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TOPICAL SAFETY ANALYSIS REPORT FOR THE CASTOR Ic CASK INDEPENDENT SPENT FUEL STORAGE INSTALLATION (DRY STORAGE)

by

GNS Gesellschaft für Nuklear - Service mbH

Revision 1, November 1982

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1. Introduction and General Description of Installation

1.1 Introduction

1.1.1 General

This report is intended to address the safety aspects of storing spent fuel in casks made of cast modular iron of the CASTOR*-type design. It is a topical report in the sense that it deals essentially only with the cask portion of the storage facility.
This segregation is logical since the cask provides all the necessary safety features pursuant to the requirements for an independent spent fuel storage installation (ISFSI), namely:

- containment
- shielding
- criticality control
- heat removal

both under normal and accident conditions. Since cask storage is a modular-type system, it is sufficient to analyze the safety of one module and then consider eventual interactions between/among modules. The casks as such constitute the dry storage installation and thereby require no secondary safety preserving systems.
Any buildings present serve practical purposes such as weather protection, administration space, space for social purposes, space for radiation protection equipment and service, etc.
For the definition of the required control zone and for the purpose of access control a frame and/or buildings (if existing) will be used. Accordingly, the analysis of the cask forms a basic document that can be subsequently expanded to include facility-related safety analyses corresponding to that required for a site-specific storage license application under 10 CFR Part 72.15(a).

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* CASTOR is an acronym that designates the GNS family of dual-purpose (storage and transport capability) casks.
(CASTOR = Cast Iron Cask for Storage and Transport of Radioactive Material)

With this in perspective, the information and analyses provided in this report have been arranged in a format corresponding to that specified in the USNRC's Regulatory Guide 3.48, "Standard Format and Content for the Safety Analysis Report for an Independent Spent Fuel Storage Installation (Dry Storage)", dated October 1981.

A further feature of this report is that it is generic in nature. Although this topical report concentrates on one special cask for storing 16 BWR fuel elements, the CASTOR Ic, the main design characteristics presented under Sections 3, 4, 5 and 8 are applicable to all the different casks of the complete CASTOR-family as well as to a broad range of site parameters. As such, the report applies equally well to one cask or a group of casks of variable design and configuration that may or may not include a cover structure (building).

This topical report furthermore concentrates on an at the reactor site (AR) storage installation only. Nevertheless the principle for dry storing of spent fuel in casks is the same for an AR and AFR (away from reactor) ISFSI. For illustration purposes, however, information relating specifically to the German Wuergassen (AR ISFSI) as well as Gorleben (AFR ISFSI) storage installations is presented in Appendices of this report.

1.1.2 Principal Design Features of Installation

Pursuant to 10 CFR Part 72.15(a) the following sections provide information relative to the design of the cask storage installation.

1.1.2.1 Type of Dry Storage Mode

The dry cask storage mode consists of storing spent fuel in a sealed cask constructed principally of nodular cast iron. The GNS concept of dry storage of spent fuel, in contrast to that at conventional wet storage sites, provides for modular storage in shipping casks (CASTOR casks) specially developed for this purpose.

Through its design, the cask ensures structural integrity and sub-criticality while serving simultaneously as shielding and a barrier for the retention of radioactive materials. Decay heat is removed via the cask surface to the environment by natural convection and radiation.

1.1.2.2 Description of Installation

The installation for storing spent fuel consists of one or more CASTOR casks.

Typical configurations of the casks in a dry cask storage installation are shown in Fig. 1.1-1, where a single cask, line array - and rectangular array - of casks are shown.

The casks are free standing in an upright vertical position and are configured in appropriately spaced modular arrays on a concrete slab (see Fig. 1.1-1).

The casks, which were developed by the Gesellschaft für Nuklear-Service mbH (GNS), are designed for the storage and shipment of irradiated spent fuel-assemblies.
The casks fulfill the IAEA international specifications for Type B(U) packaging correspond to Nuclear Safety Fissile Class I.

As noted in Section 1.1 above, the primary emphasis in this report is on the CASTOR Ic cask which has a unit capacity of 16 BWR fuel assemblies.

The CASTOR cask consists of a thick-walled casting which is sealed with a multiple-cover system. The cover system is fitted with a leak-testing device meeting the same safety standard. The system has a multiple seal consisting of metal and radiation-resistant elastomer o-rings. The casting (cask body) has integrated cooling fins on its outside; these serve to remove the decay heat of the fuel-assemblies via radiation and natural convection.

The inside of the cask, including the sealing surfaces, has a nickel coating for corrosion protection. On the outside, the cask is protected by an epoxy resin coating in the fin area and nickel elsewhere. The fuel-assemblies are positioned in a fuel basket constructed of borated stainless steel. The internal heat-transfer medium is an inert gas (helium), which further serves to inhibit corrosion.
Gamma and neutron radiation is shielded by the cast iron wall of the cask, which includes sections of neutron moderating material.
For a cooling time of one year, the shielding provided results in a maximum dose rate at the surface of the shipping cask of less than 30 mrem/hr (consisting of roughly equal neutron and gamma dose rates).

Safety against criticality (i.e. subcriticality), for a single cask as well as for an unlimited number of casks stored at the closest spacing, can be assured even under the most unfavorable conditions.
The thick-walled shipping cask and its combined cover-seal system offer protection against the same outside interventions as are considered in the design of nuclear power plants.

The casks may or may not be protected against weathering effects (snow, rain, solar load, etc.) by a storage building. In case a building is present air circulation is assured through appropriate openings in the roof and/or walls. In the case of multiple casks in arrays the interference with heat dissipation leads to an increased cask surface temperature, in the range of 8°C to 10°C above the surface temperature of a single cask with the same heat load.

If a further reduction of the direct radiation from the storage casks due to site specific requirements is necessary, normal-concrete shielding can be integrated into a building wall or an earth wall surrounding the storage area.

1.1.2.3 Location of Installation

Not applicable.

1.1.2.4 Capacity of the Installation

The reference cask, CASTOR Ic, has a unit capacity of 16 BWR fuel assemblies. Fuel data and cask capacities for different types of BWR fuel are listed in Tab. 1.1-1.

The total storage capacity of a Cask Type Independent Spent Fuel Storage Installation (ISFSI) varies with the number of casks. That is, the capacity may vary from as little as one LWR fuel assembly or portion thereof in one cask to as many as thousands of LWR fuel assemblies or the equivalent in hundreds of casks.

1.1.2.5 Spent Fuel Identification

The type of spent fuel considered herein for storage in CASTOR Ic casks is LWR fuel of the BWR type. Fig. 1.1-2 gives the typical design of a BWR fuel assembly. LWR fuel is made of short cylinders (pellets) of high-fired ceramic uranium dioxide (UO_2). Depending upon the specific BWR-reactor design, these pellets are in the order of 1.25 to 1.45 cm in diameter and about 1.50 cm long. Typically a 366 cm - long stack or about 250 of these pellets are loaded and hermetically sealed into a zirconium alloy tube.

Fuel rods are assembled into bundles in a square array, each spaced and supported by grid structures. The assembly has a bottom fitting and a top fitting as a handle.

Typically, a BWR assembly (see Fig. 1.1-2) consists of a 7 x 7 (49 total) or 8 x 8 (64 total) array of individual fuel rods.

The dimensions of different BWR types to be stored in the CASTOR Ic cask are given in Tab. 1.1 - 1. Usually the overall dimensions are approximately 14 cm square by 432 cm long. Each assembly contains about 200 kilograms of uranium in the form of UO_2.

A description of the physical, thermal and radiological characteristics of the spent fuel to be stored in the CASTOR Ic cask is given in Section 3.1.3.

1.1.2.6 Waste Products

In an AR ISFSI there are no handling procedures foreseen which create radioactive waste products. Furthermore there are no systems of the ISFSI creating waste products during operation of the dry cask storage.

1.1.2.7 Corporate Entities

The shareholders of Gesellschaft für Nuklear-Service mbH, GNS, are:

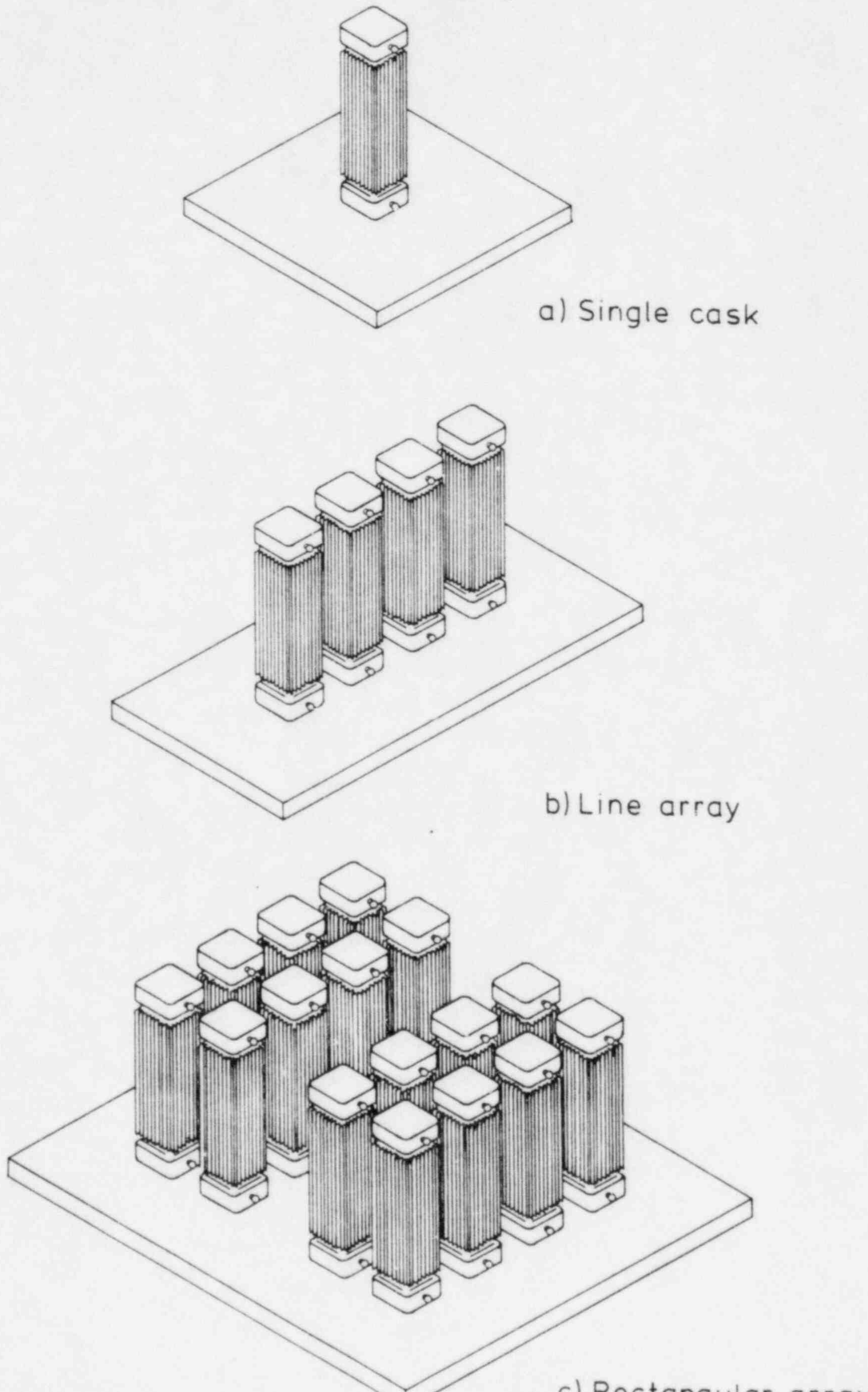
STEAG, Kernenergie GmbH	45 %
VKR, VEBA KRAFTWERK RUHR	27.5 %
DWK, Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrenn-stoffen mbH	27.5 %

STEAG Kernenergie is working in the nuclear fuel cycle and performs design and project work in the planning and construction of nuclear facilities.

VKR, the owner and operator of several coal-fired power stations, is a fully owned subsidiary of the VEBA concern which owns several nuclear power stations.

DWK was founded by the twelve leading German (nuclear based) utilities for the construction of the German Integrated Nuclear Fuel Cycle Center, and operates the small-scale reprocessing facility, WAK, in Karlsruhe.

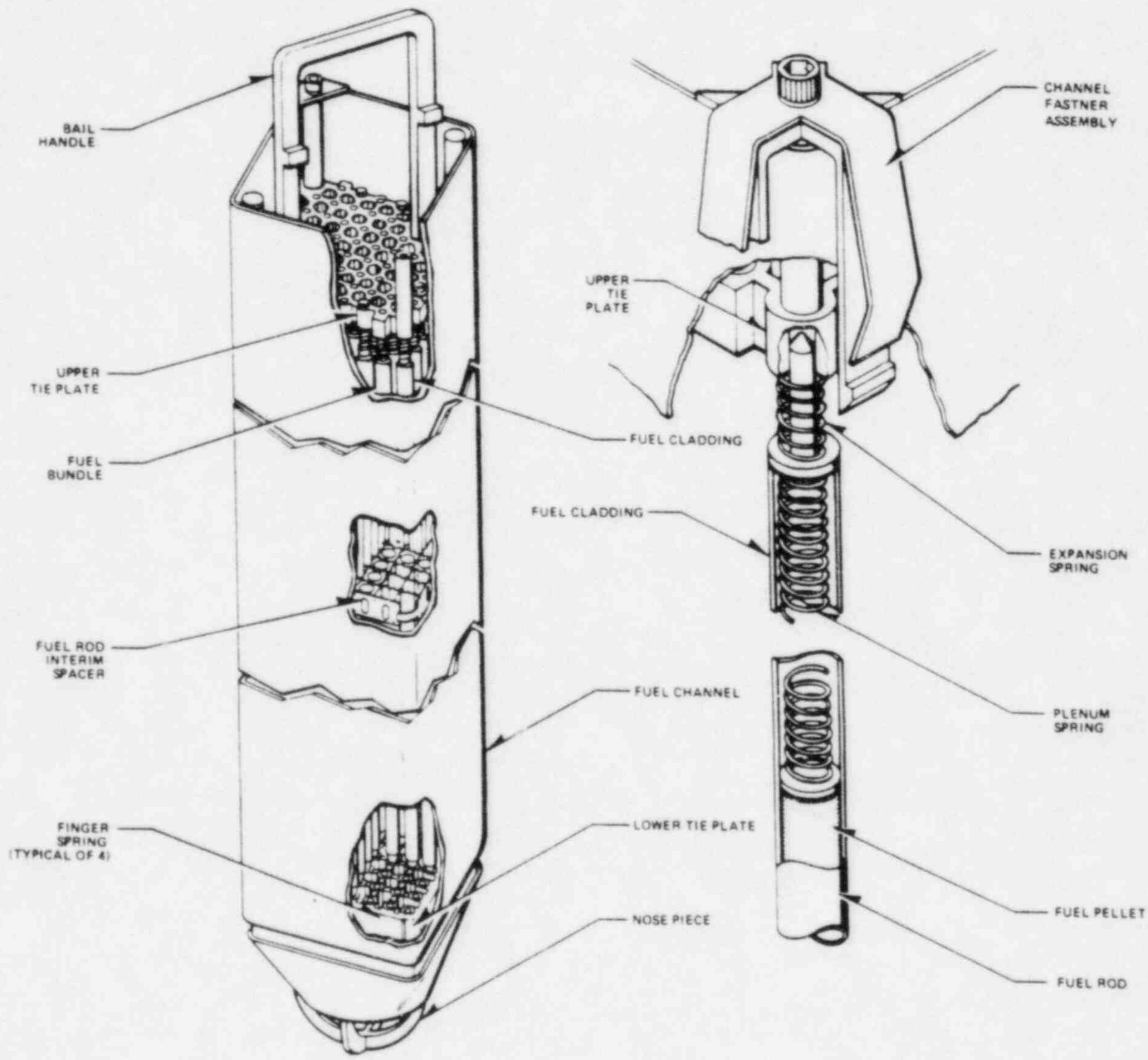
These three companies have joined their efforts and interests in the fields of waste conditioning, associated engineering and services, cask development and transportation through GNS.



GNS

Different Types of a Cask Storage Installation

Fig. 1.1 - 1



GNS	BWR Fuel Assembly	Fig. 1.1 - 2

GNS

Characteristics of BWR Fuel

Parameter		Type 1	Type 2	Type 3
Overall assembly length	(cm)	435	435	447
Active fuel length	(cm)	366	366	376
Nominal envelope	(cm)	13.8 x 13.8	13.9 x 13.9	13.9 x 13.9
Fuel rod array		7 x 7	8 x 8	8 x 8
Fuel rod O.D.	(cm)	1.45	1.25	1.25
Total weight per assembly	(kg)	310	275	279
Total fuel weight per cask (16 ass.)	(kg)	4960	4400	4464
Avg wt U per assembly	(kg)	195	210	185
Avg wt U per cask (16 ass.)	(kg)	3120	3360	2960

Tab. 1.1 - 1

1.2 General Description of Installation

1.2.1 Principal Characteristics of the Site

Site specific requirements are not relevant to a Topical Safety Analysis Report. However, the design of a CASTOR cask has been chosen to envelope a variety of sites in such a way that the casks are able to survive extreme actions from outside such as fires at 800°C and falls from a height of 9 m onto a rigid foundation without damage. In addition, tests have shown that the CASTOR casks can withstand all the forces, accelerations, and temperatures that can result from tornado-generated missiles, earthquakes, floods, pressure waves, and fires including their secondary effects.

Due to the fact that this report concentrates on AR storage only, the reactor site criteria of 10 CFR Part 100 can be applied for an ISFSI.

1.2.2 Principal Design Criteria

The cask structures are designed, fabricated, and tested according to the KTA Rules (body of rules for requirements on nuclear facilities and components) and the ASME Code. The quality assurance (QA) system covers every component of the cask in accordance with its relevance to safety (see Chapter 11). The cask body and components are designed and tested by experiment such that they can withstand the effects of natural phenomena such as earthquakes (with a horizontal ground acceleration of at least 0.25 g, which is far below the acceleration measured in free drop tests) tornados, lightning, huricanes, floods, etc. without impairing their capability to perform their safety function.

The cask structures can withstand forces resulting from cask accelerations in the range of 100 g. The cask represents a water tight and leak tight containment.

The design for criticality safety is done according to DIN 25 428 and according to the transportation regulations. The permissible multiplication factor k for the storage of fuel assemblies is ≤ 0.95 including statistical uncertainties.

The integrity of the fuel cladding is assured under the given storage conditions via the safe, passive removal of decay heat form the cask(s). The heat-removal capacity of the CASTOR Ic cask is in the range of 30 kW. This is sufficient to keep the cladding-tube temperatures far below the temperatures during normal reactor operation.

The radiation protection system consists of

a) Gamma-shielding in the range of 34 to 38 cm of cast iron (which, due to its carbon content functions secondarily as a neutron shield)

b) Neutron-shielding in the form of an organic neutron moderator material.

Tab. 1.2-1 and Tab. 1.2-2 summarize the principal design characteristics of the CASTOR Ic cask.

1.2.3 Operating Systems

Not applicable to a dry cask ISFSI.

1.2.4 Structural Features

The main components of a CASTOR cask are

- the cask body constructed of cast nodular iron
- cast-on cooling fins at the cask surface and integrated neutron moderator rods inside the cask wall
- the fuel basket made of stainless steel
- multiple sealing system.
- the cast lids constructed of stainless steel

In Fig. 1.2-1 a schematic of the CASTOR Ic is given. Fig. 1.2-2 shows a cross-section of the cask; and in Fig. 1.2-3 the double lid system of the CASTOR cask is shown.

The shock absorber shown in Fig. 1.2-4 is removed when the cask is installed as a storage cask. A shock absorber is present only if transportation is required.

Fig. 1.2 - 4, through Fig 1.2 - 7 show photographs of a CASTOR cask model. In Fig 1.2 - 8 a photograph of an existing CASTOR Ic is given. The main dimensions of the CASTOR Ic cask are listed in Tab. 1.2 - 1.

The cask (Fig. 1.2-1) consists of a thick-walled casting provided with integral cooling fins on the outside which serve to remove the decay heat of the fuel assemblies.
Inside the casting a fuel basket accepts the fuel assemblies. The cask is closed with a cover system and is filled with helium after closure.

The body of the cask (Fig. 1.2-4) is cast in one piece. The material used is nodular-graphite cast iron (GGG 40). This material exhibits good ductility and high resistance to corrosion. In the area of the fuel assemblies, the body has cooling fins on the outside; four trunnions, two each at the top and bottom ends, are attached with bolts.
At the top end of the cask there is a connection for rinsing, cleaning and drying of the interior during loading and unloading procedures at the nuclear power plants (see Fig. 1.2-2 and Fig. 1.2-3). The inlet and outlet channel runs inside the wall of the body; it has one end at the top and the other end at the bottom of the inside of the cask. Gas intake and exhaust are via the valve in the shield cover (primary cover).

As can be seen from Fig. 1.2-3 the CASTOR cask has two covers and a protective cover plate.

The shield cover (primary cover) is constructed of stainless steel. The overall thickness is about 340 mm. It is fastened to the body with bolts. The inlet and outlet hole and the gas inlet and exhaust opening, along with their closures, are located in the shield cover.

The secondary cover is also made of stainless steel. The overall thickness is about 130 mm, including neutron-moderating material. It is bolted to the body.

The protective cover plate is made of carbon steel and is bolted to the cask body. It serves as a general mechanical protection against actions from outside, as well as against dust and humidity.

A combination of multiple elastomeric and metallic seals for each cover guarantee a high level of leak tightness.
A more detailed description of the closing system and confinement barriers is given in Chapter 3.3.

The fuel basket accepts the spent fuel assemblies and, by way of design, ensures that at no time will criticality occur. In addition, it ensures exact positioning of the individual fuel assemblies. It is of welded construction and is made of borated stainless steel.

1.2.5 Passive Decay Heat Dissipation System

In wet storage of spent fuel assemblies in the storage pool of the reactor building decay heat is dissipated to the pool water from which the heat is extracted by a cooling system. During dry storage of spent fuel in shipping casks no active systems for the dissipation of the decay heat are necessary. The decay heat is taken up by the casks and transferred to the surrounding air by natural convection and radiation.
In a thermal-load test on a test cask it was found that the CASTOR cask has a heat-removal capacity of 30 kW.

If a storage building is present the heat removal takes place also by natural convection. The heated air surrounding the casks rises and exits through air outlets in the roof. Outside air flows through air inlets in the side walls of the building.

Extensive theoretical and experimental investigations have been performed to confirm the temperature field of a single CASTOR cask and of cask arrays. In Section 5.1.3.6 the heat transfer design of a CASTOR Ic cask is described.

1.2.6 Fuel Handling

Not applicable to AR ISFSI.

1.2.7 Special Features that are Safety Related

The safety related features of the storage casks are:

- Cask tightness and barrier against activity release

- Structural integrity and stability as a safe confinement against external impacts and cask handling failures

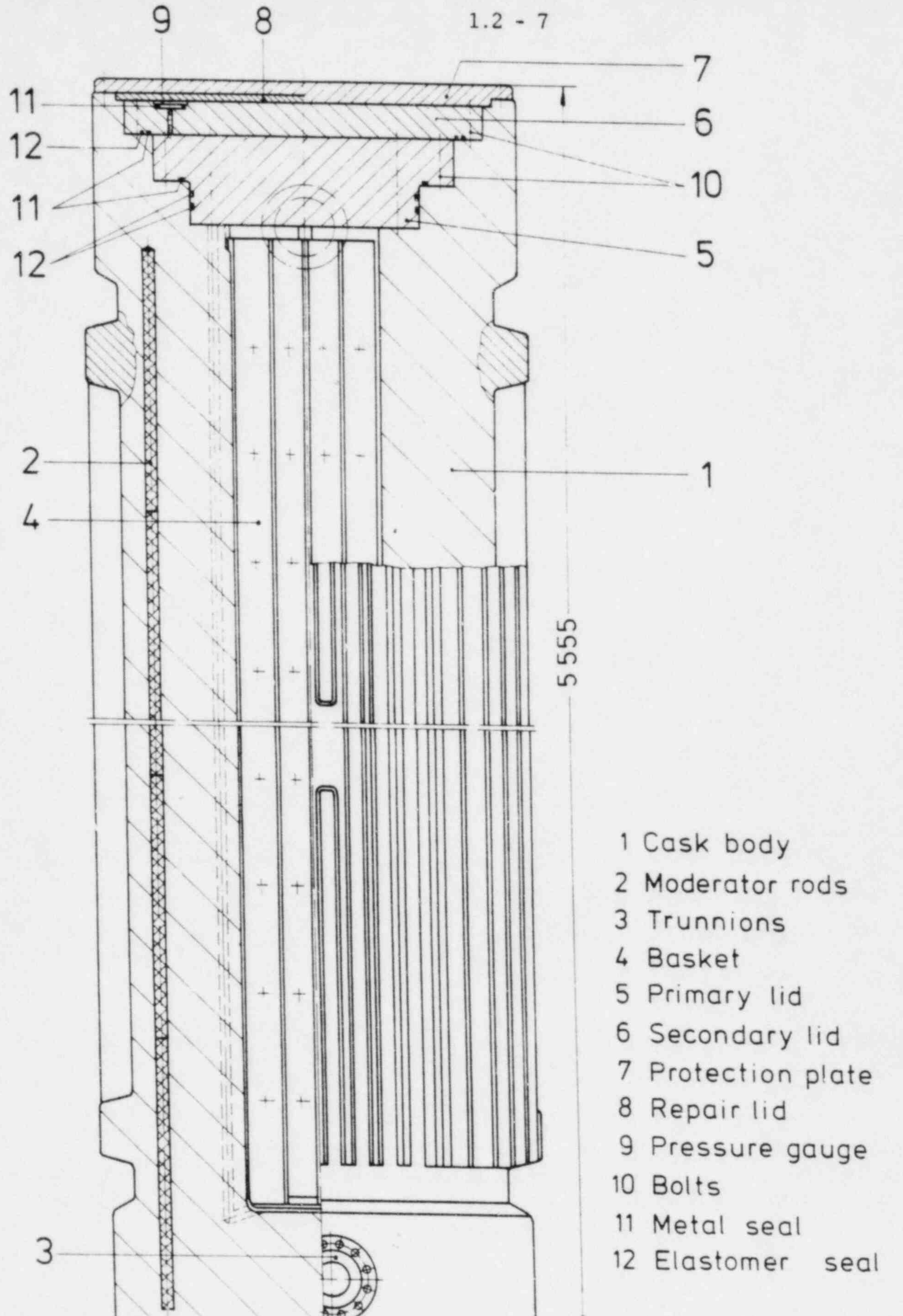
- Criticality safety to assure that the fuel inside the cask remains subcritical and that arrangements of an infinite number of casks can be stored in close proximity

- Radiation protection based on sufficient gamma and neutron shielding such that no additional shielding is necessary for transportation and storage

- Passive heat removal of the spent fuel decay heat by natural convection

The above listed safety related features of the cask are the design bases for the cask design. A more detailed description of the safety related cask functions is given in Chapter 3.

Tab. 1.2-1 and 1.2-2 summarize the main design characteristics and values according to the listed safety related cask features.



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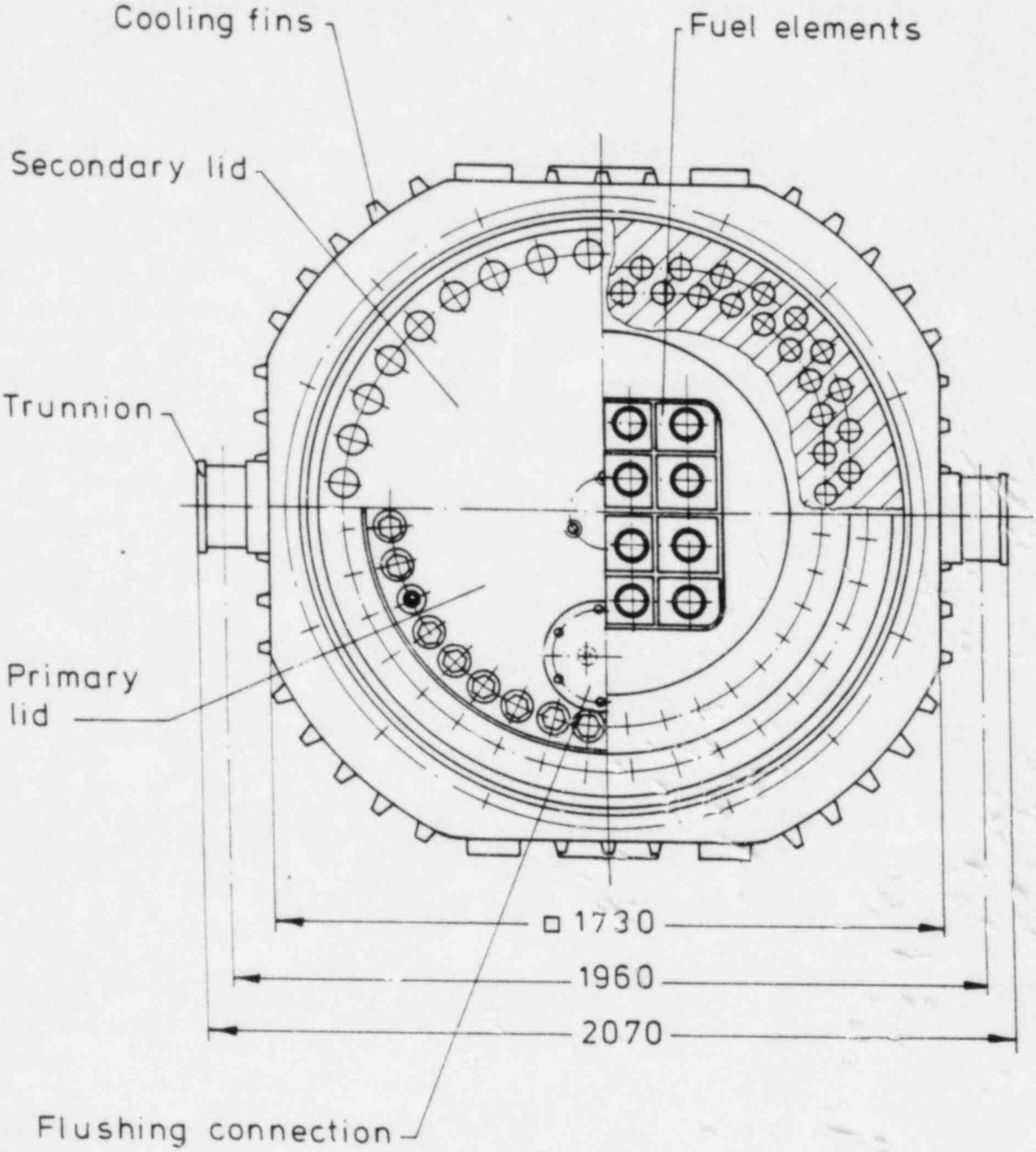
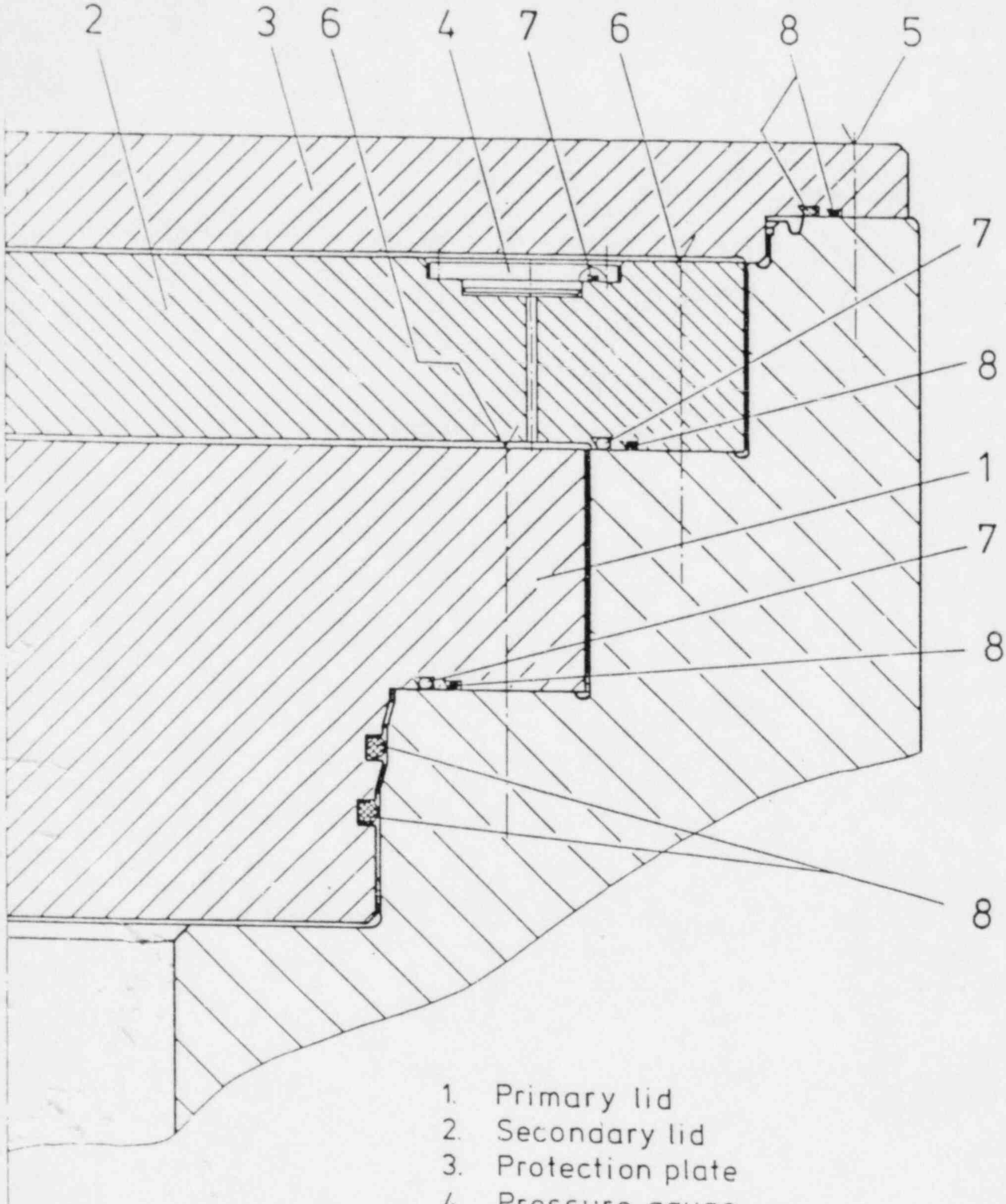
CASTOR Ic Cask

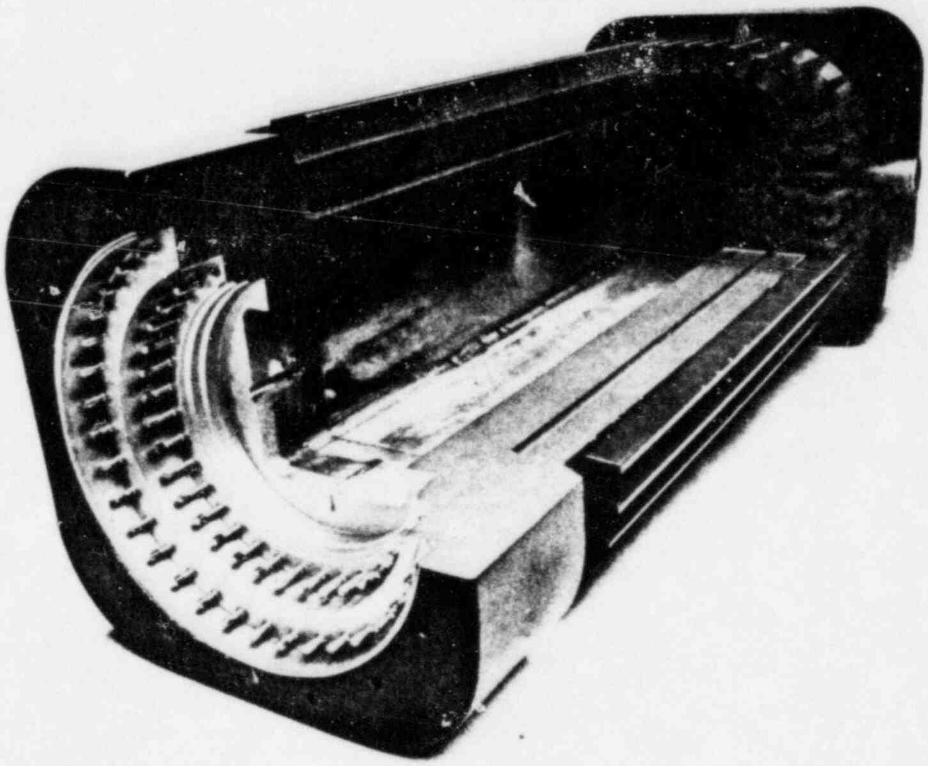
Fig. 1.2 - 1



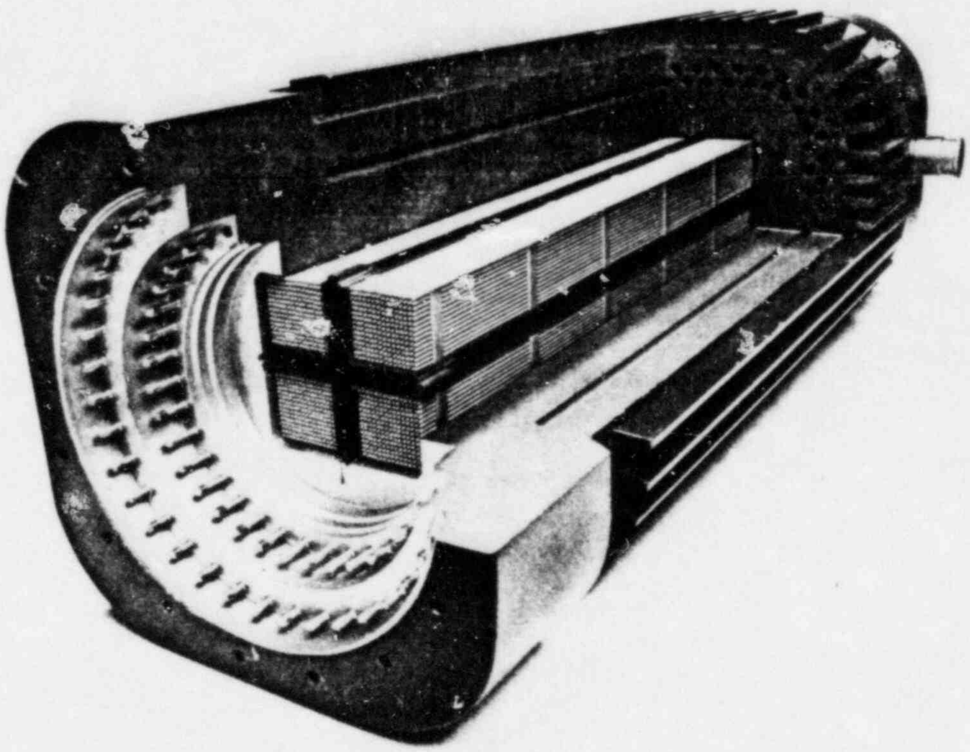
GNS	Cross-Section of the CASTOR Ic Cask	Fig. 1.2-2



1. Primary lid
2. Secondary lid
3. Protection plate
4. Pressure gauge
5. Bolts
6. Bolts
7. Metal seal
8. Elastomer seal



GNS	View of a CASTOR cask model, empty	Fig. 1.2 - 4



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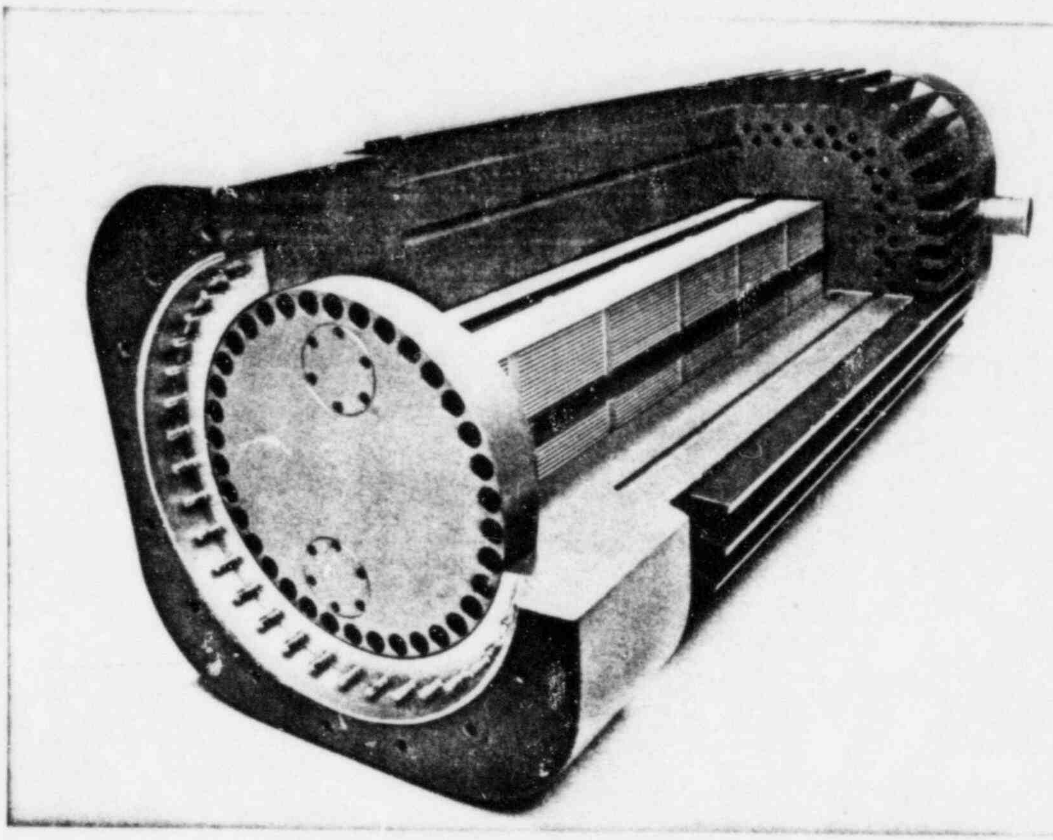
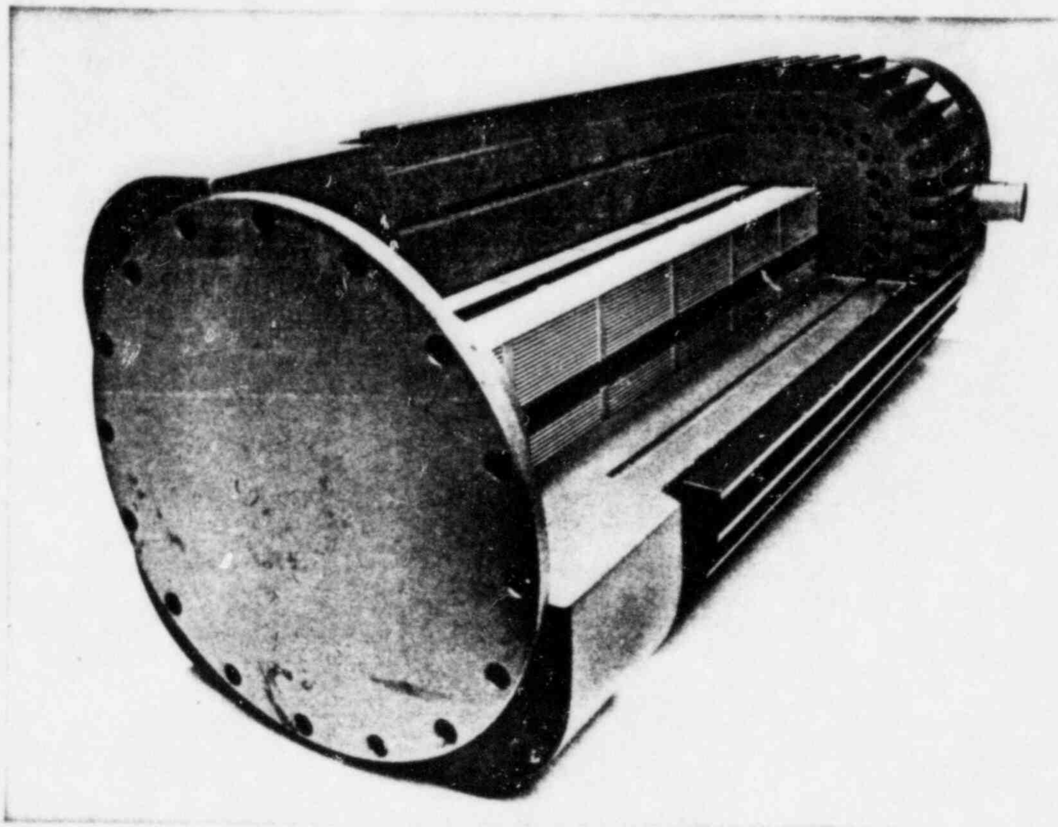
View of a CASTOR cask model, loaded with PWR-fuel assemblies

Fig. 1.2 - 5



GNS	View of a CASTOR - Model with primary lid	Fig. 1.2 - 6



GNS	View of CASTOR-Model with secondary lid	Fig. 1.2 - 7

GNS	CASTOR Ic, cask completed	Fig. 1.2 - 8

Cask length in cm	551
Cross section in cm	173
Cask cavity width in cm	66.6
Cavity length in cm	456
Wall thickness in cm	44
Lid thickness in cm:	
primary lid	34
secondary lid	13
protection plate	8
Number of moderator rods	80
Neutron moderator material	polyethylene
Number of cooling fins	48
Cask capacity	16 fuel assemblies
Cask atmosphere	helium
Cavity pressure	0.8 bar
Barrier pressure	6 bar
Weights:	
empty cask	76.6 Mg
loaded cask	81.1 Mg

Cask features	Design values
tightness	$\leqq 10^{-7}$ mbar l/s
possible mechanical load impact	$\geqq 7 \cdot 10^6$ Nm
multiplication factor	$\leqq 0.95$
surface dose rate	< 200 mrem/h
heat removal capability	30 kW

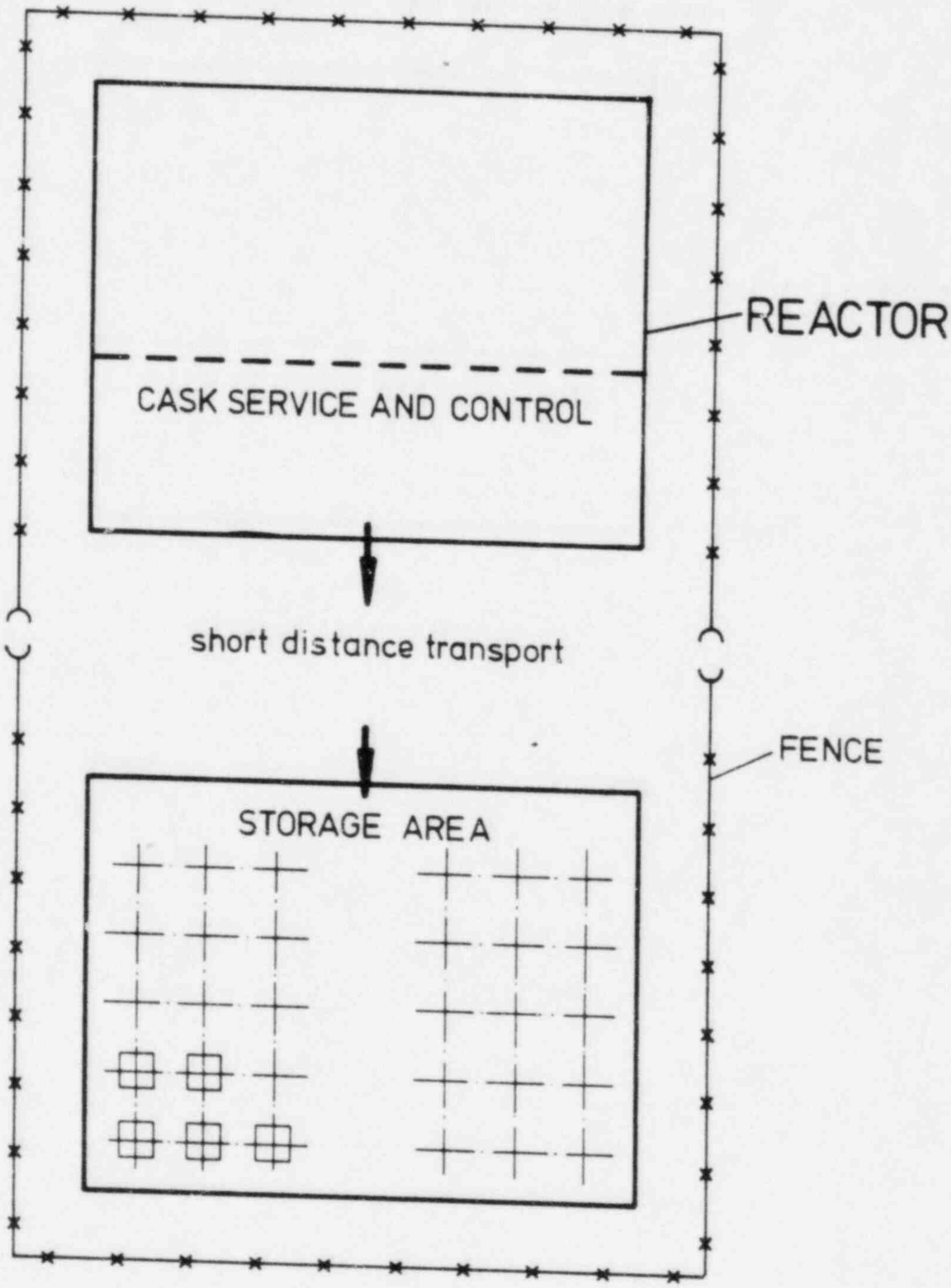
1.3 General Systems Description

The storage system consists of the storage cask alone. A general description of the cask is given in Section 1.2. This TSAR concentrates on dry cask storage at the reactor site (AR storage). An AR-storage (Fig. 1.3-1) consists of a storage area only, which is located either directly at or within a short distance of the reactor site.

For an AR-storage system little or no transportation of the casks using roads/rail is foreseen to be necessary. All cask services, radiation control, decontamination, etc. will be done inside the buildings using the existing equipment, and will be performed under the existing operation license of the nuclear power plant.

The storage area may be covered by a hall. The casks are typically stored in an upright position. Different types of cask arrangements are shown in Fig. 1.1-1. For cask handling purposes either a mobile or stationary crane is used. In case a building is used openings in the side walls and in the roof will provide for natural air convection.

A typical design of an AR cask storage is given in APPENDIX 2 as an example.



GNS | AR Dry-Storage System | Fig. 1.3 - 1

1.4 Identification of Agents and Contractors

The dry cask storage system described in this TSAR has already received the German Type B (U) Packaging License (applicable to 10 CFR Part 71) according to the IAEA "Regulations for the Safe Transport of Radioactive Materials". Additionally the dry cask storage concept based on CASTOR casks has been approved by the German nuclear licensing authorities. Related to these two licensing procedures the following consultants, testing labs, technical inspection and supervision associations, governmental institutes etc. are involved besides GNS:

BAM: Federal Institute for Materials Testing, Berlin - Performance of the cask testing according to the packaging requirements and as consultant for the German licensing authority PTB.

PTB: Federal Physical and Technical Institute, Braunschweig - Licensing authority for dry cask storage and transportation of spent nuclear fuel

MPA: Materials Testing Institute operated by the state North Rhine - Westphalia, Dortmund Performance of corrosion tests

GRS: Reactor Safety Association, Munich - Performance of the criticality and shielding analyses,

TÜV: Technical Inspection Association, Hannover - Consultant to the German licensing authority, PTB

RSK: Reactor Safety Commission, Bonn - Govermental consultant for the Minister of the Interior responsible for the storage license

EXXON: EXXON Nuclear Company, Inc. Washington - Spent Fuel behaviour under dry storage conditions

RWTH: Technical University of Aachen, Aachen - Structural cask analysis

FCC: Fracture Control Corporation, Goleta Calf. - Materials analysis

2.0 Site Characteristics

It should be noted that from a safety viewpoint CASTOR casks for spent fuel storage application can be considered independent of the site. That is, the design criteria (discussed in Section 3) under which the casks were developed is sufficiently stringent as to overshadow any safety concerns related to variations in site characteristics. Additionally, it should be noted that due to the topical aspect of this report, site-specific characteristics per se are not herein provided. Information related to specific site characteristics should be submitted in subsequent safety analysis reports associated with site storage license applications in accordance with 10 CFR Part 72.

2.1 Geography and Demography of Site Selected

Information related to geography and demography of the ISFSI site selected will be submitted in subsequent safety analysis reports. The operation of an ISFSI described in this report will be at existing sites of nuclear power plants for which the site-specific information can be taken from the 10 CFR Part 50 licensing documents.

In comparison to the activity release to be taken in consideration for the operation of a nuclear power plant at the same site, the ISFSI has negligible activity releases. The contributions to the maximum permissible dose rate of an ISFSI is limited to direct radiation. A quantitative description of the radiation field is given in Section 3.3 of this report.

2.2 Meteorology

A meteorological description of the site will be submitted in subsequent safety analysis reports. Independent of a given site the cask design allows a wide range of extreme meteorologic conditions under which the ISFSI will operate:

Extreme winds caused by tornadoes etc. with wind speeds from 30 m/s to more than 140 m/s will neither change the cask position nor lead to cask tipping. A verification of this statement is given in Section 3.2.1. The load impact resulting from extreme winds is not significant to the structural cask design because of the weight of the cask.

Extreme precipitation and floods will not influence the storage safety. Water spray tests with an amount of water per unit ground area approximately equivalent to a rainfall of 5 cm per hour, and water in-leakage tests of the cask for a period of not less than eight hours under a head of water of a least 0.9 m have demonstrated the water tightness of the cask.

Extreme temperatures will not influence the heat removal capability of the cask. The thermodynamic cask design is done under the assumption of an permanent ambient air temperature of 38 °C (100 °F) assuming an additional solar insolation of 400 cal/cm^2 (1,475 Btu/ft^2) for 12 hours per day. In Section 5 it is shown that higher outside air temperatures, i.e. 50° C (122° F), only slightly increase the inside fuel cladding temperatures.

The mechanical behaviour of the cask materials has been evaluated for a cold environment with cask temperatures of -40 °C (-40 °F).

Earthquake accelerations are orders of magnitude below those measured in the free drop tests for the Type B (U) approval of the CASTOR cask.

Lightning protection is given through the cask itself because the cask acts as a faraday cage

3. Principal Design Criteria

The following sections provide information relevant to sections 72.71 and 72.72 under Subpart F of 10 CFR Part 72.

3.1 Purpose of installation

Due to the lack of sufficient spent fuel storage capacity at the storage pool of nuclear power plants the ISFSI based on dry cask storage provides a solution for extending the storage capacity at the reactor site. Most U.S. utilities with LWR fuel have already taken action to expand the storage capability of their original power plant pools using high-density storage racks. Dry cask storage at the reactor site is, among other solutions, an alternative to the wet pool storage of spent fuel.

A modular form of storage facility is attractive to onsite storage. Storing fuel at the reactor site will minimize fuel transportation and may be no more costly than interim storage away from the reactor.

The storage of spent fuel in an ISFSI is considered as an interim action, not a final solution. The interim dry storage of spent nuclear fuel in CASTOR casks will be done prior to reprocessing or final disposition and is considered for a period of approx. 20 to 50 years. From today's point of view the fuel will be held where it is generated, until far reaching decisions on alternatives has been adequately explored.

3.1.1 Material to be Stored

The physical, thermal, and radiological characteristics of spent fuel can be obtained from ORIGEN burnup calculations. A listing of the main fission product nuclides present in spent fuel for storage is given in Tab. 3.1 - 1. Fission product activities in curies per metric ton uranium of typical spent BWR fuel are listed in Tab. 3.1 - 2. These data are taken from NUREG - 0404, Vol. 2, and are generated from on ORIGEN computer code calculations based on operation of a typical large BWR with fuel exposed to 25,000 MWd/MTU at a specific power of 35 MW/MTU. The values shown represent the average burnup under current conditions of BWR plants, although expected values for maximum burnup of 32,000 to 34,000 MWd/MTU has been indicated by certain utilities. With this higher burnup the activity of a number of the long-lived fission products and transuranics would be increased, but by no more than 30 %. However, due to periodic reactor shutdowns as necessary for partial refueling of the core and for plant maintenance, the actual life time of fuel residence in the reactor will always be longer than that implied by the specific power and burnup values calculated. Therefore, the activity of the intermediate-lived fission products is expected to be lower than the values given in Tab. 3.1-2.

Specific spent fuel data will be submitted with the site specific safety analysis report for the ISFSI. The relation between different cooling times, burnup and decay heat production can be taken from Fig. 3.1-1. The total production of spent BWR fuel with different burnup for fully loaded CASTOR Ic cask (16 fuel assemblies with approx. 3.1 MTU) is shown in Fig. 3.1 - 2. Considering a heat removal capacity of approx. 30 kW the cooling time necessary for the different burnup varies between 0.5 year and 1.5 year.

For a further discussion of the physical, thermal, and radiological characteristics of the spent BWR fuel to be stored, results of ORIGEN calculations based on an average burnup of 27,000 MWd/MTU at an specific power of 22 MWd/MTU can be taken as a reference. In Fig. 3.1 - 3 through Fig. 3.1 - 6 the decay heat production, total fission product activity, photon emission and the neutron emission of 27,000 MWd/MTU burnup spent fuel vs decay time is shown.

3.1.2 General Operating Functions

3.1.2.1 Waste Processing

No radioactive waste is generated in an AR dry cask storage installation. For AR ISFSI storage conditions the cask will be decontaminated if necessary in the reactor service area prior to transfer to the storage area. No other service operations resulting in waste generaton is necessary and foreseen.

3.1.2.2 Transportation

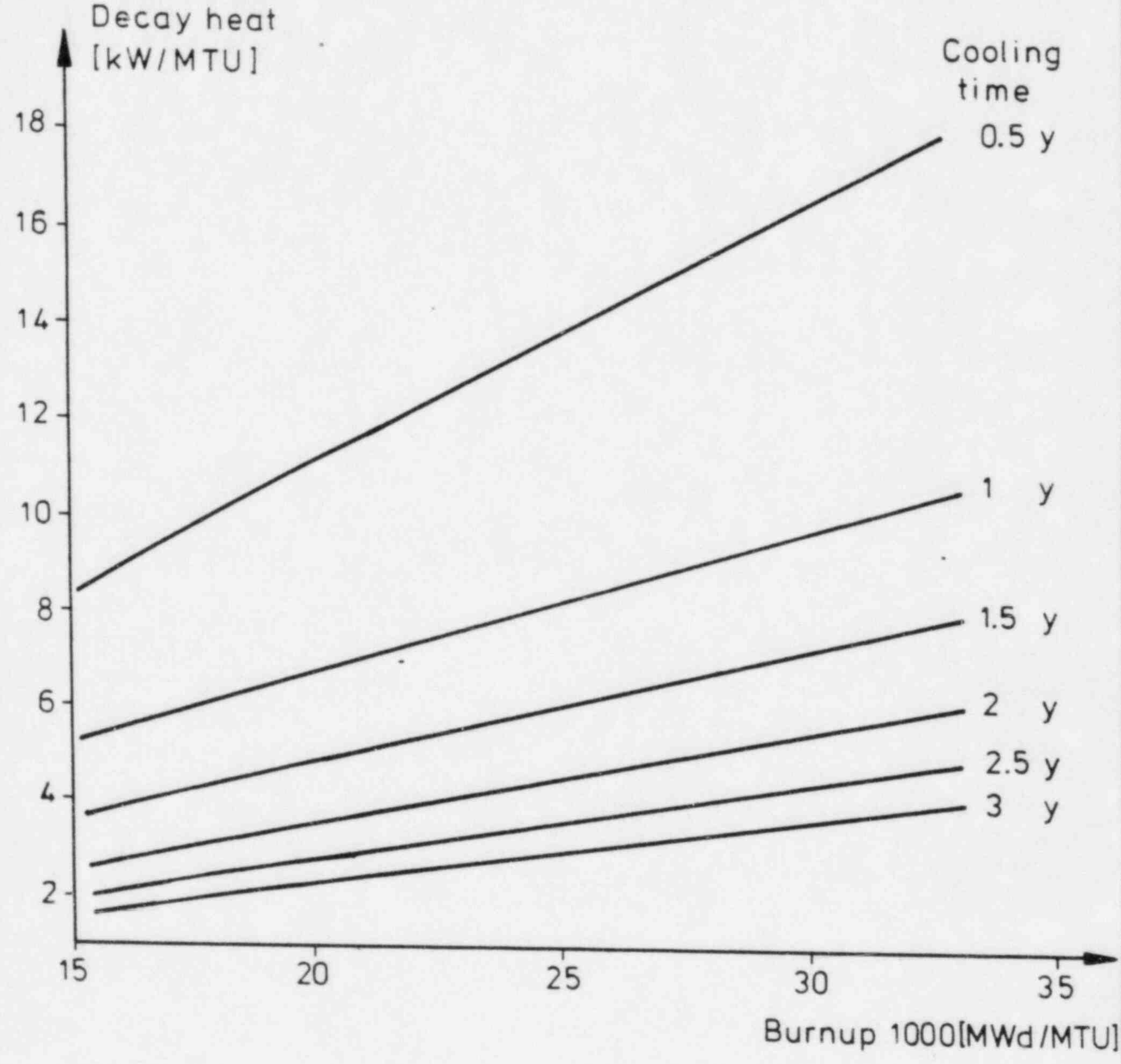
Transportation to and from the storage installation as well as within the confines of the storage site will consist of storage cask movement only. The CASTOR Ic cask is designed as a shipping container as well as a storage cask. The storage casks can survive testing conditions appropiate for a transport casks under accident conditions.

Fuel loading / unloading in connection with onsite transportation of a shipping cask (without shock absorber) is covered by the 10 CFR Part 50 operation license. No additional requirements for the cask will result from onsite transportation.

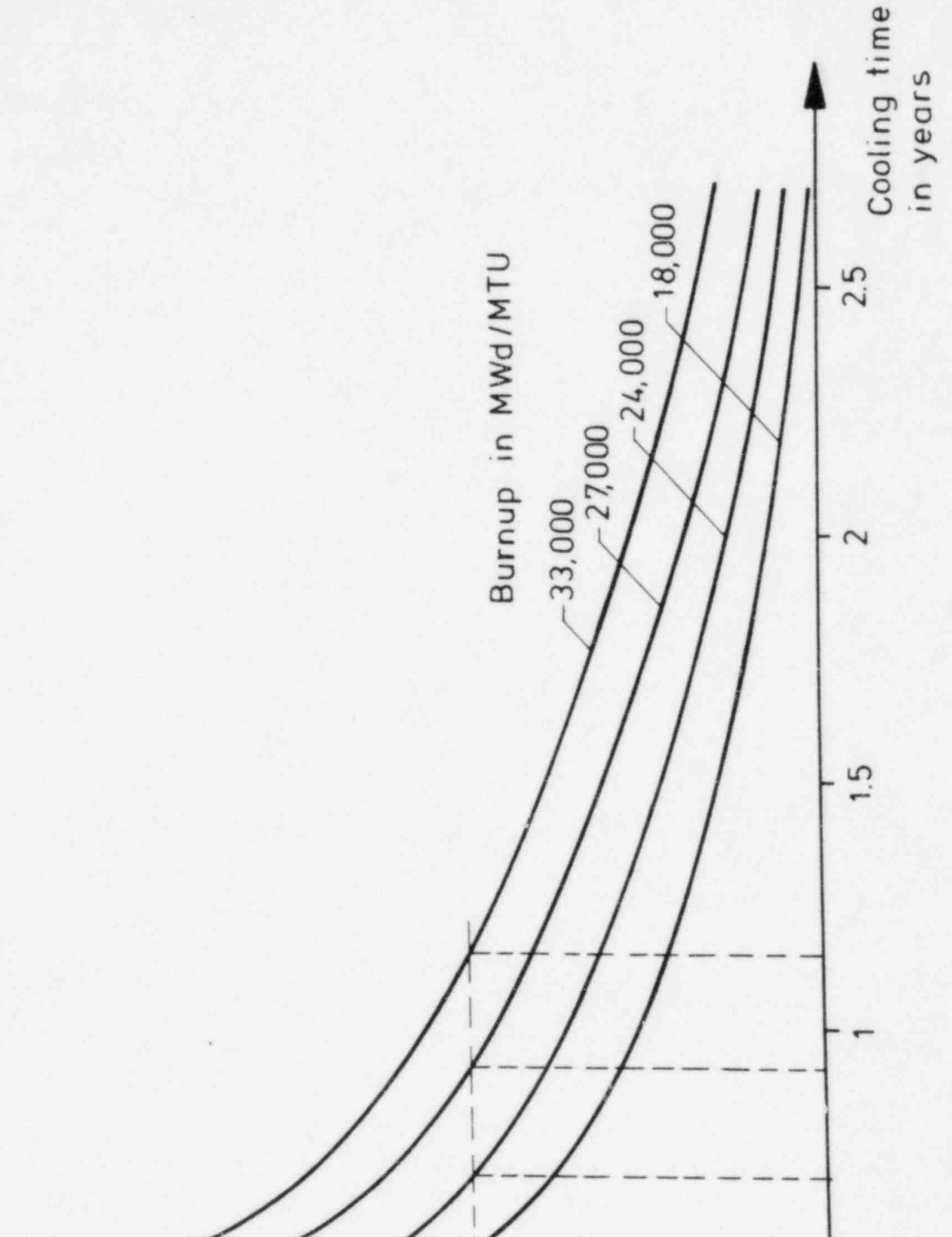
Off normal and accidental situations resulting from cask transportation are discussed in the following sections.

3.1.2.3 Utilities

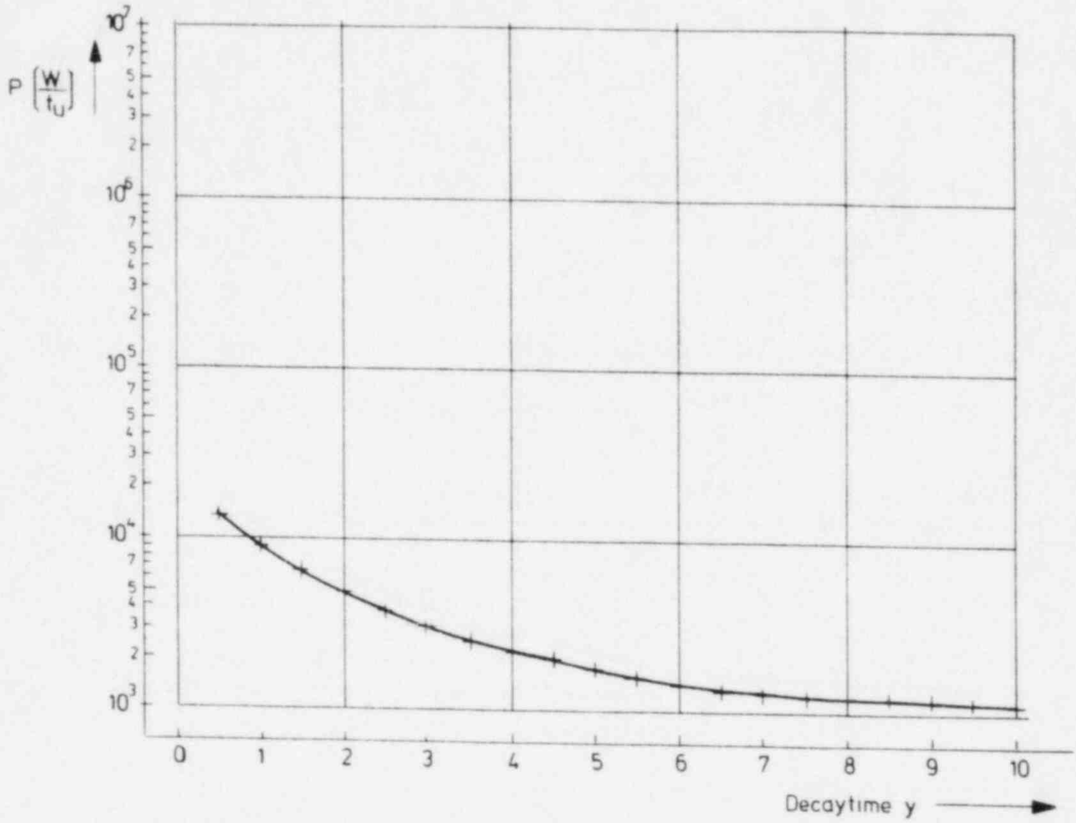
Not applicable



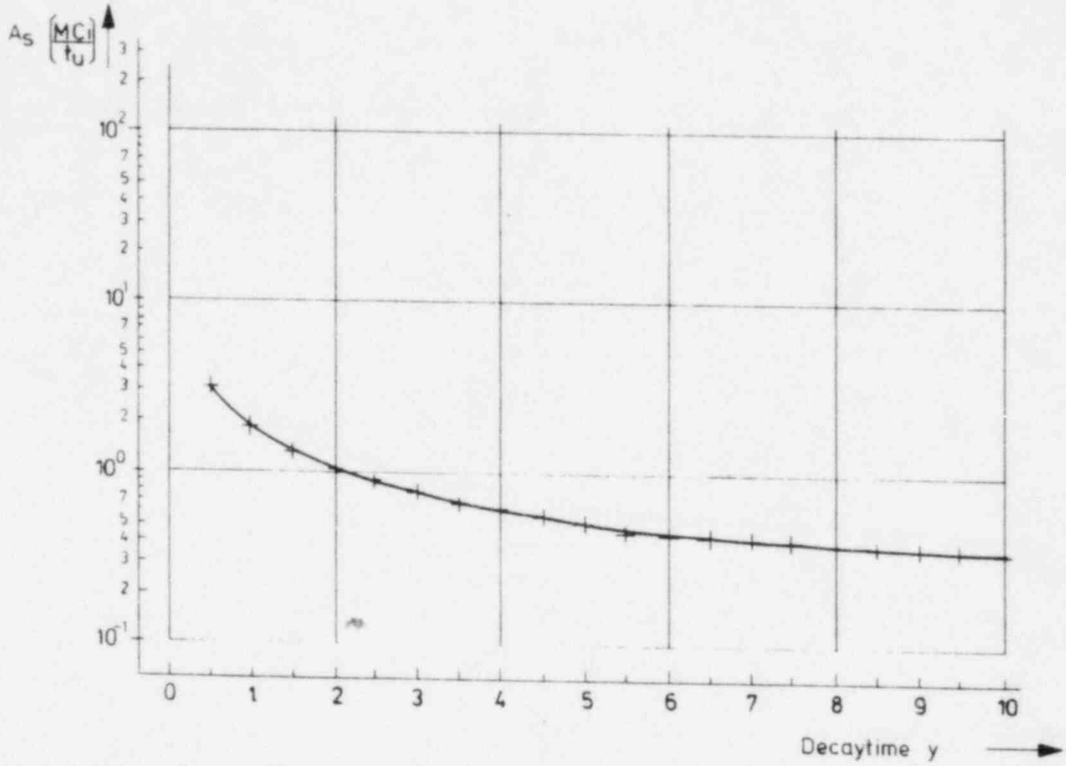
GNS	Decay Heat vs Cooling Time and Burnup	Fig. 3.1 - 1



GNS	Thermal Power of a Loaded CASTOR I c Cask	Fig. 3.1 - 2



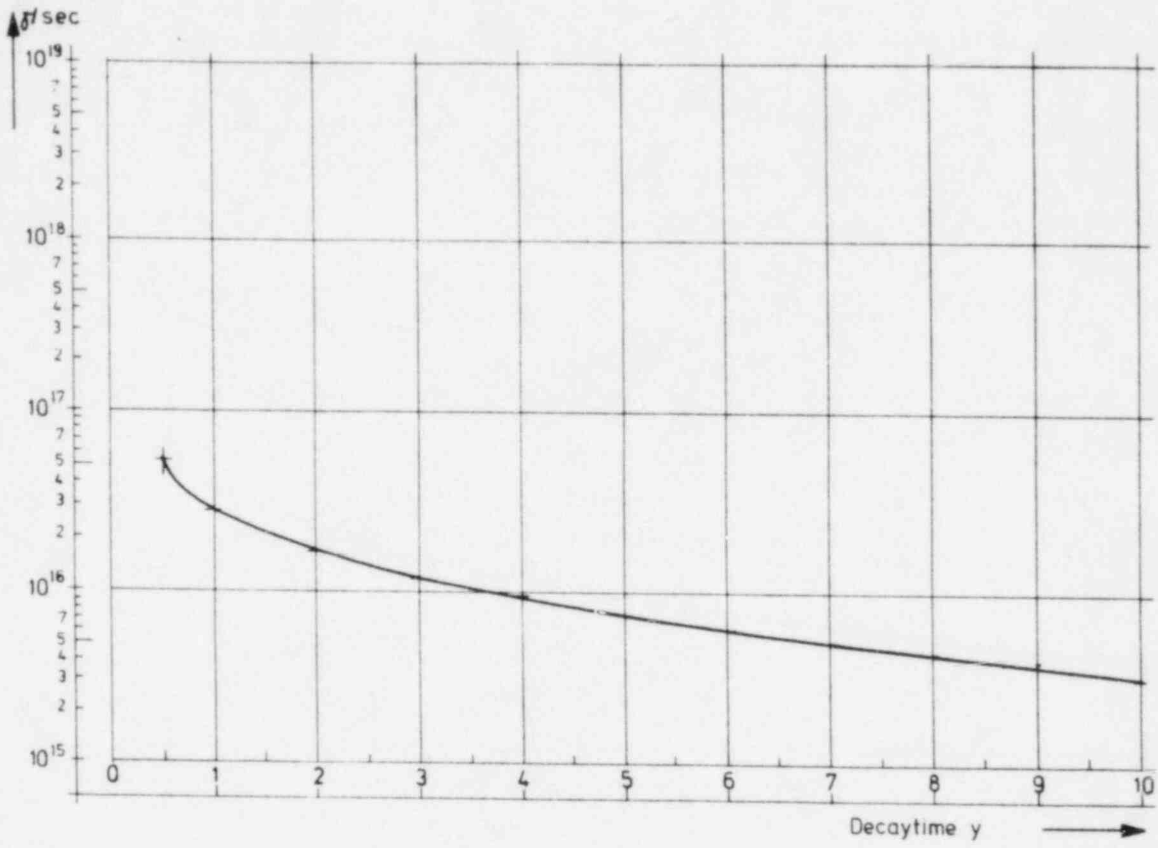
GNS	Decay heat vs Decay Time for Typical BWR Spent Fuel	Fig. 3.1 - 3



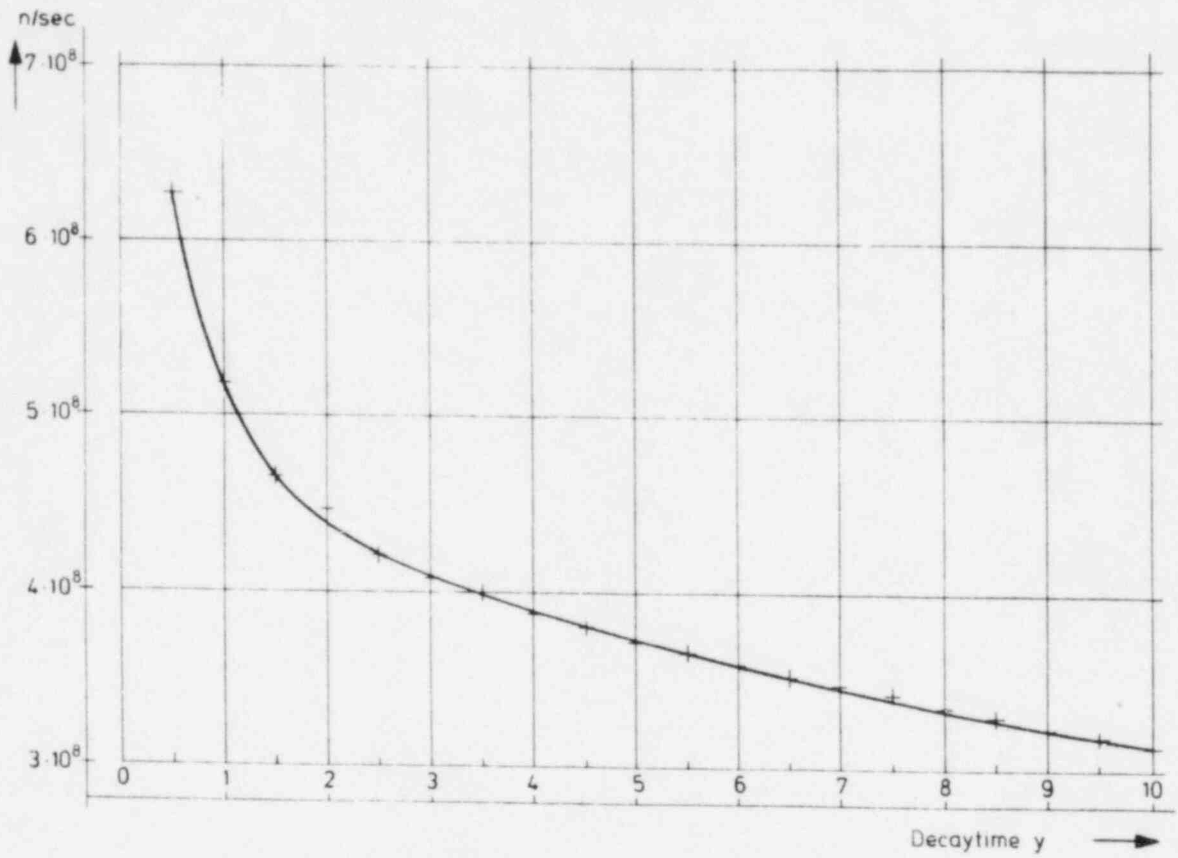
GNS

Total Activity vs Decay Time for Typical BWR Spent Fuel

Fig. 3.1 - 4



GNS	Gamma Emission vs Decay Time for Typical BWR Spent Fuel	Fig. 3.1 - 5



GNS

Neutron Emission vs Decay Time for Typical BWR Spent Fuel

Fig. 3.1 - 6

NUCLIDE	SYMBOL	HALF-LIFE	MODE OF DECAY	SPECIFIC ACTIVITY Ci/gm	MEV - MAJOR MODE OF DECAY		PRIMARY DAUGHTER
					β	γ	
TRITIUM	H 3	12.3Y	β	9,600	0.019	-	He 3
SELENIUM 79	Se 79	$6.5x10^4$Y	β	0.07	0.15	-	Br 79
KRYPTON 85	Kr 85	10.7Y	β,γ	390	0.67	0.51	Rb 85
RUBIDIUM 86	Rb 86	18.7D	β,γ	82,000	1.77	1.08	Sr 86
STRONTIUM 89	Sr 89	50.5D	β,γ	28,000	1.49	0.91	Y 89
STRONTIUM 90	Sr 90	29Y	β,γ	140	0.55	1.76(?)	Y 90
YTTRIUM 90	Y 90	64 H	β,γ	540,000	2.29	1.76(?)	Zr 90
YTTRIUM 91	Y 91	58.6D	β,γ	240,000	1.55	1.21	Sr 91
ZIRCONIUM 93	ZR 93	$9.5x10^5$Y	β,γ	0.004	0.06	0.03	Nb 93
NIOBIUM 93m	Nb 93m	12 Y	β	320	0.03	-	Nb 93
ZIRCONIUM 95	Zr 95	65.5D	β	21,000	0.366	0.76	Nb 95
NIOBIUM 95m	Nb 95m	3.6D	γ	380,000	-	0.23	Nb 95
NIOBIUM 95	Nb 95	35.1D	β,γ	38,000	0.16	0.77	Mo 95
TECHNICIUM 99	Tc 99	$2.1x10^5$Y	β	0.017	0.29	-	Ru 99
RUTHENIUM 103	Ru 103	39.6D	β,γ	32,000	0.225	0.50	Rh 103m
RHODIUM 103m	Rh 103m	56 M	γ	$3.2x10^7$	-	0.04	Rh 103
RUTHENIUM 106	Ru 106	369D	β,γ	3,400	0.039	0.51	Rh 106
RHODIUM 106	Rh 106	2.2H	β,γ	$1.3x10^7$	0.92	0.51	Pd 106
PALLADIUM 107	Pd 107	$6.5x10^6$Y	β	0.0005	0.035	-	Ag 107
SILVER 110m	Ag 110m	252D	β,γ	4,700	0.08	0.66	Cd 107
SILVER 110	Ag 110	24S	β,γ	$4.3x10^9$	2.89	0.66	Cd 110
SILVER 111	Ag 111	7.5D	β,γ	160,000	1.03	0.34	Ag 111
CADMIUM 113m	Cd 113m	14.6Y	β,γ	220	0.59	0.26	In 113
CADMIUM 115m	Cd 115m	44.6D	β,γ	25,000	1.63	0.93	In 115
TIN 119m	Sn 119m	245D	γ	4,500	-	0.024	Sn 119
TIN 123m	Sn 123m	129D	β,γ	8,100	1.41	1.08	Sb 123
TELLURIUM 123m	Te 123m	120D	β,γ	9,000	0.089	0.16	Te 123
ANTIMONY 124	Sb 124	60D	β,γ	17,000	0.61	1.69	Te 124
ANTIMONY 125	Sb 125	2.73Y	β,γ	1,000	0.03	0.43	Te 125
TELLURIUM 125m	Te 125m	58D	β,γ	18,000	0.11	0.035	Te 125
TIN 126	Sn 126	10^5Y	β,γ	0.028	0.25	0.88	Sb 126
ANTIMONY 126m	Sb 126m	19M	β,γ	$7.8x10^7$	1.9	0.67	Sb 126
ANTIMONY 126	Sb 126	12.4D	β,γ	83,000	1.1	0.70	Te 126
TELLURIUM 127m	Te 127m	109D	β,γ	9,300	0.088	0.058	I 127
TELLURIUM 127	Te 127	9.4H	β,γ	$2.6x10^6$	0.69	0.24	I 127
TELLURIUM 129m	Te 129m	33.4D	β,γ	30,000	1.1	0.70	I 129
TELLURIUM 129	Te 129	70M	β,γ	$2.1x10^7$	1.47	0.028	I 129
IODINE 129	I 129	$1.6x10^7$Y	β,γ	0.00017	0.15	0.04	Xe 129
XENON 131m	Xe 131m	12D	β	83,000	0.16	-	Xe 131
IODINE 131	I 131	8D	β,γ	120,000	0.61	0.36	Xe 131
CESIUM 134	Cs 134	2Y	β,γ	1,300	0.66	0.80	Ba 134
CESIUM 135	Cs 135	$2.3x10^6$Y	β	0.001	0.21	-	Ba 135
CESIUM 136	Cs 136	13D	β,γ	74,000	0.34	0.82	Ba 136
CESIUM 137	Cs 137	30.1Y	β,γ	87	0.51	0.66	Ba 137
BARIUM 137m	Ba 137m	2.5M	γ	$5.5x10^8$	-	0.66	Ba 137m
BARIUM 140	Ba 140	12.8D	β,γ	73,000	1.0	0.54	La 140
LANTHANUM 140	La 140	40H	β,γ	560,000	1.36	1.60	Ce 140
CERIUM 141	Ce 141	32.5D	β,γ	28,000	0.44	0.15	Pr 141
PRASEODYMIUM 143	Pr 143	13.6D	β	66,000	0.931	-	Nd 143
CERIUM 144	Ce 144	284D	β,γ	3,200	0.32	0.03	Pr 144
PRASEODYMIUM 144	Pr 144	17.3M	β,γ	$7.55x10^7$	3.0	0.70	Nd 144
NEODYMIUM 147	Nd 147	11D	β,γ	8,000	0.80	0.91	Pm 147
PROMETHIUM 147	Pm 147	2.6Y	β,γ	940	0.23	0.21	Sm 147
PROMETHIUM 148m	Pm 148m	41.3D	β,γ	21,000	0.40	0.55	Sm 148
PROMETHIUM 148	Pm 148	5.4D	β,γ	160,000	2.48	0.55	Sm 148
SAMARIUM 151	Sm 151	93Y	β,γ	25.5	0.076	0.022	Eu 151
EUROPIUM 152	Eu 152	13Y	β,γ	180	0.74	0.12	Gd 152
GADOLINIUM 153	Gd 153	242D	γ	3,500	-	0.097	Tb 153
EUROPIUM 154	Eu 154	16Y	β,γ	145	0.58	0.12	Gd 154
EUROPIUM 155	Eu 155	4.8Y	β,γ	480	0.16	0.09	Gd 155
EUROPIUM 156	Eu 156	15.2D	β,γ	160,000	0.49	0.09	Gd 156
TERBIUM 160	Tb 160	72.3D	β,γ	11,000	0.57	0.88	Dy 160
GADOLINIUM 162	Gd 162	10M	β,γ	$1.2x10^8$	1.0	0.44	Tb 162
TERBIUM 162m	Tb 162m	7.5M	β,γ	$1.5x10^8$	1.3	0.26	Tb 162

PCWER= 35.00MW, BURNUP= 25000.MWD, FLUX= 3.26E 13N/CM**2-SEC

NUCLIDE RADIOACTIVITY, CURIES
BASIS = MT OF HEAVY METAL CHARGED TO REACTOR

	CHARGE	DISCHARGE	30. D	90. D	160. D	365. D	3653. D
SE 79	0.0	2.97E-01	2.97E-01	2.97E-01	2.97E-01	2.97E-01	2.97E-01
KR 85	0.0	7.87E 03	7.83E 03	7.74E 03	7.65E 03	7.38E 03	4.12E 03
RB 86	0.0	5.31E 02	1.74E 02	1.87E 01	1.39E 00	6.80E-04	0.0
SR 89	0.0	9.47E 05	6.35E 05	2.85E 05	1.12E 05	7.30E 03	6.80E-16
SR 90	0.0	6.40E 04	6.38E 04	6.36E 04	6.33E 04	6.24E 04	5.00E 04
Y 90	0.0	6.65E 04	6.38E 04	6.36E 04	6.33E 04	6.24E 04	5.00E 04
Y 91	0.0	1.23E 06	8.65E 05	4.25E 05	1.86E 05	1.64E 04	2.13E-13
ZR 93	0.0	2.31E 00	2.31E 00	2.31E 00	2.31E 00	2.31E 00	2.31E 00
ZR 95	0.0	1.67E 06	1.22E 06	6.44E 05	3.07E 05	3.51E 04	2.73E-11
NB 93M	0.0	1.27E-01	1.37E-01	1.56E-01	1.78E-01	2.43E-01	1.03E 00
NB 95	0.0	1.69E 06	1.56E 06	1.07E 06	5.81E 05	7.42E 04	5.88E-11
NB 95M	0.0	2.07E 04	1.54E 04	8.18E 03	3.90E 03	4.46E 02	3.46E-13
TC 99	0.0	1.11E 01	1.11E 01	1.11E 01	1.11E 01	1.11E 01	1.11E 01
RU103	0.0	1.55E 06	9.15E 05	3.20E 05	9.39E 04	2.60E 03	2.63E-22
RU106	0.0	4.18E 05	3.95E 05	3.53E 05	3.09E 05	2.10E 05	4.38E 02
RH103M	0.0	1.55E 06	9.15E 05	3.20E 05	9.40E 04	2.60E 03	2.63E-22
RH106	0.0	6.34E 05	3.95E 05	3.53E 05	3.09E 05	2.10E 05	4.38E 02
PD107	0.0	7.13E-02	7.13E-02	7.13E-02	7.13E-02	7.13E-02	7.13E-02
AG110	0.0	5.58E 04	5.14E 04	4.36E 04	3.59E 04	2.05E 04	2.42E 00
AG111	0.0	4.92E 04	3.05E 03	1.16E 01	1.76E-02	9.63E-11	0.0
CD113M	0.0	2.06E 01	2.05E 01	2.03E 01	2.01E 01	1.96E 01	1.28E 01
CD115M	0.0	1.05E 03	6.57E 02	2.59E 02	8.71E 01	3.60E 00	2.32E-22
IN114	0.0	4.46E 00	1.98E 00	8.54E-01	3.21E-01	1.82E-02	1.87E-22
IN114M	0.0	3.12E 00	2.05E 00	8.85E-01	3.32E-01	1.88E-02	1.94E-22
SN117M	0.0	3.45E 01	7.81E 00	4.01E-01	1.25E-02	4.92E-07	0.0
SN119M	0.0	7.92E 01	7.28E 01	6.14E 01	5.04E 01	2.82E 01	2.58E-03
SN121M	0.0	1.16E-01	1.16E-01	1.16E-01	1.16E-01	1.15E-01	1.01E-01
SN123	0.0	4.36E 03	3.72E 03	2.69E 03	1.85E 03	6.15E 02	1.32E-05
SN125	0.0	9.71E 03	1.13E 03	1.51E 01	9.92E-02	4.04E-08	0.0
SN126	0.0	4.01E-01	4.01E-01	4.01E-01	4.01E-01	4.01E-01	4.01E-01
SB124	0.0	2.65E 02	1.87E 02	9.39E 01	4.19E 01	3.96E 00	1.44E-16
SB125	0.0	7.27E 03	7.20E 03	6.92E 03	6.59E 03	5.71E 03	5.81E 02
SB126	0.0	6.41E 02	1.20E 02	4.24E 00	1.40E-01	5.62E-02	5.62E-02
SB126M	0.0	5.09E 02	4.01E-01	4.01E-01	4.01E-01	4.01E-01	4.01E-01
TE123M	0.0	2.40E-01	2.02E-01	1.43E-01	9.52E-02	2.90E-02	1.56E-10
TE125M	0.0	1.45E 03	1.51E 03	1.57E 03	1.56E 03	1.39E 03	1.42E 02
TE127	0.0	9.12E 04	1.18E 04	7.80E 03	5.00E 03	1.36E 03	1.13E-06
TE127M	0.0	1.36E 04	1.17E 04	7.96E 03	5.10E 03	1.39E 03	1.16E-06
TE129	0.0	2.97E 05	2.78E 04	8.00E 03	1.87E 03	2.66E 01	0.0
TE129M	0.0	[illegible] 04	4.37E 04	1.26E 04	2.95E 03	4.19E 01	0.0
I129	0.0	[illegible]-02	2.36E-02	2.37E-02	2.38E-02	2.38E-02	2.38E-02
I131	0.0	9.63E 05	7.48E 04	4.24E 02	1.02E 00	2.15E-08	0.0
XE131M	0.0	6.02E 03	2.49E 03	1.05E 02	1.92E 00	1.39E-05	0.0
XE133	0.0	1.98E 06	5.21E 04	2.01E 01	2.09E-03	4.52E-15	0.0
CS134	0.0	1.62E 05	1.57E 05	1.49E 05	1.40E 05	1.16E 05	5.59E 03
CS135	0.0	2.68E-01	2.68E-01	2.68E-01	2.68E-01	2.68E-01	2.68E-01
CS136	0.0	4.88E 04	9.85E 03	4.02E 02	9.61E 00	1.72E-04	0.0
CS137	0.0	8.32E 04	8.30E 04	8.27E 04	8.23E 04	8.13E 04	6.61E 04
BA136M	0.0	7.80E 03	1.58E 03	6.43E 01	1.54E 00	2.75E-05	0.0
BA137M	0.0	7.90E 04	7.85E 04	7.82E 04	7.79E 04	7.69E 04	6.25E 04
BA140	0.0	1.72E 06	3.38E 05	1.31E 04	2.95E 02	4.41E-03	0.0
LA140	0.0	1.76E 06	3.89E 05	1.51E 04	3.39E 02	5.08E-03	0.0
CE141	0.0	1.64E 06	8.68E 05	2.42E 05	5.44E 04	6.90E 02	0.0
CE144	0.0	1.17E 06	1.09E 06	9.38E 05	7.91E 05	4.80E 05	1.61E 02
PR143	0.0	1.48E 06	3.56E 05	1.66E 04	4.66E 02	1.33E-02	0.0
PR144	0.0	1.18E 06	1.09E 06	9.38E 05	7.91E 05	4.80E 05	1.61E 02
PR144M	0.0	1.40E 04	1.30E 04	1.13E 04	9.49E 03	5.76E 03	1.93E 00
ND147	0.0	6.68E 05	1.01E 05	2.29E 03	2.77E 01	6.72E-05	0.0
ND154	0.0	3.57E 04	2.43E 03	1.12E 01	2.12E-02	2.23E-10	0.0
PM147	0.0	1.06E 05	1.10E 05	1.06E 05	1.01E 05	8.73E 04	8.09E 03
PM148	0.0	2.15E 05	6.13E 03	6.30E 02	1.94E 02	6.22E 00	6.75E-24
PM148M	0.0	4.13E 04	2.49E 04	9.11E 03	2.81E 03	9.01E 01	9.79E-23
PM154	0.0	4.56E 04	2.43E 03	1.12E 01	2.12E-02	2.23E-10	0.0
SM151	0.0	9.80E 02	9.86E 02	9.84E 02	9.83E 02	9.79E 02	9.15E 02
EU152	0.0	8.06E 00	8.02E 00	7.95E 00	7.87E 00	7.64E 00	4.73E 00
EU154	0.0	6.90E 03	6.85E 03	6.76E 03	6.66E 03	6.37E 03	3.08E 03
EU155	0.0	1.60E 03	1.58E 03	1.55E 03	1.50E 03	1.39E 03	3.78E 02
EU156	0.0	1.43E 05	3.65E 04	2.36E 03	9.70E 01	8.44E-03	0.0
GD153	0.0	1.44E 01	1.32E 01	1.11E 01	9.07E 00	5.03E 00	3.90E-04
TB160	0.0	8.44E 02	6.33E 02	3.56E 02	1.82E 02	2.55E 01	5.24E-13
SUBTOT	0.0	2.40E 07	1.21E 07	6.62E 06	4.25E 06	2.06E 06	2.53E 05
TOTALS	0.0	1.65E 08	1.21E 07	6.62E 06	4.25E 06	2.06E 06	2.53E 05

3.2 Structural and Mechanical Safety Criteria

The mechanical design of the CASTOR Ic cask is described under Section 4.2. Due to the generic nature of this report, site-specific environmental and geologic features are not used as design criteria for safety related structures, systems, and components. Instead, performance criteria applicable to the transport aspect of the cask system are utilized. This approach results in a conservative design with respect to the storage function of the cask components since design criteria predicated on the transport function more than adequately cover the natural phenomena typically addressed in a storage-type safety analysis. This is applicable both to normal operation-and accident-conditions.

It is not intended to establish a precedent in the above respect but merely to take advantage of the inherent safety margin resulting from the dual (storage and shipping capability) design approach utilized by GNS.

3.2.1 Tornado and Wind Loadings

Windspeeds caused by tornados have been estimated from 30 m/s to more than 140 m/s. For evaluating the cask stability under tornado wind forces the cask can be approximated by a rectangular cylinder. The wind force on the cask can be estimated from

$$F_W = \frac{1}{2} C_W \cdot \delta \cdot A v^2$$

where

C_w	=	1.56	geometry factor
δ	=	1.18 kg/m^3	air density (20 °C, 100 % humidity)
v	=	140 m/s	wind speed
A	=	9.8 m^2	cask ground area

The stability condition for the cask assuming a linear force is

$$F \cdot \frac{h}{2} < G \cdot \frac{b}{2}$$

where

h	=	550 cm,	cask height
G	=	81.100 kg,	cask mass
b	=	172 cm,	cask width

The tipping momentum M_t is

$$M_t = F \cdot \frac{h}{2} = 4.9 \cdot 10^5 \text{ Nm}$$

is smaller than the gravity momentum M_G

$$M_G = G \cdot \frac{b}{2} = 7.0 \cdot 10^5 \text{ Nm}$$

This conservative estimation shows that a single cask will remain on its place during a tornado with wind speeds of appro... 140 m/s. A discussion of tornado-generated missiles is given under Section 8.2 (Accident Analyses).

3.2.2 Water Level (Flood) Design

The most severe extreme for the casks is a complete flooding under a head of several meters of water. The cask is watertight. This has been proven during water immersion tests in which a prototype cask was subjected to an external water pressure of 1.5 kg/cm^2.

The criticality analysis described in Section 3.3.4 is valid for the most reactive state, that is, in the flooded state as when the cask is being loaded at the reactor storage pool. There is no influence on criticality safety during external floods or heavy rainfall.

3.2.3 Seismic Design

The CASTOR casks are designed in such a way that they do not tip over in the design earthquake (horizontal acceleration of 0.1 g). Safety against tipping is adequate even in a "maximum potential earthquake" (horizontal acceleration of 0.2 g). To find the factor of safety against tipping, we divide the moment of stablity

$$M_S = gB$$

by the tipping moment

$$M_K = aH$$

to get

$$K = gB/aH,$$

where g is the acceleration due to gravity and a is the horizontal acceleration. The factor of safety against tipping for the CASTOR Ic cask is 1.40.

Because this factor of safety against tipping is greater than 1.0, the casks can be expected not to tip over even in the "maximum potential earthquake".

3.2.4 Snow and Ice Loading

The load on the cask structure due to snow pack is not relevant because of the heavy structures of the CASTOR Ic cask.

3.2.5 Combined Load Criteria

A combination of the cask loads to be considered is discussed under the sections below. Credible load combinations resulting from natural events are:

- Tornado wind forces and tornado missiles (discussed under Section 3.2.2)

- Tornado impact with flood. The tornado impact result in tipping of the cask (a 9 m drop test on a prototype cask has demonstrated the cask tightness). Flooding in combination with cask tipping will not create a cask leakage.

- Hot environment with max. solar insolation and decay heat

- Cold environment with no solar insolation and no decay heat

A summary of load combinations for normal and hypothetical accident conditions is given in Tab. 3.2 - 1.

3.2.6 Thermal Loading

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).

3.2.6.1 Ambient Air Temperature Range

The ambient air temperature range considered for the cask design and the ISFSI operation varies between 54° C (130° F) and - 40° C (-40° F).

3.2.6.2 Solar Insolation Range

The storage cask typically stands in an upright position at the ISFSI. Due to the sun's movement the cask surface will be exposed only partially during the day time.

As a conservative assumption a permanent solar insolation for 12 hours a day of

$$400 \text{ gcal / cm}^2 \quad (1{,}475 \text{ Btu/ft}^2)$$

for all the exposed cask surfaces (approx. 50 m^2)

3.2.6.3 Temperature Transients

The CASTOR Ic cask standing in an ISFSI has a total weight of approx. 83 metric tons. Neccessarily there is a reasonably high heat capacity of the cask of approx. $4.5 \cdot 10^4$ kJ/°K. Rapid changes in the ambient air temperature result in a very slow change in the cask body temperature.

Normal or accident condition	Applicable initial condition							
	Ambient temperature		Insolation		Decay heat		Max. internal pres.	Max. wt. of contents
	100°F	-20°F	Max.*	0	Max.	0		
Normal conditions								
Hot environment - 130°F ambient temp.			x		x		x	
Cold environment - -40°F ambient temp.				x	x		x	
				x		x	x	
Free drop - 1 foot drop	x		x		x		x	x
		x		x	x		x	x
		x		x		x	x	x
Accident conditions								
Free drop - 30 foot drop	x		x		x		x	x
		x		x	x		x	x
		x		x		x	x	x
Puncture - Drop onto bar	x		x		x		x	x
		x		x	x		x	x
		x		x		x	x	x
Thermal†† - Fire accident	x		x		x		x	

3.3 Safety Protection Systems

3.3.1 General

A two barriere system for all the cask openings consisting of multiple lids and seals assures the tightness of the cask. If leaks should develop in individual fuel-rod cladding tubes during long-term storage, the gases will be contained in the cask. Because each cask is cast in one piece radioactive gases can escape only through the cover portion of the cask. However, a combined cover-seal system, which always meets the requirement of a two-barrier enclosure, guarantees tight, permanent containment of the fuel assemblies. The seal system of the primary and secondary covers consists of metal seals. These possess long-term stability and, by virtue of the material chosen and the protected arrangement, have high corrosion resistance over the entire storage period. When the casks are placed in storage, an excess pressure is set up in the inaccessible space between the secondary and primary covers. A pressure drop in this zone is signaled optically and acoustically by the cask monitoring system.

3.3.2 Protection by Multiple Confinement Barriers and Systems

3.3.2.1 Confinement Barriers and Systems

The confinement system of CASTOR casks is given in Fig. 3.3. - 1 and Fig. 3.3 - 2. The cask cover system consists of two lids, separately sealed, one atop the other.

The primary cover (shield cover) is made of stainless steel and has an overall thickness of about 350 mm. It is fastened to the body with bolts. The flushing connections are integrated into the primary cover (Fig. 3.3 - 1).

The secondary cover is bolted on over the primary cover. This cover likewise consists of stainless steel, with a thickness of about 150 mm. The pressure measuring apparatus is installed in this cover. The space between the primary and secondary covers is used as a gas barrier and pressure-monitoring space.

Furthermore, an additional seal surface with the required threaded holes is present; the protective plate can be installed on this surface. This plate guards the cover system from mechanical actions, as well as dust and moisture.

As shown in Fig. 3.3 - 2 an additional cover can be used as a repair concept if it becomes necessary. The space cover is formed in such a way that an insert cover can be inserted and welded or brazed in place. An inaccessible zone remains between the insert cover and the secondary cover, this space then is used as a gas barrier and for pressure monitoring. The pressure measuring apparatus is also installed in the insert cover.

The seal system of the CASTOR cask is shown in Fig. 3.3 - 3. The seal system of the primary cover consists of one metal seal, acting in the axial direction, and two elastomer seals, acting in the radial direction. Between each two seals in the primary cover there is a leak-test connection to the surface of the cover.

For longer-term storage only the metal seal is evaluated. The metal seal of the primary cover is the first long-lived barrier. Sealing of the washing connections in the primary cover meets the same standard. In the area of the bearing surface of the secondary cover one metal seal and one elastomer seal are used. The seals can be checked from outside through test connections.

The metal seal of the secondary cover represents the second long-lived barrier.

The metal joint seal of the insert cover serves as a backup barrier (second barrier) if the metal seal of the primary cover should leak.

The protective plate has a replaceable seal that protects the seal system from dirt and moisture.

The sealing principle of metallic seals used for the CASTOR casks is illustrated Fig. 3.3 - 4. The metallic seals are made up of one or two metal linings around the toroidal section of a helically wound spring. An external or internal compression limiter can be incorporated. The sealing principle of the metallic seals is based on the plastic deformation of a lining material with greater ductility than the materials surrounding it, between a flat surface constituting the sealing surface of the flange and an elastic core of a helical spring with its coils compressed against each other. Permanent contact of the seal against the sealing surface is ensured because of the reaction caused by the radial elasticity of the spring giving a permanent compressive force on the lining. The use of a helical spring, with its coils compressed against each other as an elastic core, gives total independence on each coil during the radial compression of the section which in turn energizes the coils edgewise.

3.3.2.2 Activity Release

Activity release from a CASTOR cask is a function of the released fuel inventory, gas temperatures inside the cask cavity, and the tightness of the system.

The sealing system of the CASTOR cask consists of two lids: a primary lid with one metal and three elastomer seals, and a secondary lid with one metal and one elastomer seal. Conservatively only the two metallic seals are considered in this analysis. The guaranteed He-standard leak rate for each seal is 10^{-7} mbar l sec^{-1}, for both normal and accident conditions. The total leak rate of both seals combined is $2 \cdot 10^{-11}$ mbar l sec^{-1}, at the time of cask loading and $5 \cdot 10^{-8}$ mbar l sec^{-1} after 1 year. The standard He-leak rate of a double seal system vs storage time is shown in Fig. 3.3 - 5.

Leak rates of the above order of magnitude can be attributed to molecular streaming processes and can therefore easily be transformed from He-leak rates to leak rates of other gases by using the molecular part of the Knudsen formula for gas streaming in capillaries. Under the assumption that 100 % of the cladding tubes of the described BWR fuel will be damaged at the initial phase of storage and that the gas temperature inside the cask is 423° K, the gas leakage from the fuel into the cask is that listed in Tab. 3.3 - 1.

The resulting annual activity releases for the nuclides H-3, Kr-85, I-129, Cs-134 and Cs-137 are shown in Fig. 3.3 - 6 and Fig. 3.3 - 7 as well as in Tab. 3.3 - 2.

3.3.3. Protection by Equipment and Instrumentation Selection

3.3.3.1 Equipment

Conventional equipment only, such as for fire fighting, etc. has been selected to provide protection within the installation. Accordingly, no special design criteria apply.

3.3.3.2 Instrumentation

Two types of instrumentation are utilized within the facility. One of these is portable radiation monitors which have no specific design criteria (i. e. they represent standardized instrumentation). The second type of instrumentation used is that of the tightness surveillance system which is of a pressure transducer type.

Fig. 3.3 - 8 gives a schematic drawing of the diaphragm-type pressure gage used in the CASTOR cask. This pressure gage has the function of monitoring the pressure set up between the primary and secondary covers of the cask. The pressure between these covers is made higher than that inside the cask; in this way, no activity can be released even if the primary cover leaks, because the flow of gas is always directed toward the cask interior.

The pressure-actuated switch in the main gage (Fig. 3.3 - 8) changes its position if the pressure changes, thus opening a contact. In this way, an electrical signal is generated; it is displayed visually and by an annunciator. The electrical lead-throughs are welded vacuum-tight. A reference pressure of 3 bar is set in the vacuum-tight measuring instrument so that pressure changes will be signaled, even with allowance for diffusion leaks, over long storage periods.

The reference pressure is also monitored by another diaphragm-type pressure-actuated switch monitor gage so that the functioning of the main diaphragm is made secure. If the reference pressure of the main membrane were to fall, a visual and acoustic signal would again be actuated at 2.5 bar. The switching precision of the diaphragm is about ± 10 mbar. The design specifications of the pressure gage are listed in Tab. 3.3 - 3.

The function of the pressure monitoring system can be seen in Fig. 3.3 - 8. The operating space (1) of the main gage is connected with the space between the primary and secondary covers. The reference space of the main gage (2) at the same time is serving as the operation space (3) of the monitor gage. The reference space of the monitor gage (4) is connected with the space between the secondary cover and the protection plate.

3.3.4 Nuclear Criticality Safety

3.3.4.1 Control Methods for Prevention of Criticality

The CASTOR Ic cask holds 16 BWR fuel assemblies in a lattice with 4 x 4 positions. The fuel basket is made of borated-steel plates, 2 cm thick, containing o.2 wt % of boron.

3.3.4.2 Error Contingency Criteria

The design of the cask is such that the highest multiplication factor that occurs is less than 0.95. All the fuel assemblies are assumed to be in a fresh, undepleted condition, and burnup poisons are neglected. A mean enrichment of 2.8 % for the BWR fuel is assumed.

In addition, calculations assume infinite closely-packed cask arrays with internal and external flooding. The verification analysis described under section 3.3.4.3 is done with internationally recognized and internationally used codes which have been successfully tested in numerous experiments and "benchmarks".

3.3.4.3 Verification Analysis

The verification analyses for the criticality safety of the CASTOR Ic cask were done with the KENO Monte Carlo code (see APPENDIX 10 for the description of the codes used). The cross-sectional geometry used for the calculation is shown in Fig. 3.3 - 9. The fuel specifications considered are taken from Tab. 1.1 - 1 and Tab. 3.3 - 4.

The subject of investigation was the criticality safety of the shipping casks in the most reactive state, that is, in the flooded state as when the cask is being loaded. All the fuel assemblies were assumed to be in a fresh, undepleted condition, and burnup poisons were neglected.

3.3.4.3.1 Computational Method

All the cask calculations were done with the KENO Monte Carlo code. The cross-sectional geometry shown in Fig 3.3 - 9 was utilized. For the axial direction, the conservative assumption of an infinitely long active zone was made. In most of the cask calculations the fuel assemblies were arranged centered in the transport positions.

In addition, eccentric placements were also studied. The fuel assembly width considered was 15.125 cm. Casks lying next to one another were represented by total neutron reflection at the outside walls of the casks. The calculation of multplication factors was usually based on 63 cycles, each with 300 neutrons, the first three cycles always being discarded. When higher precision was necessary, a greater number of cycles or a larger number of neutrons per cycle was taken.

In the cask calculations, 16-group cross sections in the P_1 approximation were used. The 16-group cross sections for the fuel assemblies and structural materials were computed with the GAMTEC code; the B_1 approximation ($B^2 = 1 \cdot 10^{-4}$) was used for the fast spectrum the Maxwell spectrum for the thermal spectrum, and the Wigner-Wilkins approximation in the case of flooded fuel assemblies was determined by the pseudo-cell method. Empty tubes and spacers were conservatively neglected. The ambient temperature was normally assumed for the temperature. In order to investigate the temperature effect, cross sections for 100°C were generated.

To determine the maximum reactivity of the fuel assemblies with some fuel rods removed, the reactivity of the corresponding lattices of rods was also investigated as a function of the moderation ratio. The HAMMER code was used for this pupose. The temperature assumed in all these calculations was room temperature.

3.3.4.3.2 Structural Data

The fuel specifications used in the verification analysis are listed in Tab. 3.3 - 4. The conservative assumption of pure zirconium was made in the calculations for the cladding tubes. In the assembly the empty tube was not considered, since its effect on reactivity is not important.

The following densities were used as the base for calculating the cross sections of the structural materials and that of water:

Steel	= 7.566 g/cm^3
Nodular-graphite cast iron	= 7.150 g/cm^3
Water	= 1.000 g/cm^3

The steel composition corresponds to DIN 1.4301 or XCrNi189 (equivalent to U.S. Standard SS-304). The boron content of 0.2 % in the steel is considered in the steel density cited above. Nodular-graphite cast iron has a carbon content of approx. 3.25 % and a silicon content of 1.35 %.

3.3.4.3.3 Criticality Calculations

For BWR assemblies the rod lattices in the normal case have moderation ratios of about 1.58 and 1.61 respectively. Fig. 3.3 - 10 shows K_∞ and B^2 for BWR assemblies as functions of the moderation ratio. From this figure it can be seen that these assemblies are likewise undermoderated in the normal case. At higher moderation ratios, 8 x 8 rod lattices (Type 2 fuel) are more reactive, while at lower moderation ratios, 7 x 7 lattices are more reactive. In this region, however, the differences in K_∞ and B^2 are small, so that the corresponding values for Type 2 Fuel are not plotted in Fig. 3.3 - 10. The rod lattices for fuel assemblies of Type 1 fuel are somewhat more reactive up to the maxiumum of K_∞ and B^2, and these fuel assemblies also have a greater fuel-assembly width; for these reasons, the calcultions for BWR shipping casks are based only on these fuel assemblies.

Because poisoning of the fuel baskets with boron (0.2 % boron) resulted in very low multiplication factors, unpoisoned fuel baskets were studied as well. The computed results are shown in Tab. 3.3 - 5. Total neutron reflection at the outside of the cask was assumed in all calcultions; this situation corresponds to an unlimited number of shipping casks lying right next to one another.

In Case 3, the reactivity effect of off-center fuel-assembly placement in the transport positions was studied. The corner assemblies were shifted diagonally outward and the edge assemblies were shifted outward in a parallel manner, while the 2 x 2 inside assemblies were placed centered in the transport positions. The decrease in reactivity from Case 2 shows that the increase in reflector action for the fuel assemblies on the outside is overcompensated by the increasing decoupling from the fuel assemblies on the inside. Because the cask multiplication factors as a whole were lower, no further reactivity effect was studied here. A positive effect on reactivity due to withdrawn rods was assessed at 1.5 - 2 %. In each case the multiplication factor plus two standard deviations is less than 0.95.

3.3.5 Radiological Protection

This section adds to the radiological protection design criteria discussed in Section 3.3.2 (pursuant to 10 CFR Part 72.74).

3.3.5.1 Access Control

Pursuant to 10 CFR Part 72.68 (a) and 10 CFR Part 72.74 (a) (3), the storage installation is divided into radiation-protection areas (e. g. controlled areas, monitoring areas, etc.) on the basis of the local dose rates. The cask receiving section of the storage area (or building, when present) is a controlled area part of the time, while the cask storage area per se is a permanently controlled area.

Access to the site whereupon the installation is located, i. e. at the site boundary, is controlled by a peripheral fence so as to meet the intent of 10CFR Part 72.67 (a).

3.3.5.2 Shielding

The γ and n shielding are two of the most essential components of a CASTOR cask. The shielding criteria for the cask are those applied for transport and permit free movement on public roads without additional shielding. The design values for the cask shielding are:

- Surface dose rate below 200 mrem/h

- Dose rate at 1 m distance from a single cask below 10 mrem/h

Results of the cask shielding calculation are listed in Tab. 3.3 - 6. The S_n codes ANISN and DOT in the S_8 approximation were used for the shielding calculations. The coupled neutron-gamma cross-section library in the P_3 approximation, with 13 neutron and 9 gamma groups, was used. To fit the emission rates to this group structure, a typical fission spectrum (Cranberg spectrum in U-235) was used for neutrons from spontaneous fission processes, and a Gaussian distribution with a mean energy of 3 MeV (S. J. Rimshar et al., Curium Data Sheets, ORNL-4537) was used for neutrons from (α, n) reactions.

Because of the length of the cask, it was possible to compute the dose rate at the side of the cask in a one-dimensional model, using the ANISN code. For this pupose, the square cask cross section was taken as a cylinder, the optical path length being preserved. Both rows of holes were represented by a polyethylene layer with an effective thickness of d_{eff} = 4.64 cm. Fig. 3.3 - 11 gives the cask cross section considered as a cylinder. The neutron and gamma sources, considered isotropically, were referred to unit length and assumed to have a homogeneous distribution in the interior, just as were the fuel baskets and the fuel assemblies. A more complete description of the shielding calculation is given in APPENDIX 3.

Besides the theoretical shielding design an experimental verification of the cask shielding was conducted. Fig. 3.3 - 12 represents a typical curve of the total dose rate (Gamma + Neutron) measured at the cask surface for a fully loaded CASTOR Ic.

The different storage modes of a cask in an ISFSI and the related contributions to the dose from direct radiation and sky-shine are schematically shown in Fig. 3.3 - 13. Typical values for the total annual dose at the ISFSI boundary are given in Fig. 3.3 - 14.

3.3.5.3 Radiological Alarm Systems

Not applicable

3.3.5.3.1 Area Monitoring

Not applicable

3.3.5.3.2 Personnel Monitoring

Not applicable

3.3.5.3.3 Cask Monitoring

The function of the cask monitoring system is described under Section 3.3.3.2. A pressure measuring system is used as a tightness surveillance system. A gas pressure of 6 bar is set up in the exclusion space between the primary and secondary covers and monitored with the pressure gage. A pressure drop to 3 bar due to a leak is signaled. If this pressure drops to a value determined ahead of time, an alarm will be set off. Because the decay-heat output of the stored fuel assemblies falls off significantly over the intended storage time, the temperature of the gage also varies. The temperature change results in a change in the pressure inside the several chambers of the gage.

The sensitivity threshold to switch the main contact of the diaphragm-type pressure gage (minimum difference between Chamber 1 and 2 in Fig. 3.3 - 8) is 0.5 mbar.

The sensivity threshold to switch the monitoring contact (minimum pressure difference between Chamber 3 and 4 in Fig. 3.3 - 8) 1.5 + 0.25 bar

In the main gage, (see Fig. 3.3 - 8), the actual pressure difference of 2.4 bar at the beginning of the storage period decreases to 2.0 bar. Since the contact is switched at a pressure difference of 0.5 mbar, the functioning of the main gage with respect to the actual pressure difference is still guaranteed even after 40 years' storage time. The functioning of the monitoring gage (see Fig. 3.3 - 8) is likewise guaranteed, since the pressure difference in this case decreases from 2.4 bar to 2.1 bar and the sensitivity threshold of the gage is 1.5 + 0.25 bar.

The electrical leads are connected directly to the current lead-through pins. The pins are 2 mm in diameter and gold-plated. The switches are ungrounded. The normally-open switch is a gold-plated disk, which is connected to the diaphragm through a ceramic insulator. The gages are connected electrically to a display unit. The monitoring system is equipped so that either a signal or a malfunction in the monitoring system is detected and displayed. The system is continously monitored for malfunctions, such as breaks in wires, short circuits, or outage of the line current.

The annunciator system consists of a horn. The signal horn is controlled by the electronic monitoring system, giving the acoustical signal when a signal is received from a measuring instrument. The signal is sounded both in the administration building and in the central security office.

3.3.5.3.4 Monitoring in the Vincinity

For monitoring in the vicinity, phosphate-glass thermoluminescent dosimeters are typically placed at the fence in the most critical locations in order to determine the integrated local dose.

3.3.6 Fire and Explosion Protection

The cask per se is made of noncombustible material and is designed and sized to withstand the effects of more severe fires in accordance with transport regulation test conditions. Experimental tests with a prototype cask have demonstrated that no damage to the cask will occur.

The cask was exposed for 30 minutes to a fire produced by the burning of 1500 liters of normal fuel oil. The cask temperatures resulting from this test were measured with built-in thermocouples. In the framework of the cask, temperature measurements were made both while the fire was active and after it was extinguished.

Temperatures of the outer and inner cask surfaces during the fire test are shown in Chapter 8.2, Fig. 8.2-2.

The temperature measured within the fire per se could not be determined exactly, because it was above the limit of the measuring range, 1200° C, of the temperature recorder used in the measurement. The temperatures at the fin crests rose to 600-650° C, while the temperature in the interior of the cask did not change markedly during the fire. After the fire was extinguished, the temperatures in the interior of the cask were observed to continue rising. Only after four hours was a temperature equilibrium reached.

Explosive materials are neither stored nor used in the storage area. Because of their large wall thickness the storage casks can withstand external pressures due to chemical explosion. The seal function is not impaired by such events. The effect of a gas cloud explosion may include tipping of the cask. However, the impact momentum upon tipping of the cask is significantly less than the impact momentum for a drop from a height of 9 m.

3.3.7 Materials Handling and Storage

3.3.7.1 Spent Fuel Handling and Storage

No actual fuel handling occurs at the cask storage site since the casks are moved directly after receipt into the storage area. No activity during the storage period is related to direct fuel handling. The maximum external contamination limits of the storage casks are:

Beta/Gamma emitters	10^{-4} µCi/cm²
Alpha emitters	10^{-5} µCi/cm²

The basic design criteria for the ISFSI are listed under Section 1.2. Cooling requirements for the cask storage system have been established based on transportation regulations (10 CFR Part 71) as well as the related U.S. Nuclear Regulatory Guide 7.8. An additional - but not heretofore limiting - criterion is that the average fuel cladding temperature of the hottest fuel rod inside the cask shall not exceed a maximum temperature. For the typical CASTOR Ic cask this temperature is in the range of 400° C for fuel with a cooling time of 1 year. The basic idea is that the maximum cladding temperature in dry storage casks should be comparable with values during reactor operation. The heat transfer design of the CASTOR Ic cask is given under Section 5.1.3.6 of this report.

The handling and dry storage of defective fuel assemblies involves no restrictions beyond those for intact fuel assemblies.

The design criteria for criticality control as previously noted in Section 3.3.4 permits an infinite array of casks under normal and accidental conditions in any configuration. This is based on the fact that the single cask must conform to transport regulations (cavity filled with water, fresh fuel assumption) resulting in an effective neutron multiplication factor (k_{eff}) of less than 0.95 (including two standard deviations) and that it has been demonstrated that no inleakage of water is possible under accident conditions.

Due to the barrier and confinement of the cask, contamination control as such relates only to the cask surfaces. The corresponding design criterion is that the surface contamination level (upon cask receipt and during operation) not exceed that specified in the transport regulations.

Regarding the handling of damaged (defective) fuel elements no specific design criterion has been established. That is, in principle, fuel assemblies with defective fuel rods can be placed in dry storage with no special additional measures. Most of the gaseous fission products have already been released during reactor operation and during the decay time in the fuel-assembly storage pool at the reactor. Further damage of defective rods can be ruled out since they have no internal pressure and the defective fuel assembly is stored under inert conditions.

3.3.7.2 Radioactive Waste Treatment

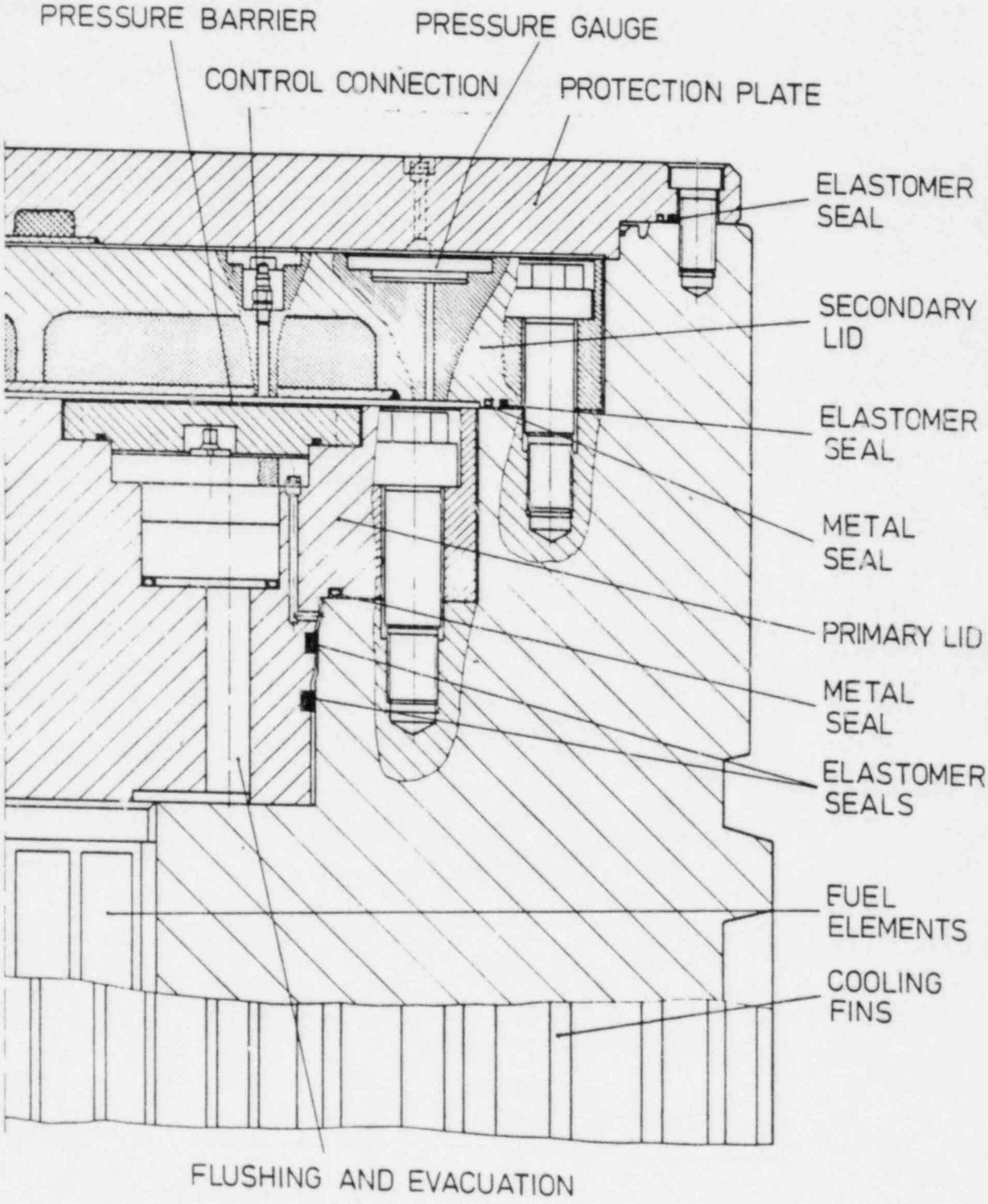
A distinguishing feature of this type of fuel-assembly storage is that radioactive materials are handled in casks that remain permanently sealed, thereby providing a containment system that securely prevents the escape of radioactive materials. In addition, only clean casks are accepted and stored. From this it results that in AR-type CASTOR-cask dry storage modes no waste is generated, ie. since the cask must be cleaned at the reactor site in case of contamination.

3.3.7.3 Waste Storage Facilities

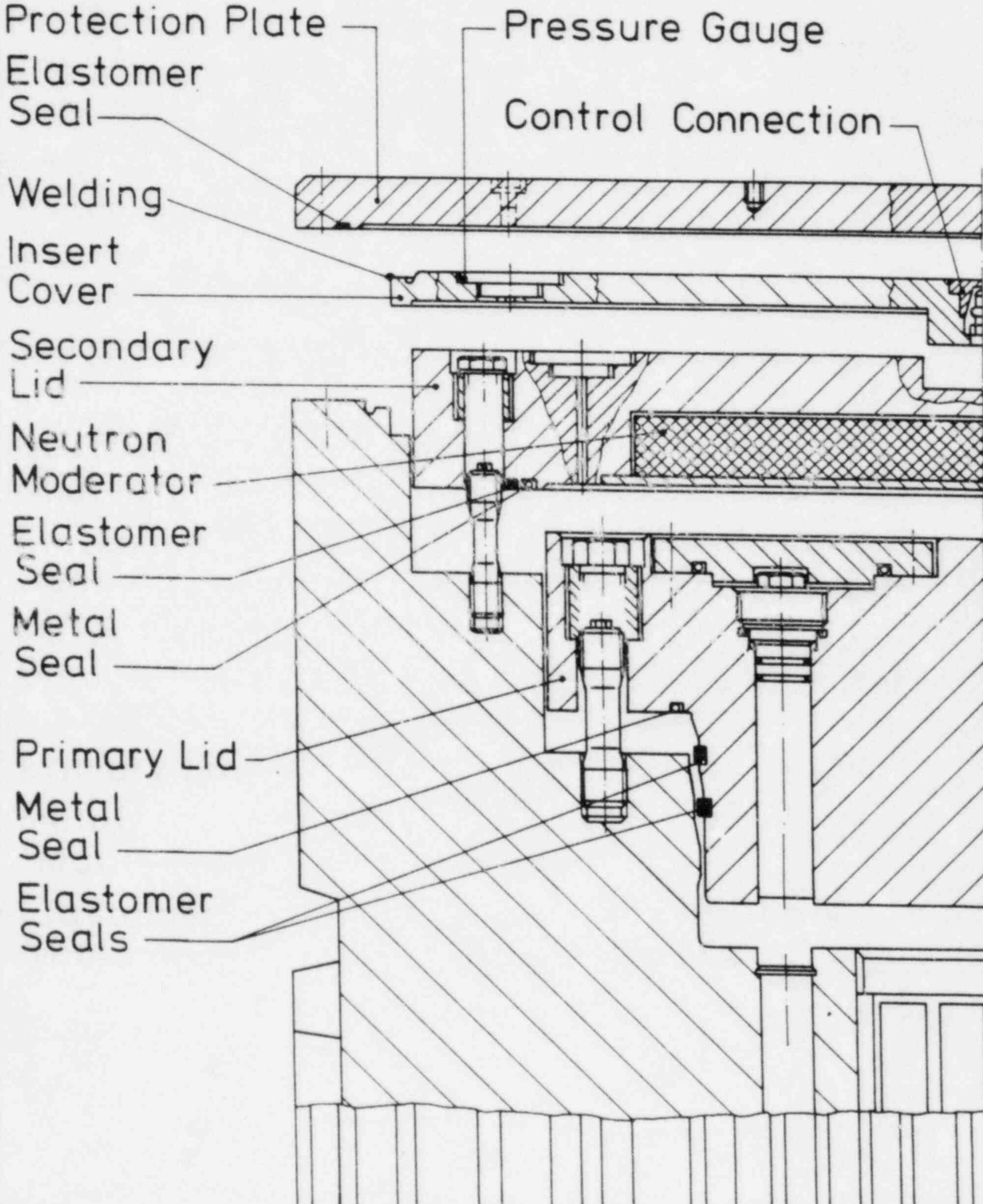
Not applicable for AR installations.

3.3.8 Industrial and Chemical Safety

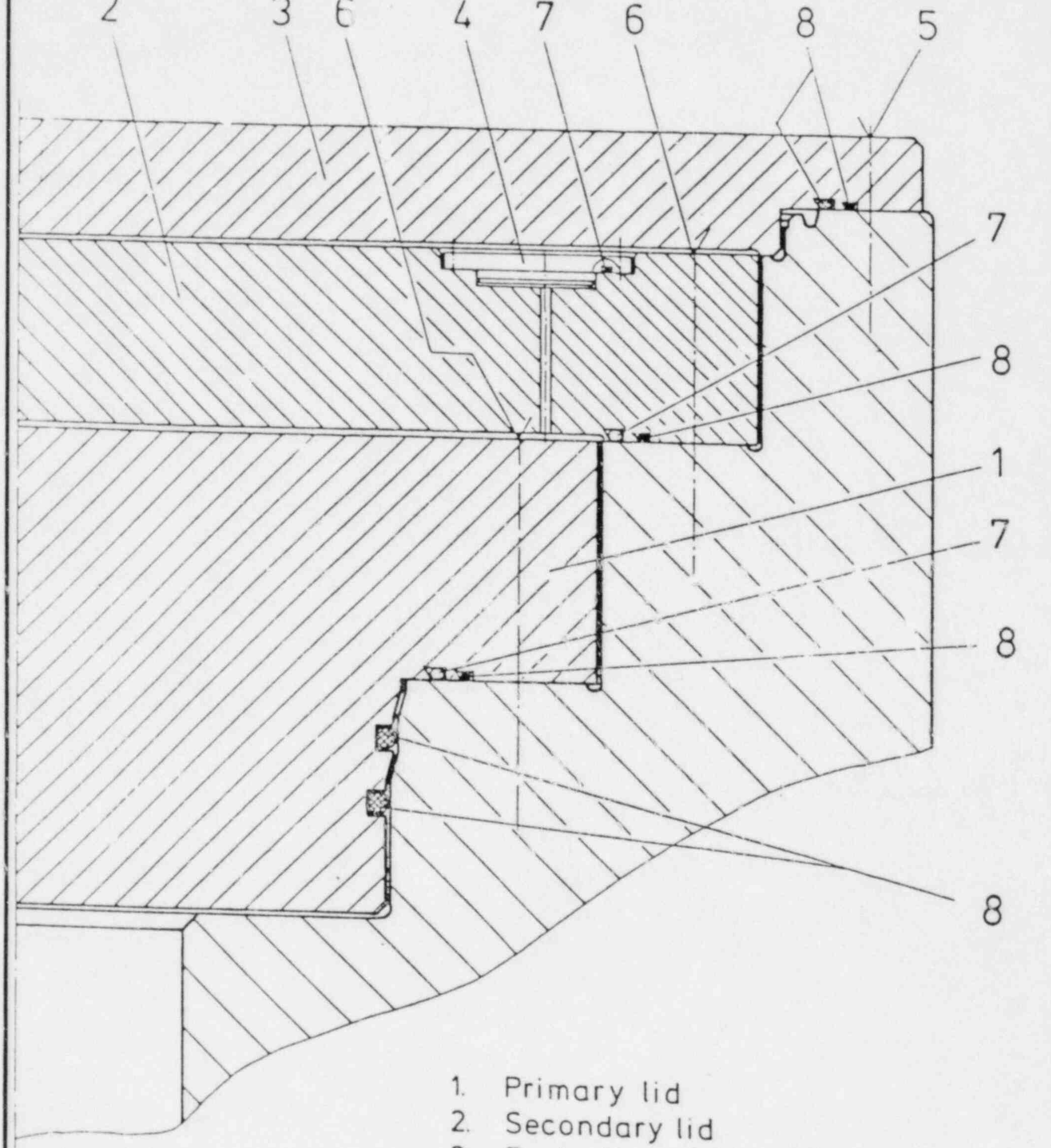
See comments under Section 3.3.6



GNS	CASTOR Confinement System	Fig. 3.3 - 1

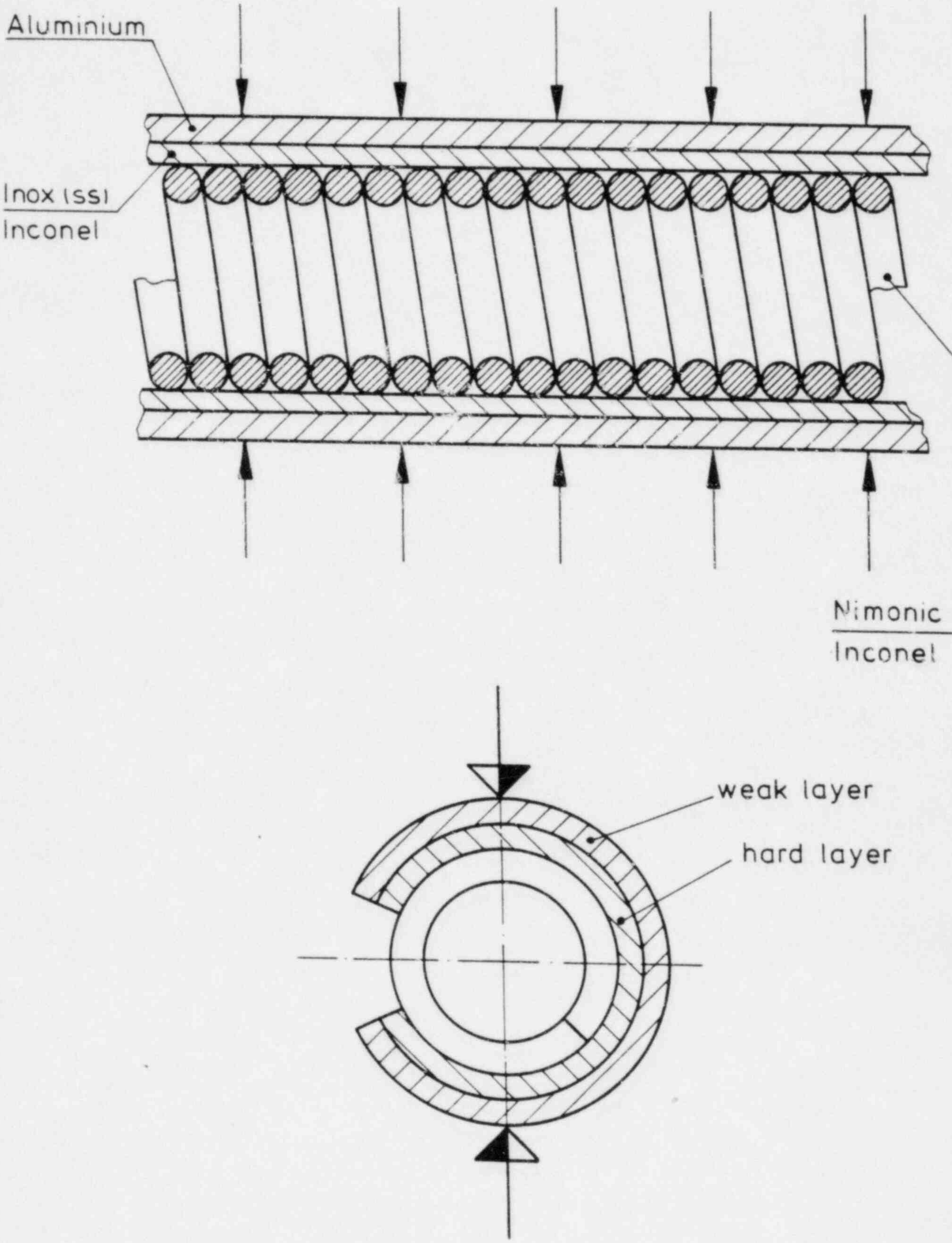


GNS	CASTOR Confinement System with Insert Cover	Fig. 3.3 - 2



1. Primary lid
2. Secondary lid
3. Protection plate
4. Pressure gauge
5. Bolts
6. Bolts
7. Metal seal
8. Elastomer seal

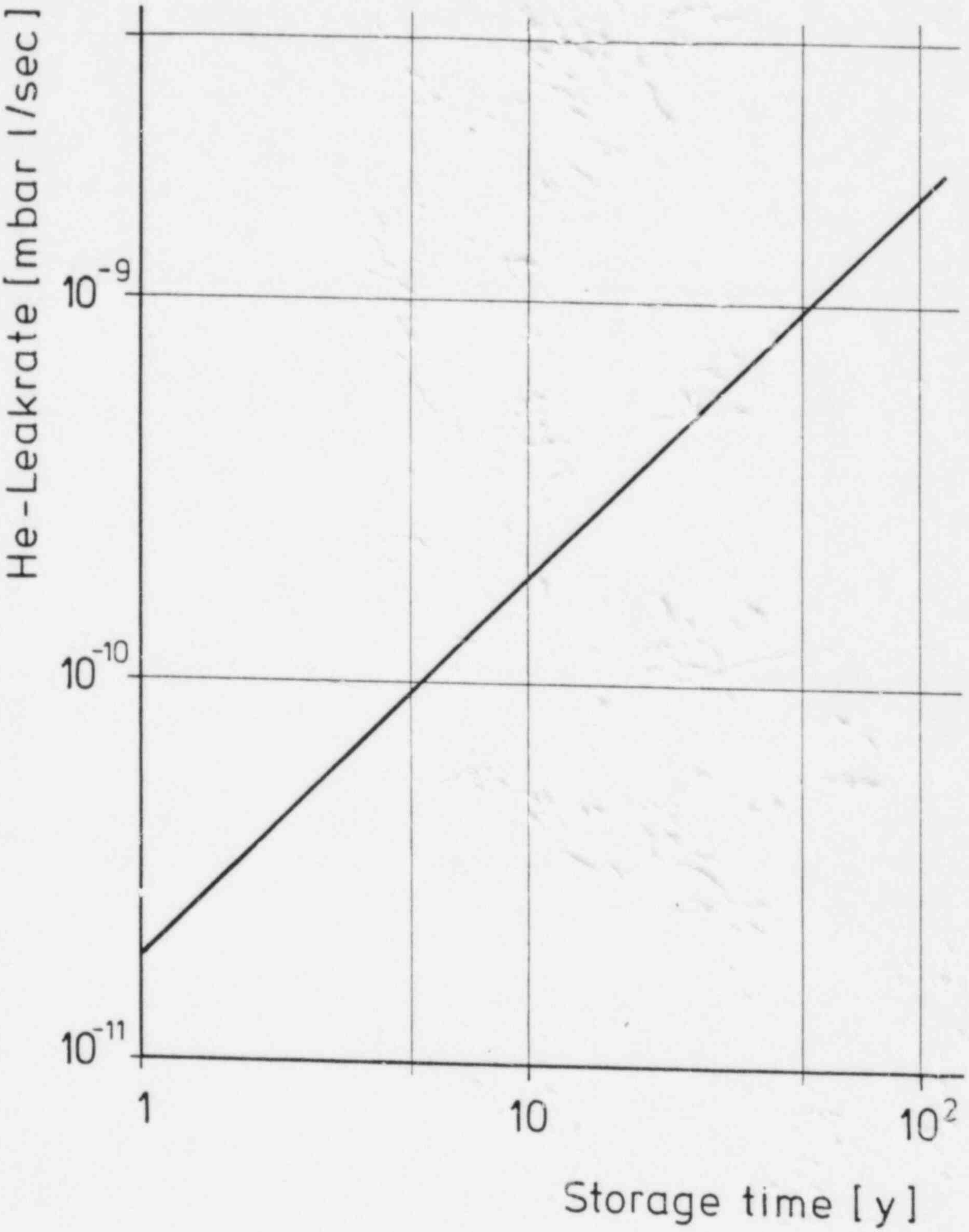
GNS	CASTOR Seal System	Fig. 3.3 - 3



GNS

Principle of Metal Seals

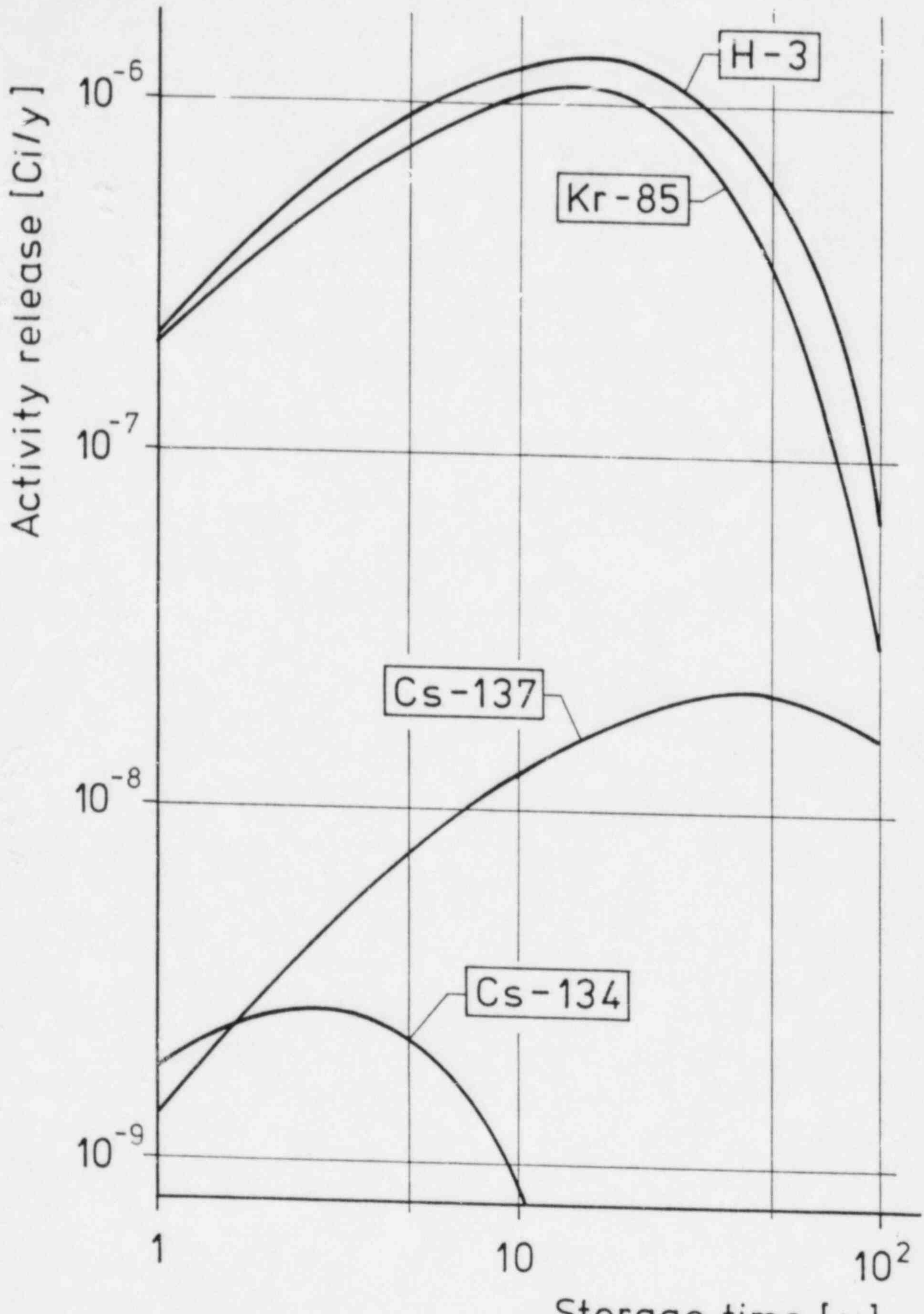
Fig. 3.3 - 4



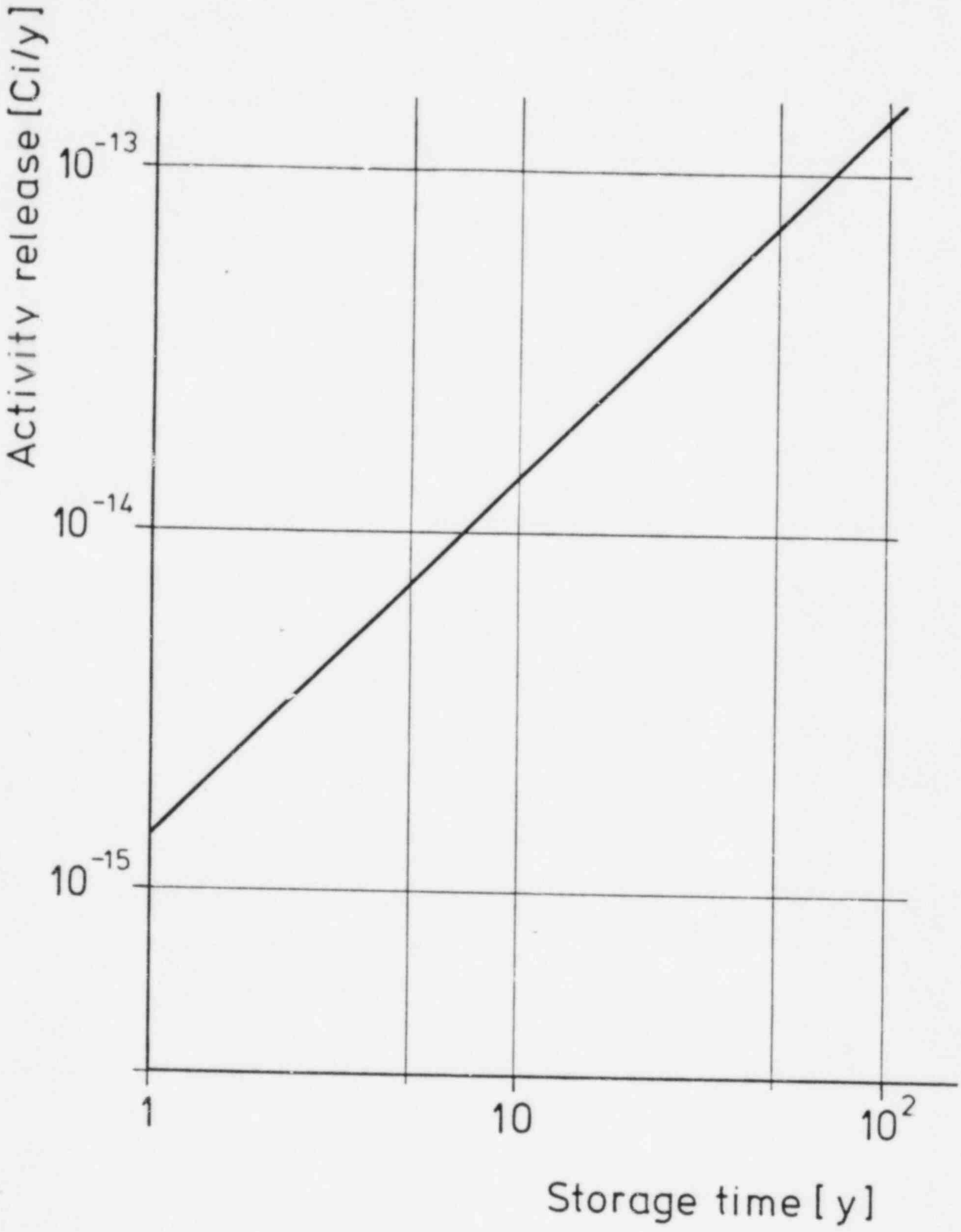
GNS

He - Leak rate of a CASTOR Cask vs Storage Time

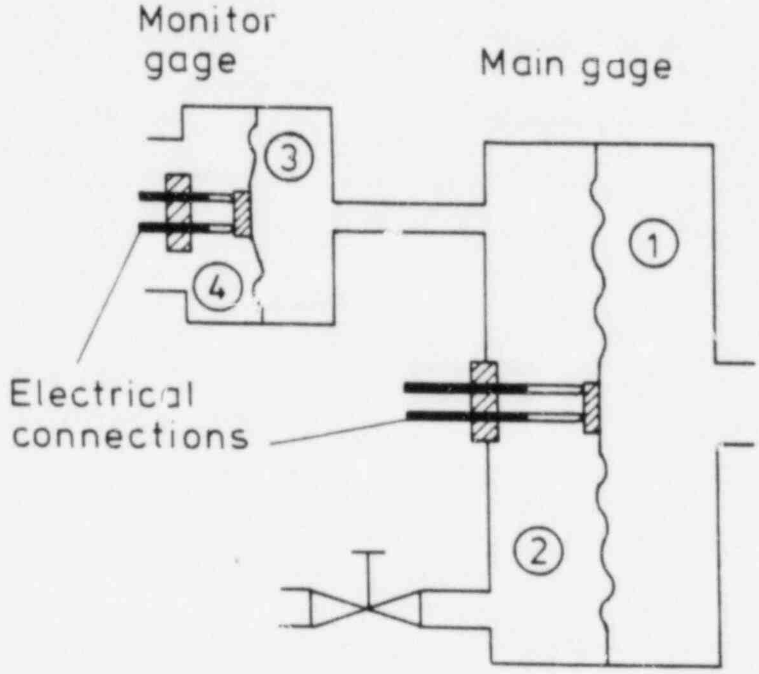
Fig. 3.3 - 5



GNS	Activity Release of the CASTOR-Confinement (Double-Seal) System	Fig. 3.3 - 6



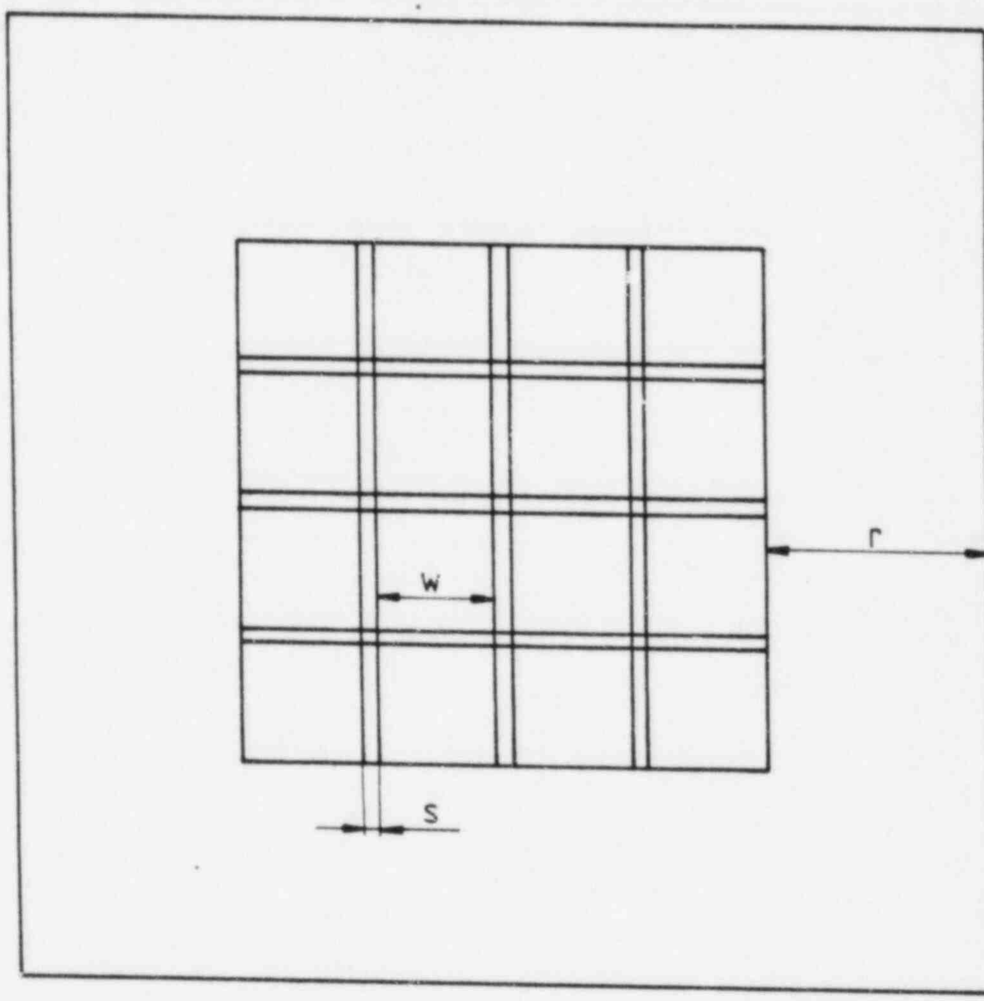
GNS	Iodine Release of a CASTOR - Confinement (Double-Seal System)	Fig. 3.3 - 7



① Operating space
②,③ Reference space
④ Outer space

Schematic of the CASTOR Pressure Gage

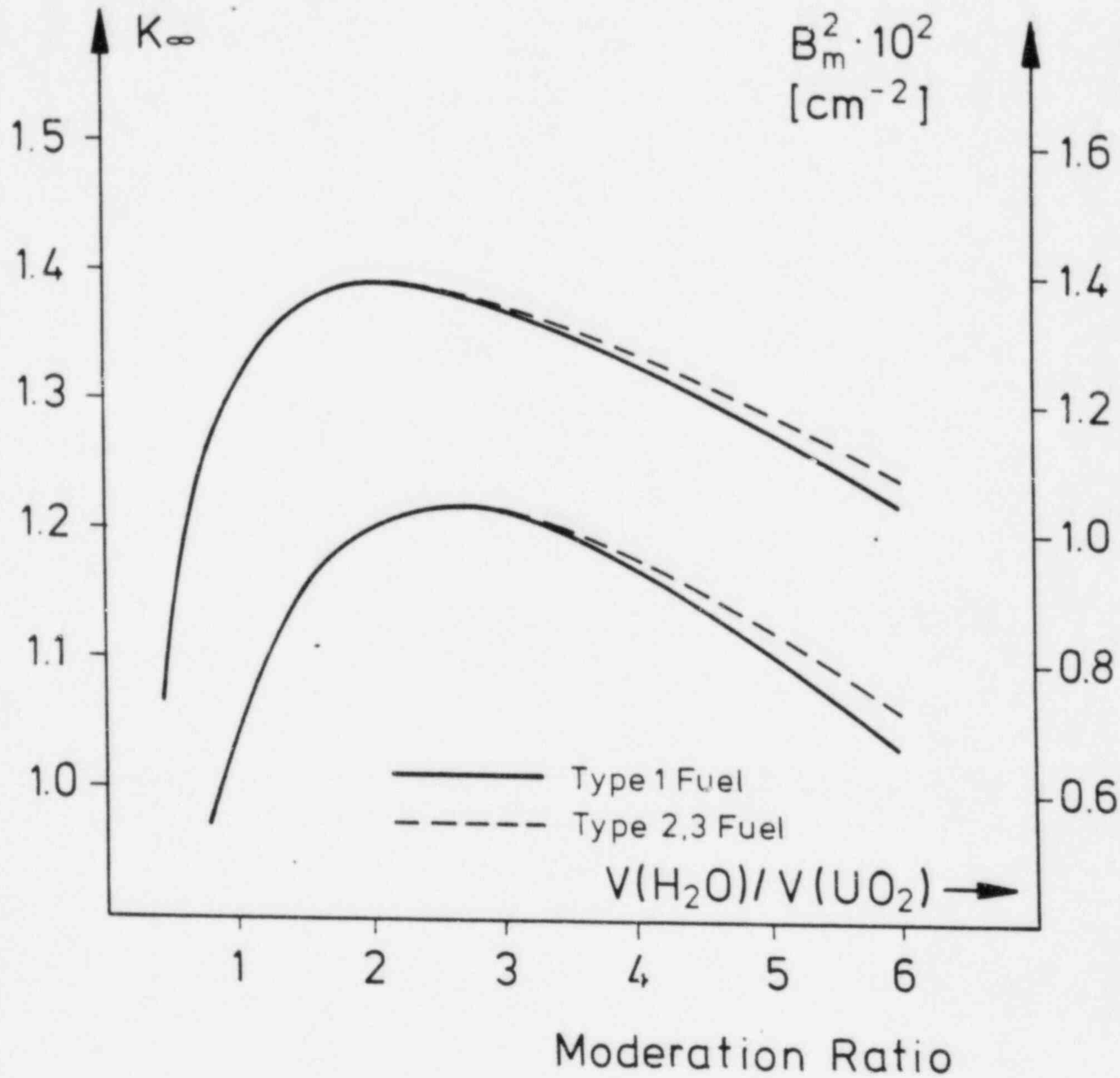
Fig. 3.3 - 8



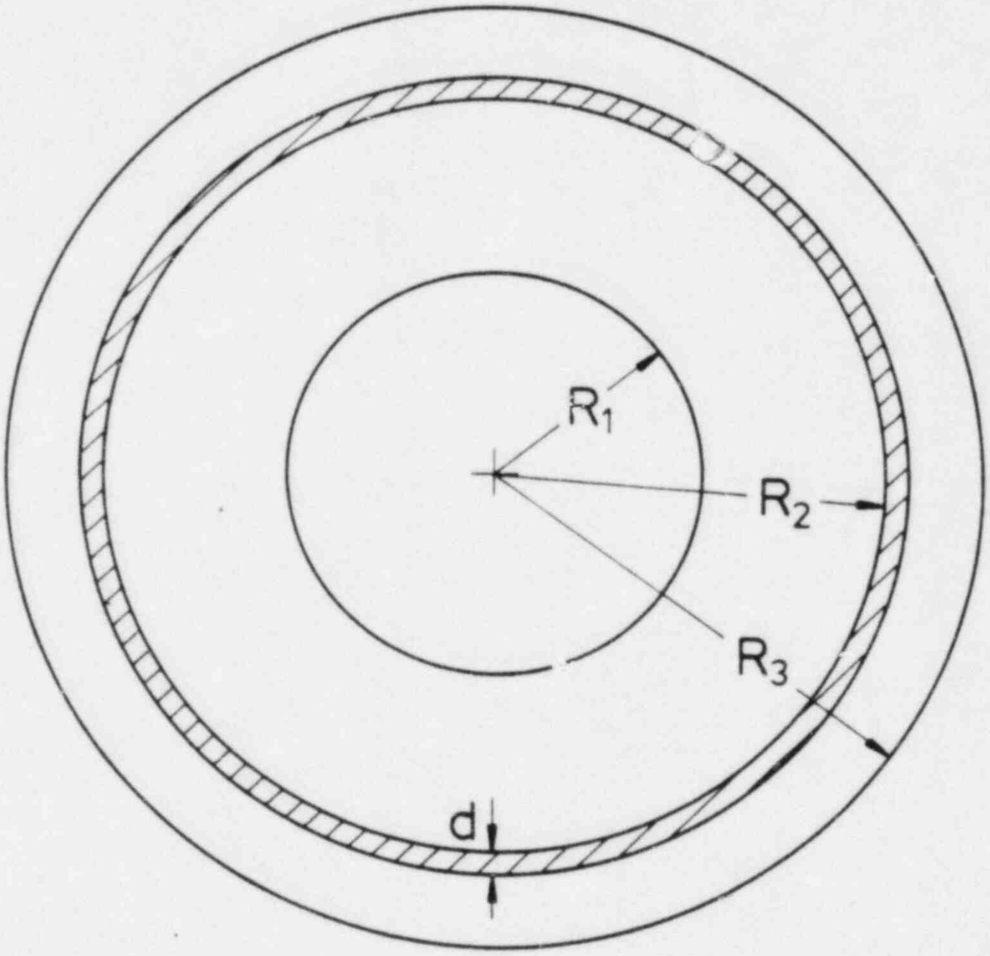
r = Reflector thickness (30 cm)
w = Width of fuel assembly (16 cm)
s = Boron-steel plate thickness (2 cm)

Cask Cross Section

Fig. 3.3 - 9

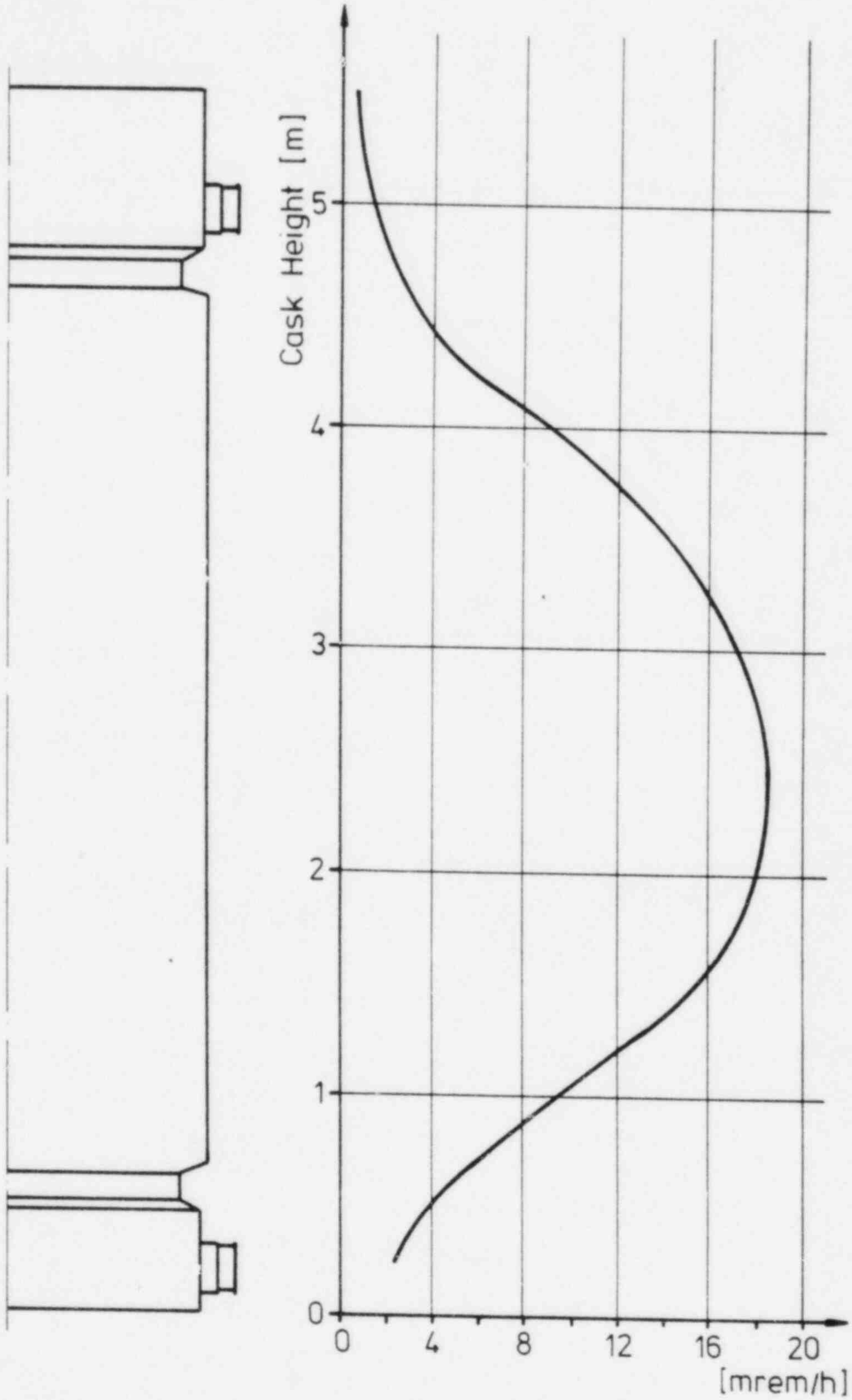


GNS	K_∞ and B^2_m vs Moderation Ratio	Fig. 3.3 - 10

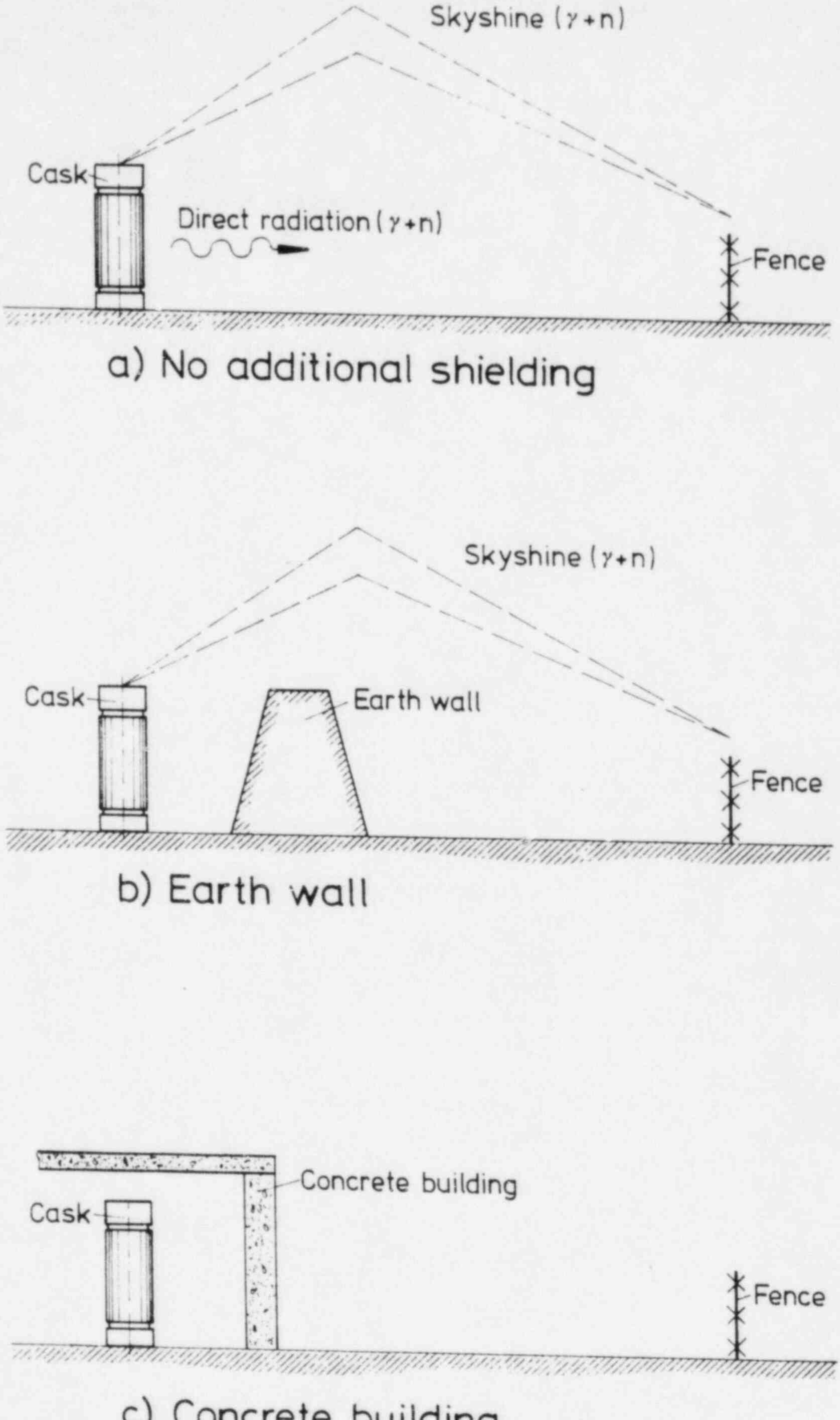


R_1 = 33.0 cm
R_2 = 63.0 cm
R_3 = 80.1 cm
d = 4.64 cm

GNS	Cask Cross-Section Considered as a Cylinder	Fig. 3.3 - 11



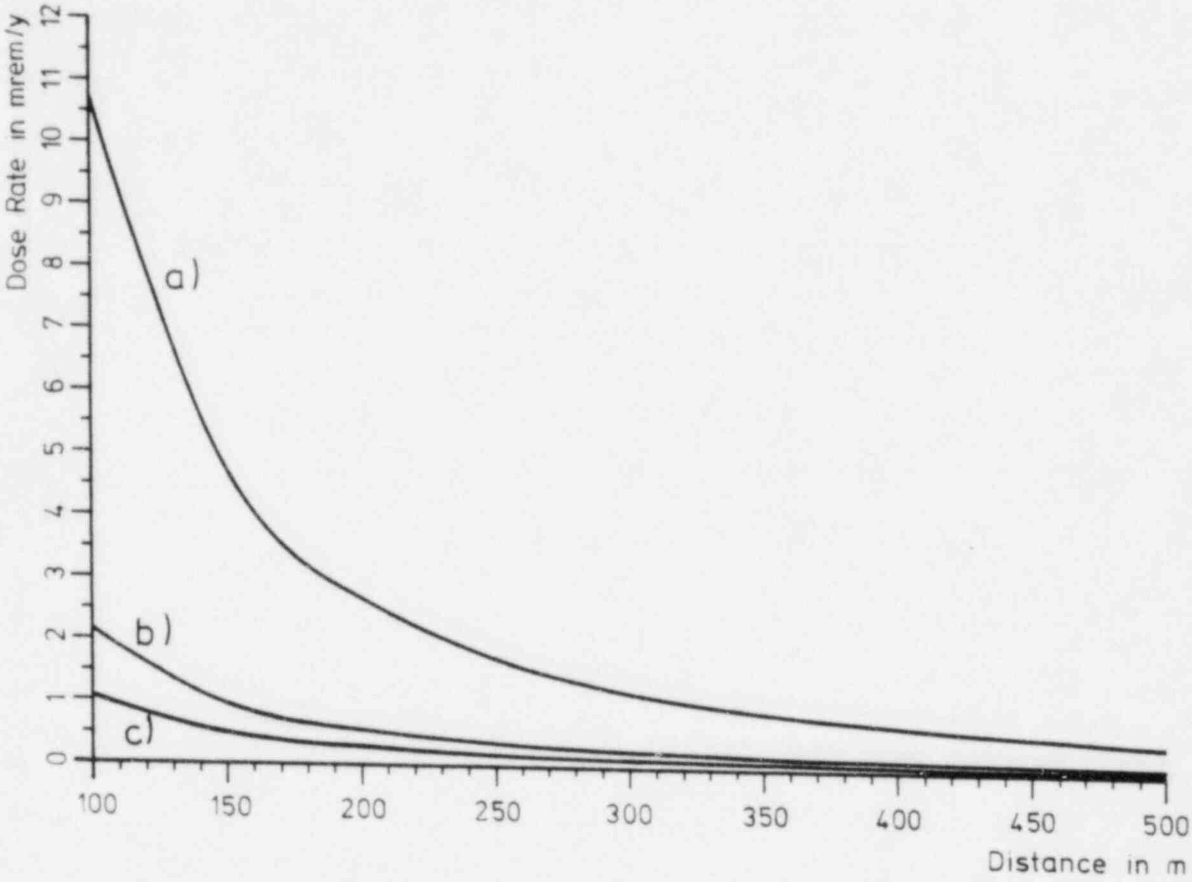
GNS	Measured Surface Dose Rate of a Castor Ic Cask	Fig. 3.3 - 12



GNS

Different Shielding Modes in an ISFSI

Fig. 3.3 - 13



a) No addional shielding
b) Building structures
c) Earth wall

GNS

Annual Dose Rate vs Distance from a Single Cask

Fig. 3.3 - 14

Nuclide	Release Fraction from Fuel %	Cavity Inventory Ci
Tritium H - 3	10	1.8
Krypton Kr - 85	10	24
Iodine I-129	1	10^{-5}
Cesium Cs - 134	0.01	0.5
Cesium Cs - 137	0.01	0.3

Nuclide	Calculated Release in Ci/Year
Tritium H - 3	$1.0 \cdot 10^{-6}$
Krypton Kr - 85	$7.8 \cdot 10^{-7}$
Iodine I - 129	$4.0 \cdot 10^{-14}$
Cesium Cs - 134	$4.6 \cdot 10^{-10}$
Cesium Cs - 137	$8.2 \cdot 10^{-9}$
Total	$1.8 \cdot 10^{-6}$

Release Rates for Normal Operation

Tab. 3.3 - 2

1. Physical specifications

Switching pressure, working space	3 bar
Switching pressure, reference space	2.5 bar
Maximum pressure difference, long-term service	3.5 bar
Response sensitivity	0.5 mbar
Switching precision	± 10 mbar
Leak rate	10^{-9} mbar-L-sec^{-1}

2. Electrical specifications

Maximum allowable switch contact voltage	10 V
Maximum allowable switch contact current	10 mA

3. Environmental requirements

Maximum allowable service temperature	150 °C
Temperature coefficient	10^{-2} mbar/°C

4. Materials of constructions

Measuring side	Stainless steel (1.4301)
Reference side	Ag, Au, ceramic
Diaphragm	CuBe, nickel-plated; stainless steel version in preparation

	BWR Fuel * Type 1	Typ 2 and 3
Fuel	UO_2	UO_2
Enrichment	2.8 %	2.8 %
Percent of theoretical density	96 %	96 %
Pellet diameter in cm	1.240	1.058
Cladding material	Zr-2	Zr-2
Density in g/cm^3	6.55	6.55
Rod diameter in cm	1.43	1.25
Wall thickness in cm	0.081	0.085
Rod lattice	7 x 7	8 x 8
Lattice spacing in cm	1.875	1.625

* See Tab. 1.1 - 1

Case	Fuel Assembly Placement	% Boron	k_∞
1	centered	0.0	0.9098
2	centered	0.2	0.8619
3	outward	0.2	0.8293

Criticality Calculation Results

Tab. 3.3 - 5

Cask Postion	Dose Rate in mrem/h		
	Neutron	Gamma	Total
Surface			
Side	3.9	6.5	10.4
Middle of bottom	5.8	11.4	17.2
MIddle of cover	9.3	7.5	16.8
1 m distance			
Side	1.4	2.7	4.1
Middle of bottom	2.1	4.7	6.8
Middle of cover	3.3	3.1	6.4
2 m distance			
Side	0.9	1.8	2.7
Middle of bottom	1.3	3.0	4.3
Middle of cover	2.0	2.0	4.0

3.4 Classification of Structures, Components and Systems

A dry cask storage installation has, in principle, two classes of structures, components, and systems in regard to their safety functions, namely:

- Cask structures and confinement systems which comply with all nuclear safety requirements, and are subject to quality assurance according to nuclear standards.

- Auxiliary components of the cask which have no safety functions

A classification of the cask components into two different classes is presented in Tab. 3.4 - 1. The classification is done for storage operations of the cask only.

Components with Safety Functions	Components with no Safety Functions
Cask Body	Protection plate
Cask Confinement	Trunnions
Primary lid	Elastomer seals
Secondary lid	
Lids for the openings	
Metal seals	Flushing connection
	Drainage connection
Monitoring system	Surface protection
Bolts	
Cask Internals	

3.5 Decommissioning Considerations

3.5.1 Storage Casks

The casks are only slightly activated by the neutron flux emanating from the spent fuel. Activation calculations were performed with the ORIGEN code under the following assumptions:

(1) The cask contains 16 BWR (boiling-water-reactor) fuel assemblies with a burnup of 27,000 MWd/MTU, after a cooling time of 1 year.

(2) The cask is stored under such constant conditions for 10 years.

(3) For the calculations of the activation in 20, 30 and 40 years the thermal neutron flux shown in Fig. 3.5 - 1 was assumed.

(4) Only the material outside the polyethylene layer is activated (inside this layer, the neutrons are too fast to be absorbed).

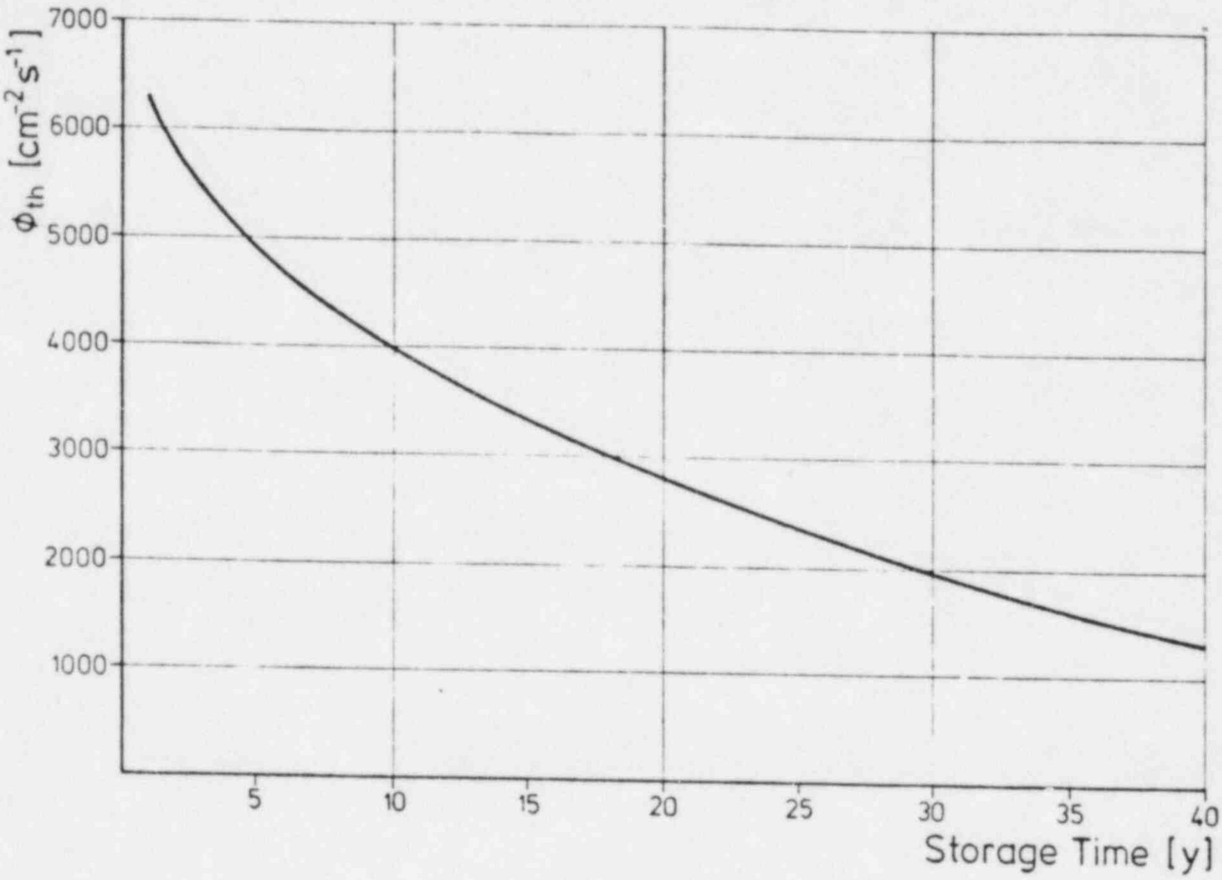
(5) All neutrons leaving the polyethylene layer have thermal energies.

(6) The neutron flux is held constant over the cask volume; that is, there is no local decrease is flux due to capture.

According to the shielding calculations performed, the above assumptions imply a neutron flux of about 6300 cm^{-2}-sec^{-1} at the beginning of storage. Table 3.5 - 1 gives the activities of individual radionuclides in 10, 20, 30 and 40 years.

3.5.2 Building and Facilities

Not applicable



Thermal Neutron Flux inside the Cask Wall

Fig. 3.5 - 1

Nuclide	Half-life	Cask wall activity in Ci vs storage time 10y	20y	30y	40y
Mn - 54	2.6 h	$2.1 \cdot 10^{-5}$	$1.3 \cdot 10^{-5}$	$9.2 \cdot 10^{-6}$	$6.6 \cdot 10^{-6}$
Fe - 55	2.4 y	$1.1 \cdot 10^{-4}$	$7.2 \cdot 10^{-5}$	$5.0 \cdot 10^{-5}$	$3.6 \cdot 10^{-5}$
Fe - 59	44.6 d	$2.7 \cdot 10^{-6}$	$1.7 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	$8.5 \cdot 10^{-7}$

4. Installation Design

4.1 Summary Description

4.1.1 Location and Layout of Installation

Not applicable

4.1.2 Principal Features

4.1.2.1 Site Boundary

Not applicable

4.1.2.2 Controlled Area

Not applicable

4.1.2.3 Emergency Planning Zone (EPZ)

Not applicable

4.1.2.4 Site Utility Supplies and Systems

Not applicable

4.1.2.5 Storage Facilities

The AR storage facility of an ISFI consists of a single cask or representative arrays of casks as shown in Fig. 1.1 - 1 under Section 1.1.

4.1.2.6 Stack

Not applicable

4.2 Storage Structures

The design bases for the CASTOR cask storage systems are the performance criteria cited in Section 1.2 against which the cask design is checked.

4.2.1 Structural Specification

The structural specifications of the CASTOR Ic cask are not derived from calculated permissible mechanical stresses in the cask structure materials but only result from the necessary heavy shielding. In the sense of the mechanical design of the cask according to nuclear guides the cask is overdimensioned.

4.2.1.1 Calculation of the Cask Body

The stress that arises in an inscribed circular cylinder at a internal pressure of 7 bar is calculated. The approximation of the cylinder is shown in Fig. 4.2 - 1 The calculation is done under the maximum-distortion-energy theory (Ref. Dubbel I., p. 405 ff.)

D_a = 1543 (outer cylinder diameter)

$D_i = \sqrt{2} \cdot 666 = 964$ mm (inner cylinder diameter)

$S_e = \frac{D_a - D_i}{2} = \frac{1543 - 946}{2} = 298$ mm (wall thickness)

The reduced stress can be calculated with

$$\sigma_{red} = \sqrt{\frac{1}{2}\left[(\sigma_t - \sigma_r)^2 + (\sigma_r - \sigma_x)^2 + (\sigma_x - \sigma_t)^2\right]}$$

$$\sigma_t = p_i \frac{\eta^2 + 1}{\eta^2 - 1} \quad \text{(tangential stress)}$$

$$\sigma_r = -p_i \quad \sigma_x = p_i \frac{1}{\eta^2 - 1} \quad \text{(radial stress)}$$

$$\eta = \frac{D_a}{D_i} = \frac{1543}{946} = 1.63$$

$$\sigma_t = p_i \frac{(1.63)^2 + 1}{(1.63)^2 - 1} = 2.21 \; p_i$$

$$\sigma_r = -p_i \quad T_x$$

$$\sigma_x = p_i \frac{1}{(1.63)^2 - 1} = 0.60 \; p_i \quad \text{(axial stress)}$$

$$\sigma_{red} = \sqrt{\frac{1}{2} p_i^2 \, [(2.21 + 1)^2 + (-1 - 0.60)^2 + (0.60 - 2.21)^2}$$

$$\sigma_{red} = 2.78 \; p_i.$$

Calculation for Internal Pressure of 7 bar

$$p_i = 7 \text{ bar} = 7 \cdot 10^5 \text{ N/m}^2 = 0.7 \text{ N/mm}^2$$

$$\sigma_{red} = 2.78 \cdot 0.7 = \underline{\underline{1.95 \text{ N/mm}^2}}$$

4.2.1.2 Calculation of the Primary Lid

The dimensions used for the calculations of the primary lid are shown in Fig. 4.2 - 2.
The progress of the dimensions of the sections and of the reference strain are represented as a curve over the radius of the cover and the maximum reference strain is compared with the yield point quoted for the cover material. In addition the burst strength is determined from the tensile strength quoted.

For the primary cover the following mechanical properties apply:

Tensile strength R_m = 780 .... 980 N/mm^2

Yield point $R_{p\,0.2} \geq$ 635 N/mm^2

A lateral contraction of $\mu = 0.30$ was assumed in the calculations.

The dimensions of the sections of the cover are calculated in accordance with the Kirchoff Plate Theory for rotationally symetrical plates which only sag slightly under load. The dimensions of the sections are based on the following equations:

$$m_r = - K \left(\frac{d^2w}{dr^2} + \frac{\mu}{r} \cdot \frac{dw}{dr} \right)$$

$$m_\mu = - K \left(\frac{d^2w}{dr^2} \mu + \frac{1}{r} \cdot \frac{dw}{dr} \right)$$

$$q_r = - K \left(\frac{d^3w}{dr^3} + \frac{1}{r} \cdot \frac{d^2w}{dr^2} + \frac{1}{r^2} \cdot \frac{dw}{dr} \right)$$

Hereby m_r and m_μ represent the unit of the section moment related to the unit of the circumference and q_r the transverse force. The stiffness of the plate is K and w is the displacement of the individual plate elements. The derivation of the further relationships of the plate theory equations used in the following sections will not be considered here.

The strains calculated from the sections dimensions m_r, m_μ and q (see Fig. 4.2 - 3 to Fig. 4.2 - 5) are combined to the reference strain according to the hypothesis of the maximum work of shape alteration.

$$\sigma_v = \sqrt{\sigma^2_r + \sigma^2_\mu - \sigma_r \sigma_\mu + 3 \tau^2_r}$$

The bolt holes are taken into account by assuming that the strains in the radial direction increase analogically with the reduction in the cross section.

The strains in a tangential direction are the same as for a plate without holes. If one were to calculate on the basis that the ends of the plates were beams, then the strains in the tangential direction would be ignored in any case.

The bearing loads and the clamping moments are assumed to be uniformly distributed over the pitch circle. The acceleration in the operating situation is transformed to an internal pressure uniformly distributed within the seal and is added to the internal pressure by the computer program.

For the case of significantly higher loadings acting than are foreseen for normal operations, it is assumed that the bolt connection will lift up as the weaker unit at the separating line and that a freely rotatable support will be given whereas otherwise clamping which is completely resistant to bending is assumed.

Strains during operation

The strains were calculated in accordance with the previously described calculational model for each millimeter and represented with a plot. The plate height was put in as a constant as 338 mm from r = 0 to r = 483 mm and as 163 mm from r = 483 mm up to the pitch circle.

At the pitch circle 36 holes as smooth through bores having a diameter of 76 mm were assumed.

The maximum reference strain occurs, as can be seen from Fig. 4.2 - 6, at the pitch circle. For this the value of

$$\sigma_V = 69.1 \ N/mm^2$$

was calculated. With the yield strength quoted for the material of $R_{p0.2}$ = 635 N/mm^2, the strain inventory for the situation during operation is found to be:

$$\sigma_V = 69.1 \ N/mm^2 < R_{p0.2} = 635 \ N/mm^2$$

Bursting strength

For this, the section along the pitch circle d_T for a plate which is supported in such a way that it can be freely rotated is again taken. Since again here the bolts cannot exert any clamping moment, the plane perpendicular strains are put at zero. The critical cross section which remains is found to have the area:

$$A_s = (d_T \cdot \pi - 36 \cdot d_B)\, h = (1090 \text{ mm} \cdot \pi - 36 \cdot 76 \text{ mm})\, 163 \text{ mm}$$

$$A_s = 112.2 \cdot 10^3 \text{ mm}^2$$

According to the hypothesis of the maximum work of shape alteration, the tangential strain at the lower limit of the tensile strength amounts to:

$$\tau_m = \frac{R_m}{\sqrt{3}} = \frac{780 \text{ n/mm}^2}{\sqrt{3}}$$

$$\tau_m = 450 \text{ N/mm}^2$$

$$p_{max} = \frac{4 \cdot A_s \cdot \tau_m}{d_1^2 \cdot \pi} = \frac{4 \cdot 112.2 \cdot 10^3 \text{ mm}^2 \cdot 450 \text{ N/mm}^2}{1005^2 \text{ mm}^2 \cdot \pi}$$

$$p_{max} = 63.6 \text{ N/mm}^2 = 636 \text{ bar}$$

The progress of the reference strain (Fig. 4.2 - 6) shows that the latter is almost constant at approx. 1 N/mm2 up to the first jump at the alteration of height. Up to the median seal radius, the reference strain can again be seen to increase only very slowly, it being of an order of magnitude of approx. 6 N/mm2. As a result of the introduction of the lineal load form the contact pressure of the seal, a further jump then takes place to some 10 N/mm2, and, a little further on, the commencement of the holes can be recognized from the rapid increase of the reference strain. The maximum reference strain lies on the pitch circle and has been shown to be 69.1 N/mm2. There is thus a safety factor of approx. 9 in relation to the possibility of the yield point of 635 N/mm2 being attained.

4.2.1.3 Calculation of the Secondary Cover

The dimensions used for the calculation of the secondary lid are given in Fig. 4.2 - 7. The same calculational model was used for the secondary cover as has already been described for the primary cover under section 4.2.1.2.

Strains During Operation

The strains were calculated in accordance with the calculational model described in Section 4.2.1.2 for each millimeter and represented with a plot. The plate height was put in as a constant as 53 mm from r = 0 to r = 515 mm and as 127 mm from r = 515 mm to the pitch circle. At the pitch circle 36 holes as smooth through bores having a diameter of 61 mm were assumed.

The maximum reference strain occurs, as can be seen from Fig. 4.2 - 11, in the middle of the cover. The value here was found to be

$$\sigma_v = 62.9\ N/mm^2$$

With the yield strength quoted for the material of $R_p0.2 = 635\ N/mm^2$, the strain inventory for the situation during operation is found to be:

$$\sigma_v = 62.9\ N/mm^2 < R_{p0.0} = 635\ N/mm^2$$

Bursting Strength

The middle point of the plate is critical for the bursting strength. The assumption is again made that the bolt connection will lift up before the bursting strength is attained. The cover is then supported in a freely rotatable manner.
For reasons of simplicity the pressure is assumed to be constant up to the pitch circle. The maximum internal pressure at the minimum tensile strength of 780 N/mm² is found to be:

$$p_{max} = \frac{8 \cdot \sigma_{max} \cdot h^2}{d^2_T\ (3 + \mu)} = \frac{8 \cdot 780\ N/mm^2 \cdot 53^2\ mm^2}{(1325)^2\ mm^2\ (3 + 0,3)}$$

$$p_{max} = 3.025\ N/mm^2 = 30.25\ bar$$

The progress of the reference strain (shown in Fig. 4.2 - 11) shows that the latter attains its maximum value at the midpoint of the plate.

In the operating situation, the reference strain has its maximum value of 62.9 N/mm² at the middle of the plate, falls then continuously to approx. 28 N/mm² and then increases to approx. 36 N/mm² at the first jump at the alteration in height. After that the strain remains at low levels until it increases again rapidly in the region of the holes following a jump brought about by the seal as a result of the addition of the lineal force; however it does not attain the value it has at the midpoint of the plate.

The quoted lower tensile strength of 780 N/mm² is attained in the middle of the cover at an internal pressure of 30.25 bar.

4.2.1.4 Calculation of the Primary Cover Bolts

The loading on the primary cover bolts is determined by two different types of loading which, however, do not occur together:

- the loading of the bolts at the fitting of the cap nuts
- the loading of the bolts during operation.

The technical data on which the calculations are based are:

- Size of bolt	M 42 x 3
- Mass of cover	2175 kg
- Number of bolts	36
- Material of bolts	X 5 Cr Ni 13 4
- Yield point of bolt material	685 N/mm²
- Tensile strength	780 - 980 N/mm²
- Necessary contact pressure of the Metal-O-Ring seal	≦ 500 N/mm

The tightening torque of the cap nuts of 620 ± 30 Nm necessary for the calculation of both types of loading is so large that, in the case of an internal pressure of 7 bar and an additional acceleration of 10 g (operational value), a contact pressure of 500 N/mm in a circumferential direction is attained.

From this a maximum bolt force per bolt of $F_{s\,max.}$ in operation can be calculated:

$$F_{smax} = F_v + \varnothing_n \cdot F_A = 95{,}217 \text{ N}$$

F_v	=	Pretensioning force	=	92,873 N
$\varnothing_n$	=	Force ratio for centric initiation of the axial force	=	0.11
F_A	=	Operating force on the bolt	=	21,305 N

Loading of the bolts at fitting:

$$M_t = F_v \cdot \frac{d_2 \cdot \tan(\alpha + \gamma')}{2} = 297 \text{ Nm}$$

$$\sigma_v = \sqrt{a^2 + 3\,\tau^2} = \sqrt{\left(\frac{F_V}{A_S}\right)^2 + 3\left(\frac{16\,M_t}{\pi d^3}\right)^2}$$

d_2	=	root thread diameter	= 3.9 cm
$\tan(\alpha + \gamma')$	=	frictional factor	= 0.164
A_S	=	bolt core cross section	= 8.29 cm²
d	=	core diameter	= 3.25 cm
G_v	=	136 N/mm²	

The loading of the bolts at fitting of 136 N/mm² lies well below the 0.2 - yield point of the material of the bolts of 685 N/mm²

Loading of the bolts in operation:

$$\sigma = \frac{F_{smax.}}{A_S} = \frac{95{,}217\ N}{829\ mm^2}$$

$$\sigma = 115\ N/mm^2$$

The loading of the bolts during operation of γ = 115 N/mm² lies well below the 0.2 - yield point of the bolt material of 685 N/mm².

4.2.1.5 Calculation of the Secondary Cover Bolts

As with the primary cover bolts, the loading on the secondary cover bolts is determined by two different types of loading which, however, do not occur at the same time:

- the loading of the bolts at the fitting of the cap nuts

- the loading of the bolts during operation

The technical data on which the calculations are based are:

- Size of bolt	M 36
- Mass of cover	1175 kg
- Number of bolts	36
- Material of bolts	x 5 CrNi 13 4
- Yield point of bolt material	685 N/mm²
- Tensile strength	780 - 980 N/mm²
- Necessary contact pressure of the Metal-O-Ring seal	≤ 500 N/mm

The tightening torque ot the cap nuts of 640 ± 30 Nm necessary for the calculation of both types of loading is so large that, in the case of an internal pressure of 7 bar and an additional acceleration of 10 g (operational value), a contact pressure of 500 N/mm in a circumferential direction is attained.
From this a maximum bolt force per bolt of $F_{S\ max.}$ in operation can be calculated:

$F_{smax.}$	=	$F_v + \varnothing_n \cdot F_A$	=	112.993 N
F_V	=	pretensioning force	=	110,133 N
$\varnothing_n$	=	force ration for centric initiation of the axial force	=	0.11
F_A	=	operating force on the bolt	=	26.000 N

Loading of the bolts at fitting:

$$M_t = F_V \cdot \frac{d_2}{2} \cdot \tan(\alpha + \gamma') = 327{,}381 \text{ N mm}$$

$$\sigma_V = \sqrt{\sigma^2 + 3\tau^2} = \sqrt{\left(\frac{F_V}{A_S}\right)^2 + 3\left(\frac{16\ Mt}{\pi d^3}\right)^2}$$

$$\sigma_V = \sqrt{\left(\frac{110{,}133 \text{ N}}{594 \text{ mm}^2}\right)^2 + 3\left(\frac{16 \cdot 327{,}381 \text{ Nmm}}{\pi \cdot (27.5)^3 \text{ mm}^3}\right)^2}$$

$$\sigma_V = 231 \text{ N/mm}^2 < R_{p0.2} = 685 \text{ N/mm}^2$$

d_2	=	root thread diameter	=	3.34 cm
Tan $(\alpha + \delta')$	=	frictional facator	=	0.178
A_S	=	bolt core cross section	=	5.94 cm^2
d	=	core diameter	=	2.75 cm

$$\sigma_V = 231 \text{ N/mm}^2$$

The loading of the bolts at fitting of 231 N/mm^2 lies well below the 0.2-yield point of the bolt material of 685 N/mm^2.

Loading of the bolts in operation:

$$\sigma = \frac{F_{S\ max.}}{A_S} = \frac{112.993}{594 \text{ mm}^2}$$

$$\sigma = 190 \text{ N/mm}^2$$

The loading of the bolts during operation of $\sigma = 190$ N/mm^2 lies well below the 0.2-yield point of the bolt material of 685 N/mm^2.

4.2.1.6 Material Properties

The material of the cask body is a ferritic type of nodular cast iron similar to GGG-40.3 described in the German DIN-Standard DIN 1693, Sheet 1. A typical specimen analysis gives the following material composition in weight percent:

C	:	3.2	....	3.8 %
Si	:	1.3	....	2.0 %
Mn	:	0.20	....	0.25 %
P	:	max.		0.03 %
S	:	max.		0.01 %
Cu	:	max.		0.15 %
Ni	:	0.9	....	1.3 %
Mg	:	0.1	....	0.3 %
Fe	:	92	....	94 %

For the tensile properties the DIN 1693 Standard is not applicable because the material values required (tensile strength and yield point) are only specified for pieces up to 20 cm thickness.
There is also reference to the observation that the large thickness of the casting leads to slower rates of crystalization and segregation effects which degrade some mechanical properties, particularly the ductility. Consequently, it is implied that mechanical properties are to be established on the basis of fabrication experience. That is, the mechanical properties are to reflect those of the samples taken from the cask body. The following material values can be guaranteed for the cast nodular iron taken from all parts of the cask body (minimum values):

Tensile strength	:	$R_m \geq$	250 N/mm^2
Yield point	:	$R_{p0.2} \geq$	200 N/mm^2
Elongation at fracture	:	$A_5 \geq$	3 %
Reduction of area	:	$Z \geq$	4 %

On the basis of positive tests with the prototype CASTOR cask and available mentioned data on this cask, in particular, values from test pieces such as pieces from the bottom, side and cover regions, the actual values established from the CASTOR prototype apply as nominal values for the mass-produced casks of the CASTOR - family.

The positive results of drop tests with the CASTOR prototype cask can also be transferred to the CASTOR Ic cask type if at least the same level is guaranteed for the material properties of safety significance. To characterize these properties, extensive material studies are used, especially on specimen material from the CASTOR prototype, proceeding from the following arguments.

To ensure an adequate factor of safety against impermissible plastic deformation under mechanical loads in the 9 m free drop test, it is sufficient to guarantee the yield strength of the material (0.2 % offset yield strength $R_{p0.2}$). Local plastic strains, which may occur chiefly in the cooling fins, do not impair the functioning of the cask. The corresponding factor of safety can be quantified. To insure an adequate factor of safety against loss of integrity by fracture in the 9 m drop, the material ductility required for this factor of safety must be guaranteed.

The CASTOR prototype put through a drop test at ambient temperature and 233° K is adequately safe in this regard, so that the factor of safety is at least unity. The ductility of the CASTOR Ic material to be demonstrated in the casting must be at least equal to or better than that of the test specimen in order to provide an equal or greater factor of safety.

Material studies have shown that the ductility values (elongation at fracture, A_5, reduction of area, Z) are relatively small over most of the cask wall in the CASTOR prototype. On account of the difficult reproducible measurability and the large scatter, it is not appropriate to specify these values. However, there is a systematic relation between A_5 or Z on the one hand and the far more reproducible determinable ratio of yield strenghts $R_{p0.2}/R_m$ on the other-a relation based on the mechanics of the material. For this reason, the ratio of yield strengths can be used as an indirect measure of the ductility to be guaranteed. If metrologically reproducible ductility values are demonstrated, with a smaller scatter, then these can be used directly as guaranteed values.

The material properties characterized in terms of these values ($R_{p0.2}/R_m$, A_5 and Z) based on more than 120 material tests are listed in Tab. 4.2 - 1.

4.2.2 Installation Layout

As previously noted information relevant to this section is of a site-specifc nature. Typical cask arrangements of an AR ISFSI are shown in Fig. 1.1 - 1 under Section 1.1.

The storage casks are usually placed in an upright position on the floor slab. The floor is usually made of reinforced concrete, made in sections with joints. The type of foundation as well as the floor dimensions is site-specific and should be investigated separately.

In case certain cask arrangements are present, for handling purposes the distance between the cask rows can be optimized. For the storage installation described in APPENDIX 4, an optimum distance of 2.80 m from cask center to center has been found.
Typical arrangements of CASTOR casks are shown schematically in Fig. 4.2 - 12.

4.2.3 Individual Unit Description

The individual unit consists of a single cask as described under Section 1.2 and 3.

4.2.3.1 Function

The function of a single cask is described under Section 1.2 and 3.3.

4.2.3.2 Components

Components used for the operation are the cask with its particular components:

- shielding
- double confinement system
- criticality control (basket)
- heat transfer system

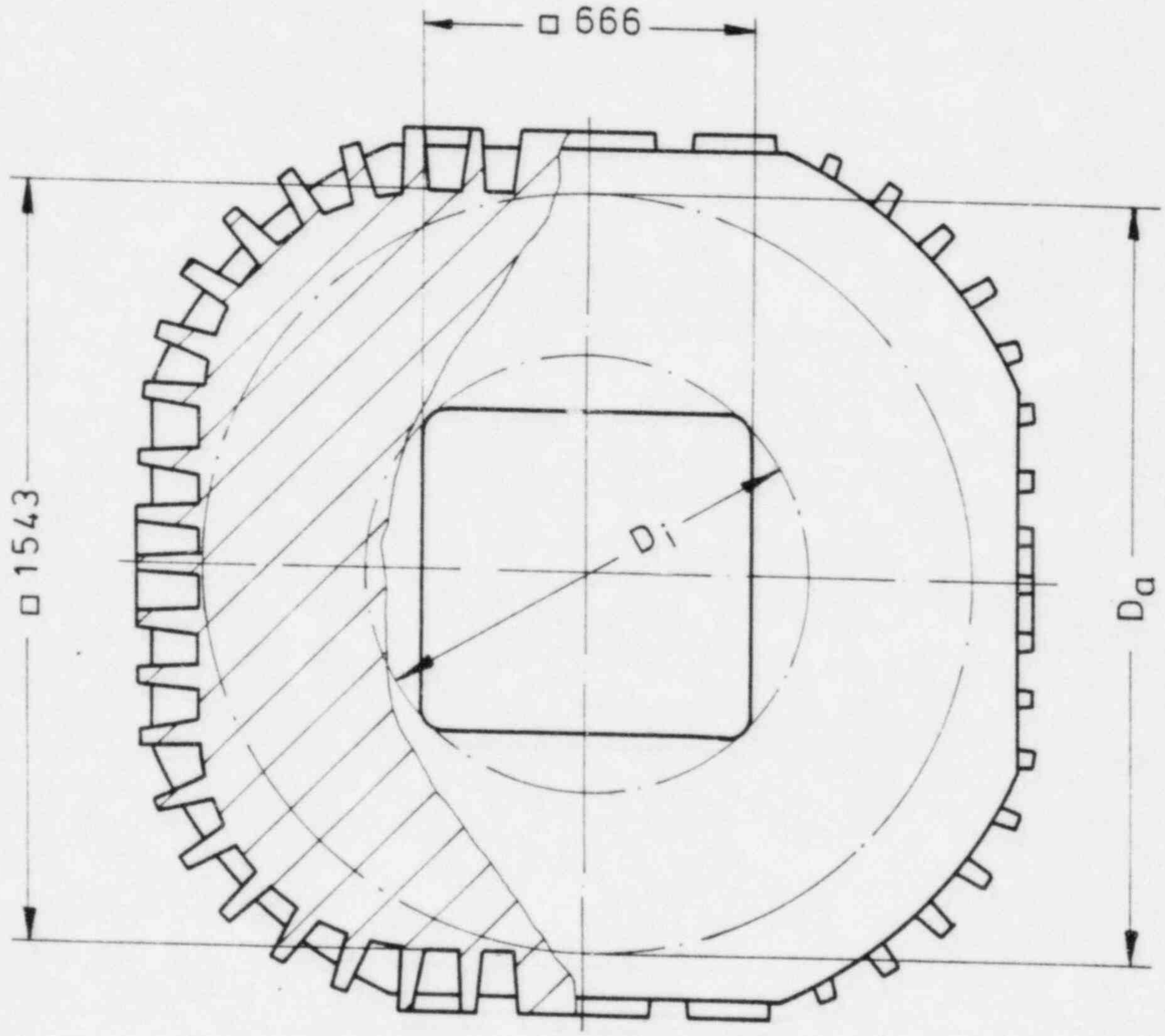
as described under Section 1.2

4.2.3.3 Design Bases and Safety Assurance

The safety related components of the CASTOR cask are :

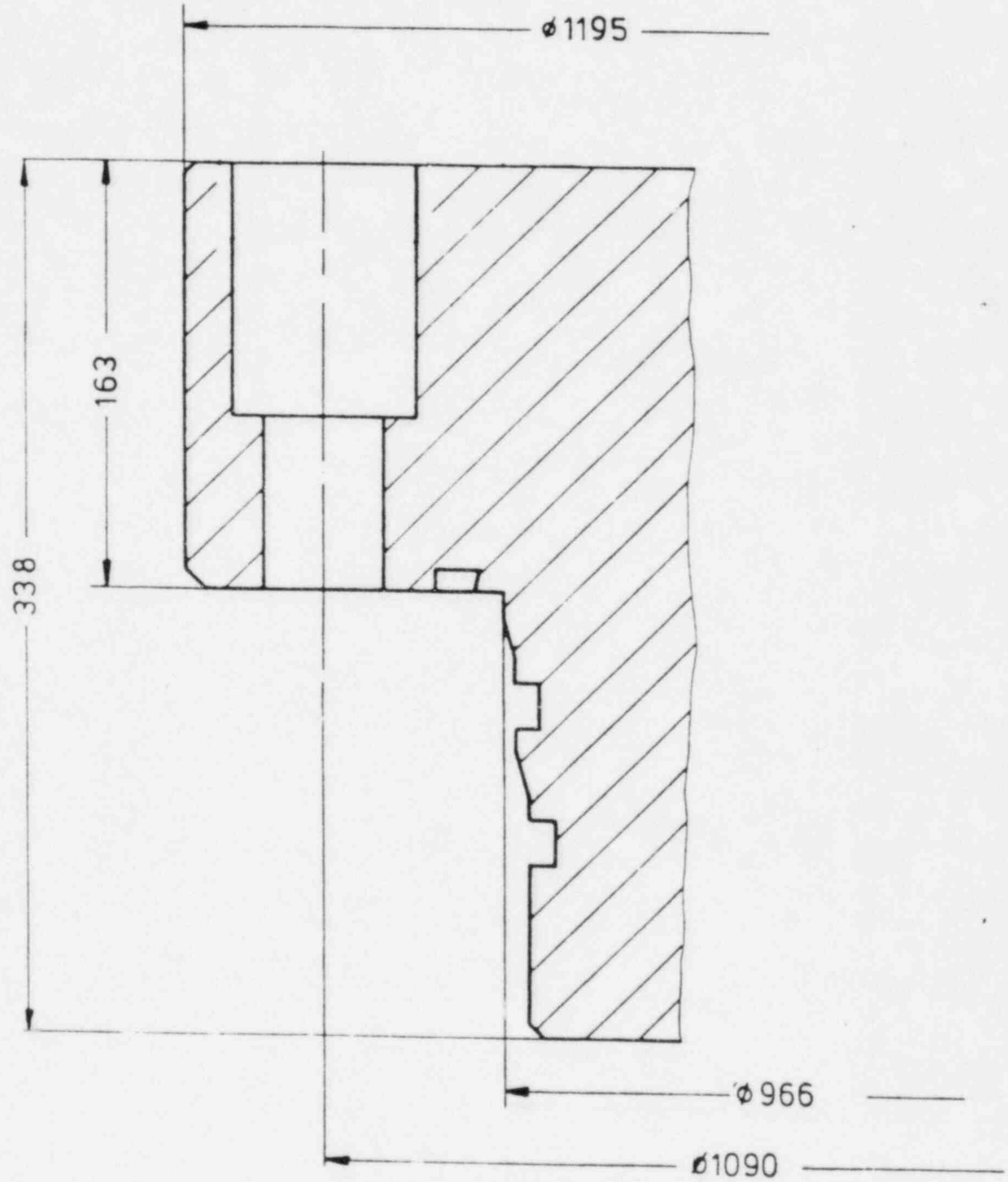
- cask body
- primary lid
- secondary lid
- metal seals
- bolts
- small lids
- basket

These components underlie an extensive quality assurance program. A description of this QA-program is given in Section 11.

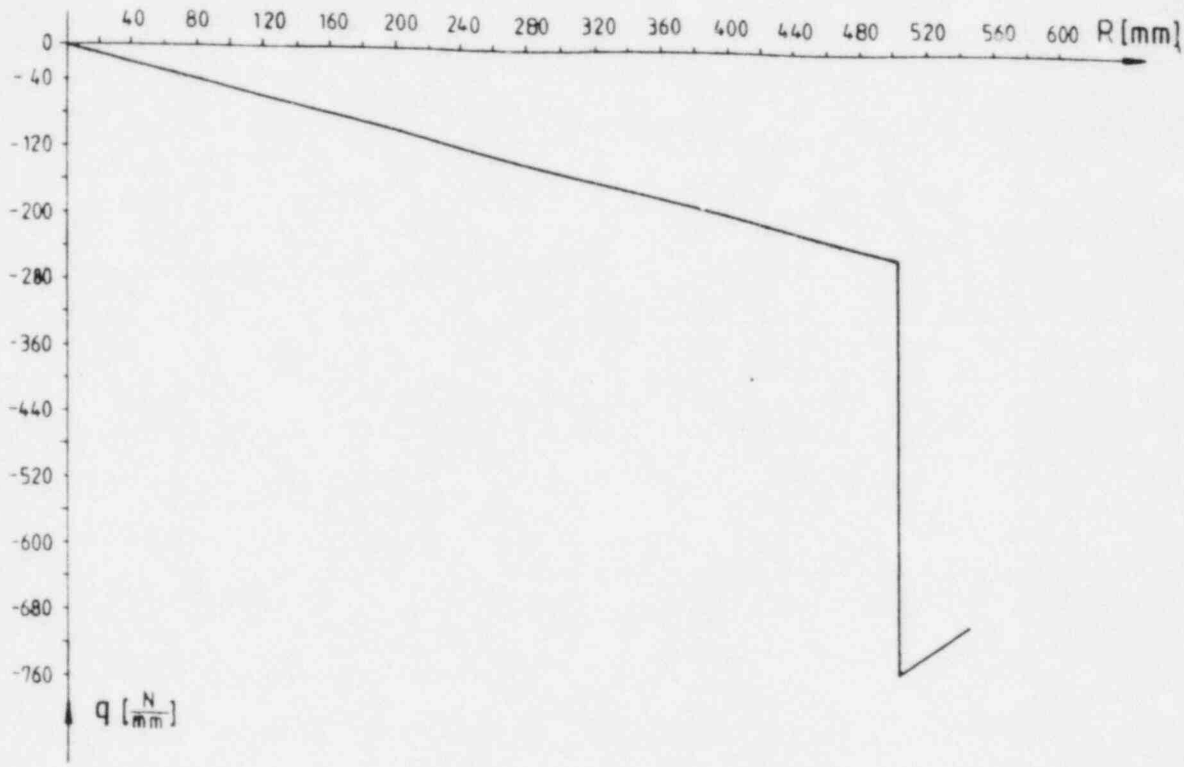


D_i = Inner Diameter (66.4 cm)
D_a = Outer Diameter (154.3 cm)

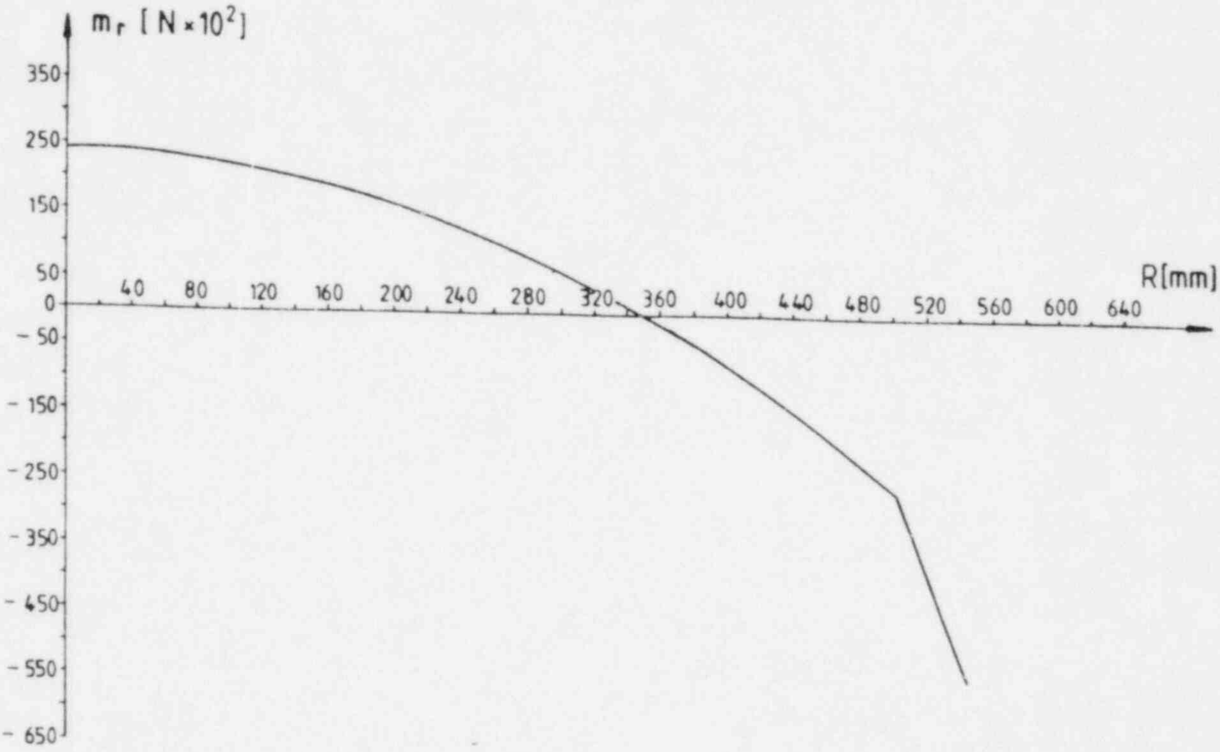
GNS	Approximation of the Cask as a Cylinder	Fig. 4.2 - 1



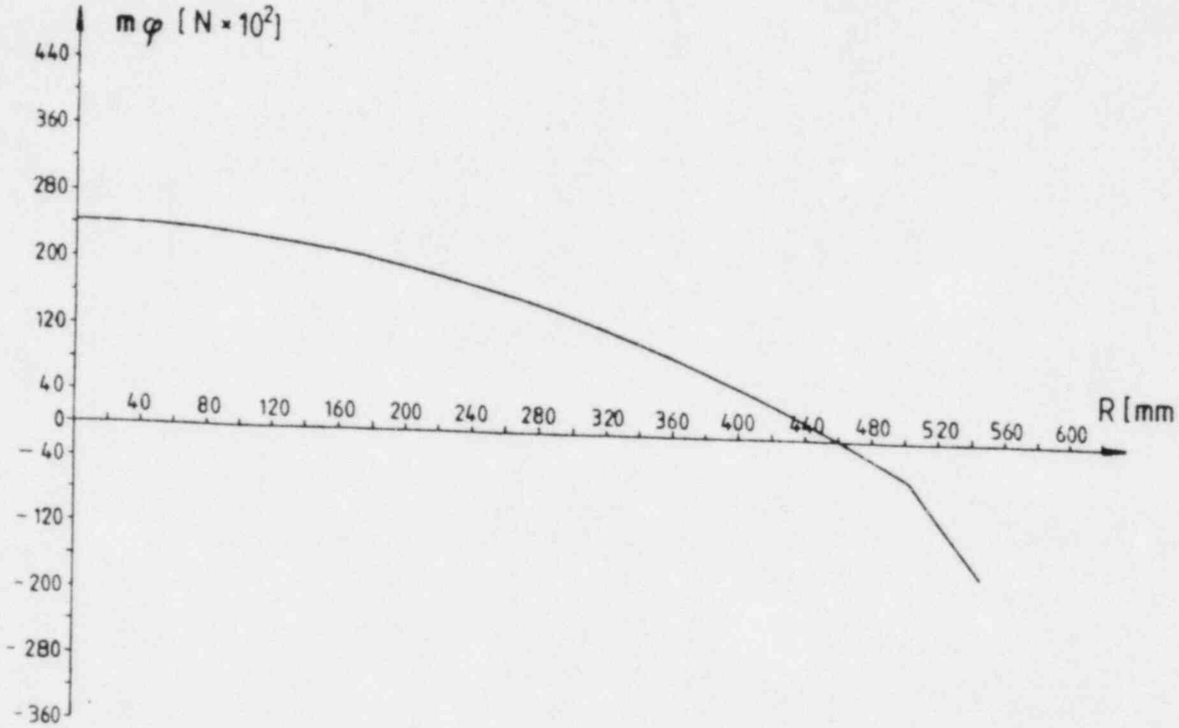
GNS	Dimensions of the Primary Lid	Fig. 4.2 - 2



0
40
80
120
160
200
240
280
320
360
400
440
480
520
560
600
R [mm]
- 40
- 120
- 200
- 280
- 360
- 440
- 520
- 600
- 680
- 760
q [N/mm]

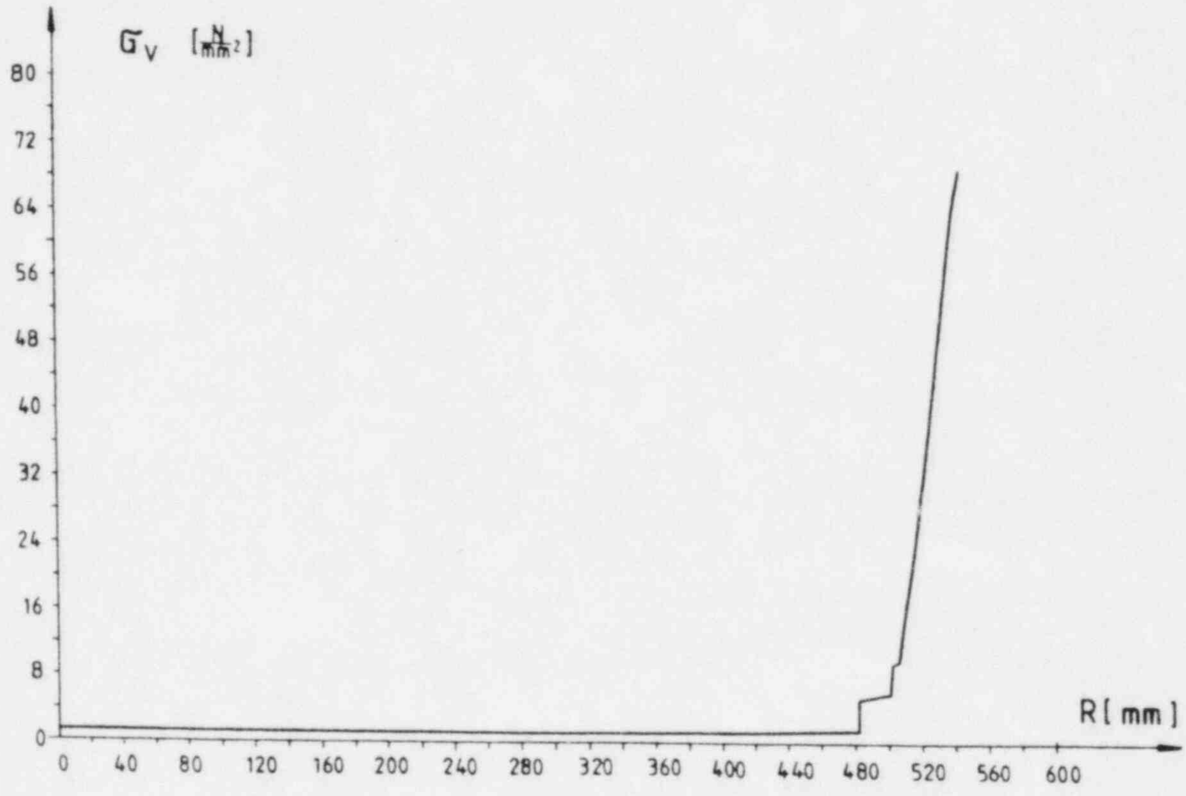


GNS	Momentum Line (m_r), Primary Lid	Fig. 4.2 - 4



GNS

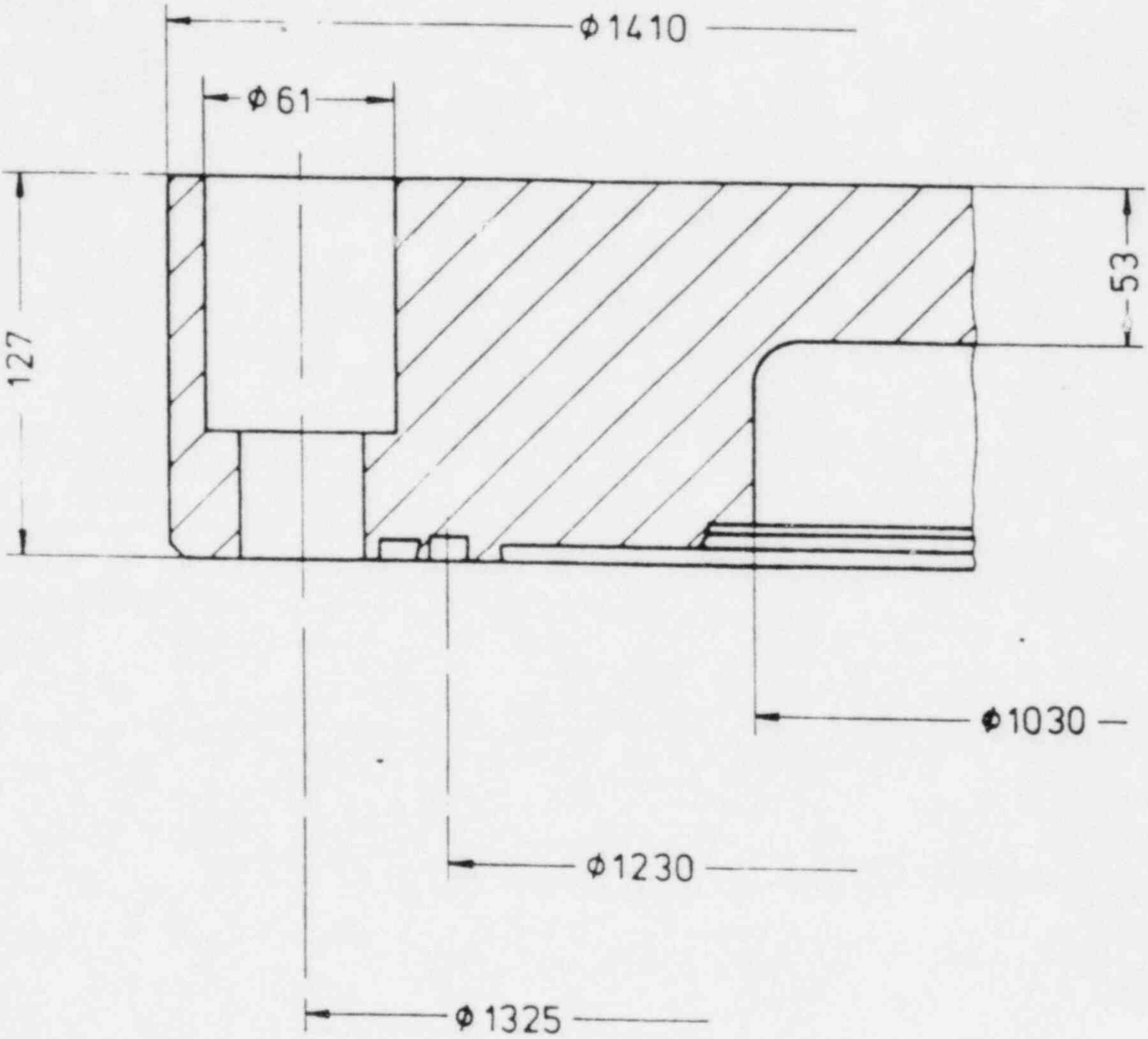
Momentum Line (mψ), Primary Lid



GNS

Reference Strain,
Primary Lid

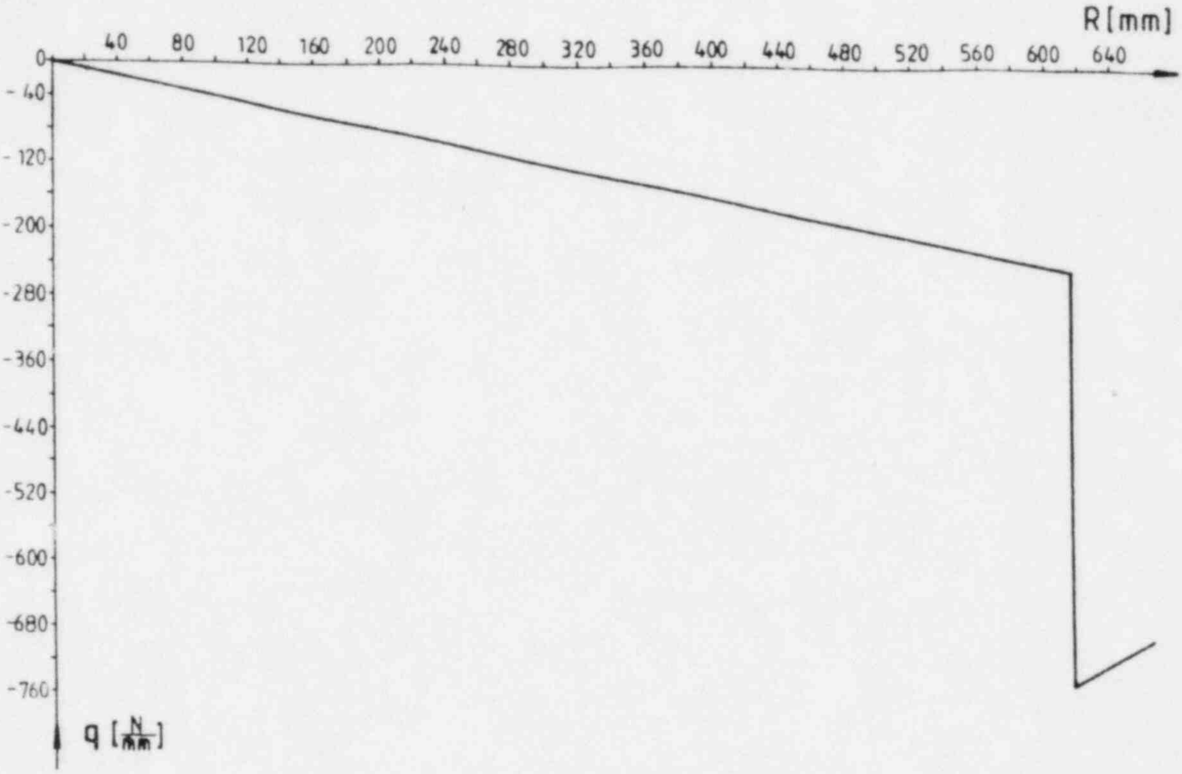
Fig. 4.2 - 6



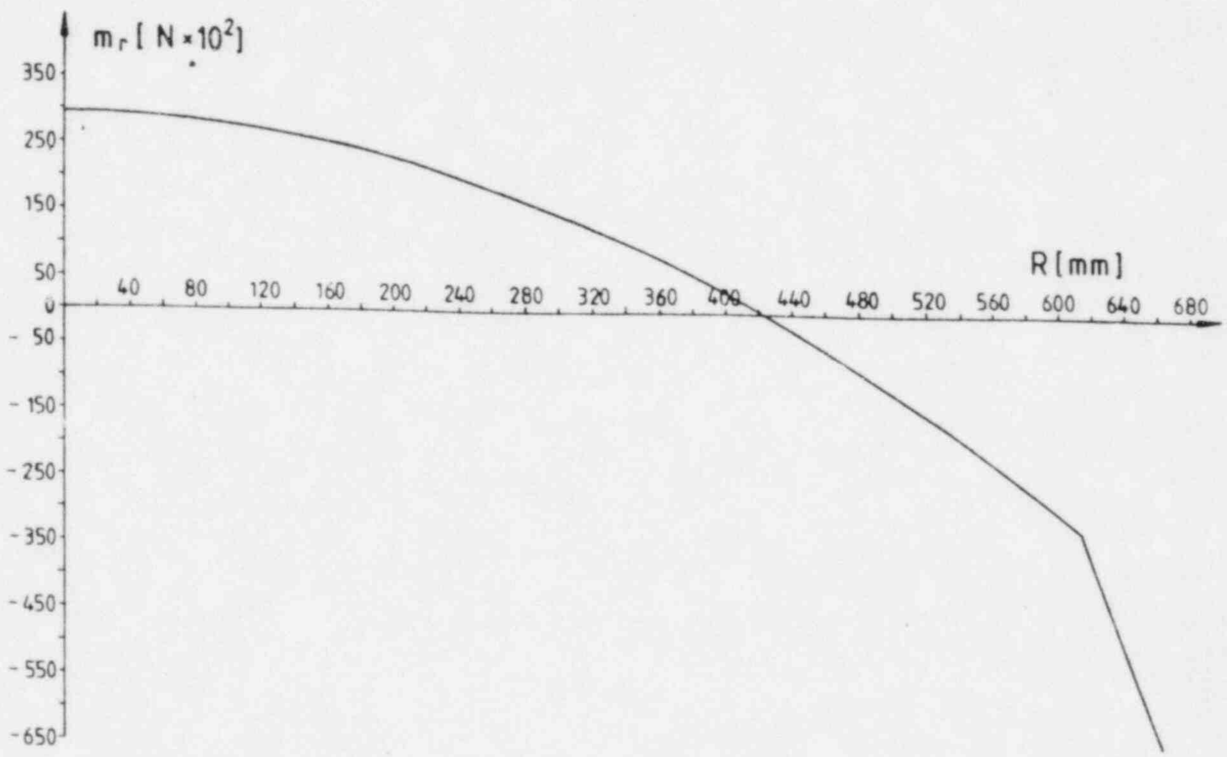
GNS

Dimensions of the Secondary Lid

Fig. 4.2 - 7



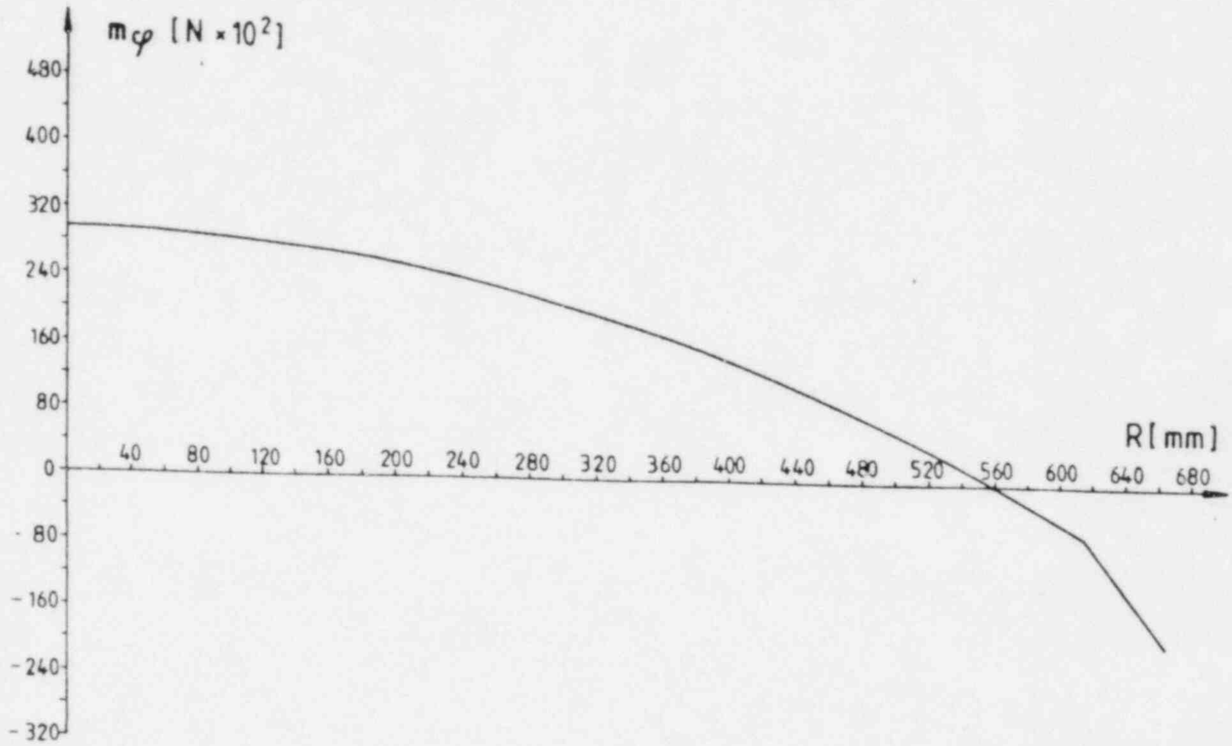
GNS	Tangential Force of the Secondary Lid	Fig. 4.2 - 8



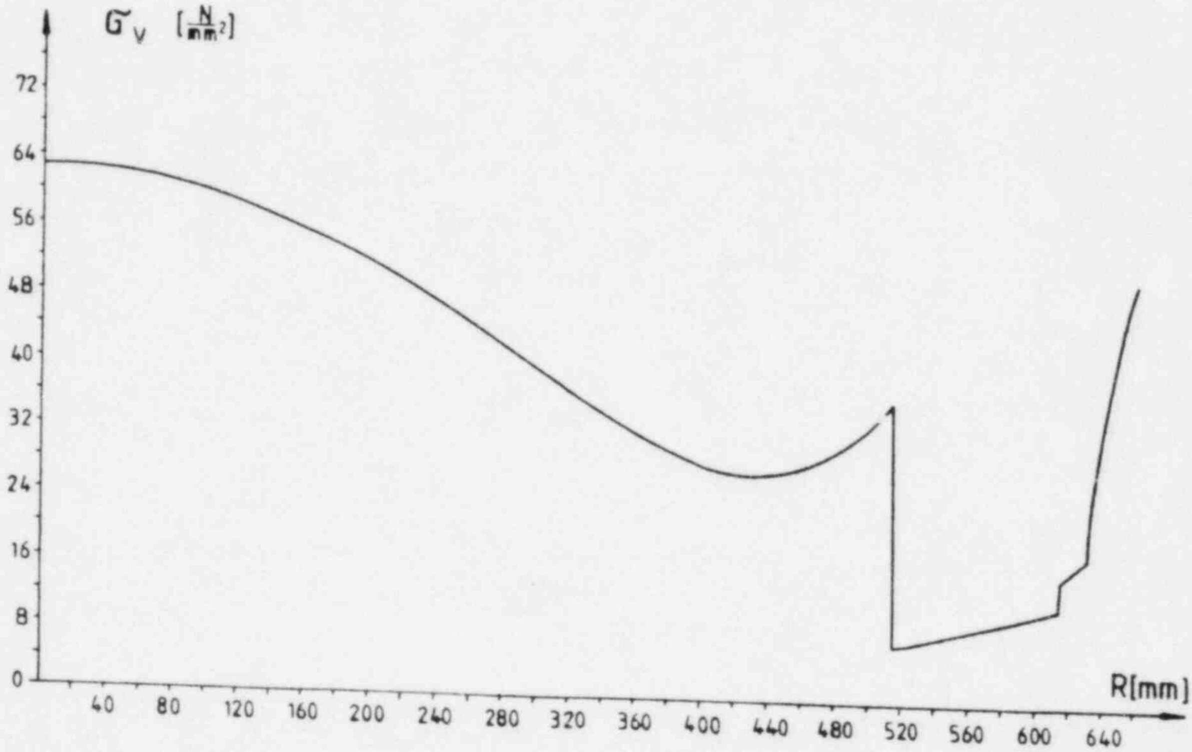
GNS

Momentum Line (m_r), Secondary Lid

Fig. 4.2 - 9



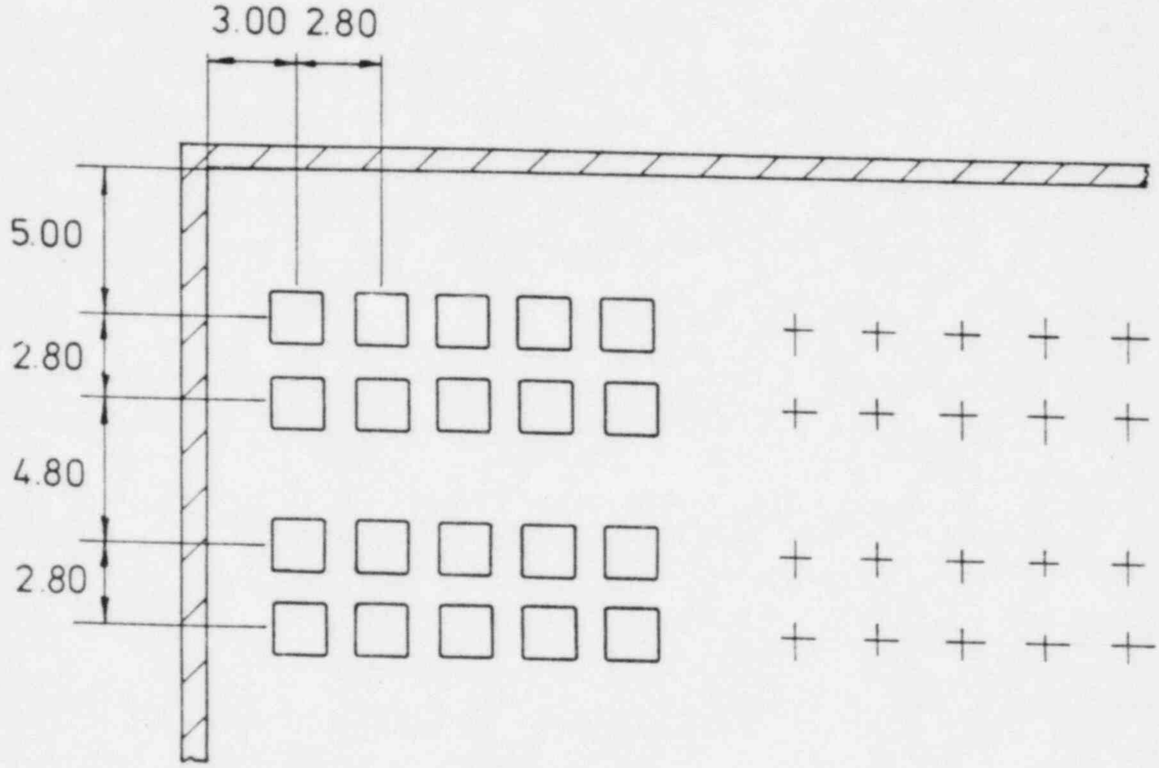
GNS	Momentum Line (mψ), Secondary Lid	Fig. 4.2 - 10



GNS

Reference Strain,
Secondary Lid

Fig. 4.2 - 11



GNS

Typical Arrangements of Casks in an ISFSI

Fig. 4.2 - 12

Material Property	Average Value	Data Range
Ratio of yield strength, $R_{p0.2}/R_m$	0.86	0.65 .... 1.0
Elongation of fracture, A_5	3.7 %	1 % .... 24.5 %
Reduction of Area, Z	3.9 %	1 % .... 18 %

Material Data for Nodular Cast Iron

Tab. 4.2 - 1

4.3 Auxiliary Systems

Not applicable

4.3.1 Ventilation and Offgas Systems

Not applicable to single cask analysis.

4.3.2 Electrical Systems

Not applicable to single cask analysis.

4.3.3 Air Supply Systems

Not applicable to single cask analysis.

4.3.4 Stream Supply and Distribution System

Not applicable to single cask analysis.

4.3.5 Water Supply System

Not applicable to single cask analysis.

4.3.6 Sewage Treatment System

Not applicable to single cask analysis.

4.3.7 Communications and Alarm Systems

The communications and alarm systems are site-specific and do not apply. A description of the alarms associated with the tightness surveillance system is given under Section 3.3.5.

4.3.8 Fire Protection System

The fire protection system is more closely related to the site characteristics than to the cask itself. See Section 2.9.8 and 2.10 of Appendix 5 for comments relevant to a typical cask storage facility.

4.3 9 Maintenance System

The only maintenance considerations relevant to the cask storage unit per se are discussed under Section 4.5, Shipping Cask Repair and Maintenance.

4.3.10 Cold Chemical Systems

Not applicable

4.3.11 Air Sampling Systems

Not applicable

4.4 Decontamination Systems

For AR storage, decontamination, whether related to cask or personnel, is the responsibility of the power plant.

4.5 Shipping Cask Repair and Maintenance

Due to the specific design of CASTOR casks repair is not necessary. Maintenance is restricted to minor procedures such as

- elimination of defects of the outer decontamination coating

- routine inspections if requested

In the case of an AR storage, restoration of double confinement in the improbable case of failure of one of the sealing systems will be executed inside the power plant building.

4.6 Cathodic Protection

After appropriate pretreatment in accordance with specifications, the outer surface of the fin region is painted with a multi-coat decontaminable paint (e.g. an epoxy-based paint).

The other regions of the surface of the cask body (bottom and top, interior) are nickel electroplated, again after appropriate pretreatment in accordance with specifications. The coating thickness will be about 1.5 mm. This treatment is also performed for the region of the drainage channel. Alternatively, the drainage channel may be cladded with a welded-in, nonrusting tube.

All seats and seal surfaces are mechanically finished after plating; other regions are mechanically finished only when necessary.

4.7 Fuel Handling Operation Systems

Not applicable

5.0 Operation Systems

5.1 Operation Description

5.1.1 Narrative Description

Dry cask storage is characterized by the simplicity of its operation. The arriving cask is controlled for contamination, temperatures and function of the tightness surveillance system. This control can be executed in the case of an AR at the reactor building.

The protective plate is bolted onto the cask top. The cask is then moved to its specific place in the storage area. The cask is stored in an upright position. The pressure transducer is connected to a recording device. During the licenced storage period no further operations, except for inspection and eventual maintenance, are necessary.

For shipment from the site the same procedures as for reception will be applied in a reversed sequence. For the description of the acceptance procedure in a typical CASTOR cask storage facility see Appendix 5, Section 4.

Since it is essential that the CASTOR transport and storage cask is properly prepared for storage during the loading operation, the sequence of this operation which takes place at the reactor pool and is not part of the operation system at the storage site is described below:

After the cask is loaded with spent fuel it is closed with the primary lid. It is then lifted to the pool surface and the seal systems of the primary lid are tested for tightness.
After lifting the cask out of the reactor pool it is pumped empty and dried by using a vacuum system. The cask is filled with helium at a pressure slightly below atmospheric pressure.

The secondary cover is applied, fastened and its sealing systems are controlled. The space between the covers is filled with gas at a pressure significantly above atmospheric pressure (pressure barrier).

5.1.2 Flow Sheets

All of the handling operations, such as

- wipe tests and cleaning of the cask, if neccessary
- functional tests of the metal seals
- installation of the pressure gage in the cover system
- filling of the inaccessible space with inert gas
- checking the pressure gage
- installation of the protection plate

will be done before moving the cask to the storage area. In the case of an AR ISFSI these procedures are executed inside the reactor building.

The procedures performed in the storage area are:

- setting the cask in its storage position
- connecting the cask to the cask monitoring system

A handling flow sheet showing the sequence of operations in a typical AR dry cask storage facility is given in Fig. 5.1 - 1.

Equipment descriptions with dimensions, design and operating characteristics, materials of construction, special design features, and operating limitations are specifically provided in Appendix 6.

A description of the functional tests and the installation of the pressure gage is given in Section 5.1.3.4.

Radiation source terms for radiation exposure of personnel during the mentioned handling procedures prior to the storage operation can be derived from Fig. 3.3 - 12, and from Tab. 3.3 - 6.
The time necessary for the handling procedures described in Fig. 5.1 - 1 is approx. 4 hours. Two people are usually present for these operations. Assuming a mean distance of approx. 1 m, the total exposure is about 0.08 manrem.

5.1.3 Identification of Subjects for Safety Analysis

5.1.3.1 Criticality Prevention

As previosuly noted in Section 3.3.4.1 of this report, criticality prevention is achieved via the utilization of neutron poison-impregnated fuel basket contruction materials within the cask. This feature is essential only to the loading operations of the cask which occur at the reactor site pool (underwater). That is, due to the low reactivity of the cask during the dry storage mode and the sealed nature of the cask which precludes inleakage of water, criticality control within the storage installation is not necessary. Flooding of the facility would simply further isolate the cask within the cask array thereby lowering the overall neutron multiplication factor (k_{eff}).

5.1.3.2 Chemical Safety

Not applicable

5.1.3.3 Operation Shutdown Modes

Not applicable

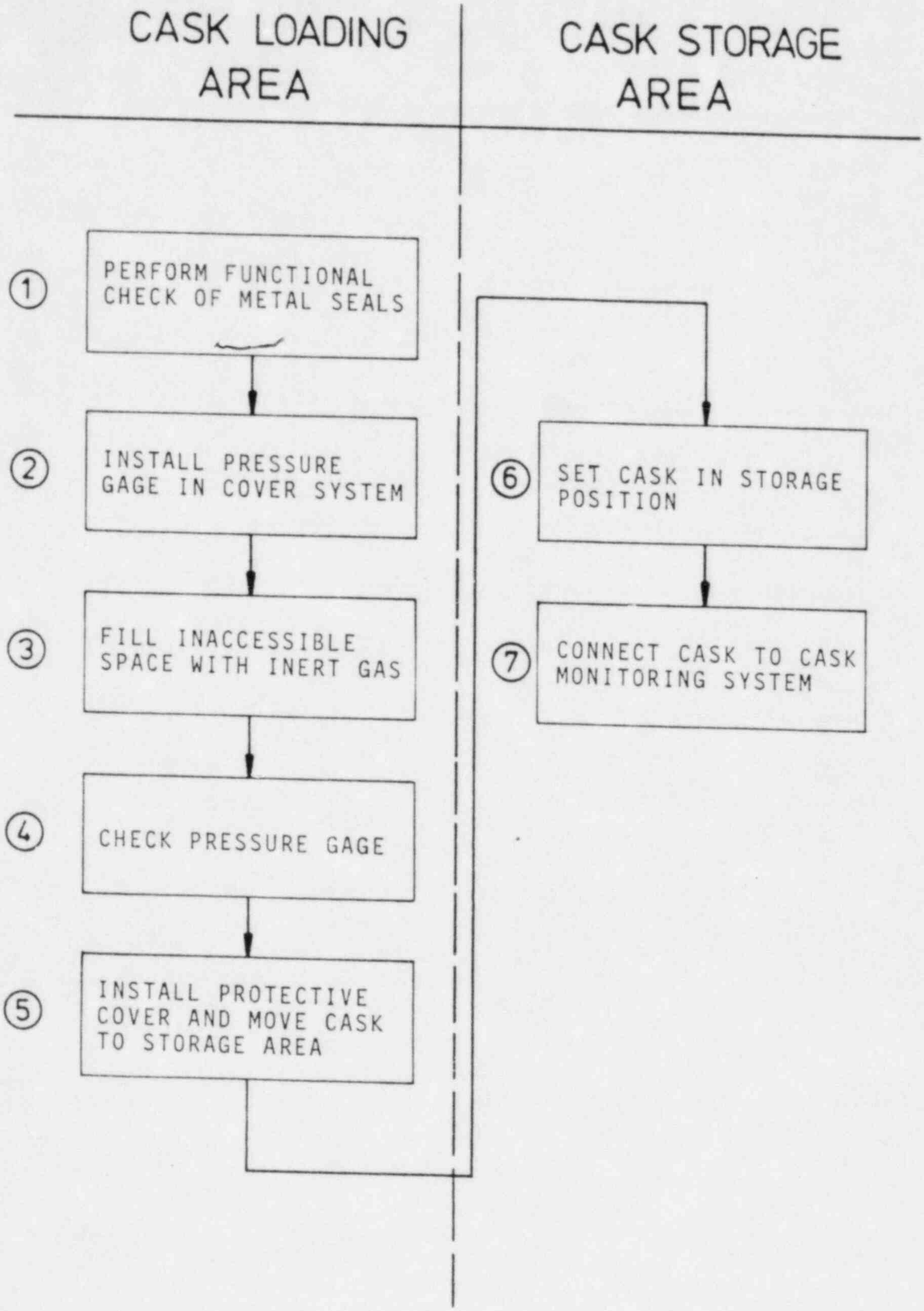
5.1.3.4 Instrumentation

The only instrumentation pertinent to cask storage as discussed earlier in Section 3.3.3.2 is that of cask tightness monitoring equipment. For the cask monitoring system there are long-lived mechanical parts of the measuring instrument and the self-monitoring circuitry which guarantee the safe functioning of the monitoring system during the ISFSI storage operation.

An initial function check on the measuring instrument is performed at the manufacturer's plant. The instrument is put throught another functional check during preparation for placement in storage. The following measures ensure proper functioning during service, making periodic tests unnecessary.

- Use of pressure staging, with signaling when pressure changes.
- Monitoring of the reference pressure of the main diaphragm.
- Prestressed diaphragm (signaling if the diaphragm is damaged).
- Selection of materials (contacts are gold-plated to prevent fusing or corrosion).
- Inert-gas filling.
- Limiting of maximum current through the contacts.
- Avoidance of dynamic loads.

As described above, the electrical system is continously checked during service.



GNS	HANDLING FLOW SHEET	Fig. 5.1 - 1

5.1.3.5 Maintenance Techniques

Maintenance tasks associated with the storage cask are not foreseen. There are no periodic tests necessary for the cask monitoring system.

The placement of an insert cover as a repair measure is an off-normal situation and is discussed under Section 8.1.

5.1.3.6 Heat Transfer Design

The decay heat of the fuel elements is taken up by the cask structures and removed to the air surrounding the cask by natural convection.
To determine the heat removal capacity of a cask during normal operation several thermal-load tests on a prototype cask were conducted.
In Appendix 7 the results of "Studies to determine the surface temperatures of the CASTOR Ia shipping and storage cask" are given.
The results of these thermal-load tests are also valid for the CASTOR Ic, since the dimensions of the prototype studied are very close to the CASTOR Ic pattern.

The calculation of the heat removal of a CASTOR Ic standing upright in a vertical position is based on the following boundary conditions and material properties:

- Outside wall temperature of the cask, + 82°C; ambient temperature, + 38° C

- Cast iron with thremal conductivity of λ = 35,08 W/m

- The outside wall of the cask has an emission coefficient of ε = 0,93

- All dimensions of importance for the thermal calculation are as in Fig. 1.2 - 1, Fig. 1.2 - 2, and in Tab. 1.2 - 1
  The geometry of the outer cask surface is given in Fig. 5.1 - 2.

In order to determine the total heat flux $\dot{Q}_{tot}$ issuing from the cask, the heat fluxes $\dot{Q}_R$, $\dot{Q}_C$ and $\dot{Q}_F$ are calculated. These represent heat fluxes from the cask by radiation, by convection on free portions of the cask, and by convection on finned portions of the cask.

Calculation of $\dot{Q}_C$ and $\dot{Q}_F$ requires a determination of the heat-transfer coefficient α. This can be found from the equation

$$N_u = \frac{\alpha \cdot H}{\lambda_{air}}$$

where N_u is the Nusselt number,
H is the length of the cask, and
λ_{air} is the thermal conductivity of air.

The Nusselt number can be determined only when the type of flow (laminar or turbulent) is known; this can be found from the product of the Prandtl number P_R and the Grasshoff number G_R. The two numbers are given by

$$G_R = \frac{g \cdot \beta \cdot \Delta\vartheta \cdot H^3}{v^2}$$

$$P_R = \frac{v}{a}$$

where g is the acceleration due to gravity,

β	=	is the cubical coefficient of expansion,
$\Delta\vartheta$	=	is the temperature difference between the cask wall and the ambient air,
H	=	is the length of the cask,
v	=	is the kinetic viscosity of air, and
a	=	is the thermal diffusivity of air

If

$$g = 9.81 \text{ m} \cdot \text{sec}^{-2}$$

$$\beta = \frac{1}{273} \cdot \frac{1}{°K}$$

$$\Delta\vartheta = 82° - 38° = 44° \text{ (°C equivalent °K)}$$

$$H = 5.455 \text{ m}$$

$$v = 21.11 \cdot 10^{-6} \text{ m}^2 \cdot \text{sec}^{-1}$$

$$a = 26.96 \cdot 10^{-6} \text{ m}^2 \cdot \text{sec}^{-1}$$

the product of Prandl P_R and Grasshoff number is given

$$P_R \cdot G_R = 4.51 \cdot 10^{11}$$

The value of the Nusselt number can be determined from Eq. (5)

$$N_u = C\,(P_R \cdot G_R)^n \cdot m = 1035$$

where

$$C = 0.135$$

$$n = 0.33$$

$$m = 60 \text{ K (average temperature } \frac{(82 + 38)}{2} \text{ K)}$$

with this value, the heat-transfer coefficient α is

$$\alpha = 5.41 \frac{W}{m^2 \, ^\circ K}$$

Using the heat-transfer coefficient α, one obtains the following expression for the heat flux:

$$\dot{Q}_C = \alpha \cdot A_G \cdot \Delta\vartheta$$

Here A_G denotes the total area of the cask not provided with fins. As the design drawing shows, this consists of

1. The area between fins,

   $48 \cdot 0.062 \text{ m} \cdot 3.955 \text{ m} = 11.8 \text{ m}^2$

2. The area at the ends of the cask,

   $2 \cdot 1.73^2 \text{m}^2 = 5.98 \text{ m}^2$

3. The remaining unfinned area:

   $4 \cdot 1.73 \text{ m } (0.865 + 0.635) \text{ m} = 10.38 \text{ m}^2$

totaling gives $A_G = 28.16 \text{ m}^2$

so that

$$\dot{Q}_C = 6.7 \text{ kW}$$

For the calculation of $\dot{Q}_F$ the rate of heat dissipation at a single fin by convection of the air is calculated. The cask has 48 fins each 3.955 m long. The calculational result of the heat dissipation for one fin gives a value of

$$\dot{Q}_F = 257 \text{ W}$$

The total rate of heat dissipation by the finned area of the cask is

$$\dot{Q}_F = 48 \cdot 257 \text{ W} = 12.3 \text{ kW}$$

The heat flux dissipated by thermal radiation from the cask $\dot{Q}_R$ is given by

$$\dot{Q}_R = C_s \cdot \varepsilon \cdot A_R \left[\left(\frac{T_B}{100} \right)^4 - \left(\frac{T_{air}}{100} \right)^4 \right]$$

In this equation,

$C_s = 5.77 \text{ W-m}^{-2} - {}^\circ\text{K}^{-4}$

ε_{GG} is the emission coefficient of the cask wall

A_R is the total radiating area, 43.7 m^2

T_B is the temperature of the cask wall in °K, and

T_{air} is the temperature of the air surrounding the cask in °K.

Hence,

$$\dot{Q}_R = 15.3 \text{ kW}$$

The total heat flux from the cask is then

$$\dot{Q}_{tot} = \dot{Q}_R + \dot{Q}_C + \dot{Q}_F$$

$$\dot{Q}_{tot} = 34.3 \text{ kW}$$

This calculated result of the passive decay heat dissipation has been proven in a thermal load test on a test cask and it was found that the CASTOR Ic cask has a heat removal capacity of at least 30 kW. Accordingly the CASTOR Ic cask can accept sixteen fuel assemblies with a heat output of approx. 1.9 kW each.

The basic idea for the design of the cask heat transfer system is that the max. cladding temperatures in the dry storage environment should be comparable with values during reactor operation, In Tab. 5.1 - 1 cladding temperatures in BWR fuel assemblies during reactor operation are presented.

The experimental and computational results presented in APPENDIX 4, Section 2.7, show that, given the prevailing loads on the fuel assemblies, dry storage, even for long spans of time, involves no mechanical or corrosion damage that could threaten the integrity of the fuel assemblies and make their later removal difficult. The failure of just a few pre-damaged rods cannot be ruled out with absolute certainty. The effects of such damage are limited and have no safety consequences.

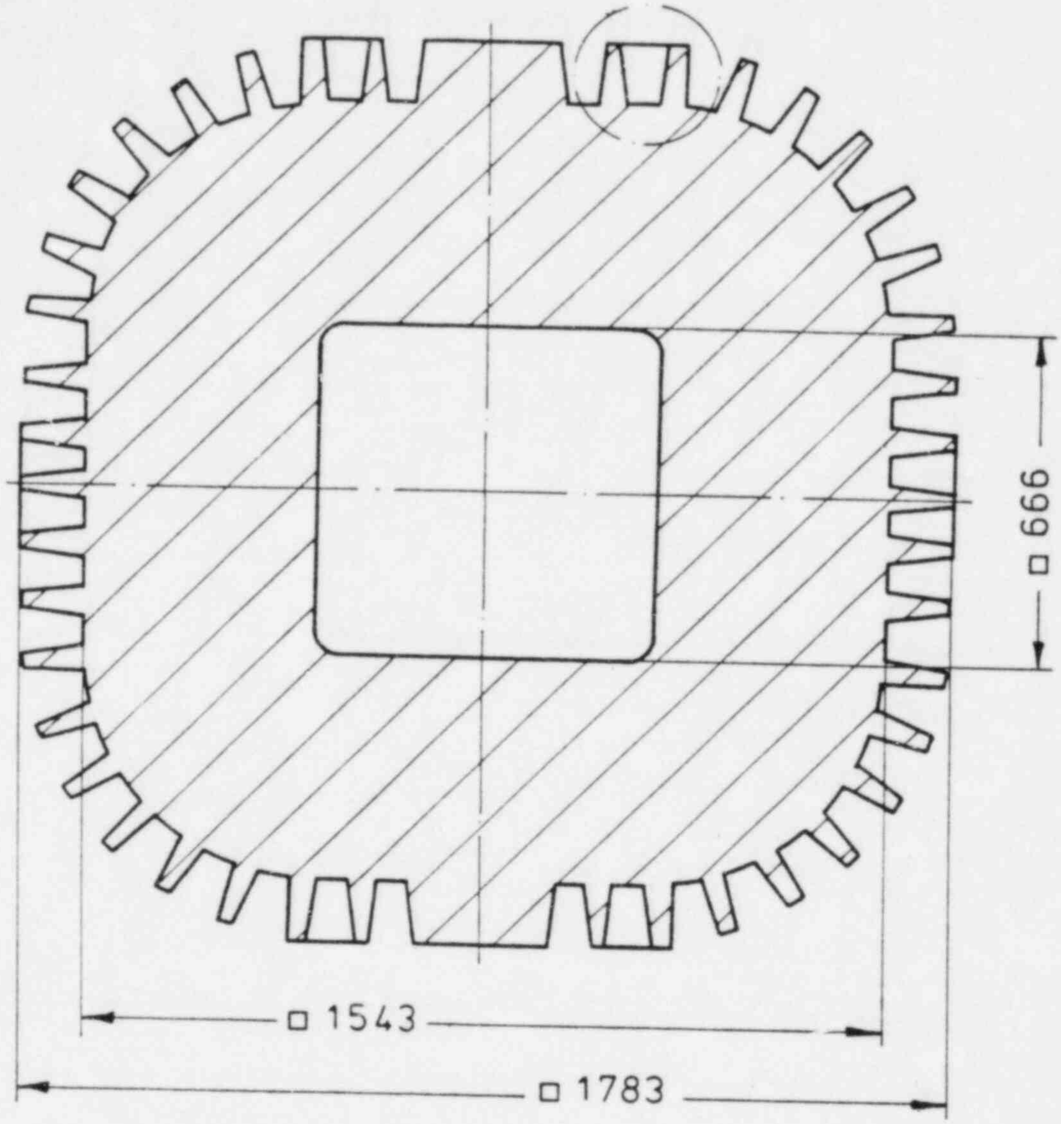
The maximum cladding temperatures in dry storage in shipping casks are comparable with the values in reactor operation (see Tab. 5.1 - 1). Under dry-storage conditions, these cladding temperatures occur only for a few fuel rods in the middle of the shipping cask, and they decrease with the time of storage. The temperatures remain below the limiting values above which cladding damage could occur.

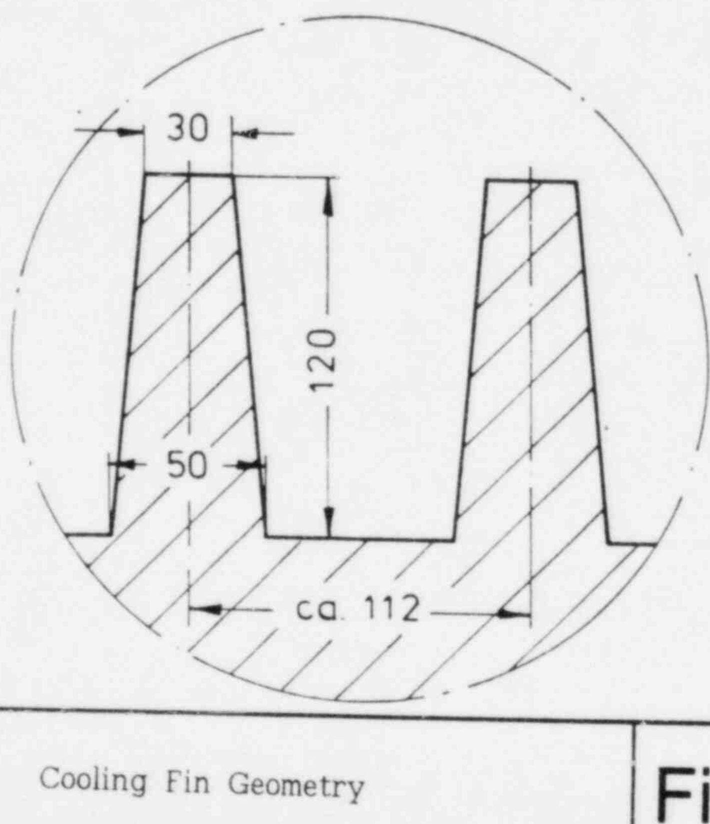
Results of a nonlinear temperature field calculation of a CASTOR Ic cask loaded with eight assemblies of the 8 x 8 fuel rod type and eight assemblies of the 7 x 7 fuel rod type are presented in APPENDIX 8. These calculations were carried out with the "FEABL Finite Element Analysis Basic Library" (Ref.: O. Orringer, S. E. French, Rep. AFOSR TR, ASRLTR 162-3, Massachusetts Inst. of Technology, Cambriedge Mass. (1972)). In Fig. 5.1 - 3 a typical three-dimensional temperature field plot is given. The maximum cladding temperature calculated is approx. 370 °C, assuming an ambient air temperature of 20 °C. There is no significant difference between 8 x 8 fuel rod and 7 x 7 fuel rod arrays.

It can be shown from two-dimensional heat transfer calculations presented in Fig. 5.1 - 4 for a quarter section of the middle part of the CASTOR Ic cask that a variation of the ambient air temperature has a minor effect on for the maximum cladding temperatures of the fuel rods.

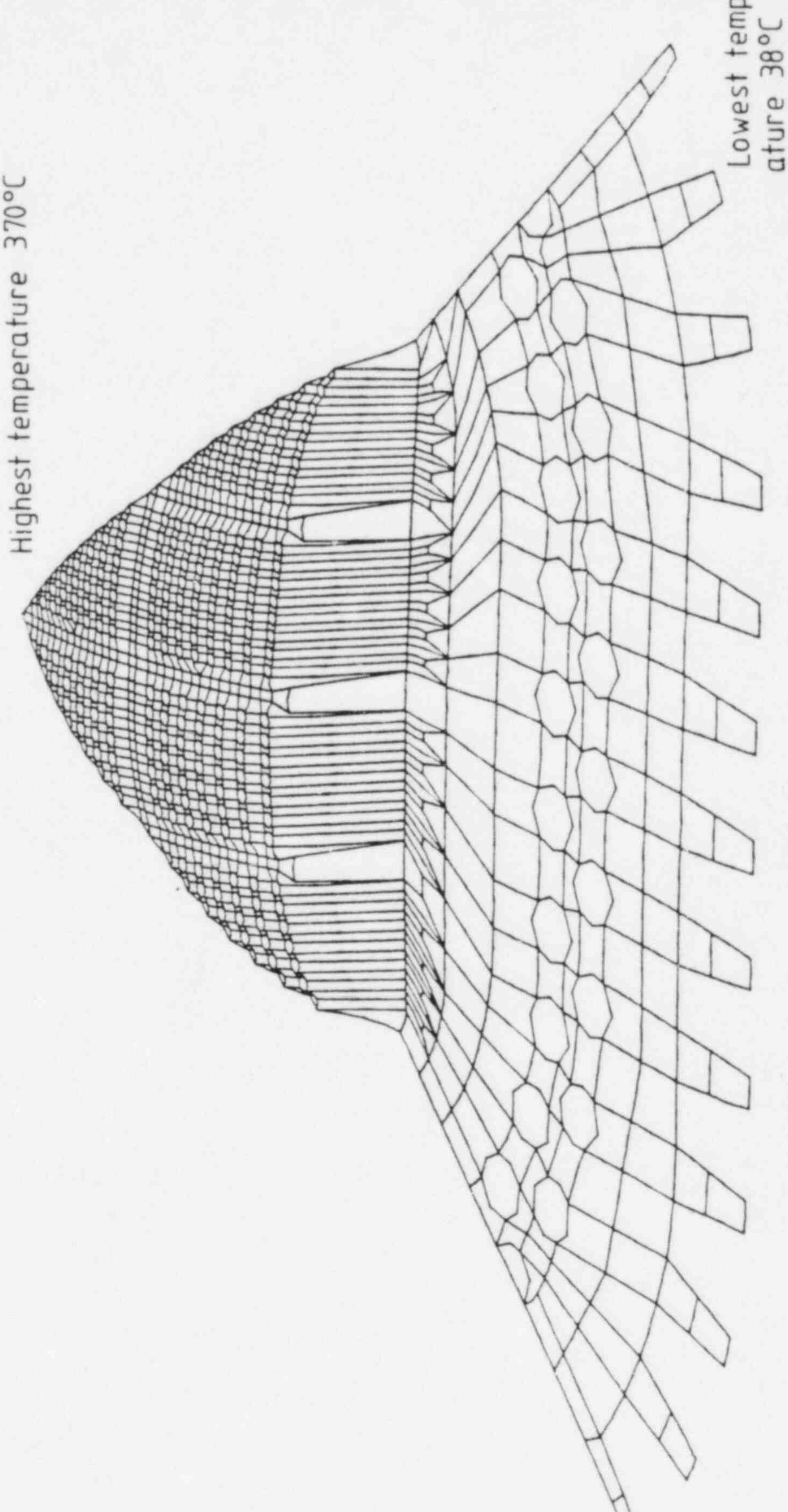
It can be seen in Fig. 5.1 - 5 how the total decay heat production of the cask inventory relates to the cladding temperature.

In Fig. 5.1 - 6 temperature profiles of the surface temperatures of a single cask and a cask surrounded by other casks are shown. In the case of square arrays the max. cask surface temperature will increase approx. 8 °C to 10 °C.





GNS	Cooling Fin Geometry	Fig. 5.1 - 2

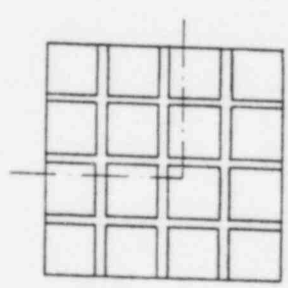


GNS	Temperature - Field Plot of a CASTOR Ic Cask loaded with 16 BWR Fuel Assemblies	Fig. 5.1 - 3

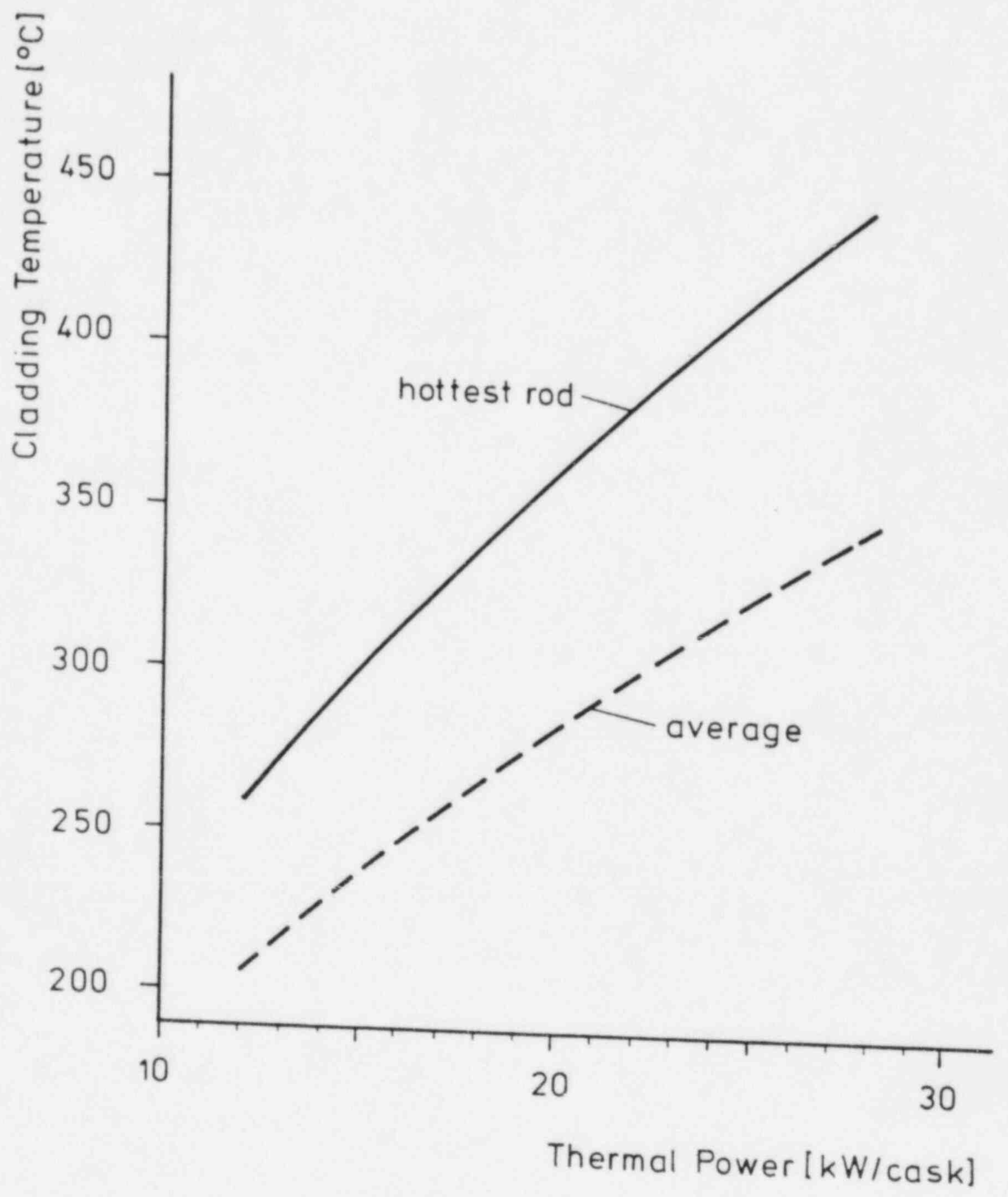
Cask Wall

92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.	92.
92	151.	164.	174.	182.	187.	191.	196	203	206.	207.	210.	211.	212.	212.	214	217
92	164.	180.	193.	203.	210.	214.	218	217	230.	235.	238.	240.	241.	241.	240	234
92	174.	193.	209.	220.	228.	233.	235	231	249.	257.	261.	263.	264.	264.	261	250
92	182.	203.	220.	232.	241.	246.	248	244	264.	273.	278.	281.	282.	281.	277	266
92	187.	210.	228.	241.	250.	256.	258	256	276.	285.	290.	293.	295.	294.	291	279
92	191.	214.	233.	246.	256.	262.	266	266	285.	294.	299.	302.	304.	304.	301	292
92	196.	218.	235.	248.	258.	266.	272	275	292.	299.	305.	308.	310.	311.	310	303
92	203.	217.	231.	244.	256.	266.	275.	285.	295.	302.	307.	312.	315.	316.	316.	315.
92	206.	230.	249.	264.	276.	285.	292	295	315.	324.	331.	335.	337.	338.	336	327
92	207.	235.	257.	273.	285.	294.	299	302	324.	334.	341.	345.	348.	348.	345	335
92	210.	238.	261.	278.	290.	299.	305	307	331.	341.	347.	352.	354.	354.	351	341
92	211.	240.	263.	281.	293.	302.	308	312	335.	345.	352.	356.	358.	358.	356	346
92	212.	241.	264.	282.	295.	304.	310	315	337.	348.	354.	358.	360.	361.	358	349
92	212.	241.	264.	281.	294.	304.	311	316	338.	348.	354.	358.	361.	361.	359	351
92	214.	240.	261.	277.	291.	301	310	316	336.	345.	351.	356.	358.	359.	358	352
92	217.	234.	250.	266.	279.	292	303.	315.	327.	335.	341.	346.	349.	351.	352.	352.

Fuel Rods Basket



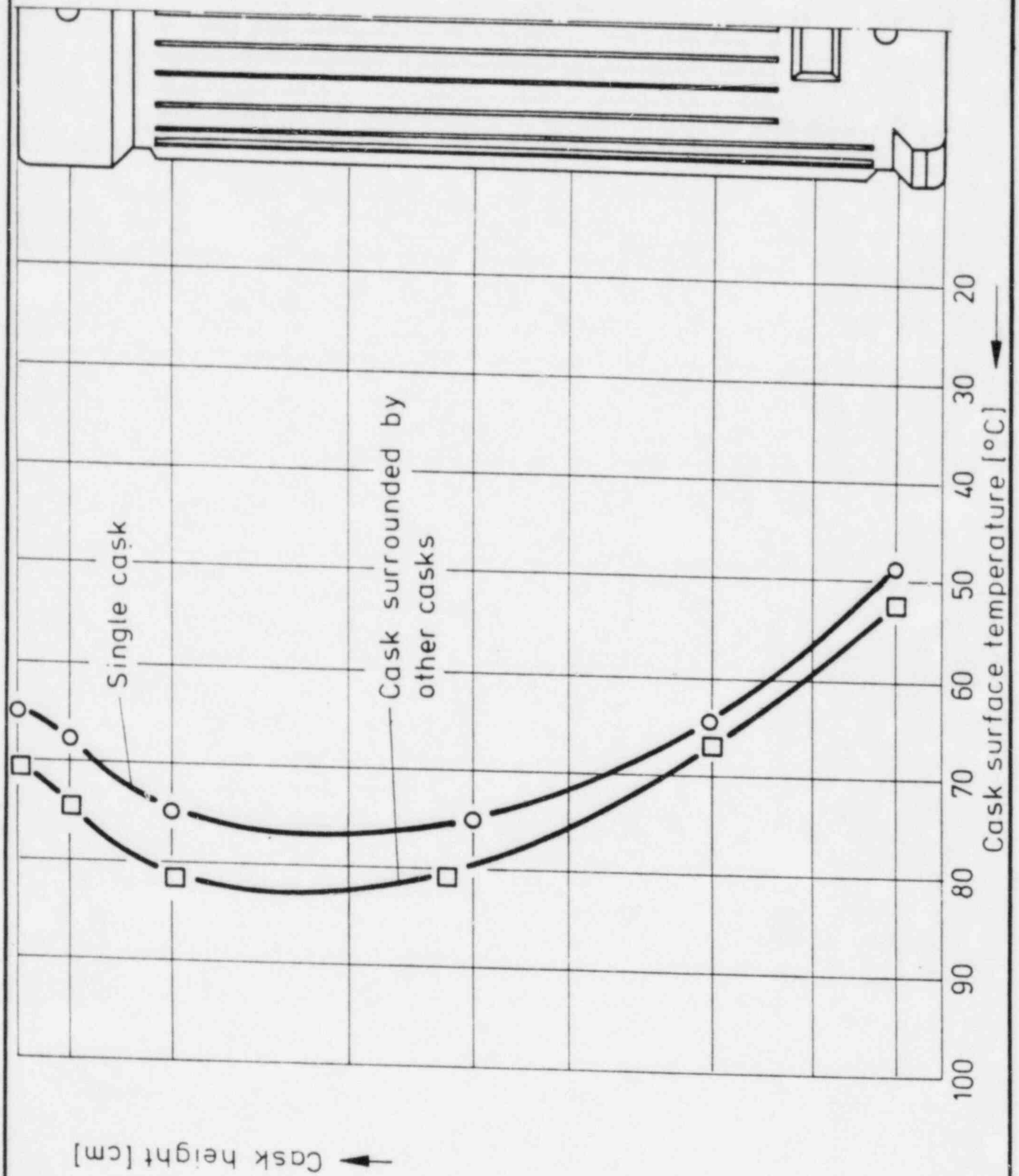
GNS	Cladding Temperatures in a CASTOR Ic Cask (two-dimens. calc., 40°C ambient air)	Fig. 5.1 - 4



GNS

Cladding Temperatures vs
Thermal Power of a CASTOR Ic Cask

Fig. 5.1 - 5



GNS	Surface Temperatures of a Single Cask and Cask Arrays	Fig. 5.1 - 6

Specific Rod Power W/cm	Temperatures in °C	
200 *	outer	334
	inner	362
400 **	outer	364
	inner	424

* average values

** max. values

Air Temp.	30°C		40°C		50°C	
Heat Prod. of one cask	Temperature av.	max.	Temperature av.	max.	Temperature av.	max.
12 kW	198	253	205	259	211	265
20 kW	278	357	282	361	289	368
28 kW	343	441	348	445	352	449

Cladding Temperatures for Different Ambient Air Temperature and Heat Production

5.2 Fuel Handling Systems

Not applicable.

6. Waste Confinement and Management

6.1 Waste Sources

As noted in earlier Sections of this report and in response to 10 CFR Part 72.15 (a)(6), it is noted that no contaminated wastes are generated during CASTOR cask storage of spent fuel. In an AR ISFSI only clean casks are accepted. All decontamination measures which cause contaminated wastes are taken inside the reactor building. According to the transportation regulations a cask is clean if the surface activity is below (see Section 3.3.7):

10^{-10}	Ci/cm^2	for	β/γ - activity
10^{-11}	Ci/cm^2	for	α - activity

6.2 Offgas Treatment and Ventilation

Not applicable

6.3 Liquid Waste Treatment and Retention

Not applicable

6.4 Solid Wastes

Not applicable

6.5 Radiological Impact of Normal Operations

The annual activity releases for the nuclides H-3, Kr-85, I-129, Cs-134 and Cs-137 are shown in Fig. 3.3 - 6 and Fig. 3.3 - 7 as well as in Tab. 3.3 - 2. The total annual activity release is in the range of 10^{-9} Ci/year.

In order to estimate radiological effects the short time diffusion for evaluating atmospheric diffusion can be used. The calculation of the radiation dose at the most unfavorable point beyond the controlled area is site - specific. But considering a short - time diffusion factor of

$$X = 4.0 \cdot 10^{-4} \text{ sec/m}^3$$

and a distance of the dose-point of 100 m, the resulting annual dose exposure for the principal exposure path, inhalation, is in the range of $10^{-12} \ldots 10^{-11}$ rem/year.

7. Radiation Protection

7.1 Ensuring That Occupational Radiation Exposures Are As Low As Is Reasonably Achievable (ALARA)

7.1.1 Policy Consideration

The CASTOR cask per se is optimized to meet ALARA principles, in compliance with Regulatory Guides 8.8, 8.10 and 8.15.

- It is a static system without any moving parts.

- The simplicity of the design and the ruggedness of its components minimizes maintenance requirements.

- The double confinement system assures the absence of any measurable release under normal, abnormal or accident conditions.

- The continuous surveillance of the cask tightness guarantees that even in the highly unlikely case of a failure of one of the sealing systems, double containment can be restored by simple methods without release of activity.

- The only safety function to be controlled is the surveillance of the pressure between the two covers by a pressure transducer system based on standard technique.

- It is not necessary to approach the cask for control since the signals from the pressure transducer are transferred to a control area outside the radiation field.

Based on these policy and design principles occupational exposure would result only during cask receipt and positioning. This is reduced to a minimum by administrative procedures:

- handling manuals which will be revised periodically taking into account exposure experience.

- shielding will be provided where necessary i.e. concrete structures in the reception and service area, shielding of the operator cabin during positioning procedures. Attention is drawn to the point that occupational exposure described above is limited to the loading and emptying operations of the storage facility.

  For the storage operation as such, occupational exposure is limited to unavoidable maintenance work and routine optical inspection.

7.1.2 Design Considerations

Many of the design considerations are site specific. Different shielding modes are discussed under Section 3.3 and illustrated in Fig. 3.3-13 and Fig. 3.3-14.

7.1.3 Operational Considerations

See comments under Section 7.1.1 and 7.1.2.

7.2 Radiation Sources

7.2.1 Characterization of Sources

The sources of radiation are irradiated BWR fuel assemblies. They are the bases for the radiation protection design and are described in Section 3.1.1 of this report.

7.2.2 Airborne Radioactive Material Sources

Since the radioactive sources are safely confined during the storage lifetime a very small amount of airborne radioactive material sources have to be considered for the operation of the ISFSI.

A calculation the annual activity release is discussed in Section 3.3.2.2 of this report.

7.3. Radiation Protection Design Features

7.3.1 Installation Design Features

For a description of the installation design features see comments under Sections 1.2, 3 and 4.

7.3.2 Shielding

See Section 3.3.5.2 and Appendix 2 for a discussion of the cask shielding and corresponding analyses. Shielding parameters pertinent to typical facility structures (e.g. walls of buildings) are also discussed in Section 3.3.5.2.

7.3.3 Ventilation

Not applicable.

7.3.4 Area Radiation and Airborne Radioactivity Monitoring Instrumentation

See comments under Section 3.3.3.2 and Section 3.3.5.3. of this report.

7.4 Estimated Onsite Collective Dose Assessment

Considering an optical routine inspection once a year of a ISFSI with a single cask, this procedure can be done within one hour. The collective dose for one man is below 0.01 rem.

Considering control of the cask confinement system including tightness test of a single cask the time required is 4 to 6 hours for two workers persons. The collective dose for this procedure is below 0.05 rem.

7.5. Health Physics Program

Not applicable.

7.6 Estimated Offsite Collective Dose Assessment

For collective offsite dose assessment, only direct plus scattered radiation has to be considered. Due to rapid attenuation of radiation by distance the impact of radiation is limited to a small area at the boundary of the storage site (see Fig. 3.3 - 14).

The actual collective dose will be site-specific (topography, distance to fence, influence of building structures, population density, etc.) and therefore cannot estimated for this report.

Since very small amounts of effluents of radioactive material are generated no effluent monitoring is required (see comment under Section 6).

8. Accident Analyses

The basic design criteria (especially the shielding requirements) for the dry storage cask system result in an extremely rugged confinement structure represented by the individual casks. With only few technical additions, such as selecting high quality, seals, resisting radiations, corrosion and elevated temperatures, the cask is able to survive all effects of abnormal operations and credible potential accidents without losing either its shielding or its confinement function and without adding significantly to the admissible annual dose $\leq$ 25 mrem beyond the control area.

This has been shown in many calculations and numerous experiments, a large part of them in full scale, undertaken to qualify CASTOR casks not only for storage, but additionally for transport in Europe.

In addition, the simple structure of a storage site permits to exclude or at least minimize causes for abnormal operation and/or accidents; no inflammable or explosive material has to be used, the effects of handling failures can be minimized by simple measures, such as limited values for all measurements mechanically limiting the lifting height etc.

The inherent safety of the cask (once installed) makes it independent of utilities and machinery, i.e. practically immune to human error. This will be shown in the following paragraphs.

8.1 Off - Normal Operations

8.1.1 Event

Off - Normal operations of the ISFSI could result from

- malfunctions of cask components
- operator error during cask positioning

The consequences of such events will not have any significant effects within or beyond the controlled area.

The following categories for off - normal operation of the ISFSI can be postulated:

a) Seal failures of a single cask
   - failure of the primary lid seal
   - failure of the secondary lid seal

b) Malfunction of the cask monitoring system
   - malfunction of pressure gage components
   - malfunction of monitoring instruments

c) Operator error or material failure during cask positioning
   - cask tipping
   - cask drop from max. 2m height
   - cask collision with wall structures or with another cask in storage position during positioning.

8.1.1.1 Postulated Cause of the Event

Malfunctions of cask components are not expected during the operation of the ISFSI. The only cask components with a potential possibility of malfunction are:

- lid seals
- pressure gage
- pressure gage monitoring system

Failure mechanism for seal malfunction can not be identified since the function of the seal system is checked after cask loading and the choice of corrosion-resistant material for the seal material guarantees unimpaired operation.

Only long-lived mechanical parts for the pressure gage and the measuring instruments are used. Nevertheless a hypothetical failure of the pressure gage components (i.e. diaphragm membrane) or interruption of the electrical energy supply for the monitoring system can be considered.

For cask tipping or drop human error or material failure of the transportation equipment will be responsible.

8.1.1.2 Detection of Event

In a case of seal malfunction both visual and audible alarms will be inidiated through the cask monitoring system. The annunciator system consits of a horn. The signal can be sounded in the storage area, in the administration building, or in an central security center. A functional description of the cask monitoring system is presented in Section 3.3.3 and under 3.3.5.

Cask tipping will be immediately detected by the operational personnel.

8.1.1.3 Analysis of Effects and Consequences

The function of the cask closure system is described in Section 1.2 and illustrated in Fig. 1.2 - 3. In Tab. 8.1 - 1 different cases of the cask operation are listed. The CASTOR - cask closure design of double containement with multiple seals assures cask tightness for all cases of off - normal operation through at least one metal seal. The duration of the off - normal operation (case C and D in Tab. 8.1 - 1) will be one week until corrective actions have replaced the is reestablished with defective seal, or the double contaniment system with an additional sealed cover.

As described in more detail in Section 8.2, the mechanical integrity of the cask body under the mechanical loads during off - normal operation (i.e. cask tipping, drop from max. 2m height) is guaranteed.

The activity release during the time of off - normal operation is not detectable and can be derived only theoretically from Fig. 3.3 - 5 and Tab. 8.1 - 2. During the time of off-normal operation an increased activity release can theortically considered for the following cases (Tab. 3.3 - 2):

Case B:	100 % defective fuel cladding; 100 % function of primary and secondary lid seals, no corrective action
Case C :	1 % defective fuel cladding; 100 % function of the secondary, malfunction of the primary lid seal corrective action within one week
Case D :	1 % defective fuel cladding; 100 % function of the primary, malfunction of the secondary lid seal corrective action within one week
Case E:	100 % defective fuel cladding; 100 % function of only one lid seal corrective action within one week

Tab. 8.1 - 3 shows the calculated activity releases for the different cases of off - normal operation. For case B no corrective action will be taken and the activity release is calculated for a period of 50 years' storage time. For cases C, D and E corrective action as described in Section 8.1.1.4 will be taken within the first week after detection of the event.

For off-normal operation which leads to cask tipping it has to be determined whether the tipping of a single cask in at cask storage site can also cause other casks to tip over. In particular, it must be determined whether an initial impulse can bring about a chain reaction that tips over all the casks in the storage site (domino effect). A discussion of this effect is given in APPENDIX 9 (Chapter 6). Using a cask center - to - center spacing in the range of 3.00 m as illustrated in Fig. 4.2 - 12, the domino effect can be neglected.

8.1.1.4 Corrective Actions

Corrective action in the case of component failure of the cask tightness monitoring system entails replacement of the defective component.

Corrective action for seal failures starts with the identification of the defective seal. In case the sealing system of the secondary lid is defective, the lid is lifted off and the defective seal replaced. In case the sealing system of the primary lid is defective, replacement of the seal is not neccessary. By Adding a third lid with an adequate sealing system double confinement will be restored. Following this step the tightness surveillance system can be put back into service. A summary of the corrective actions for the assurance of cask tightness is schematically shown in Fig. 8.1 - 1.

An alternative method would be to take back the cask reactor and to lift off the primary lid to replace the defective seal.

After mechanical impact such as cask tipping the cask tightness will be checked. If the cask tightness system is unimpaired no corrective actions are necessary. In case of any system failure corrective actions described above will be implemented.

8.1.2 Radiological Impact from Off-normal Operations

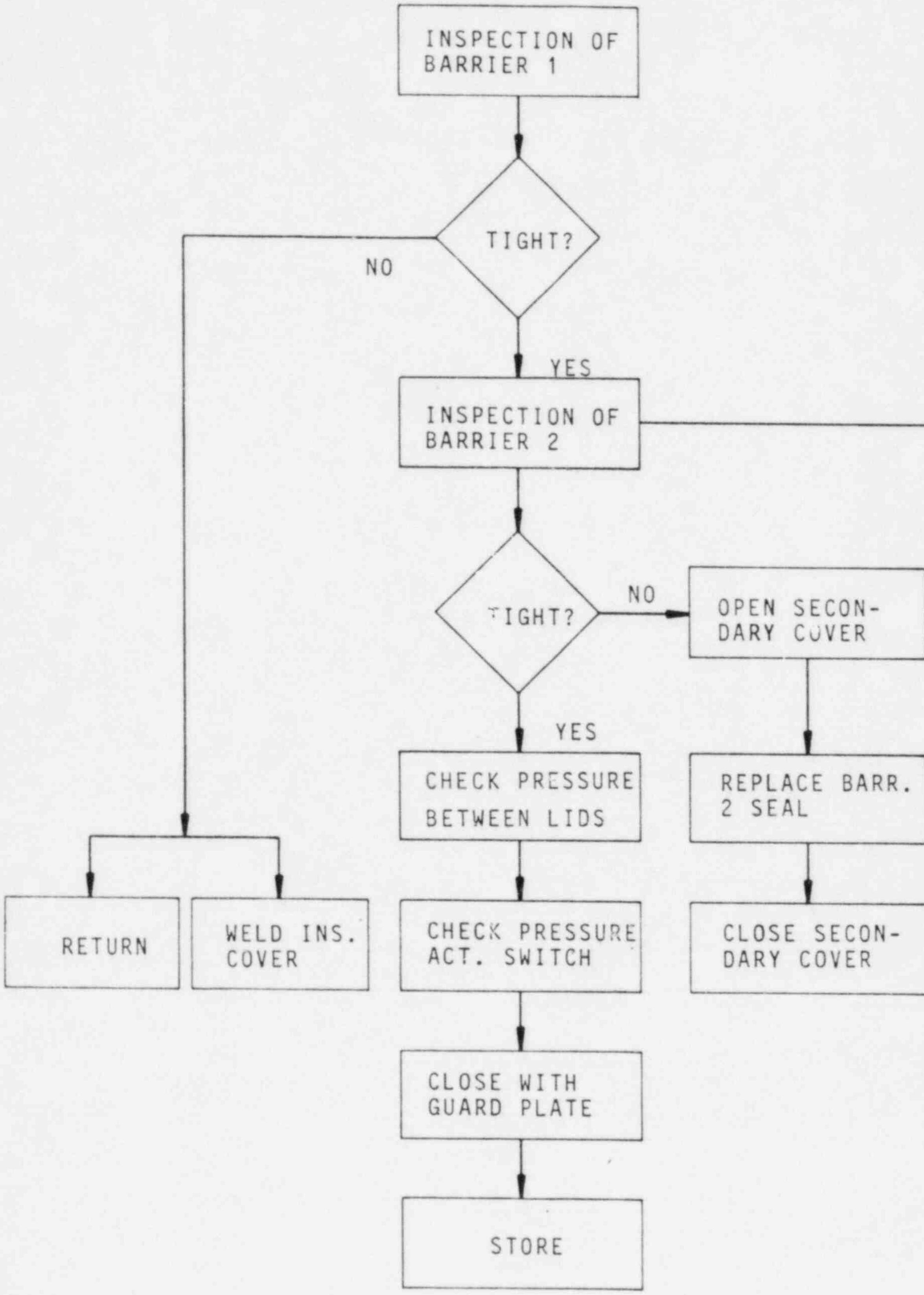
It can be seen from Tab. 8.1 - 3 that no radiological effect will occur beyond the controlled area. The reestablishment of the double confinement system will result in limited personnel radiation exposure. This exposure is dependent on

- cask / lid surface dose rate
- time necessary for corrective action
- number of personnel necessary for corrective action
- dose rate at the point where the personnel have to work during the corrective action.

From Fig. 3.3 - 12 or Tab. 3.3 - 6 in Section 3.3 an average surface dose rate of approx. 10 mrem/h. Considering 8 hours for the time required and two people necessary for the corrective action:

8 hours x 2 men x 0.01 rem/hour = 0.16 manrem

are the maximum occupational dose exposure.



GNS | Corrective Action for Off-Normal Operation | Fig. 8.1 - 1

Case	Event	Type of operation	Number of tight metal seals	Defective fuel cladding	Corrective action
A	None	normal	2	< 1 %	No
B	Fuel cladding rupture caused by mechanical impact	off-normal	2	100 %	No
C	Failure of primary lid seal	off-normal	1	< 1 %	Yes
D	Failure of secondary lid seal	off-normal	1	< 1 %	Yes
E	Failure of secondary or primary lid seal	off-normal	1	100 %	Yes

Nuclide	Release Fraction from Fuel %	Cask Cavity Inventory in Ci for Cladding Rupture of 1 %	100 %
H - 3	10	1.8	180
Kr-85	10	24	2,400
I - 129	1	10^{-5}	0.001
Cs - 134	0.01	0.5	48
Cs - 137	0.01	0.3	27

Nuclide	Activity Release during Off - normal Operation in Ci			
	B*	C*	D*	E**
H - 3	$5.5 \cdot 10^{-5}$	$1.2 \cdot 10^{-7}$	$1.2 \cdot 10^{-8}$	$1.2 \cdot 10^{-5}$
Kr - 85	$4.2 \cdot 10^{-5}$	$4.1 \cdot 10^{-7}$	$4.1 \cdot 10^{-7}$	$4.1 \cdot 10^{-5}$
I - 129	$2.0 \cdot 10^{-12}$	$1.0 \cdot 10^{-14}$	$1.0 \cdot 10^{-14}$	$1.0 \cdot 10^{-12}$
Cs - 134	$2.3 \cdot 10^{-8}$	$6.4 \cdot 10^{-9}$	$6.4 \cdot 10^{-11}$	$6.4 \cdot 10^{-9}$
Cs - 137	$4.1 \cdot 10^{-7}$	$7.9 \cdot 10^{-11}$	$7.9 \cdot 10^{-11}$	$7.9 \cdot 10^{-9}$
Total	$9.7 \cdot 10^{-5}$	$5.4 \cdot 10^{-7}$	$5.4 \cdot 10^{-7}$	$5.4 \cdot 10^{-5}$

* No corrective action, release during 50 Years storing time

** Time between detection and corrective action of 1 week

8.2 Accident

In general the definition of an accident is any incident that would potentially result in a dose of $\geq$ 25 mrem beyond the controlled area. It is shown in the following sections that in an ISFSI with dry CASTOR cask storage there are no such credible potential accidents wherein direct radiation or radioactive materials may be released in such quantity as to endanger personnel either within or beyond controlled area.

8.2.1 Accidents Analyzed

Accident of the ISFSI could result from

- natural events
- man - made events

8.2.1.1 Cause of Accident

Natural events such as tornados, floods and earthquakes can and man-made events and man-made events such as fires, esplosures etc. may be the causes of an accident.

Operator errors, equipment malfunction, or equipment failures as discussed in Section 8.1 can potentially cause only off-normal ISFSI operation.

8.2.1.2 Accident Analysis

Accidents with mechanical loads on the casks are:

- tornado - missiles
- cask drop
- collapse of roof truss
- gas cloud explosion

Accidents with thermal loads on the casks are:

- fires
- building collapse (insulation effect)

As shown in Section 3.2.1 tornado and wind loadings will lead neither to a cask movement nor to cask tipping. Therefore the wind forces the impact of tornado - generated missiles is considered.

In the IAEA Safety Guide No. 50 - SG - S11 A, p. 59, the following examples of tornado - generated missiles are mentioned:

- 1800 kg automobile
- 125 kg 20 cm armour-piercing shell
- 2.5 cm solid steel sphere

For these missiles the impact speed may be taken to be 35 % of the maximum horizontal wind speed. Assuming 140 m/sec wind speed of the basic tornado, the missile speed will be approx. 50 m/s. The kinetic energy impact to the cask resulting from the 1800 kg missile is approx.:

$$E = \frac{1}{2} m v^2 = 2.25 \cdot 10^6 \text{ Nm}$$

Experimental tests on a prototype cask and a kinetic energy impact of 45 · 10^6 Nm, resulting from a 1000 kg missile with an approx. speed of 300 m/s, have demonstrated the cask integrity. For further details see APPENDIX 9.

Generally the mechanical integrity of the cask during accident situations can be derived from experimental results of the cask behavior in free drop tests. For a complete discussion of the drop test result see APPENDIX 10. The result from a free drop test of a CASTOR - prototype cask, the CASTOR Ia, which is very similar to the CASTOR Ic cask, can be used to show the cask integrity under mechanical loads. Only those drop tests with the greatest mechanical load on the cask body, i.e. drops onto the trunnions and onto a horizontal line parallel to the cask axis at - 40°C ambient temperature, will be considered for the stress analyses.

The bending load resulting from this drop position leads to a primary bending stress in the middle of the cask that over the entire wall cross section, in the limiting fiber on the impact side of the cask body, the maximum loads is a tensile one.

In comparison with the tested CASTOR Ia prototype the CASTOR Ic cask exhibits the following differences (that are decisive in the analysis that follows):

- Shorter distance between trunnions.
- Higher moment of resistance in the middle of the cask, since the wall thickness is greater for equal outside dimensions.
- Greater total weight

The following arguments concerning the transferability of CASTOR Ia prototype tests (with the maximum loads) to the CASTOR Ic cask were considend:

Investigations of the cask body and tightness control after the CASTOR Ia drop test have shown that the cask function is unimpaired and that fuel shielding and cask tightness are preserved. Thus, if the geometrical values for the CASTOR Ic are used and an equal maximum deceleration (120 g) is assumed, the bending stress is about 20 % less.

The effect of 20 % more mass and thus more drop energy is compensated by further plastic deformation of the trunnions or fins. As a result, the distances traveled during deformation will tend to be longer, so that the decelerations will tend to be less. (This fact also justifies the assumption of equal maximum acceleration of 120 g).

The positive results of drop tests with the CASTOR Ia prototype can also be transfered to the CASTOR Ic type cask if at least the same level is guaranteed for the material properties of safety significance. To characterize these properties extensive material studies, especially on specimen material from the CASTOR Ia prototype, have been done. A discussion of the material properties is given in Section 4.2.1.6. Further details are presented in APPENDIX 5 and APPENDIX 6.

To ensure an adequate factor of safety against impermissible plastic deformation under mechanical loads in the 9 m free drop test, it is sufficient to guarantee the yield strength of the material (0.2 % offset yield strength $R_{p0.2}$). Local plastic strains, which may occur chiefly on the cooling fins, do not impair the functioning of the cask. The corresponding factor of safety can be quantified. To ensure an adequate factor of safety against loss of integrity by fracture in the 9 m drop, the material ductility required for this factor of safety must be guaranteed.

The mechanical loads can be transfered provided it is shown that, when the above differences are considered, the primary bending stresses that occur are, at most, equally large.

In Tab. 8.2 - 1 deceleration values measured for two different drop tests on to an "unyielding" 1000 ton concrete foundation where impact was on the side, are given. The maximum acceleration values in free drop tests on the cask prototype occur on the line of impact.

The maximum stress σ_M on the limiting fiber can be determined from the peak value of 120 g measured in the middle of the cask and the relation

$$\sigma_M = \frac{M_M}{W} \quad \frac{m \cdot a}{W \cdot 2} \quad \left(\frac{\ell}{4} - c \right)$$

In this formula M_M is the bending moment of a cantilever beam with a rectangular line load resting on two supports; W is the moment of inertia of the cask cross section, represented by a box-shaped profile with the cooling fins neglected; m is the mass of the cask with load; a is the peak accel⁻ration, expressed as a multiple of the acceleration of gravity $g = 9.81\ m/sec^2$; ℓ is the cask length; and c is the length of the projected cask end.

In Tab. 8.2 - 2 the parameters used for the tensile stress calculation of the CASTOR Ia prototype and the CASTOR Ic reference cask are listed. For the CASTOR Ia prototype, the figures in Tab 8.2 - 1 give a maximum tensile stress of $\sigma_M = 127\ N/mm^2$ in the limiting fiber of the cask side. For the CASTOR Ic (under the conservative assumption that c = 200 mm), $\sigma_M = 100\ N/mm^2$.

Building structures to be considered in an ISFSI are site-specific and part of the applicant's SAR. Nevertheless, in APPENDIX 9, (Chapter 3) it is shown that collapse of a roof truss weighing a total of 20 metric tons will not effect the cask integrity. The impact momentum of the roof truss is substantially smaller than that of a projectile impact or a drop from a 9 m height.

During gas cloud explosions mechanical loads on the cask occur only if a cask tips over and hits the floor or a neighboring cask. The load-time curve for a gas cloud explosion can be taken from Fig. 8.2-1. To start the tipping process, the lateral load per unit area due to the pressure wave must be greater than the load per unit area p_k, where

$$p_k = mg/H^2,$$

H is the cask height and m is the cask mass. For the pressure wave specified in Fig. 8.2-1, tipping of the CASTOR Ic cask cannot be ruled out with certainty. The greatest cask load occurs upon impact against the floor. The energy analysis is shown in APPENDIX 9. The impact momentum upon tipping of the cask is significantly less than the impact momentum for a drop from a height of 9 m. A comparison of the resulting impulses and reduced stresses of different accidents with the mechanical loads of the cask during projectile impact and 9 m drop test is given in Tab. 8.2-3.

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. Starting and spreading of fires can be ruled out considering a single cask with no building structures. If a building is present, the design of the ISFSI usually incorporates passive fire protection measures. Furthermore the CASTOR-casks are designed to withstand fires in accordance with the test conditions (30 min. fire; 800°C).

Experimental tests with a prototype remote type cask have demonstrated that no damage to the cask will occur during a 30 min./ 800°C fire. The cask tightness and shielding remain unimpaired.

The cask was exposed 30 minutes to a fire produced by the burning of 1500 liters of normal fuel oil. The cask temperatures occurring in this test were measured with built-in thermocouples. In the framework of the cask, temperature measurements were made both while the fire was active and after it was extinguished.

Temperatures of the outer and inner cask surfaces during the fire test are shown in Fig. 8.2-2. For the outer surface the temperatures of the cask body between the fins are plotted.

Another thermal load on the cask can be postulated in case a storage building is present and the collapse of this building is assumed, i.e. the heat removal from the cask is disturbed. The temperature behavior of a CASTOR Ic cask when its outside surfaces are insulated was also tested by experiment. The burial of the cask was simulated by wrapping the whole cask in a thermally-insulating glass-wool mat.

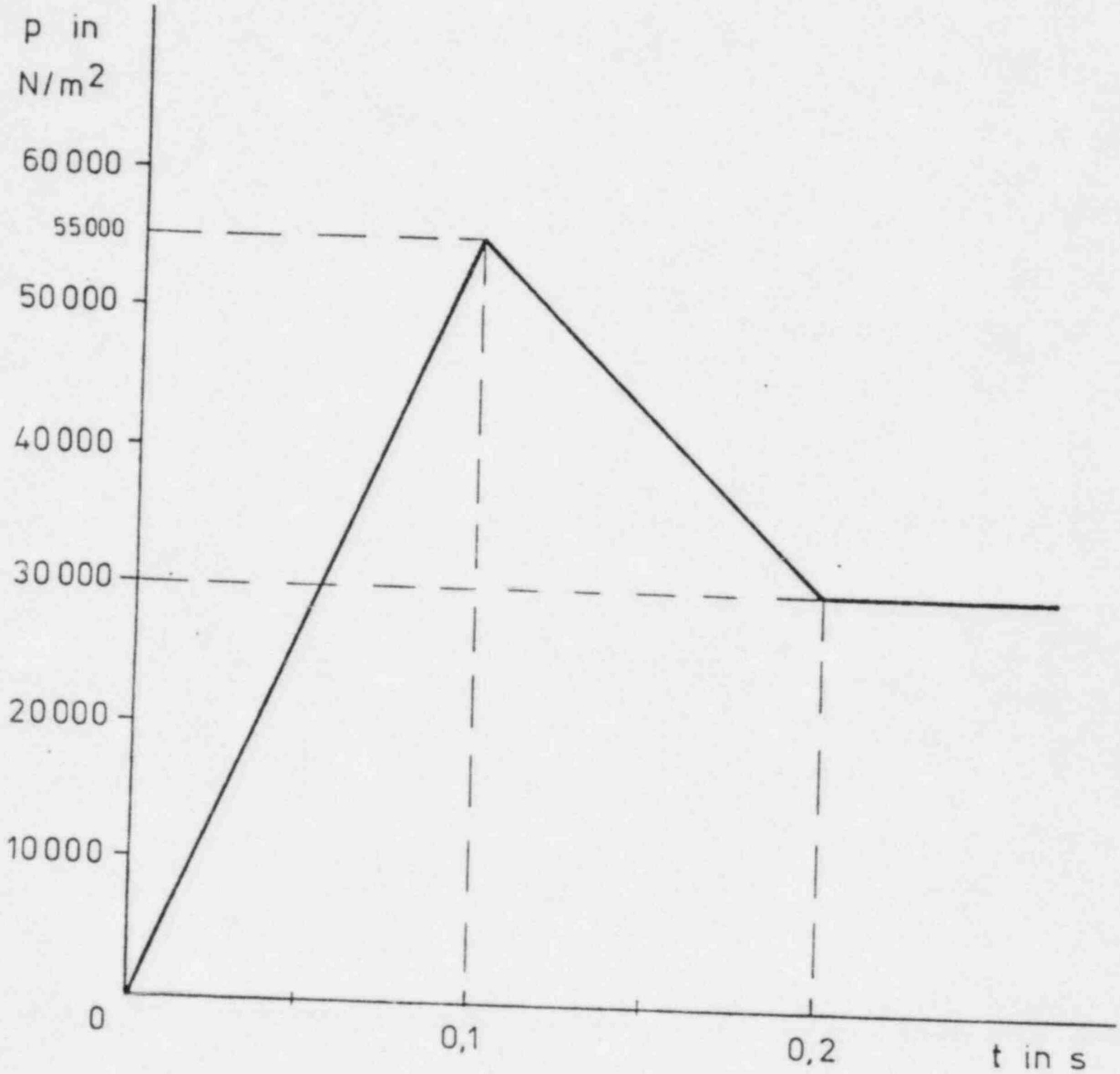
The test results can be seen in Figures 8.2-3 and 8.2-4. Figure 8.2-3 shows the increase of fuel rod temperatures at measuring points 1, 4 and 17 after the additional thermal insulation was put on the cask. Figure 8.2-4 compares the final rod temperatures with and without additional thermal insulation. The following conclusions can be drawn from the collection of measured results:

1) The final equilibrium rod temperatures have been established at measuring points 1, 4 and 17 inside the fuel-assembly simulator after 120 hours. The strip charts of the temperature recorder (not shown here) imply that this is the case for all the other measured temperatures.

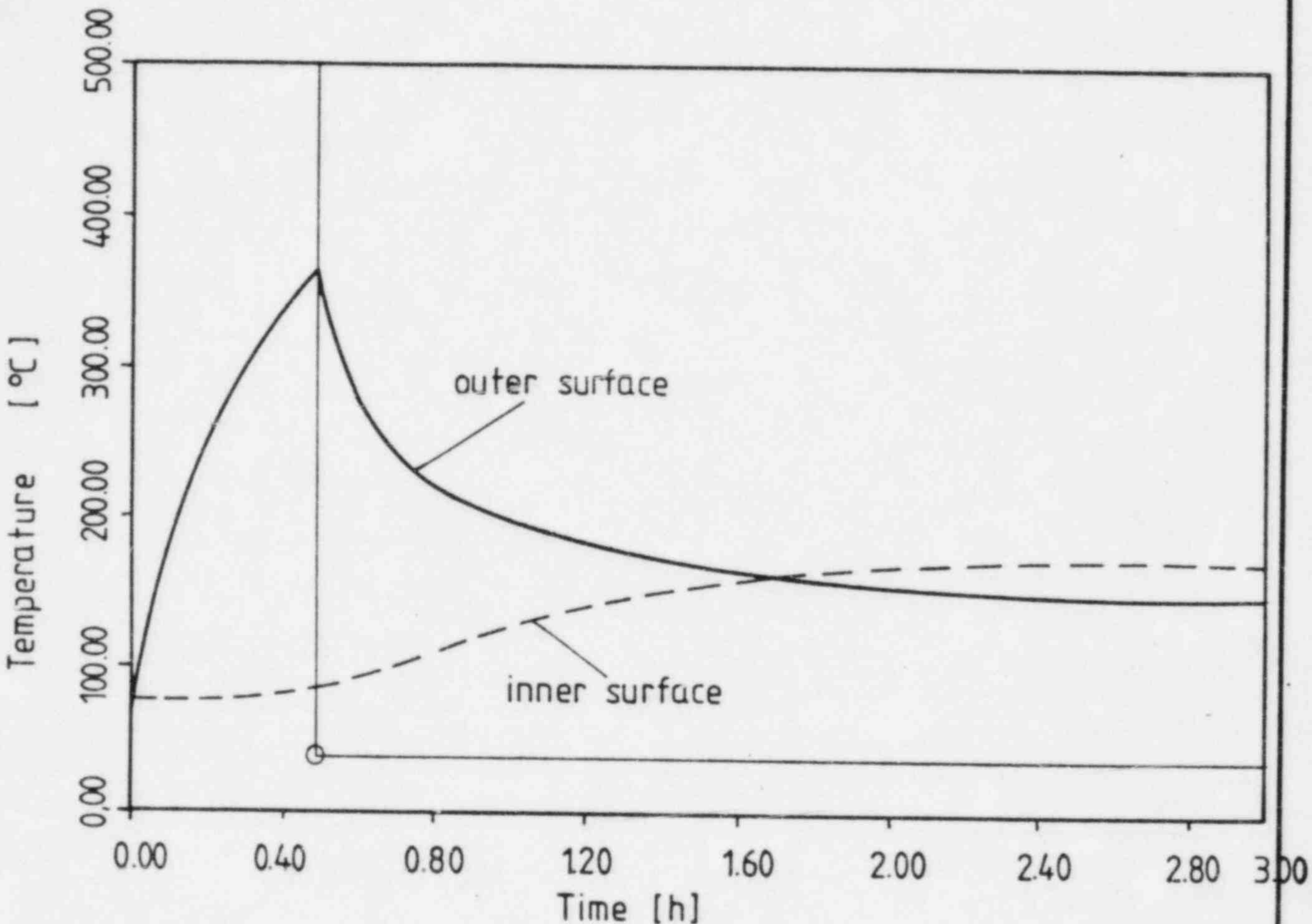
2) Burial of the cask results in a temperature rise of no greater than 48°C inside the fuel-assembly simulator.

3) The greatest temperature rise due to burial of the cask, 70°C occurs at the cask wall (fin, outside).

There is no detectable activity release or increased radiation level after the accidents described because the cask tightness and shielding remain unimpaired. This has been experimentally proven. Theoretically an activity release can be calculated which is identical with case B or case E investigated in Section 8.1.1.3 of this report (see Tab. 8.1-3).



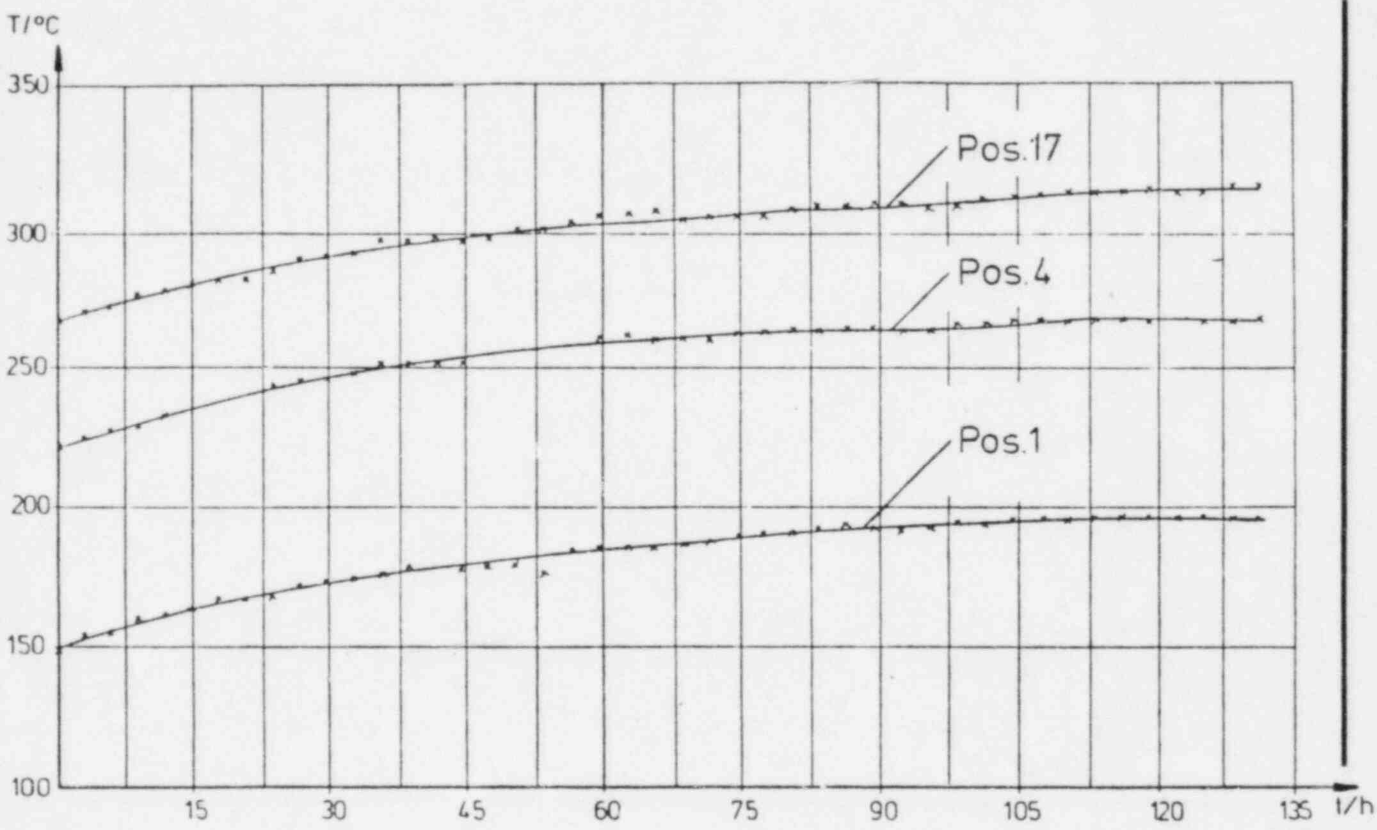
GNS	Load-time History for Gas Cloud Explosion	Fig. 8.2 - 1



Max. Temperatures

outher surface 363 °C

inner surface 171 °C



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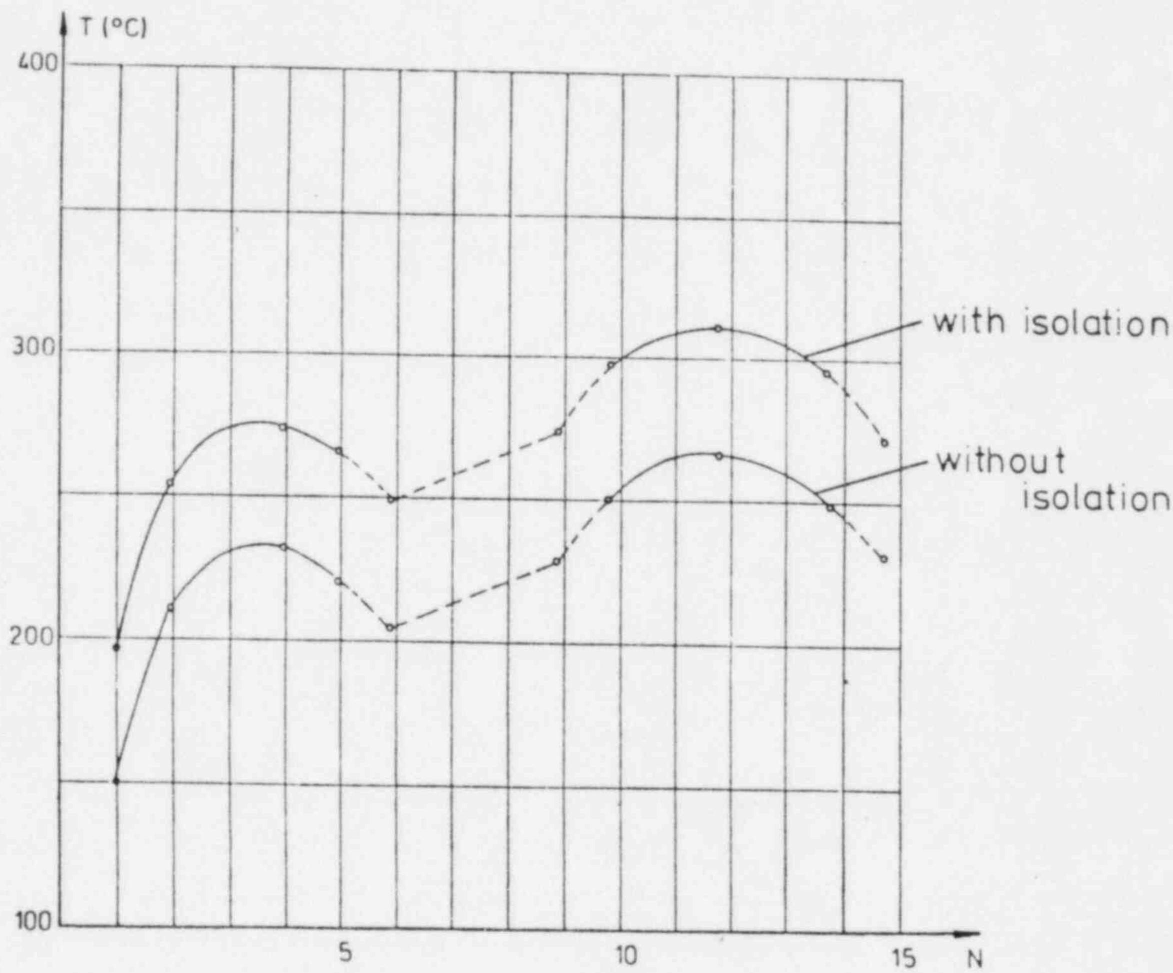
Increasing of Fuel Rod Temperatures of an Isolated Cask

Fig. 8.2 - 3



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Fuel Rod Temperatures vs Location

Test No.	Deceleration at cask position
3	Cover end, a = 120 g
4	Middle of cask, a = 120 g

	CASTOR Ic	CASTOR Ia Prototype
m, kg	85,000	70,600
a, multiple of g	120	120
ℓ, mm	5505	5730
c, mm	200 bottom	300
	750 cover	
W, m^3	0.59	0.37

Test/Accident	Impulse kg-m/sec	Reduced Stresses N/mm²
9 m drop	$1.13 \cdot 10^6$	78
Projectile impact on top surface on middle	$0.3o \cdot 10^6$ $0.3o \cdot 10^6$	70.6 51.4
Gas cloud explosion	$0.31 \cdot 10^6$	only tipping possible
Roof truss collapse	$0.06 \cdot 10^6$	only tipping possible

9. <u>Conduct of Operations</u>

This chapter addresses items related to a specific license application and thus is not relevant from a topical report standpoint.

10. Operating Controls and Limits

10.1 Proposed Operating Controls and Limits

10.1.1 Contents of Operating Controls and Limits

Operating controls and limits pertinent to a CASTOR cask-type storage installation (cask component only) include the following:

- cask surface temperature limit
- cask surface (or off-surface) dose rate limit
- cask tightness (monitoring system) control

10.1.2 Bases for Operating Controls and Limits

10.1.2.1 Cask Surface Temperature Limit

The basis for specifying a cask surface temperature limit is that of limiting the corresponding average temperature of the hottest fuel rod which, in turn, protects against degradation and gross rupture of the fuel cladding as specified in 10 CFR Part 72.72 (h) (1).

10.1.2.2 Cask Surface/Off-Surface Dose Rate Limit

The basis for specifying a limit on the cask exterior dose rate is that of assuring compliance with the annual dose equivalent specified in 10 CFR Part 72.67 (a) and the ALARA direct radiation levels referenced in 72.67 (b) and (c).

10.1.2.3 Cask Tightness Control

The basis for controlling the cask tightness (via detection with the tightness monitoring system) is the same as that identified in Section 10.1.2.2 above together with the need to comply with 10 CFR Part 72.74 (d).

10.2 Development of Operating Controls and Limits

Pursuant to 10 CFR Part 72.33 (c) and 72.16 technical specifications relevant to CASTOR cask storage installations are provided under the following categories.

10.2.1 Functional and Operating Limits, Monitoring Instruments, and Limiting Control Settings

This category includes the controls and limits specified in Sections 10.1.2.1 through 10.1.2.3 above. See section 10.2.2. below.

10.2.2 Limiting Conditions for Operations

10.2.2.1 Equipment

Specifications for the performance of the cask tightness monitoring system (cf. Section 10.1.2.3 above) are provided in Appendices 11 and 15.

10.2.2.2 Technical Conditions and Characteristics

10.2.2.2.1 Cask Surface Temperature

The cask surface temperature will be limited to a value that assures that the average temperature of the hottest fuel rod identified in Section 3.3.7 will not be exceeded. Actual cask surface temperatures will depend on the type, quantity, and cool time of the fuel as well as the specific type of cask.

10.2.2.2.2 Cask Exterior Dose Rate

The surface dose rate of the cask will be limited to a value consistent with ALARA principles and the requirements of 10 CFR part 72.67 (a). The maximum value will not exceed 200 mrem/h on the cask surface.

Any cask scheduled for off site shipment would be limited to a surface dose rate which is consistent with transportation regulations, i.e. that resulting in a dose rate of less than 10 mrem/hr at 6 feet from the transport vehicle (sole source shipment).

10.2.3 Surveillance Requirements

Surveillance of the cask to confirm limiting surface temperature and dose rate (cf. Section 10.2.2.2.1 and 10.2.2.2.2 above) is required only at time of cask receipt for storage; periodic surveillance is not necessary. Surveillance of cask tightness (see Section 10.1.2.3 above) is performed and signalled automatically via the cask tightness monitoring system (cf. Sections 3.3.3.2 and 5.4.1), thereby obviating the need for direct surveillance by facility personnel.

10.2.4 Design Features

Design features of the cask pertinent to safety (tightness, content of fuel basket, shield thickness) are controlled by means of the quality assurance program implemented during construction (see Chapter 11).

10.2.5 Administrative Controls

Adiministrative controls will be site specific at least in part. The principles of the organization and the corresponding administrative controls for an AFR dry cask storage are given in Section 4.2 of Appendix 4.

10.2.6 Operating Controls and Limits

Due to the specific properties of dry cask storage, operating controls concentrate on cask acceptance (contamination, dose rate, tightness, overall function). Operational controls can be limited to tightness monitoring after reaching thermal equilibrium.

Due to the properties of the passive safety systems of the cask increases in dose rate and temperature are not anticipated possible. Corresponding measurements are executed for routine purposes only.

11. Quality Assurance

Full quality assurance is executed for the cask body and all cask components. The Quality Assurance System for the manufacture of spant fuel shipping and storage casks is patterned on the KTA Rules (body of rules for requirements on nuclear facilities and components) and the ASME Code (American body of rules for, among other things, requirements on nuclear facilities and components). The Quality Assurance System covers every component of the cask in accordance with its relevance to safety.

In particular, the Quality Assurance System is divided into

- Quality Assurance Handbook (QSH)
- Quality Assurance Program (QSP)
- Material Data Sheets (WB)
- Test Sequence Plans (PP)
- Manufacturing Specifications (HV)
- Operational Specifications (AV)
- Test Specifications (PV)

Quality Assurance Handbook

The Quality Assurance Handbook gives a building description of the manufacturer's system for the following areas of activity:

- Development
- Component design
- Awarding of contracts and filling of orders
- Fabrication
- Documentation

The Quality Assurance Handbook states and describes its organization. The provisions in the Quality Assurance Handbook apply as instructions to all persons and offices involved in all the areas of activity named above.

In APPENDIX 11 an example for a Quality Assurance Handbook is given.

Quality Assurance Program

The Quality Assurance Program sets down the minimum requirements that the customer imposes on the quality assurance of the manufacturers.

Material Data Sheets

For all the components of the cask, the Material Data Sheets establish the minimum requirements on chemical analysis and also mechanical properties of the material.

Test Sequence Plans

The Test Sequence Plans describe the individual testing steps and define the delay points at which decisive intermediate tests or acceptance tests take place. The scope of testing (i.e., per piece, per lot, per charge, etc.) is also stated; in accordance with DIN 50049, the tests will be done in this form.

Manufacturing Specifications

The Manufacturing Specifications are instructions for the manufacturer or manufacturer's subcontractor, in order to make sure that parts and components being supplied have been manufactured and delivered in accordance with the applicable requirements.

Operational Specifications

The Operational Specifications embody the requirements on production processes, such as welding, heat treating, and so forth. They state in detail what requirements are to be imposed on personnel, apparatus and material and how the operations are to be carried out and documented.

Test Specifications

The specifications include instructions for the performance of tests, and so forth, and describe the requirements on qualifications of the tester, type of test instrument, data to be reported, and type and scope of testing, as well as the limiting values for the specified test.

Certificates and Documentation

All tests are covered by certificates and are documented.

The Quality Assurance System just described insures that the requirements imposed on a shipping and storage cask are reproducible for every cask and that the packaging requirements are met.

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APPENDIX 2 - Shielding Report, GNS Nodular Cast Iron Cask for 16 Würgassen - Type BWR Fuel Assemblies with a Burnup of 27 GW-days / MTU, GRS-A-401 (1980).

APPENDIX 3 - CASTOR Cask Pressure Gauge Behaviour During Storage Operation, GNS B 49/82.

APPENDIX 4 - Safety Analysis Report for Gorleben Shipping - Cask Storage Site (1979)

APPENDIX 5 - Opinion Based on an Assessment of the Cast Material GGG 40 As to Its Suitability for CASTOR Shipping and Storage Casks BAM 1.2 - H.A. 1.02/3022 - T.A. 1.20/12521 March 14, 1982

APPENDIX 6 - Fracture Toughness Evaluation Of Nodular-Graphite Cast Iron for Nuclear Shipping Cask Applications by P. McConnell, R.A. Wullaert, October 1982 Fracture Control Corporation, 340G South Kellogg Avenue, Goleta, California 93117 USA

APPENDIX 7 - Thermal Load Tests on a Horizontal Castor Ia Shipping and Storage Cask with a Fuel-Assembly Simulator, GNS-Report B4/80.

APPENDIX 8 - Temperature Analysis of the Spent Fuel Storage Cask CASTOR, KFA-Report by Dr. F. Stelzer, 1982.

APPENDIX 9 - External Hazards to CASTOR Casks, GNS B 44/81.

APPENDIX 10 - Test Certificate 1.2/12273, "Type Test of a Type B(U) Packaging for the Transport of Radioactive Materials, Designed CASTOR Ic, BAM, 1. Revision February 19, 1982.

APPENDIX 11 - Quality Assurance for the Manufacture of Fuel-Assembly Storage Casks for Use at Nuclear Power Plants in the USA, August 31, 1981.