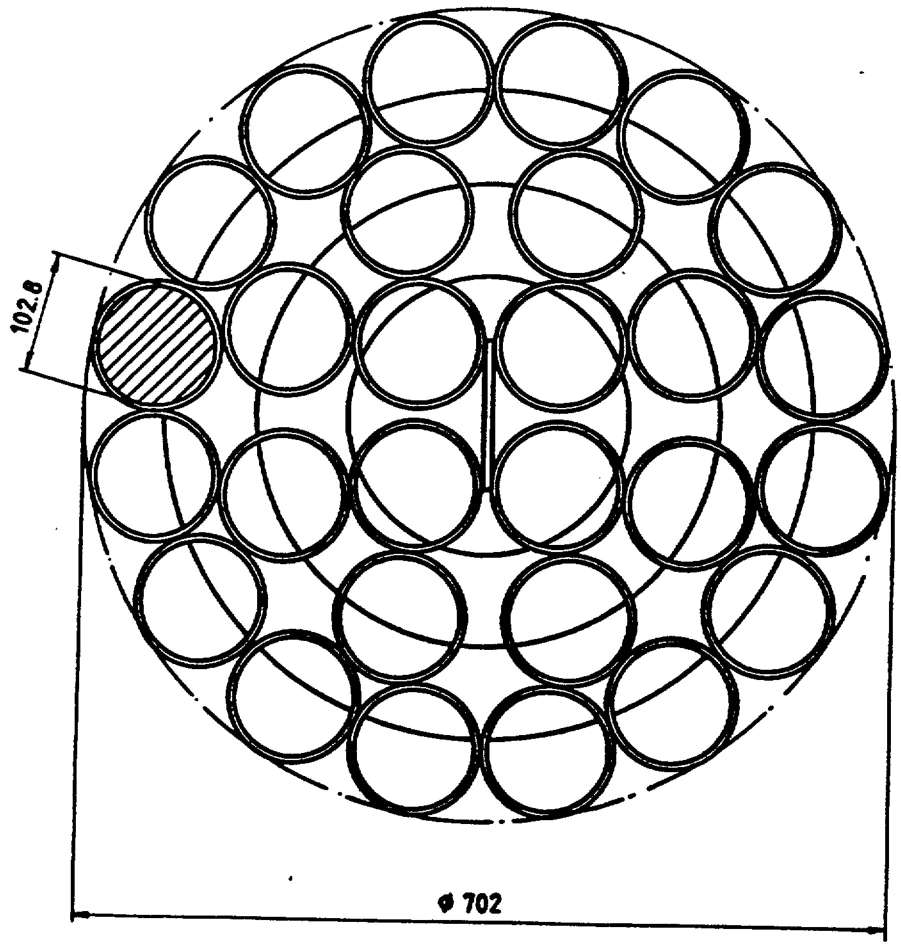


b) Basket for 33 F/A

GNS	GNS 11 Basket for Square MTR-F/A	Fig. 3-4



a) Basket for 21 F/A



b) Basket for 28 F/A

GNS	GNS 11 Basket for Tubular MTR-F/A	Fig. 3-5

3.5 Trunnions and Lifting Equipment

For handling of the GNS 11, two trunnions are located on the cask body in the head region. The trunnions are fabricated from high-quality stainless steel (AISI 414). The trunnion housing penetrates the 40 mm (1.6 in) thick outer shell and is welded to it. The trunnions are fitted into the trunnion housing with force- and positive fastening and are fixed with 12 bolts. Fig. 3-6 shows the trunnion construction.

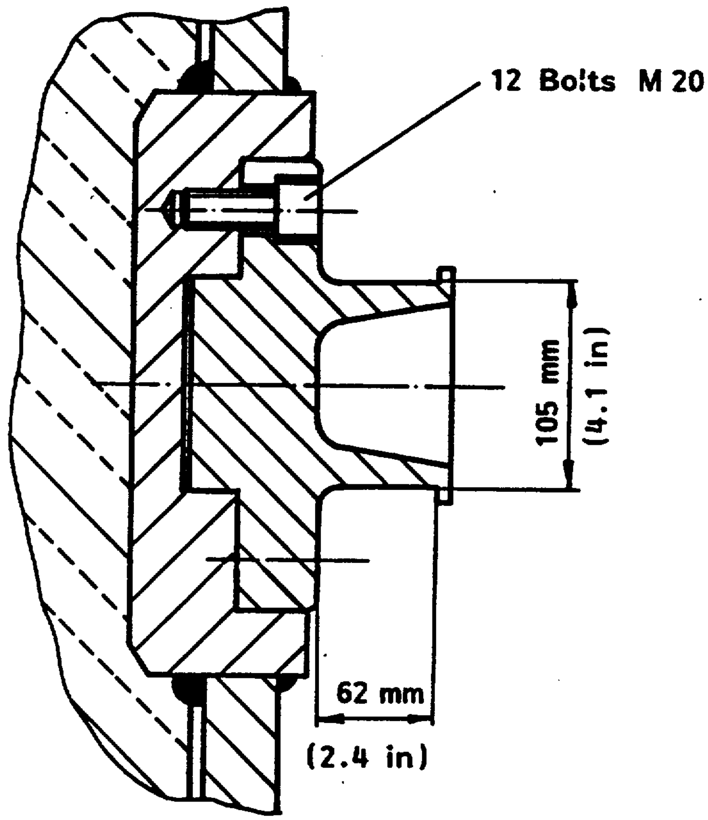
The cask lid is handled with the aid of a lifting device, screwed to the lid.

The protective plate and impact limiters are handled by means of eyebolts and cables.

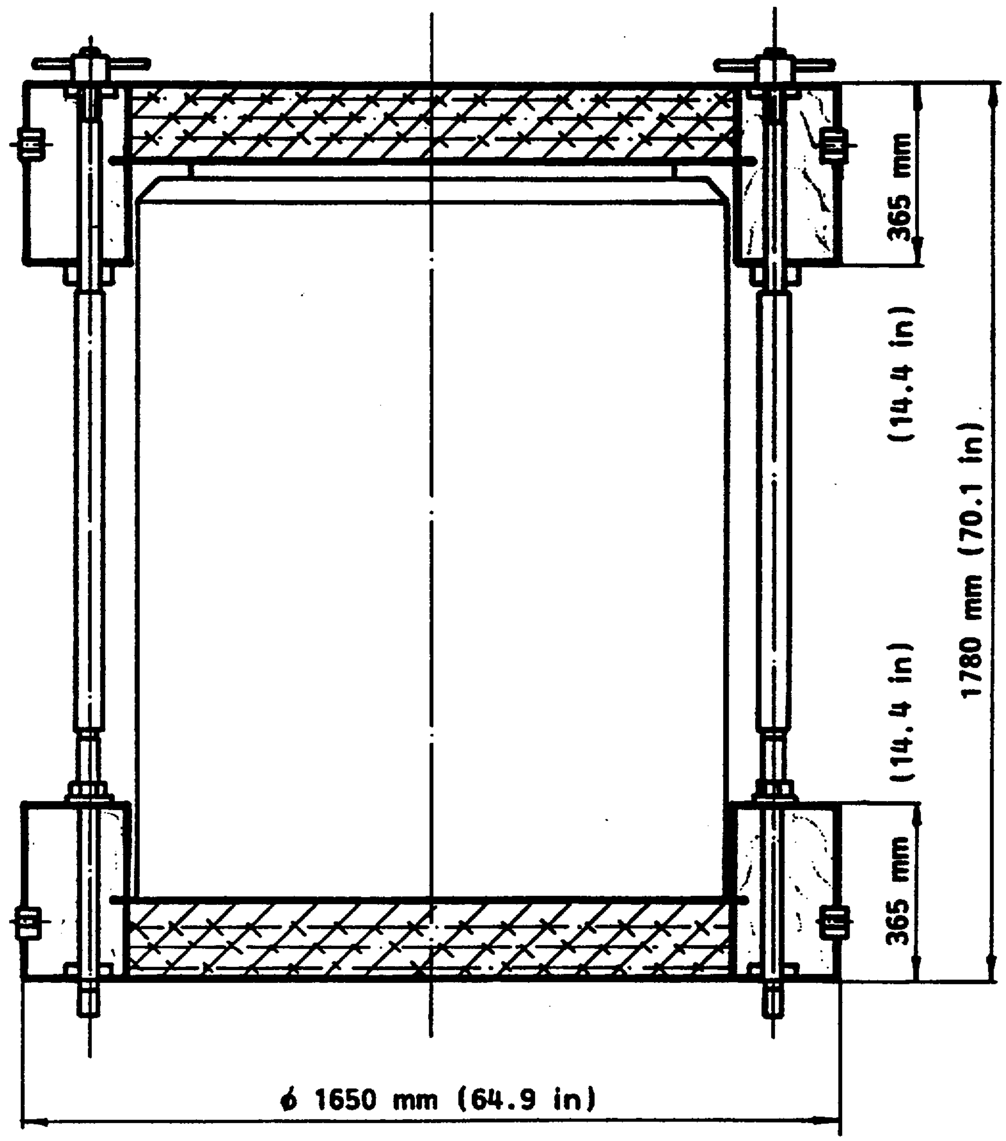
3.6 Impact Limiters

In order to reduce shock loads, as in accident conditions, the shipping cask has two shock absorbers (impact limiters), one each at the top and bottom ends, which are largely identical in design. The shock absorber consists of an enclosed steel-sheet structure filled with several layers of wood. The wood inlays consist of spruce planed on all sides, an glued together parquet-style. This structure is prolonged in the form of a cylindrical shell and encloses the whole top or bottom section of the cask body. The shock absorber is securely fastened to the cask body with tie bolts.

The construction and main dimensions of the lid and bottom impact limiters are shown in Fig. 3-7.



GNS	GNS 11 Trunnion	Fig. 3-6



GNS	GNS 11 Impact Limiter	Fig. 3-7

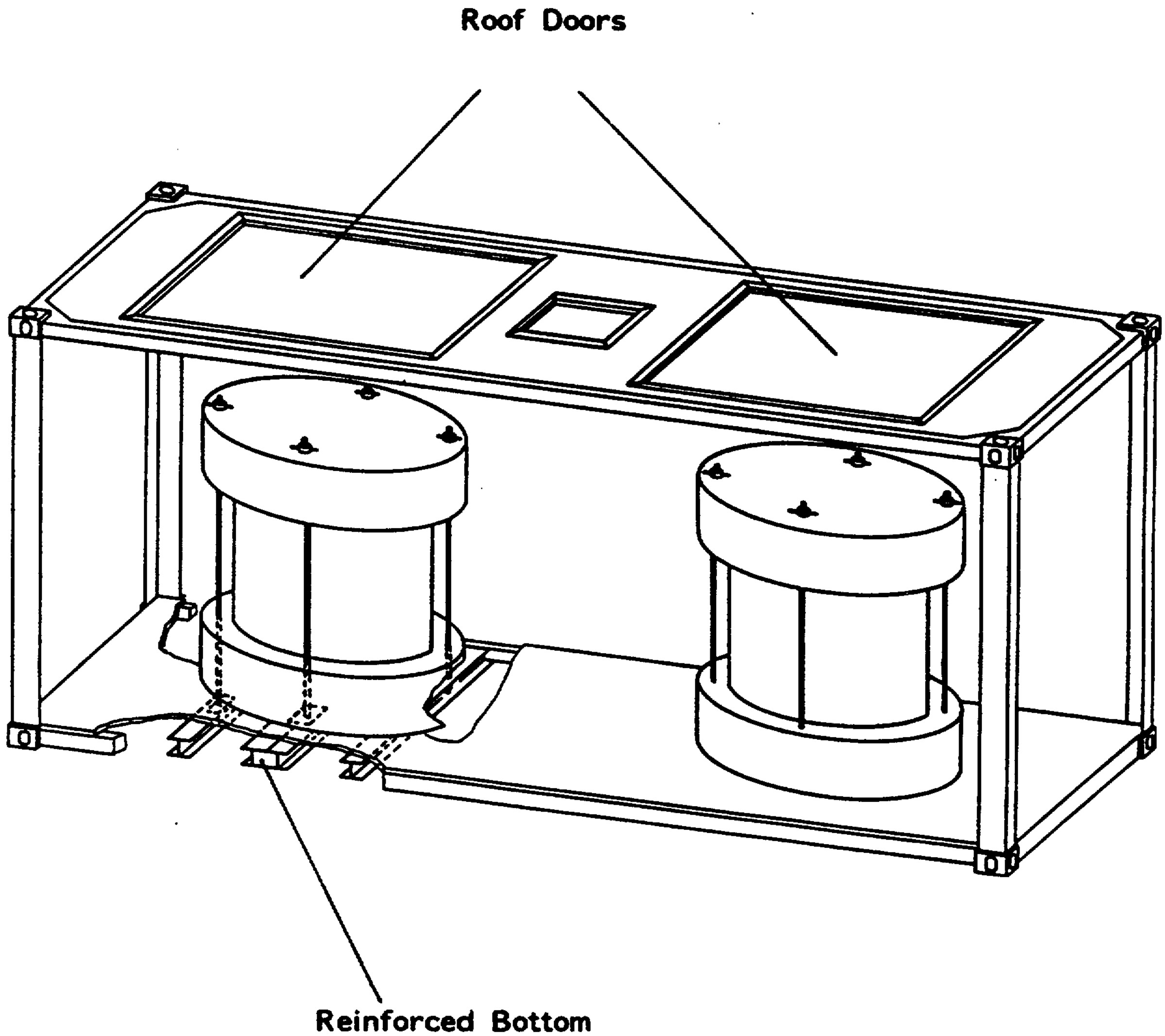
3.7 Shipping and Tiedown System

The GNS 11 is usually shipped in an upright position. A single cask will be transported on a shipping platform. The cask is secured with four cables which are fastened on the trunnions to the shipping platform. Shear blocks (four) are incorporated in the platform to react to longitudinal loadings on the cask.

Instead of the shipment of a single cask, two GNS 11 casks can be shipped in a 20` standard container which is reinforced in the bottom region and at the load attack points. Although this container provides considerable mechanical protection for the casks, the container is not taken into account in the design of the cask or impact limiters.

A schematic drawing of the cask arrangement in the container is given in Fig. 3 - 8. A lockable door is located at the front end for entering the container. Two lockable openings are located in the roof of the container, through which the GNS 11 casks can be loaded and unloaded. All openings are sealed off such that the GNS 11 casks are protected from spray water and rain water. The container also has ventilation holes in the bottom and top regions so that an air exchange and circulation is possible in the interior of the container.

The GNS 11 casks are bolted to the container floor with M30 screws fastened to the bottom impact limiter and 4 holding rods. The nuts and bolts of these screws are secured with point welds. The bottom of the container is reinforced with double-T-griders and load distribution plates, in contrast to the usual commercial containers.



GNS	GNS 11 Shipping and Tie Down System	Fig. 3-8

4. Description of Intended Contents

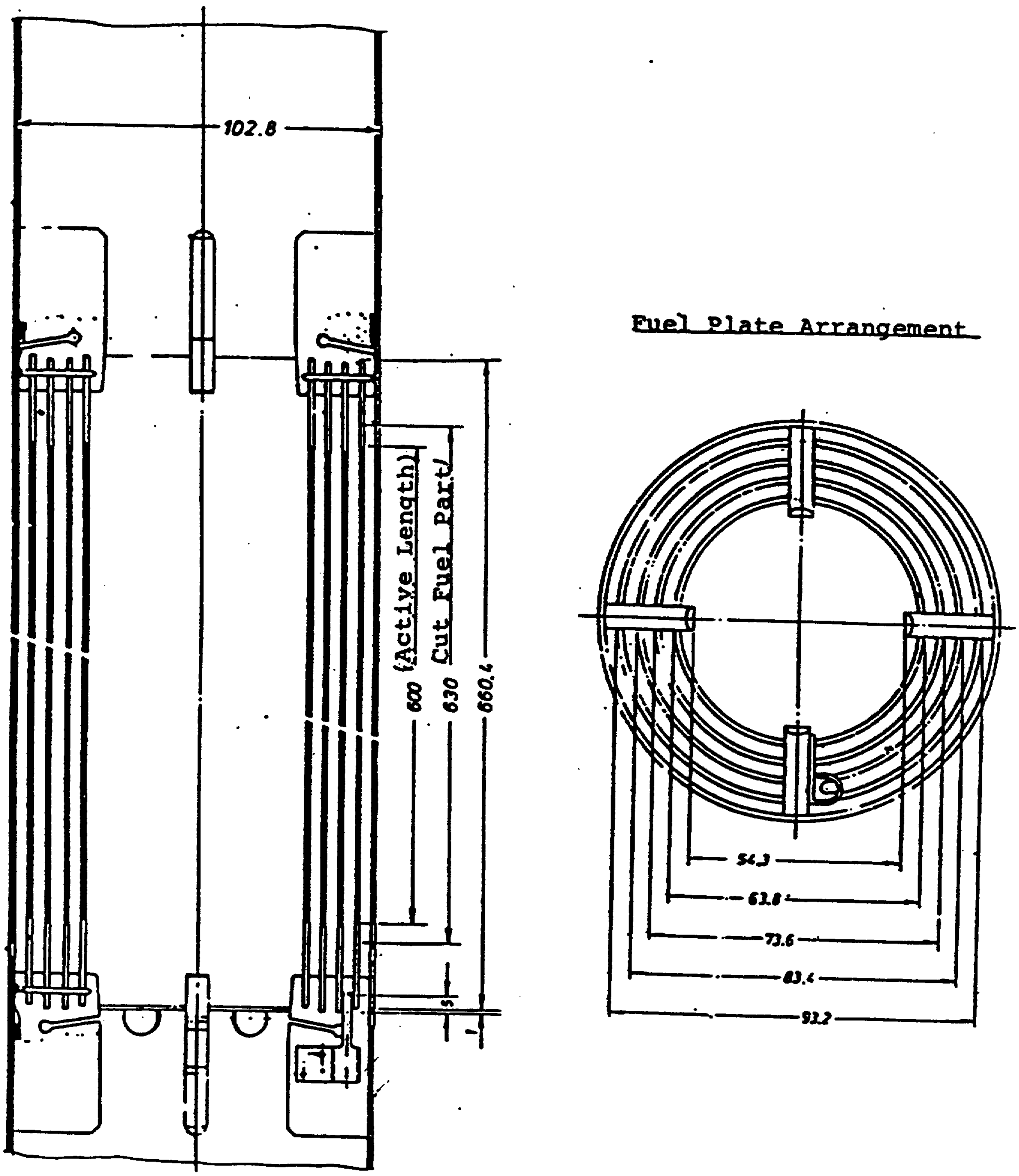
The GNS 11 will accomodate either up to 28 tubular or up to 33 square MTR-type fuel assemblies. The characteristics of the different fuel assembly types are summarized in the following sections.

Besides MTR fuel assemblies the GNS 11 package can also be utilized for the transport of high-level or intermediate level radioactive materials (waste) in 55-gallon drums or radiation sources composed of different radionuclides.

4.1 Tubular MTR-Fuel Assemblies (Type DIDO)

Tubular MTR fuel assemblies are used in the DIDO research reactor at the Jülich nuclear research center. They consist of a fuel portion, the tube-shaped upper part, as well as an end fitting. Before loading, the two fittings are separated, so that only the fuel portion of the assemblies is inserted. This is composed of 4 concentrically arranged fuel tubes and an outer tube. The tubes are fixed at both ends with 4 spacers and consist of 3 fuel plates each with aluminium cladding, soldered together. The outer tube consists likewise of 3 plates, enclosed all around in aluminium, which contains neutron poisons. The construction of a tubular MTR fuel assembly (type DIDO) is shown in Fig. 4-1.

After separation of the top and bottom pieces, the tubular MTR fuel assemblies have a length of 630 mm. As a rule, the fuel-free outer tube is likewise removed from the MTR-fuel assembly, before the assemblies are placed into the fuel basket of the GNS 11.



GNS	Tubular MTR-Fuel Assembly (Type DIDO)	Fig. 4 - 1

For the GNS 11 transport cask, two different tubular MTR fuel assemblies are to be considered, differing in their enrichment and fissionable content of U-235:

	Highly-enriched fuel assembly	Low-enriched fuel assembly
Fissionable content of U-235:	170 g	200 g
Enrichment in U-235:	80 %	20 %

In Tables 4 - 1 and 4 - 2, fuel assembly data for unirradiated and spent tubular MTR fuel assemblies are listed. The fuel, U-235, is present in the fuel assemblies in a UAl_x-Al compound or as a U_3O_8-Al compound.
The average burn-up among the MTR fuel assemblies is about 50 % of the U-235, with respect to the U-235 content of unirradiated fuel assemblies. The cooling time of fuel assemblies before transportation in GNS 11 casks is 6 - 12 months.

a) Highly enriched fuel assemblies

Enrichment in U-235		80 %
Chemical form of fuel		UAl - Al - Cermet
		U / Al - Alloy
Physical form of fuel		solid
Mass per fuel assembly (after cutting)		
- Aluminium	approx.	2440 g
- Uranium 235		170 ± 2 %
- Uranium total	approx.	212.5 ± 2 %
- Total mass	approx.	2650 g
Active length		600 ± 10 mm
Length after cutting	approx.	630 mm

b) Low enriched fuel assemblies

Enrichment in U-235		20 %
Chemical form of fuel		U_3O_8-Al-Cermet
Physical form of fuel		solid
Mass per fuel assembly (after cutting)		
- Aluminium	approx.	2190 g
- Uranium 235		200 ± 2 %
- Uranium total		1013 g
- Total mass	approx.	3200 g
Active length		600 ± 10 mm
Length after cutting	approx.	630 mm

Average Burnup in % U-235	40 - 50 %
Minimum cooling time	180 days
Peak thermal power per fuel assembly	120 W
Average thermal power per fuel assembly	60 W
Maximum activity per fuel assembly	4.1×10^4 Ci

<u>Amounts of fissionable fuel still present in spent fuel assemblies</u>
(based on 50 % burnup of U-235)

a) highly enriched fuel assemblies

U-235	85 g/assembly	2380 g/cask
Pu-239	0.68 g/assembly	19 g/cask
Pu-241	4.4×10^{-2} g/assembly	1.2 g/cask

b) low enriched fuel assemblies

U-235	100 g/assembly	2800 g/cask
Pu-239	4.7 g/assembly	131.6 g/cask
Pu-241	0.37 g/assembly	10.4 g/cask

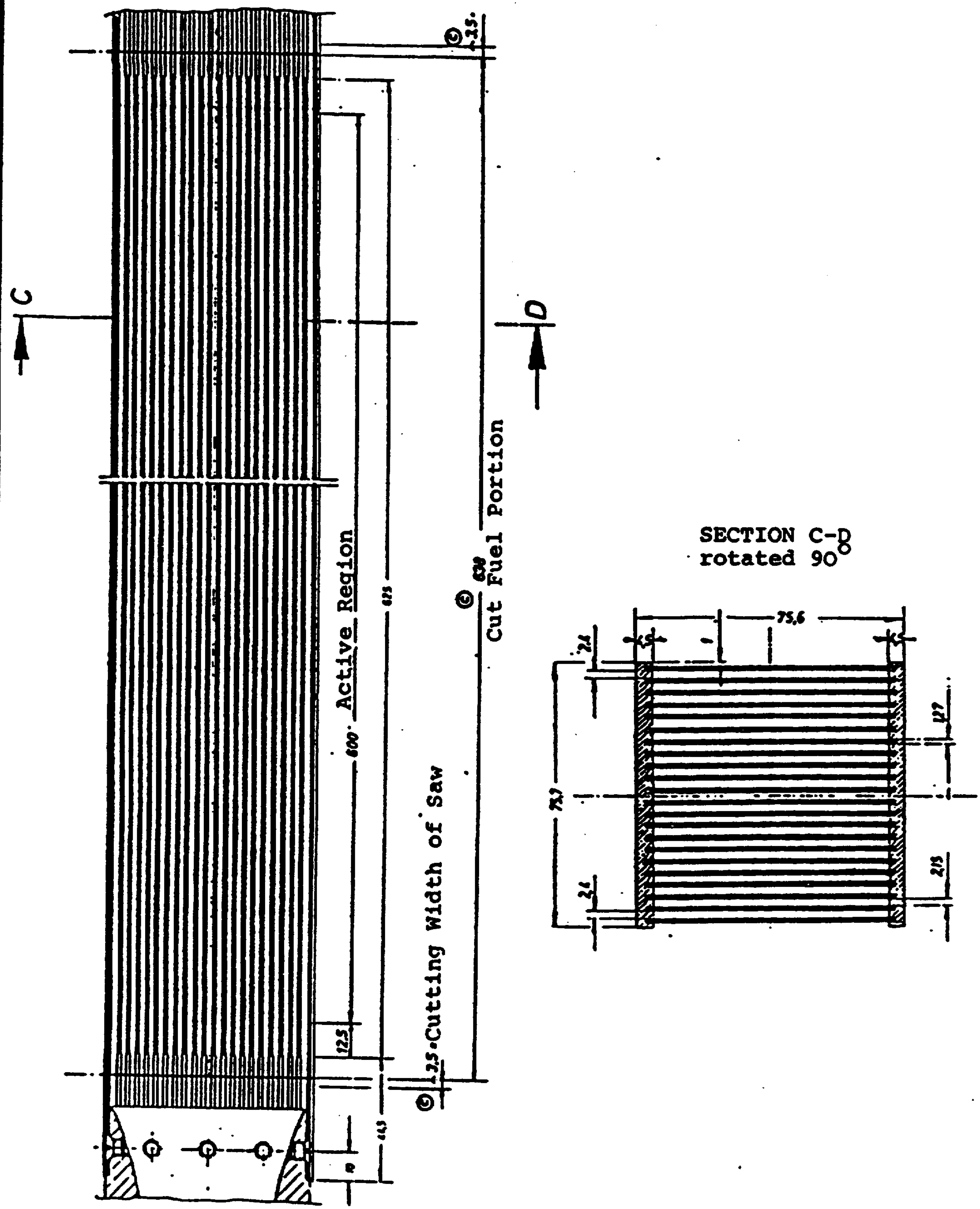
4.2 Square MTR Fuel Assemblies

Square MTR fuel assemblies, used in research reactors of the swimming-pool type, are largely standardized fuel assemblies, with the fuel contained in plates. The constructions are nearly the same in the square fuel assemblies used in the various research reactors in Germany, except for slight differences. In the older fuel assemblies the fuel is composed of a uranium- aluminum alloy. The newer fuel assemblies contain fuel in the form of a uranium-aluminum dispersion (UAl_x-Al).

The fuel part of a plate consists of a fuel region, sealed in aluminum and metallically connected. The fuel plates are fastened in grooves in the side plates. The construction of a square MTR fuel assembly is depicted in Fig. 4-2.

Before cask loading the top and bottom end fittings are separated, after which the fuel assemblies have a cut length of approx. 640 mm. In Tab. 4-3 data for the unirradiated and spent square MTR- fuel elements are listed. Beside the normal assemblies described here, there are material test assemblies and control rods, which contain less fuel. These fuel assemblies shall also be transported in the GNS 11; the nuclear properties are however the same as those of the normal fuel assemblies described.

In average burnup for square MTR-fuel assemblies is about 50% of the U-235, with respect to the U-235 content in unirradiated fuel assemblies. The cooling time of the fuel assemblies before transport in the GNS 11-cask is 6-12 months.



GNS

Square MTR-Fuel Assembly
(Type: MERLIN)

Fig. 4 - 2

a) Data for unirradiated square MTR-F/A

Enrichment in U-235		max. 93%
Chemical form of the fuel		UAl_x-Al-Cermet U/Al alloy
Physical form of the fuel		solid
Mass per fuel assembly (cut)		
- Aluminum	approx.	4,220 g
- Uranium-235	max.	264 g ± 1.5%
- Uranium - total	max.	330 g ± 1.5%
- Total mass	approx.	4,550 g
Active length		600 mm ±10mm
Cut length	approx.	640 mm
Cross section Type MERLIN		(75.6x75.7) mm
Type FRM, BER		(80.5x76.1) mm

b) Data for irradiated square MTR-F/A

Average Burn-up in % U-235	50
Minimum cooling time	180 Days
Peak thermal power per F/A	120 W
average thermal power per F/A	60 W
Maximum activity per F/A	2.7×10^4 Ci

Approx. amounts of fissionable fuel still in spent F/A's

U-235	132 g/assembly	4356 g/cask
Pu-239	0.98 g/assembly	32.3 g/cask
Pu-241	0.02 g/assembly	0.66 g/cask

GNS | Data for unirradiated and spent square MTR-fuel assemblies | Tab. 4 - 3

4.3 Cask Inventory

The GNS 11 transport cask can accommodate two different fuel baskets for tubular and square fuel-assemblies. Thereby, either up to 28 tubular or up to 33 square MTR assemblies can be transported. During cask loading, transport regulations for the maximum allowable dose rates and surface temperatures must be met. The maximum allowable activity- and heat-inventories per cask stem therefore from these regulations.

The essential data for the cask contents are summarized in Tab. 4-4. This data is based on an average burn-up of 50% of the fuel used (U-235). Before each transport the given data for the cask contents are determined based on the actual burn-up history and cooling time; thereby, compliance of the limiting dose-rate values and temperatures is documented with measurements.

Max. Cask Inventory	21 Tubular F/A	28 Tubular F/A	26 Square F/A	33 Square F/A
Mass of U-235, g	4,285	5,712	7,020	8,910
Total F/A mass, kg	67.2	89.6	118.3	150.2
Thermal power, kW	1.6	1.6	1.6	1.6
Activity, Ci	$8.6\cdot10^5$	$1.15\cdot10^6$	$7.0\cdot10^5$	$8.9\cdot10^5$

5. Cask Design

5.1 Structural Design

The structural design covers all safety related parts of the packaging cask in compliance with the requirements for transport. This includes the computation of all considered loads, stresses and safety factors which are necessary to meet the transport standards for type B packages under normal operation and accident conditions. The cask drop from a height of 9 m is the structural design criteria for the GNS 11. The cask is designed for an average g-load of 250 g, which has been measured on prototype casks. These prototype casks have a design similar to the GNS 11 cask, and have identical impact limiters.

An experimental full scale test of the impact limiters was performed to verify mechanical and physical properties.

The GNS 11 consists five basic components which maintain the structural integrity and the safe confinement:

(1) Impact limiters, which protect the ends of the outer cask

(2) Outer shell with fire protection system (Secondary containment)

(3) Inner vessel (primary containment)

(4) Lid and seal system (double lids, double seals)

(5) Basket to keep the fuel assemblies in position and maintain criticality safety

The structure of the outer shell and inner vessel consists entirely of stainless steel (Type 304) materials. The annular region between the outer shell and the inner vessel is filled with lead. The lid housing consists of a thick-walled forging which welds directly to the inner and outer shells. A stainless steel lid is bolted with twenty-four bolts to the lid housing (forging).

5.1.1 Design Criteria (Allowwable Stresses)

The maximum allowable stresses used as design criteria for containment structures of the GNS 11 cask are listed in Tab. 5-1. The maximum allowable stresses used for the non-containment structures are listed in Tab. 5-2.

The material data used in the evaluation correspond to the design stress values, S_m, yield strengths, S_y, and ultimate strengths, S_u, given in the ASME code, Section III, Class I /Ref. 5-1/. Material properties and design stress intensity values, S_m, used in the structural analysis can be found in Tab. 5-5, Tab. 5-6 and Tab. 5-7 of Section 5.1.3.

Stress Category	CONTAINMENT STRUCTURE ALLOWABLE STRESSES	
	Normal Conditions	Accident Conditions
Primary Membrane Stress Intensity	S_m	Lesser of: 2.4 S_m 0.7 S_u
Primary Membrane + Bending Stress Intensity	1.5 S_m	Lesser of: 3.6 S_m S_u
Primary + Secondary Stress Intensity	3.0 S_m	Not Applicable
Bearing Stress	S_y	S_y for seal surfaces S_u elsewhere
Pure Shear Stress	0.6 S_m	Lesser of: 1.20 S_m 0.35 S_u

S_m = Design Stress Value
S_u = Ultimate Strength
S_y = Yield Strength

Stress Category	CONTAINMENT STRUCTURE ALLOWABLE STRESSES	
	Normal Conditions	Accident Conditions
Primary Membrane Stress Intensity	Greater of: S_m S_y	0.7 S_u
Primary Membrane + Bending Stress Intensity	Greater of:1.5 S_m S_y	S_u
Primary + Secondary Stress Intensity	Greater of:3.0 S_m S_y	Not Applicable
Bearing Stress	S_y	S_u
Pure Shear Stress	Greater of:0.6 S_m 0.6 S_y	0.35 S_u

S_m = Design Stress Value
S_u = Ultimate Strength
S_y = Yield Strength

5.1.2 Weights and Centers of Gravity

A list of total weight of the packaging and contents is tabulated in Tab. 5-3:

The total weight of the GNS 11 shipping cask including a maximum payload of 150 kg (330 lbs) and with impact limiters is 13,300 kg (29,300 lbs).

The cask is nearly symetrical, therefore, the center of gravity is very near the geometric center of the cask. The height of the center of gravity is 890 mm (35 in) from cask bottom.

5.1.3 Mechanical Properties of Materials

The only material used in the structural evaluation of the GNS 11 cask itself is austenitic stainless steel (Type 304). The material of construction for the impact limiter is carbon steel with wood inlays. The shielding material between outer shell and inner vessel is lead. In Tab. 5-4 a listing of materials used for the GNS 11 is given.

The material properties of the structural cask components (austenitic stainless steel) are presented in Tab. 5-5, Tab. 5-6 and Tab. 5-7. An operating temperature of 100 ^{o}C (212 ^{o}F) is considered for the cask structures. The lowest operating temperature considered in the structural evaluation is -40^{o}C (-40 ^{o}F).The properties of the structural cask material selected for GNS 11 are better than the minimum material data specified by ASME code.

Component	weight kg	weight lbs
1. Top impact limiter	700	1,540
2. Protective cover	180	400
3. Primary lid	1,000	2,200
4. Cask Body (total)	10,080	22,200
4.1 Outer shell	1,800	3,970
4.2 Forging (lid housing)	880	1,940
4.3 Inner vessel	600	1,320
4.4 Lead shielding	6,700	14,760
5. Bolts etc.	190	420
6. Baskets		
6.1 26 Square F/A	270	600
6.2 33 Square F/A	300	660
6.3 21 tubular F/A	240	530
6.4 28 tubular F/A	240	530
7. Fuel Assemblies (max.)	150	330
8. Bottom impact limiter	700	1,540
Total weight (loaded):	13,300	29,300

component	Material
1. Protection plate	Austenitic stainless steel
2. Primary lid	Austenitic stainless steel Material No. 1.4313 (see Tab. 5 - 6)
3. Cask body outer liner inner liner lid housing	Austenitic stainless steel Material No. 1.4541 DIN Standard 17 440 U.S equivalent: Type 304 (see Tab. 5 - 5)
4. Basket	Austenitic stainless steel same as cask body
5. Bolts	High-strength austenitic stainless steel Material No. 1.4313 U.S. equivalent:AISI 414 (see Tab. 5 - 6)
6. Impact Liniters	Spruce wood glued together boxed in steel Material designation: St 52-2 DIN Standard 1623/2 U.S. Standard ASTM A 440
7. Lead shielding	Cast lead Material No. 2.3085 DIN Standard 1719 U.S. Standard ASTM B 29
8. Gaskets	Silicon rubber, Viton

Austenitic stainless steel X 10 CrNiTi 189 (material No. 1.4541, DIN 17440)

Chemical composition (w/o):

C	Si	Mn	P	S	Cr	Ni	Ti
0.08	1.0	2.0	0.045	0.03	17-19	9-12	0.4

Thermal Conductivity: K = 14.7 W/mK (8.5 Btu/ $(hxft^2x^oF)$)

Specific Heat: Cp = 0.50 kJ/kg K (0.12 Btu/lb ^oF)

Density: ρ = 7.9 g/cm^3 (0.285 lb/ in^3)

Coefficient of thermal expansion (α):

T (^oC)	α (10^{-6} /^oC)	T (^oF)	α (10^{-6} / ^oF)
100 - 800	16 - 19	212 - 1472	8.92 - 10.59

Elastic Modulus E = 2.00 x 10^5 N/mm^2 (29 x 10^6 psi)

	Yield Strength ($R_{p0.2}$)		Ultimate Strength (R_m)		Allowable Stress (S_m)	
T(°C)	N/mm^2	KSI	N/mm^2	KSI	N/mm^2	KSI
RT*	205	29.7	500	72.5	136.7	19.8
50	190	27.6	463	67.1	126.7	18.4
100	176	25.5	429	62.2	117.3	17.0
150	165	23.9	402	58.3	110.0	15.9
200	155	22.5	378	54.8	103.3	15.0
250	145	21.0	354	51.3	96.7	14.0
300	136	19.7	332	48.1	90.7	13.1
350	130	189.	317	46.0	86.7	12.6
400	125	18.1	305	44.2	83.3	12.1

Material : X 5 Cr Ni 134

Material No.: 1.4313 (DIN 17330)

Similar to US AISI 414

Chemical composition (w/o):

C	Si	Mn	P	S	Cr	Ni	Mo	Co
0.05	0.3/	0.5/	0.03	0.03	12.6/	3.6/	0.3/	0.2
	0.6	1.0			13.9	4.5	0.7	

Thermal conductivity

k = 25.2 W/mK (14.6 Btu / (hxftx°F / ft)

Specific Heat

Cp = 0.46 kJ /kg K (0.11 Btu / lb °F)

Density

p = 7.8 g/cm^3 (0.282 lb/in^3)

Coefficient of thermal expansion ( ):

T (°C)	(10^{-6}/ °C)	T (°F)	(10^{-6}/ °C)
100 - 500	12.0 - 13.5	212 - 932	6.69 - 7.53

	Yield Strength ($R_{p0.2}$)		Ultimate Strength (R_m)		Lid Allowable (S_m)		Trunnion Allowable S_m (1/5 σ_{ult})	
T(°C)	N/mm²	KSI	N/mm²	KSI	N/mm²	KSI	N/mm²	KSI
RT*	635	92.1	780	113.1	260	37.7	156	22.62
100	600	87.0	695	100.8	232	33.6	139	20.2
150	585	84.8	680	98.6	227	32.9	136	19.7
200	570	82.7	665	96.4	222	32.1	133	19.3
250	555	80.5	650	94.3	217	31.4	130	18.9
300	540	78.3	635	92.1	212	30.7	127	18.42
350	525	76.1	620	89.9	207	29.9	124	17.98

A) Bolts for Trunnions
Material No. 1.4313; X 5 CrNi 134 (DIN 17440)
(similar to US AISI 414)

T °C	Yield Strength ($R_{p0.2}$) N/mm²	KSI	Ultimate Strength (R_m) N/mm²	KSI	Allowable (S_m) = 1/3 σ_y N/mm²	KSI
RT*	900	130.5	1000	145.0	300.0	43.5
100	810	117.5	900	130.5	270.0	39.16
150	800	116.0	890	129.1	266.7	38.66
200	780	113.1	870	126.2	260.0	37.69
300	750	108.8	840	128.1	250.0	36.26

B) Bolts for Lids
Material No. 1.4313; X 5 CrNi 134 (DIN 17440)
(similar to US AISI 414)

T °C	Yield Strength ($R_{p0.2}$) N/mm²	KSI	Ultimate Strength (R_m) N/mm²	KSI	Allowable (S_m) = 1/3 σ_y N/mm²	KSI
RT*	685	99.3	780	113.1	228.3	33.1
100	650	94.3	745	108.0	216.7	31.4
150	635	92.1	730	105.9	211.7	30.7
200	620	89.9	715	103.7	206.7	30.0
300	590	85.6	685	99.3	196.7	28.5

* RT = Room temperature

5.1.4 Structural Analysis

A detailed structural analysis has been performes considering stresses in the cask materials during normal conditions of transport as well as hypothetical accident conditions

The stress analysis is based upon the following loads during normal conditions.

Cask component	g-loads	Gage pressure (bar)
Cask body	-	1
Primary lid bolts	3	1
Primary lid	3	1
Tunnions	1.77	-
Tunnion bolts	1.77	-
Fuel basket	3	-

The stress analysis for the cask components during hypothetical accident conditions is based upon the following loads:

Cask component	g-loads		Gage pressure (bar)
	vertical	horizontal	
Cask body	250	155	1
Primary lid bolts	250	155	1
Fuel basket	250	155	-

The boundary conditions during a 9 m drop were considered for the cask body stress analysis. The drop analysis of the cask side wall is the worst case for the GNS 11 cask. The results of the stress analysis show that the cask integrity is maintained.

The design stress values, S_m, used in the stress analysis are listed in Tab. 5-5, Tab. 5-6 and Tab. 5-7. The allowable stresses for normal conditions of transport are given as follows (100 ^{o}C = 212 ^{o}F):

1. Cask Body and Basket

   S_m is the lower of 2/3 yield or
   1/3 tensile strength,
   S_m = 117.3 N/mm^2 = 17 ksi

2. Lifting device (Trunnions)

   S_m is the lower of 1/3 yield or
   1/5 tensile,
   S_m = 139 N/mm^2 = 20.2 ksi

3. Bolts (ASME, Section III, NB 3232)

   S_m is 1/3 yield
   A) Trunnion Bolts: S_m = 270 N/mm^2 = 39 ksi
   B) Lid Bolts: S_m = 217 N/mm^2 = 31.4 ksi

The stress analysis for the primary lid was performed using the plate thoery by Kirchhoff. As a result of the analysis the design stress will be compared with the actual stress due to the different normal and accident conditions.

The cask trunnion design was proofed using a calculation method which is in compliance with the German KTA 3902 Guide for the design of lifting devices for nuclaer power plants.

The design of the lid bolts is essentially based on the tensioning theory for bolt fastening under high loads as set forth in the guidelines for Association of German Engineers (VDI) /Ref. 5-2/.

A structural fuel basket analysis for the different baskets has been performed. The results show that no damage of the basket will occur and that criticality safety is maintained.

A sumary of the results of the stress analysis performed for the cask components are shown in Tab. 5-8.

Component	Normal Conditions max. Stress N/mm²	Normal Conditions SF	Accident max. Stress N/mm²	Accident SF
Inner vessel (bottom)	6.6	27	294	1.4
Outer shell (welds)	2	88	-	-
Primary lid	2.4	87	312	1.6
Bolts				
- Lid	193	1.7	5o1	1.5
- Trunnion	-	-	-	-
Basket	-	-	65	6. 5

SF = Safety Factor compared to allowable stress

5.2 Shielding

The spent MTR-fuel assemblies require gamma shielding only. The amount of neutron-emitting materials in the loaded GNS 11 is so small that radiation exposure due to neutron radiation is of no practical importance. The neutron dose rate is therefore not calculated.

The gamma shielding is provided by the steel/lead/steel shielding of the cask body, the stainless steel lids and protection cover as well as by the impact limiters.

5.2.1 Shielding Reqiurements

The max. allowable dose rate of loaded cask or freight container with two cask is given by the international regulations for shipment of radioactive material:

2 m Sv/h (200 mrem/h)	at external package surface
0.1 m Sv/h (10 mrem/h)	at any point 2 Meter from outer surface of the transport vehicle

The fulfillment of the shielding requirements will be checked prior to each shipment.

5.2.2 Shielding Analysis

Basis for the shielding design are burn-up calculations using the Oak Ridge computer code ORIGEN/Ref.5-3/. The photon spectrum and photon sources for MTR fuel assemblies are listed in Tab. 5-9. The figures in Tab. 5-9 are presented for both fuel types and based on a cooling time of 180 days and an average burnup of 50 % U-235.

The following densities for the shielding material are used in the shielding analysis:

Stainless steel (body, basket, lid)	7.85 g/cm^3
Lead (cask body)	11.0 g/cm^3
Wood (impact limiter)	0.6 g/cm^3
Source (F/A with basket)	1.5 g/cm^3

A cylindrical source geometry with cylindrical shielding is used for the shielding calculation. The computational model is described in /Ref. 5-4/. Dose buildup factors are taken from /Ref. 5-5/ and the gamma ray flux-to-dose rate conversion factors are obtained from /Ref. 5-6/, which is identical to ANSI/ANS - 6.1.1.

The results of the shielding calculations are sumarized in Tab. 5-10.

Energy	Photons per sec		
	1 F/A	21 F/A	28 F/A
0.30	3.85 10 E13	7.52 10 E14	1.08 10 E15
0.63	5.14 10 E14	1.08 10 E16	1.44 10 E16
1.10	2.56 10 E12	5.38 10 E13	7.17 10 E13
1.55	8.29 10 E11	1.74 10 E13	2.32 10 E13
1.99	1.38 10 E12	2.90 10 E13	3.86 10 E13
2.38	2.77 10 E10	5.82 10 E11	7.76 10 E11
2.75	1.52 10 E09	3.19 10 E10	4.62 10 E10
Total	5.60 10 E14	1.17 10 E16	1.60 10 E16

A) Photon Sources in tubular MTR-F/A
(Cooling time 180 days)

Energy	Photons per sec		
	1 F/A	26 F/A	33 F/A
0.30	4.20 10 E13	1.09 10 E15	1.38 10 E15
0.63	4.15 10 E14	1.08 10 E16	1.37 10 E16
1.10	2.94 10 E12	7.64 10 E13	9.70 10 E13
1.55	9.36 10 E11	2.43 10 E13	3.09 10 E13
1.99	1.72 10 E12	4.47 10 E13	5.67 10 E13
2.38	3.27 10 E10	8.50 10 E11	1.08 10 E12
2.75	1.91 10 E09	4.97 10 E10	6.30 10 E10
Total	4.60 10 E14	1.20 10 E16	1.50 10 E16

B) Photon Sources in square MTR-F/A
(Cooling time 180 days)

Distance from cask surface m	Dose Rate, mrem/h		
	Lid	Bottom	Side wall
0	77.8	21.4	75.0
1	19.5	6.1	14.4
2	8.2	2.5	5.4

Remarks

The dose rate calculations are based on a GNS 11 loaded with 33 square F/A and 180 days cooling time, 50 % U-235 burn up

5.3 Thermal Design

The thermal loading conditions taken into consideration for the cask design are based on the IAEA "Regulations for the Safe Transport of Radioactive Materials" (1973) and the U.S. Nuclear Regulatory Guide 7.8 "Load Combinations for the Structural Analysis of Shipping Casks" (1977). The following thermal loading conditions for normal operation and accident conditions are considered:

Operating Conditions

(1) Ambient air temperature = 100° F = 38° C
(2) Thermal power = 1.6 kW (single cask)
3.2 kW (two casks in a freight container)
(3) Solar insolation = 2950 Btu/ft^2 during a 12 hour day

Accident Conditions

(1) Thermal power = 1.6 kW (single cask)
(2) 30 minute fire at 1,475 °F = 800° C

The decay heat of the fuel elements is conducted through the caskbody and transferred to the air surrounding the cask by natural convection and radiation from the exterior surface. To determine the heat removal capacity of the cask during normal operation several thermal-load tests on a prototype cask were conducted. The results of these prototype thermal-load tests can be applied to the GNS 11. Even though the dimensions differ somewhat the basic cask construction method and materials are identical.

The calculation of the heat removal capability of a GNS 11 cask in a vertical position is based on the following boundary conditions and material properties:

- Ambient air temperature,
  + 38° C (100° F)

- max. cask surface temperature 82° C (180° F)

- Thermal conductivity k = 35 W/m- K

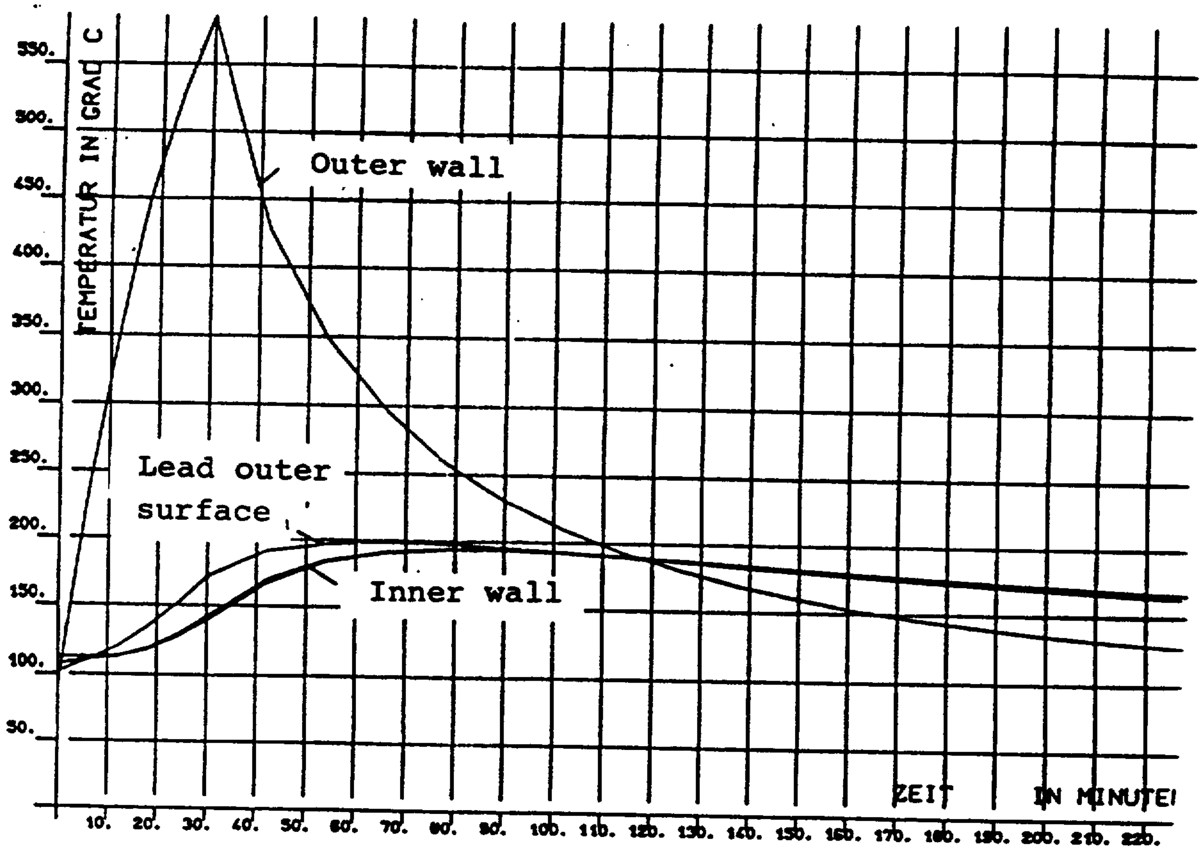
- Outer cask wall emissivity,
  $\varepsilon = 0.80$

The method of calculating the heat transfer capability of the cask body is described in /Ref. 5-7/. The total heat transferred from the cask is calculated for the above boundary conditions as:

1.6 kW	for a single cask
3.2 kW	for two GNS 11 casks in a freight container

The most severe accident with a thermal load on the cask is a fire where the cask is standing in the middle of the fire. The cask per se is made of noncombustible material. The GNS 11-casks are designed to withstand fires in accordance with transport test conditions (30 min. fire; 800° C).

A summary of temperature calculations during an accidental fire is presented in Tab. 5-11. The temperature in the cask wall and for the seal region vs. time during a 30 minute, 800° C fire is shown in Fig. 5-1.



GNS	Cask Temperatures vs Time during a Fire Test (800 °C, 30 min)	Fig. 5-1

Cask Position	max. Temperature °C	max. Temperature °F	Time after the start of fire/ Hours
Cask outer surface	580	1076	0.5
Cask inner wall	180	356	1.5
Lead (outer surface)	200	392	1.2
Seal region	130	266	4.0

5.4 Containment

For normal shipment conditions, an activity leak rate of 10^{-6} A_2/hr is not exceeded. The A_2 - values are given in Section IV of the IAEA Safety Series No. 6. The integral leak rate of the GNS 11 is less than 10^{-4} mbar l/sec for helium under standard conditions. This leak rate corresponds to an activity release much less than the permissible value of 10^{-3} A_2/week for Typ B(U) shipping containers.

Prior to the cask shipment a leak test of the GNS 11 will be performed. The water from the cask cavity is removed and a pressure below atomospheric pressure is established in the cask atomsphere.

References Section 5

/Ref. 5-1/ ASME Boiler and Pressure Vessel Code,
Section III, Division 1,
1983 Edition plus Addenda

/Ref. 5-2/ VDI 2230
VDI-Association of German Engineers
Tensioning Theory for Bolts Fastenings
under High Loads
October 1977

/Ref. 5-3/ M.J. Bell
ORIGEN - The Isotope Generation and Depletion
Code - ORNL-4628 (May 1973)

/Ref. 5-4/ R.G. Jaeger et. al.
Engineering Compendium on Radiation Shielding
Vol. 1, Shielding Fundamentals and Methods
Springer Verlag, Berlin, Heidelberg, New York

/Ref. 5-5/ H. Goldstein
Fundamental Aspects of Reactor Shielding
Page 368, Appendix D

/Ref. 5-6/ ESIS Newsletter 34, July 1980, P. 9, Tab. 9.10
Gamma Ray Flux to Dose Rate Conversion Factors

/Ref. 5-7/ Heat Atlas, VDI-Wärmeatlas
(Association of German Engineers)

6. Nuclear Criticality Safety

6.1 Control Methods for Prevention of Criticality

The CASTOR MTR cask holds either up to 28 tubular fuel assemblies of the DIDO-type or up to 33 square F/A of the MERLIN-type. To prevent criticality, a basket made of stainless steel separates the fuel assemblies. A wall thickness of 23-29 cm on the top, bottom and sides reduces reactivity.

6.2 Error Contingency Criteria

The design of the cask is such that the highest neutron multiplication factor that occurs is less than 0.95. All the fuel assemblies are assumed to be in a fresh, undepleted condition.

In order to be conservative, the amount of ^{235}U was over-estimated in the criticality calculations. Furthermore, the length of the fuel assemblies in the model was extended out of the fuel basket in the cavity. Also, all parts of the fuel assemblies except for the UO_2 fuel and the aluminium cladding were modelled with water for simplicity's sake, thus increasing the H_2O-content and the reactivity of the fuel.

The criticality analysis considers infinite closely packed cask arrays (100% reflection at the outer cask boundary). The verification analysis described under section 6.3 is done with internationally used codes which have been successfully tested in numerous benchmarks.

6.3 Verification Analysis

The theoretical verification analyses for the criticality safety of the GNS 11 cask were done with the SCALE Code System. A detailed description of the criticality analysis is given in the GNS report No. GNS B 38/86 E.

A summary of the results of the criticality analyses is provided in the table below:

Basket Type	$k_{eff} + 2\sigma$
26 square F/A	0.8790
33 square F/A	0.91018
21 tubular F/A	0.7880
28 tubular F/A	0.8660

References for Section 6

/Ref. 6-1/ Criticality Calculation for the GNS 11 Transport Cask, GNS B 38/86 E, October 1986