AREVA

ADVANCED NUCLEAR FUELS GmbH

Safety Report

for the

Shipping Container

ANF-50

as type A-package

Originator: ADVANCED NUCLEAR FUELS GmbH, Lingen / Ems

Report No.: ANFG-11.105 (05E) Rev. 3

Date of issue: 18th September 2006

Date (first issue): 31st August 2005

Certificate of Approval, No.: D/4365/AF-96

	Name	Signature	Date
Prepared by:	E. Fries	Fries	18. Sept. 2006
Verified by:	D. Steinigeweg	D. Steinigeweg	19. Sept. 2006
Released by:	H. Lampe	H. Lampe	20 Sept 2006

Description of the revisions

Revision	Date	Reason of the Modification
0	31. Aug. 2005	NEW
1	03. April 2006	Revision of the following documents: Reg. 1: Safety Analysis Report ANFG-11.106 (04E) Rev. 1 Reg. 5: Container Instruction ANFG-11.101 (29E) Rev. 1 Reg. 10: Statics calculations ANFG-11.118 (01E) Rev. 1 Reg. 19: Drawing AD-003759-001 Rev. 5 Reg. 6: Data sheets added. Reg. 7: Criticality Safety Analysis ANFG-5.061 (34) Rev. 1 added. Reg. 14: Report A1C-1314450-1 added. Reg. 19: Drawing AD-003752-001 Rev. 2 removed.
2	07. July 2006	Reg. 1: Safety Analysis Report ANFG-11.106 (04E) Rev. 2
3	18. Sep. 2006	Reg. 1: Safety Analysis Report ANFG-11.106 (04E) Rev. 3

List of the Attachments

In this list of the attachments you find documents with their valid revision which are component of the Certificate of Approval D/4365/AF-96 (Rev. 0).

Document	Revision	Register
Safety Analysis for the ANF-50 shipping container as type A-package for the transportation of uranium oxide pellets, uranium oxide pellets and uranium oxide powder not in accordance with specification Safety Analysis: ANFG-11.106 (04E)	3	**1**
Shipping container ANF-50 Drawing: AD-003750-001	3	**2**
Data Sheet for the Shipping Container ANF-50, attachment means Drawing: ANF 3-1 27-3763-03	1	**3**
Manufacture of Pellet Shipping Containers ANF-50 Specification: ANFG-11.103 (005E)	2	**4**
Handling and maintenance of ANF-50 shipping containers (type A-package) Container Instruction: ANFG-11.101 (29E)	1	**5**
Data sheets	--	**6**
Criticality Safety Analysis for the transport approval of ANF-50 Shipping Containers ANFG-5.061 (11), (ANF / Dr. Bendick)	2	**7**
Permit for air transportation of the ANF-50 Shipping Containers Criticality Safety Analysis ANFG-5.061 (34), (ANF / Dr. Bendick)	1	**7**
Periodic inspections on ANF-50 shipping containers Container Instruction: ANFG-11.101 (25E)	2	**8**
not assigned	--	**9**
Statics calculations for the pellet shipping container Work Report: ANFG-11.118 (01E), (ANF / Company Oelgemöller)	1	**10**
Results of measurement for the ANF-50 shipping container (test specimens 1-4) before/after IAEA tests Data Summary: ANFG-11.119 (003E)	0	**11**
Shipping Container ANF-50 (Test Specimen 1 to Test Specimen 4) Cover Sheet of the Manufacturing Documentation: DBL-4435	1	**12**
Test Program for ANF-50 Shipping Container for Unirradiated uranium dioxide pellets Work Report: A1C-1310729	0	**13**

Document	Revision	Register
Drop Tests with Drop Test Specimens of ANF-50 Pellet Shipping Container BAM-Test Report: 10830	0	14
Independent Data Compilation Pressure test at an ANF-50 container, Report A1C-1314450	1	14
Verification of local dose rates for the ANF-50 shipping container in accordance with IAEA standards Report: ANFG-11.109 (02E), (ANF / Company Oelgemöller)	0	15
Numerical Simulation of IAEA Thermal Test for ANF-50 Pellet Shipping Container Report: B-TA-3928 (Dr. Becker, Fa. IABG)	1	16
Laboratory tests for oxidation characteristics of UO_2 and Gd_2O_3/UO_2 pellets under the conditions of the IAEA thermal test for the ANF-50 shipping container Work Report: A1C-1311344 (FGTW / Dr. Lansmann)	0	17
Description and Assessment of Changes to Series-Production ANF-50 Shipping Container with Respect to Tested Container Prototype Work Report: A1C-1311432 (FGTM / Jahreiß)	1	18
Drawings		19

Title	Drawing No.		
shipping container ANF-50	AD-003751-001	004	
shipping rack	AD-003753-001	002	
case for pellet box	AD-003754-001	003	
case for pellet box, complete	AD-003755-001	002	
isolation plate for case for pellet box	AD-003756-001	002	
lid for case	AD-003757-001	004	
pellet tray	AD-003758-001	002	
pellet box ANF-50	AD-003759-001	005	
carrying tray	AD-003760-001	003	
clamping device	AD-003761-001	002	
protective lid	AD-003762-001	003	

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Esselte

621020

DER BLAUE ENGEL
weil aus 100% Altpapier
JURY UMWELTZEICHEN

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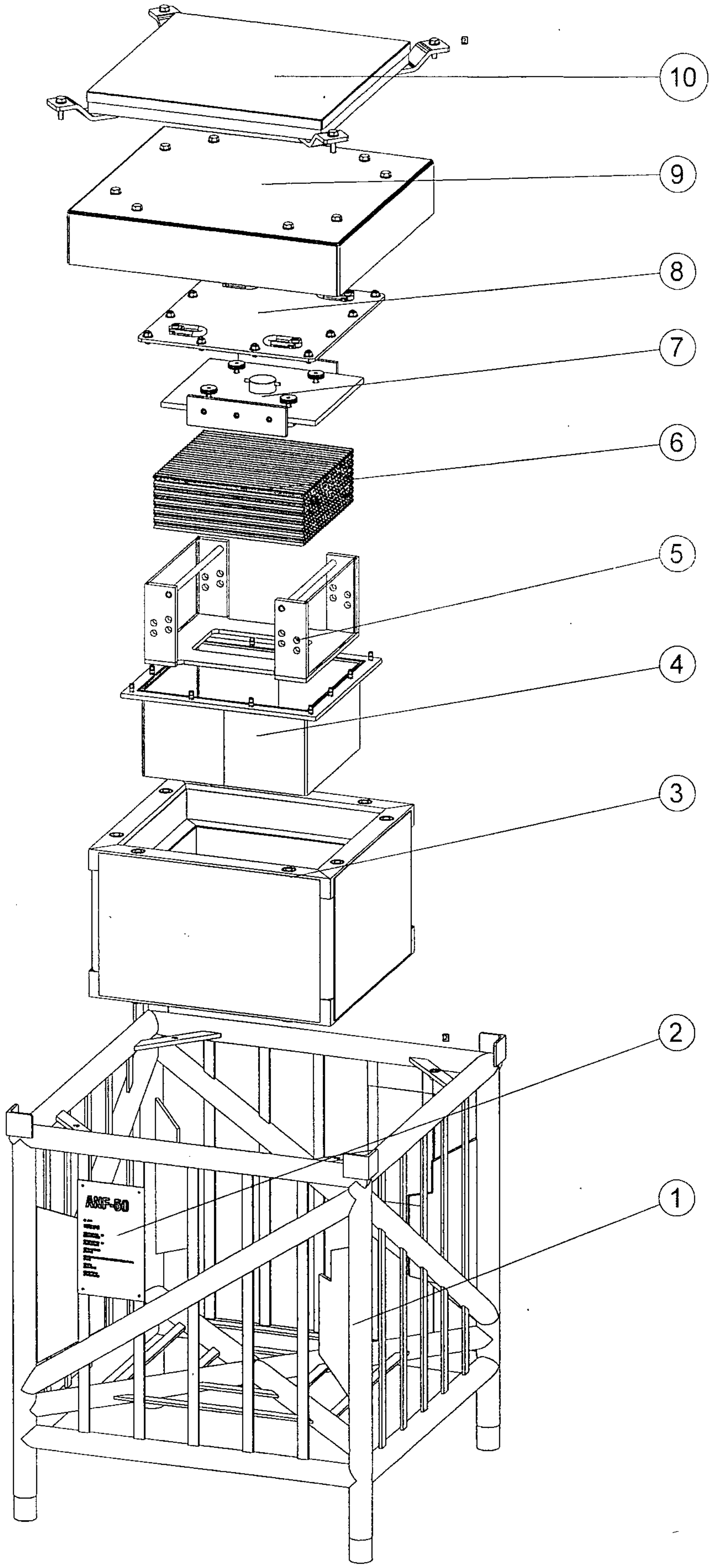

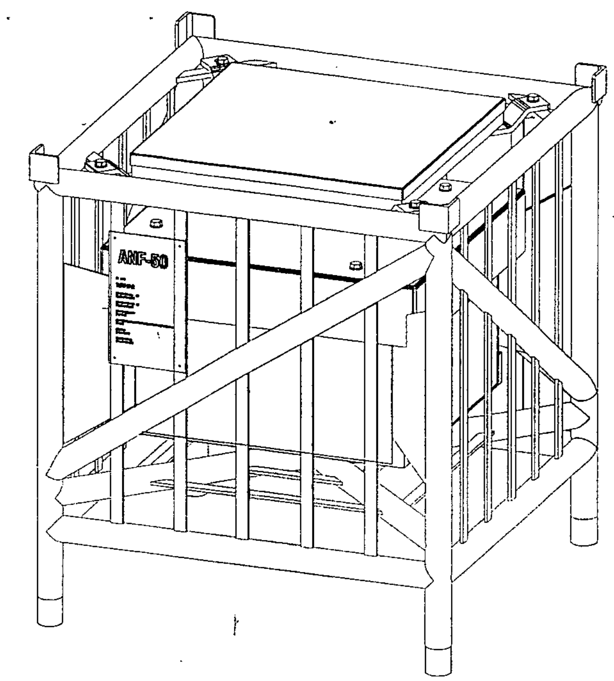

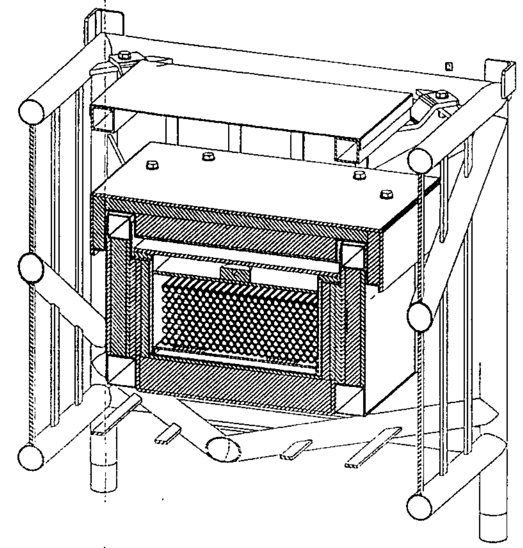

Werkstoffliste, Schweißplan, Fertigungs- und Prüffolgeplan, ANF-Spezifikation, Prüfanweisungen und Arbeitsanweisungen sind zu beachten!

list of materials, welding plan, inspection plan, ANF-specification, test inspections and work instructions are to be considered!

Hierzu gehört: AD-003751-001
also see: AD-003751-001

Zeichnungstabelle / table of drawings — ca. 173.56 kg Gesamt / kg total

Pos. item	Stck	Benennung/Fertigmaße	Quantity title/finished size	Zchg.-Nr. drawing-no.	Mat./Hst. Material	Gew.(kg) weight.(kg)	Bemerkung remarks
10	1	Schutzdeckel	protective lid	AD-003762-002		11.40	
9	1	Kastendeckel	lid for case	AD-003757-001		22.21	
8	1	Pelletbehälterdeckel	pelletlid for pellet box	AD-003759-001		6.28	
7	1	Klemmvorrichtung	clamping device	AD-003761-001		9.32	
6	15	Pelletträger	pellet tray	AD-003758-001		9.45	
5	1	Traggestell	carrying rack	AD-003760-001		9.09	
4	1	Pelletbehälter	pellet box	AD-003759-001		8.70	
3	1	Aufnahmekasten kompl.	case f. pellet b. compl.	AD-003755-001		48.35	
2	2	Typenschild	identification plate	AD-003752-002		0.92	
1	1	Transportgestell	shipping rack	AD-003753-001		46.70	

⊠ = Revisionsänderung
= revision change

Nr.	Änderung	Gez.	Datum	Geprüft	Freig.
3	Nummern geändert.	A. G.	11.Apr.2005	St Eilers	H. Lange
2	Bemerkungen nachgetragen,	Onste	17.01.2003	Glüpker	Paulinyi
1	Bemerkungen nachgetragen, Pos.10: Zchg.-Nr. geändert.	Onste	16.02.2002	Glüpker	Paulinyi

Li1-08-02-0020 | Li1- | Li1- | Li1-

Maßstab: 1:5

XXX	Datum	Name
Gezeich.	18.06.2002	Onste
Geprüft	02.08.2002	Glüpker
Geprüft	16.02.2002	Höfers
Freigeg.	16.02.2002	Paulinyi

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ADVANCED NUCLEAR FUELS GmbH

Transportbehälter ANF-50
shipping container ANF-50

AD-003750-001-003-000

Originalformat entspricht DIN A1 = 841x594

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Esselte
621020

DER BLAUE ENGEL
weil aus 100% Altpapier
JURY UMWELTZEICHEN

4 001536 003516

Certificate of Approval

Titel/Title:			
For a transport package sample of Type A for fissionable radioactive materials			
			Nummer/Number D/4365/AF-96 (Rev. 0)

Translation verified: D. Steinigeweg — 31. Okt 2006 (Date)
D. Steinigeweg

Translation approved: — 31. Okt. 2006 (Date)
R. Witten

Certificate of Approval

D/4365/AF-96 (Rev. 0)

for a transport package sample of Type A for fissionable radioactive materials

Based on the application of Advanced Nuclear Fuels GmbH, Lingen, of September 1, 2005 (File Ref.: 244/05/BfS/DST), last amended on September 21, 2006 (File Ref.: 306/06/BfS/DST), the container with manufacturer's designation "pellet shipping container ANF-50" is approved as a Type A transport package sample for fissionable radioactive materials according to the following regulations for transports by road, rail, sea and air:

Regulations for the Safe Transport of Radioactive Material, 1996 Edition (As Amended 2003), International Atomic Energy Agency (IAEA), No. TS-R-1,

European Convention of September 30, 1957 governing the international conveyance of dangerous goods by road (ADR) (BGBl. 1969, II p. 1489), last amended by the 17th ADR Amendment Ordinance of August 27, 2004 (BGBl. 2004 II p. 1274), Appendices A and B,

Ordinance for the international conveyance of dangerous goods by rail (RID) – Appendix I to Annex B of the Convention governing international rail transportation of May 9, 1980 (COTIF-Convention) (BGBl. 1985 II, p. 130), last amended by the 12th RID Amendment Ordinance of September 28, 2004 (BGBl. 2004 II p. 1434),

International Maritime Dangerous Goods Code (IMDG-Code), Amendment 32-04,

International Civil Aviation Organisation – Technical Instructions for the Safe Transport of Dangerous Goods by Air, Edition 2005/2006,

Ordinance governing the domestic and cross-border conveyance of dangerous goods by road and rail (Dangerous Goods Ordinance, Road and Rail – GGVSE) of January 3, 2005 (Dangerous Goods Ordinance, Road and Rail - GGVSE) of January 3, 2005 (BGBl. I p.37), last amended by Article 3a of the Fourth Order Revising the Orders Governing the Conveyance of Dangerous Goods of November 2, 2005 (BGBl. I p. 3131),

Ordinance governing the conveyance of dangerous goods by seagoing vessels (Dangerous Goods Ordinance , Maritime – GGVSee) of January 6, 2006 (BGBl. I p. 139),

Air Transport Approval Ordinance in the edition of the notification of March 27, 1999 (BGBl. I p. 610), last amended by the ordinance of July 27, 2005 (BGBl. I p. 2275) in connection with the ICAO dangerous goods regulations (ICAO Technical Instructions)

in connection with the Directives of the Federal Ministry for Transport, Building and Housing (BMVBW) of November 17, 2004 (VkBl. Vol. 23, p. 594, 2004) and of February 20, 1991 (VkBl Vol. 4, p. 231, 1991).

It is hereby confirmed that the Federal Agency for Radiation Protection, Salzgitter, is the authority authorised by the Federal Ministry for Transport, Building and Housing pursuant to Section 7.9 of the IMDG-Code.

Certificate holder: ADVANCED NUCLEAR FUELS GmbH
Am Seitenkanal 1
49811 Lingen

Documents:

1. Application by Advanced Nuclear Fuels GmbH (ANF), Lingen, of September 1, 2005 (File Ref.: 244/05/BfS/DST), letters of ANF of July 24, 2006 (File Ref.: 301/06/BfS/DST) and September 21, 2006 (File Ref.: 306/06/BfS/DST)
2. Safety report of ANF, No. ANFG-11.105 (05), Rev. 3, of September 18, 2006
3. Test certificate by the Federal Institute for Material Research and Testing (BAM), Berlin, of August 28, 2006 (File Ref.:III.3/21139) and BAM letter of September 27, 2006 (File Ref.:III.3/21139)

With respect to the verification of criticality safety we refer specifically to the Criticality Safety Analysis in Section 7.1.3 of the Safety Analysis Report ANFG 11.106 (04), Rev. 3, the " Criticality Safety Analysis for the approval of the ANF-50 shipping container for public traffic " No. ANFG-5.060 (11), Rev. 2 and criticality safety analysis "Approval of the ANF-50 shipping container for transport by air" No. ANFG 5.060 (34), Rev. 1.

Manufacturer's designation: **Pellet shipping container ANF-50**

Identification mark of the package: **D/4365/AF-96**

Period of validity of the certificate: **Up to and including October 31, 2009**

Criticality safety index (CSI): **0.4**

Permissible content:

Content No. 1: Max. 52 kg uranium oxide, containing a maximum of 45.9 kg uranium with an enrichment (U-235 mass content in the uranium) of max. 5%, in the form of sintered pellets with a diameter of between 7 mm and 10 mm. The parameters detailed in Table 1 regarding the composition of the fuel must be complied with.

Content No. 2: Max. 14.5 kg uranium, containing a maximum of 12.8 kg uranium with an enrichment (U-235 mass content in the uranium) of max. 5%, in the form of pellets, pellet fragments, abraded pellet materials or uranium oxide powder. The parameters detailed in Table 1 regarding the composition of the fuel must be complied with.

Table 1: Composition of content

Nuclide	Mass content in the total uranium max. [%]	Activity per gram of uranium max. [Bq]	Gamma output per gram of uranium, max. [MeV * Bq]
U-232	1.00E-08 [1)]	8.27E+01	
U-234	5.50E-02	1.27E+05	
U-235	5.00	4.00E+03	
U-236	5.00E-02	1.20E+03	
U-238	100	1.24E+04	
Fission nuclides			30
Transuranic elements		2.5	

[1)] 1.00E-08 means $1.00 \cdot 10^{-8}$

Packaging design:

In terms of its mechanical and thermal properties in accordance with the test certificate and the letter of the BAM, Berlin, as detailed above and with regard to the criticality safety and the radiation shielding, according to testing by the BfS, the design for the pellet shipping container Type ANF-50 conforms to the requirements laid down for a Type A transport package for fissionable radioactive materials (IAEA-Regulations §§ 633 and 671).

In the criticality analysis the penetration of water into all cavities of the packaging was assumed.

Description of the packaging:

The ANF-50 shipping container consists of the following main components:

- Shipping frame with protective cover and receiving casing with casing cover
- Pellet container with container cover
- Supporting frame with clamping device and pellet tray.

The shipping frame consists of a welded structure of austenitic tubes and flat-bar profiles. Four vertically arranged tubes are connected at the top and bottom to four horizontally arranged tubes. The four sides are each reinforced with a diagonally arranged tube and are enclosed with longitudinal flat-bar profiles forming a grid-type structure. The bottom is reinforced with two diagonally arranged tubes and also enclosed with longitudinal flat-bar profiles forming a grid-type structure.

The protective cover consists of a frame of rectangular profiles whose top is equipped with a cover plate. The protective cover is screwed to the frame at the four right-angle brackets at the corners.

The receiving casing consists of a sandwich-type structure with an external and an internal austenitic cover plate. Between the cover plates is a welded structure made of austenitic tubes and rectangular tubes and of austenitic round-, angular- and flat-bar profiles, in addition to a filling of inorganic insulation material. The cover plates are welded to the structure of the receiving casing. The receiving casing is welded to the vertically arranged tubes of the shipping frame at the four side edges by means of steel brackets.

The cover of the receiving casing is also designed as a sandwich-type structure with external and internal austenitic cover plates, and with inorganic insulation material between these cover plates. The casing cover is fastened to the receiving casing with eight bolts.

The pellet container and the container cover are manufactured from austenitic sheet metal. The container cover is fastened to the pellet container with 10 bolts.

The pellet holding structure consists of 15 pellet trays, the supporting frame for holding the pellet trays, two barrier plates for positioning the pellet trays in the supporting frame as well as the clamping device for bracing the layered pellet trays which can be locked in place in the supporting frame at different heights.

If the container is used for transporting Content No. 1, the pellets are enclosed in layers between the pellet trays. The pellet container with supporting structure, clamping device and pellet trays is also used for transporting Content No. 2. Content No. 2 is transported unsorted in an additional metal box in the empty space between the clamping device and the unloaded pellet trays.

A schematic description of the transport package (Drawing No. ANF–3–127-3763-03 Rev. 1) is attached as Appendix 1.

The main dimensions of the transport package are: Length approx. 712 mm, width approx. 712 mm, height approx. 756 mm.

The mass of the shipping container is: Tare approx. 190 kg, gross max. 248 kg

The packaging specified by the relevant revisions of the design documents (general drawing and list of drawings) in Appendix 2 (Type list) are at present in conformity with this Certificate of Approval (also see Supplementary Condition and list of drawings No. 7).

Supplementary conditions and notes:

Supplementary conditions and notes:

1. All quality assurance measures relating to planning, monitoring inspections and operation must be performed in accordance with the Technical Directive governing Quality Assurance (QA) and Monitoring Measures (QM) for Packaging Used to Transport Radioactive Substances (TRV 006) issued by the Federal Transport Ministry (BMV) (VkBl. Vol. 4, p. 233, 1991).
2. The remanufacture of packing materials is only permissible in accordance with the design documents with the highest revision index in Appendix 2 including the amendments in accordance with Supplementary Condition No. 7.
3. This approval is only valid in connection with the Certificate of Acceptance issued for the relevant series production sample; this Certificate shall be sent to the BAM (Federal Institute of Material Research and Testing) and BfS (Federal Office for Radiation Protection) without a specific request being issued. Any deviations tolerated by the BAM in accordance with TRV 006 and any changes as per Supplementary Condition No. 7 shall be documented in this Certificate of Acceptance. In the case of already manufactured series production samples, the deviations tolerated by the BAM and the changes as per Supplementary Condition No. 7 shall be documented in the inspection and test log book for the series production sample.
4. It must be ensured that each user of the packaging registers with the BfS before first-time use and confirms that he has received and complies with the inspection and test log book, which in particular contains the Certificate of Approval, the instructions for use and maintenance and the instructions or recurring tests. In this regard particular attention must be attached to the following:
    - Container instructions "Handling and maintenance of the ANF-50 pellet shipping containers" ANFG-11.101 (29), Rev. 1, issued on February 20, 2006, released on July 12, 2006
    - Container instructions "Recurring tests of ANF-50 shipping containers" ANFG-11.101 (25), Rev. 2, issued on August 22, 2005, released on September 9, 2006.

   Within the frame of this Approval the use of documents with a higher revision index is only permissible after prior release by the BAM and with authorisation of the BfS.
5. Each series production sample shall be subjected to recurring tests in due time. For series production samples that are to be used solely outside the Federal Republic of Germany, the recurring tests can be performed and certified by testing personnel authorised by the responsible authorities in the relevant country. The certificates for the recurring tests shall be forwarded to the Federal Institute for Material Research and Testing (BAM) and to the Federal Office for Radiation Protection (BfS) without these organisations having to request them.
6. Each series production sample must be permanently marked with the identification mark detailed above and with the date (month/year) of the next recurring test or inspection.
7. Changes relating to the design documents listed in Appendix 2, upon which the approval is based, require after release through the BAM the authorisation of the BfS of the Revision Certificate or an extended type list (in accordance with Appendix 2). They shall then form part of the present approval.
8. This approval does not release the sender from the obligation to comply with any regulations of any country through which or in which the transport package is conveyed.

Costs:

1. Costs, charges and expenses shall be levied for this Decision in accordance with § 12 paragraph 1 and 2 of the Act Governing the Conveyance of Dangerous Goods (GGBefG) in the version of the notification of September 29, 1998 (BGBl. I p. 3114), last amended by the Act of June 21, 2005 (BGBl. I p. 1818), in connection with Article 1 and Appendix (to Article 1), Part 1, Fee Number 007 in the Order Governing Costs for Safety Measures with Conveying Dangerous Goods (GGKostV) of November 13, 1990 (BGBl. I p. 2490), last amended by the Third Order Revising Orders Governing the Conveyance of Dangerous Goods of December 17, 2004 (BGBl. I, p. 3711).
2. The costs shall be borne by ANF GmbH, in accordance with § 12 paragraph 1 of the GGBefG in conjunction with § 13 paragraph 1 No. 1 of the Administrative Costs Act (VwKostG) of June 23, 1970 (BGBl. I p. 821), last amended by the Act of May 5, 2004 (BGBl. I p. 718).
3. The costs shall be determined in a separate decision.

Information about available legal remedies:

Objections against this decision may be lodged within one month of notification of this decision. Objections must be lodged either in writing to or be recorded at the Bundesamt für Strahlenschutz, Willy-Brandt-Str. 5, 38226 Salzgitter, Germany.

Salzgitter, October 18, 2006

In charge

Dr. Reiche

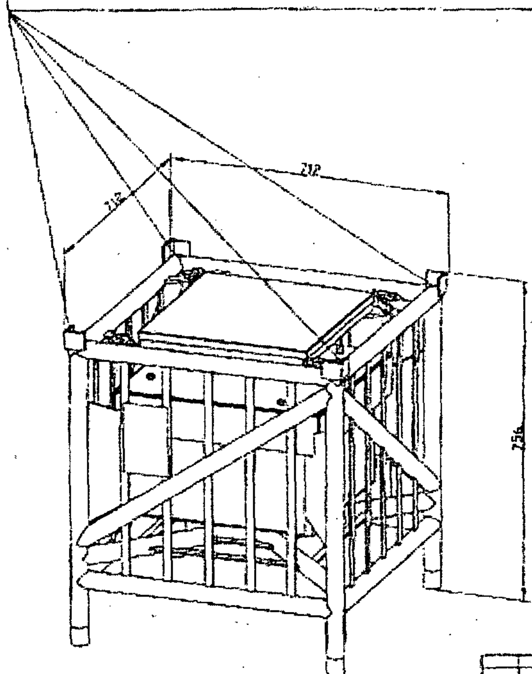
Appendices

Annex
Appendix 1: Data sheet for the ANF-50 shipping container, drawing number ANF-3-127-3763-03, Rev. 1
Appendix 2: Type list

Rev. No.	Date of issue	Validity	Reason for revision
0	Oct. 18, 2006	Oct. 31, 2009	Initial issue

The handling of the Shipping Container ANF-50 by means of crane and 4 round slings which are to be attached to the 4 top corners of the shipping frame, alternative the handling with a fork lift truck is permitted

ANFG-11.101 (24)
Rev. 0
Appendix 1
Page 1 of 1



Weight	
approx. Tare	approx. Gross
190 kg	248 kg

	Edited	19.07.2002			Scale
	verified	19.07.2002			%

Advanced Nuclear Fuels GmbH

Title: Data Sheet for the Shipping Container ANF-50, attachment means

Drawing No. ANF-3-127-3753-03

Rev. 1

Type list

for the ANF-50 pellet shipping container

Type ANF-50 shipping containers, which shall be or have been manufactured in accordance with the following ANF GmbH design documents, conform to the model type specified in this Certificate of Approval (see also Supplementary Conditions 2, 3 and 7).

Revision status of the design documents	Release by BAM
General drawing No. AD-003750-001-003-000, Rev. 3 Detailed drawings, see list of appendices to Safety Report ANFG-11.105 (05), Rev. 3, Register 19	BAM test certificate of August 28, 2006 (File Ref.: III.3/21139)

Salzgitter, October 18, 2006

In charge

Dr. Reiche

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DER BLAUE ENGEL
weil aus 100% Altpapier
JURY UMWELTZEICHEN

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AREVA

ADVANCED NUCLEAR FUELS GmbH

Prüfung und Freigabe von Übersetzungen / *Examination and release of translations*

Titel/Title:

Sicherheitsnachweis / *Safety Analysis*

ANFG-11.106 (04E) Rev. 03

Safety analysis for the ANF-50 shipping container as type A package for the transportation of uranium oxide pellets, uranium oxide pellets not conforming to specification and uranium oxide powder

Übersetzung geprüft/ Translation verified:	D. Steinigeweg	04th October 2006 **Datum/Date**
Übersetzung freigegeben/ Translation approved:	R. Witten	Oct. 09, 2006 **Datum/Date**

AREVA

ADVANCED NUCLEAR FUELS GmbH

Safety Analysis

Titel/Title: Safety analysis for the ANF-50 shipping container as type A package for the transportation of uranium oxide pellets, uranium oxide pellets not conforming to specification and uranium oxide powder			
neues Ausgabedatum/ new issue date	vorheriges Ausgabedatum/ previous issue date	Seite/Page	Nummer/Number
	05.07.2006	1 von/of 76	ANFG-11.106 (04) Rev. 03

Handling: restrictive

Prepared:	signed W. Höfers AREVA NP FES-G	(Höfers)	18. Sep. 2006 Date
Verified:	signed W. Jahreiß AREVA NP FEV-G	(Jahreiß)	19. Sep. 2006 Date
Verified:	signed R. Witten ANF LP	(Witten)	20. Sep. 2006 Date
Verified:	signed K. Groche ANF Ref. SN	(Dr. Groche)	20. Sep. 2006 Date
Verified:	signed B. Bendick ANF Ref. SK-1	(Dr. Bendick)	20. Sep. 2006 Date
Released:	signed U. Krahé ANF Ref. S	(U. Krahé)	20. Sep. 2006 Date

Exportkennzeichnung AL: N ECCN: N

Die mit „AL ungleich N" gekennzeichneten Güter unterliegen bei der Ausfuhr aus der EU der europäischen bzw. deutschen Ausfuhrgenehmigungspflicht. Die mit „ECCN ungleich N" gekennzeichneten Güter unterliegen der US-Reexportgenehmigungspflicht. Auch ohne Kennzeichen, bzw. „AL:N" oder „ECCN:N", kann sich eine Genehmigungspflicht, unter anderem durch den Endverbleib und Verwendungszweck der Güter, ergeben.

Export classification AL: N ECCN: N

Goods labeled "AL not equal to N" are subject to European or German export authorization when being exported out of the EU. Goods labeled with "ECCN not equal to N" are subject to US reexport authorization. Even without a label, or with label. "AL:N" or "ECCN:N", authorization may be required due to the final whereabouts and purpose for which the goods are to be used.

Table of Amendments

Page / Appendix	Amendment
13	Uranium oxide mass and uranium mass for pellets corrected
15	Table 1 corrected.
16	Table 2 corrected and text completed
33, 34	List of the correction factors as well as table 4 revised, dose output and TI corrected
General information	Page shifts due to text insertions and deletions are not marked.

Table of contents

Abbreviations

ADR	European Convention of 30 September 1957 governing the international conveyance of dangerous goods by road
ANF	Advanced Nuclear Fuels GmbH
BAM	Federal Institute for Materials Research and Testing
ERU	Enriched Reprocessed Uranium
GGBefG	Act governing the conveyance of dangerous goods (Gefahrgutbeförderungsgesetz – GGBefG)
GGVSE	Ordinance governing the domestic and cross-border conveyance of dangerous goods by road and railway (Gefahrgutverordnung Straße und Eisenbahn – GGVSE)
GGVSee	Ordinance governing the conveyance of dangerous goods with seagoing vessels (Gefahrgutverordnung See – GGVSee)
IAEA	International Atomic Energy Agency
ICAO	International Civil Aviation Organization
IMDG Code	International Maritime Dangerous Goods Code
KTA	Nuclear Committee
KTA Standards	Safety Standards of the Nuclear Committee
LSA Material	Radioactive materials of low specific activity (Low Specific Activity Material)
QMH	Quality Management Handbook
QAP	Quality Assurance Programme
SCO	Surface Contaminated Objects
TRV 006	Technical Directive for Measures for Quality Assurance (QA) and Quality Monitoring (QM) for Packaging for the Transport of Radioactive Material
PRR	Preliminary Review Record

Preliminary remarks

The wording of the requirements in accordance with Appendices A and B to the European Convention governing the international conveyance of dangerous goods by road (ADR 2005) /2/ and ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air (ICAO TI) /7/ precedes the verification *in italics*. For every quotation the corresponding numbers of the requirements of the Ordinance for the international conveyance of dangerous goods by rail (RID) /3/, International Maritime Dangerous Goods Code (IMDG Code) /5/ and IAEA Safety Standards Series No. TS-R-1 (ST-1, Revised), Regulations for the Safe Transport of Radioactive Material /6/, are also given.

The numbering of the quoted sections of the regulations in this safety analysis were taken as given in the respective regulations.

1 Introduction

The ANF-50 shipping container was developed to transport uranium oxide pellets that can also contain gadolinium and pellets that do not meet the specification requirements (excessive quantity of pellets, scrap, abraded pellet material) and uranium oxide powder between processing plants.

Transport is to be undertaken in conformity with the applicable national and international road, rail, maritime and air requirements as an type A package containing fissile material.

The basis for producing the verifications for the road, rail and maritime requirements is the act covering the conveyance of dangerous goods, which forms the legal basis for the related ordinances, directives etc. Here these are in particular the Dangerous Goods Ordinances Road and Rail (GGVSE) /1/, with Appendices A and B to ADR 2005 /2/ and to RID 2005 /3/, and the Dangerous Goods Ordinance, Maritime (GGVSee) /4/ with the IMDG Code (edition 2) /5/.

The basis for producing the verifications for the air requirements is the act covering the conveyance of dangerous goods and the German air traffic law, forming the legal basis for the related ordinances, directives etc. The publication "ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air, 2005-2006 Edition" (ICAO TI) is used as a basis for evidencing /7/.

Since the road is the most frequently used conveying route, the verifications for the conveying routes rail and sea are undertaken representatively with reference to Appendices A and B to ADR 2005. Where text is quoted, the text of the ADR is used, which also applies by analogy to RID and IMDG. Reference is made for each text quotation to the section numbers of the ADR / RID and IMDG Code. In addition, the corresponding section numbers of the IAEA Safety Standards Series No. TS-R-1 (ST-1, Revised) /6/ are quoted. If the texts of the regulations differ substantially in terms of contents, the diverging texts are additionally quoted. The text of the ICAO TI is available in the English language only and is always quoted in addition to the text of Appendices A and B of the ADR.

This report gives the safety analysis for the design of the ANF-50 shipping container in conformity with the regulations cited above governing Class 7 material (radioactive material).

The package, consisting of the ANF-50 shipping container and the permitted inventory described in Chapter 3, is described as follows:

Type:	Package type A as AF for the transport of fissile material
Contents:	Fissile material in the form of pellets, pellet scrap, abraded pellet material, uranium oxide powder
Criticality safety index, CSI:	CSI = 0.4
Transport index, TI:	The transport index TI is determined on the basis of dose rate measurements in accordance with /2/, /3/, /5/, and /7/
Containment system:	The containment system is formed by the pellet container
Confinement system:	The confinement system is formed by the arrangement of the fissile material and the packaging components of the ANF-50 shipping container

2 Description of the design

2.1 Packaging design and function of the ANF-50 shipping container

The basic components of the ANF-50 shipping container are the following:

- shipping rack with protective lid and case for pellet box with lid for case cover
- pellet box with lid for pellet box
- carrying rack with clamping device and pellet trays.

The ANF-50 shipping container is shown in /R2/ with its principal dimensions and basic components and described with its characteristic data in data sheet /R3/.

The dimensions of the individual components and the material used are set out in the general drawing /R2/ and in the drawings referred to therein.

The ANF-50 shipping container is manufactured in accordance with the examined and approved manufacturing specification /R4/.

2.1.1 Description of the outer frame with case for pellet box

The shipping frame of the ANF-50 shipping container is a welded construction of austenitic tubes and flat sections. Four vertical tubes are joined at the upper and lower end to four horizontal tubes. The four sides are each stiffened by a diagonal tube and closed in the form of a grid by longitudinal flat bars. The bottom is stiffened by two diagonal tubes and likewise closed in the form of a grid by longitudinal flat bars. The space between the flat bars is less than 10 cm. At the lower end of the vertical tubes, (solid) feet of the same diameter are integrated to facilitate stacking of the containers in conjunction with the angles welded to the upper end.

Sheet steel corner plates are welded to the corners of the top for attaching the protective cover. The protective cover consists of a frame of rectangular sections, the top of which is faced with a cover plate. The protective cover is screwed to the frame at the four angled brackets at the corners. When the protective lid is fitted, the clearance between the protective lid and the horizontal tubes on the top of the frame is less than 10 cm.

The case for pellet box consists of a sandwich structure with an external (sides 1.5 mm thick, bottom 5 mm thick) and internal (2 mm thick) austenitic cover plate. The welded structure of austenitic tubes and rectangular tubes as well as austenitic round, angular and flat sections is located between the cover plates. The remaining cavities between the cover plates are filled as far as possible with inorganic insulating material. The cover plates are welded to the case for pellet box structure. The case for pellet box is welded to the vertical tubes of the frame at the four lateral edges by means of sheet steel brackets.

The lid for case is also formed as a sandwich structure with an external (5 mm thick) and internal (2 mm thick) austenitic cover plate and inorganic insulating material in between. Spacer sleeves are inserted between the cover plates in the area of the screw holes to provide stiffening. The lid for case is fastened to the case for pellet box by eight screws.

There are no special attachments on the outer frame of the ANF-50 shipping container. Handling is primarily by means of fork-lift truck in accordance with the container instruction /R5/.

2.1.2 Description of the ANF-50 pellet container with pellet support structure

The pellet box and the lid for pellet box are made of austenitic plate. A seal is inserted into the flange of the pellet container. The lid for pellet box is attached to the pellet box by 10 screw fittings. Lifting lugs are fitted to the four corners of the lid for pellet box for removing the closed pellet box from the case for pellet box.

The pellet support structure consists of 15 pellet trays for storing the pellets in layers, the carrying rack for holding the pellet trays, two end plates for positioning the pellet trays in the carrying rack and the clamping device for bracing the layered pellet trays. The pellet support structure is suitable for holding 14 pellet trays filled with pellets. The 15th pellet tray lies on the top layer of pellets as a closure. The two flat sections of the clamping device are pressed down onto the topmost pellet tray by screws, thereby bracing the entire package of layered pellet trays. If a load consists of less than 14 layers of pellets, the pellet trays not filled with pellets are placed on the topmost, closing pellet tray and braced as a package with the filled pellet trays. The clamping device can be fixed in the carrying rack at various heights to ensure that it functions at all loading levels (one to fourteen pellet trays). The pellet trays can hold and store 21 rows of pellets lying adjacent to one another with a pellet diameter of 7.6 mm to 11.5 mm, thus adequately covering the basic pellet diameter range of 8.05 to 9.5 mm. The pellet diameter range of 7.00 mm to 10.00 mm is assigned in the Verification of Criticality Safety. This pellet tray is not suitable for the pellet diameter range of 7.00 mm to 7.6 mm. If pellets of diameter range 7.00 mm to 7.6 mm are to be transported, suitable pellet trays must be obtained. With a pellet diameter of 8.05 mm, the ANF-50 can be loaded with 14 pellet layers, while the loading capacity is limited to 11 layers with a pellet diameter of 9.50 mm. A pellet tray may only be filled with pellets of the same diameter. An attachment is fitted to the top of the clamping device in the centre for removing the loaded carrying rack the pellet container.

The pellet box complete with carrying structure, clamping device and pellet trays is also used to transport pellets that do not meet the specification requirements and uranium oxide powder. Pellets not meeting the specifications and uranium oxide powder are transported unsorted in an additional container, the ANF-50 scrap / powder box made of stainless steel (high-grade steel), in the space between the clamping device and the unloaded pellet trays. The maximum load with pellets not conforming to specification or uranium oxide powder is limited to 14.5 kg.

2.1.3 Principal dimensions of the ANF-50 shipping container

Overall length:	approx.	712 mm
Overall width:	approx.	712 mm
Overall height:	approx.	756 mm

2.1.4 Masses of the ANF-50 shipping container

Complete container (without load), tare:	approx.	190 kg
Complete container (with load), gross:	max.	248 kg

2.2 Handling and transport of the ANF-50 shipping container

The shipping containers loaded with tablets are normally handled and transported in the horizontal position. In the plant, containers are handled and transported in a horizontal position using a fork-lift truck.

Handling and maintenance is described in the container instructions.

- Handling and maintenance of ANF-50 shipping containers /R5/

2.3 Containment system

Definition of term in accordance with ADR/RID, Para. 2.2.7.2 /2/, /3/, IMDG code /5/, IAEA Regulations TS-R-1, (ST-1, Revised), No. 213, /6/ or ICAO TI, 2,7.2 /7/, respectively:

Quote:

"Containment system means the assembly of components of the packaging specified by the designer as intended to retain the radioactive material during transport."

The containment system is formed by the pellet container.

2.4 Confinement system

Definition of term in accordance with ADR/RID, Para. 2.2.7.2 /2/, /3/, IMDG code /5/, IAEA Regulations TS-R-1, (ST-1, Revised), No. 213, /6/ or ICAO TI, 2;7.2 /7/, respectively:

Quote:

"Confinement system means the assembly of fissile material and packaging components specified by the designer and agreed to by the competent authority as intended to preserve criticality safety."

The confinement system is formed by the basic components of the ANF-50 shipping container.

- case for pellet box with lid for case
- pellet box with lid for pellet box
- carrying rack with clamping device.

2.5 Shielding

The ANF-50 shipping container forms the shielding of the packaging with the case for pellet box closed by a lid for case and the closed pellet container.

No special shielding is necessary owing to the low radiation.

3 Description of the nuclear fuel inventory

The permissible contents are fissile materials in the form of sintered uranium oxide pellets or in the form of uranium oxide pellets not conforming to specification (excessive pellet quantities, scrap, abraded pellet material) or uranium oxide powder.

The following parameters apply for **sintered uranium oxide pellets**:

- enrichment in uranium U-235: 5.00 %,
- pellet diameter 7.60 mm to 10.00 mm,
- maximum mass in uranium oxide per container: 52 kg 03
- transportation of the uranium oxide pellets in pellet trays inside the pellet container.

The following parameters apply for **uranium oxide pellets not conforming to specification as well as for uranium oxide powder**:

- enrichment in uranium U-235: 5.00 %,
- form not defined,
- maximum mass in uranium oxide per container: 14.5 kg
- transportation as bulk goods in containers made of stainless steel which are inserted in the space of unladen pellet trays inside the pellet container.

It is demonstrated in the following sections that the content satisfies the applicable regulations.

3.1 Description of the pellets

The nuclear fuel is in the form of sintered pellets. Apart from insignificant impurities with fissile transuranic elements (in the mg range), the fissile material inventory is present as U-235. Table 1 contains a description of the uranium.

Maximum 52 kg of pellets will be transported in the ANF-50 shipping container. The weight is obtained by determining the A2 value. In the criticality safety report /R7/, the undercriticality for the optimum load mass arising under partial load is determined. For the undercriticality the pellet column length and the stack height of the pellets, with are limited in the pellet container by the system pack frame with scrap iron sheet metals, cleming devices and pellet carriers, are determining. The free space limits the pellet loading on approx. 55 kg of pellets. 03 Thus, the criticality safety for a pellet load of 52 kg is also proven. Any arbitrary number of pellets with burnable neutron poisons (e.g. gadolinium, (Gd)) is permitted /R7/.

The package contains pellets with approx. 45,9 kg of uranium.

The uranium mass was ascertained on the basis of conservative assumptions, such as:

- theoretical UO_2 density and
- disregarding the pellet dishings.

The contents include fissile material. The nuclide concentrations and the conservative package inventory are stated in Table 1.

Contamination in accordance with the specification with transuranic elements of 2.5 Bq/g is taken in total as Pu-239. Of the fissile PU isotopes, this isotope has the lowest specific activity, so that these assumptions give the greatest possible Pu_{fiss} inventory.

When determining the γ dose rate produced by this uranium, it is almost exclusively the daughter products of U-238 and U-232 and the U235 nuclide that are of significance.

Compared with the γ dose rate, the neutron dose rate to be expected is negligible.

Table 2 states the relevant uranium daughter nuclides, the relevant fissile products and all fissile nuclides. The data is based on a uranium age of 10 years.

Nuclide	Max. fraction of uranium in mass percent (%)	Inventory of the package with 45.6 kg uranium	Max. mass U per package (g)
U-232	1.00E-08	3.79E+06	4.58E-06
Th-228 (FN)		3.78E+06	
U-234	5.50E-02	5.80E+09	2.52E+01
Th-230		5.20E+05	
Ra-226(FN)		1.12E+03	
U-235	5.00	1.83E+08	2.29E+03
Th-231		1.83E+08	
Pa-231		3.91E+04	
Ac-227		5.59E+03	
Th-227		5.44E+03	
Ra-223(FN)		5.44E+03	
U-236	5.00E-02	5.48E+07	2.29E+01
Th-232		2.69E-02	
Ra-228(FN)		1.12E-02	
U-238	≥ 94.89 *)	≥ 5.41E+08 *)	≥ 4.35E+04 *)
Th-234(FN)		≥ 5.41E+08 *)	
Pu -239 /240		1.15E+05	
Ce-144		8.06E+06	
Tc-99		2.92E+05	
Total		7.32E+09	4.59E+04

*) Fraction depends on the current composition of the uranium; the mass fraction can be up to 100 %

03

Table 1: Composition of the fuel.

Covering values in accordance with ASTM C 996-04, ECGU, based on a uranium age of 10 years

3.1.1 Determination of the A_2 value and the permissible uranium mass

Nuclide	Fraction of uranium in mass %	Factor for daughter nuclide design (10 a)	Specific activity in Bq/gU	Activity C(j) per package in Bq	Fraction of total activity f(j)	Value for A_2(j) in TBq	$f(j)/A_{2}(j)$ in 1/Bq	C(j)/A_2(j) (per package)	
U-235	**5.00**	1.00E+00	4.00E+03	1.83E+08	0.03				
Th-231		1.00E+00	4.00E+03	1.83E+08	0.03	2.00E-02	1.25E-12	9.16E-03	
Pa-231		2.13E-02	8.53E-01	3.91E+04	0.00	4.00E-04	1.34E-14	9.77E-05	
Ac-227		3.05E-03	1.22E-01	5.59E+03	0.00	9.00E-05	8.49E-15	6.21E-05	
Th-227		2.97E-03	1.19E-01	5.44E+03	0.00	5.00E-03	1.49E-16	1.09E-06	
Ra-223(FN)		2.97E-03	1.19E-01	5.44E+03	0.00	7.00E-03	1.06E-16	7.77E-07	
U-234	**5.50E-02**	1.00E+00	1.27E+05	5.80E+09	0.79	6.00E-03	1.32E-10	9.66E-01	
Th-230		8.98E-05	1.14E+01	5.20E+05	0.00	1.00E-03	7.11E-14	5.20E-04	
Ra-226(FN)		1.94E-07	2.45E-02	1.12E+0	0.00	3.00E-03	5.11E-17	3.74E-07	
U-236	**5.00E-02**	1.00E+00	1.20E+03	5.48E+07	0.01	6.00E-03	1.25E-12	9.14E-03	
Th-232		4.90E-10	5.87E-07	2.69E-02	0.00				03
Ra-228(FN)		2.05E-10	2.45E-07	1.12E-02	0.00	2.00E-02	7.68E-23	5.62E-13	
U-232	**1.00E-08**	1.00E+00	8.27E+01	3.79E+06	0.00	1.00E-03	5.18E-13	3.79E-03	
Th-228(FN)		9.98E-01	8.26E+01	3.78E+06	0.00	1.00E-03	5.17E-13	3.79E-03	
U-238	**94.89**	1.00E+00	1.18E+04	5.41E+08	0.07				
Th-234(FN)		1.00E+00	1.18E+04	5.41E+08	0.07	3.00E-01	2.46E-13	1.80E-03	
Pu-239/240			**3.0**	1.15E+05	0.00	1.00E-03	1.57E-14	1.15E-04	
Ce-144			**1.76E+02**	8.06E+06	0.00	2.00E-01	5.51E-15	4.03E-05	
Tc-99	**1.00E-06**		6.36E+00	2.92E+05	0.00	9.00E-01	4.43E-17	3.24E-07	
Total			**1.60E+05**	7.32E+09	1.00		**1.36E-10**	**9.95E-01**	

Table 2: Composition of the fuel according to Table 1 with a list of the A_2 values per nuclide, based on a uranium age of 10 years

The reciprocal value of the total in the column $f(j)/A_2(j)$ is A_{2mix} for the mixture:

$$A_{2mix} = \frac{1}{\Sigma f(j)/A_2(j)} = \frac{1}{1.36*10^{-10}} Bq = \underline{\underline{7.36*10^9\ Bq \equiv 7.36E+09\ Bq}}$$

Determination of the permissible uranium mass m_U for adhering to A_{2mix}: 03

$$m_U = \frac{A_{2mix}}{\Sigma C_{spec}(j)} = \frac{7.36*10^9}{1.60*10^5} g = \underline{\underline{4.59*10^4\, g \equiv 4.59E+04\ g}}$$

The maximum permissible mass m_{Oxid} of the uranium oxide in a container is 52 kg.

3.2 Description of pellets not conforming to specification (excessive pellet quantities, scrap, abraded pellet material) and uranium oxide powder

The nuclear fuel is in the form of sintered pellets, scrap and abraded pellet material or uranium oxide powder. Apart from insignificant impurities with fissile transuranic elements (in the mg range), the fissile material inventory is present as U-235.

Maximum 14.5 kg of pellets not meeting the specification requirements or of uranium oxide powder may be transported in the ANF-50 shipping container. Pellets not meeting the specifications or uranium oxide powder that contain burnable neutron poisons (e.g. gadolinium, (Gd)) are permitted /R7/.

The package contains approx. 12.8 kg of uranium.

The nuclide concentrations and the conservative package inventory are stated in Table 1.

4 Quality assurance

ADR/RID: 1.7.3 **IMDG Code: 1.1.3.3** **TS-R-1 (ST-1, Revised) No. 310**	*Quality assurance programmes based on international, national or other standards acceptable to the competent authority must be established and implemented for the design, manufacture, testing, documentation, use, maintenance and inspection of all special form radioactive material, low dispersible radioactive material and packages and for carriage and in-transit storage operations to ensure compliance with the relevant provisions of ADR. Certification that the design specification has been fully implemented must be available to the competent authority. The manufacturer, consignor or user must be prepared to provide facilities for competent authority inspection during manufacture and use and to demonstrate to any cognizant competent authority that:* *a) the manufacturing methods and materials used are in accordance with the approved design specifications; and* *b) all packagings are periodically inspected and, as necessary, repaired and maintained in good condition so that they continue to comply with all relevant requirements and specifications, even after repeated use* *Where competent authority approval is required, such approval shall take into account and be contingent upon the adequacy of the quality assurance programme.*
ICAO TI: 1;1.4.3	*Quality assurance programmes based on international, national or other standards acceptable to the competent authority must be established and implemented for the design, manufacture, testing, documentation, use, maintenance and inspection of all form radioactive material, low dispersible radioactive material and packages, and for transport and in-transit storage operations to ensure compliance with the relevant provisions of these instructions. Certification that the design specification has been fully implemented must be available to the competent authority. The manufacturer, consignor or user must be prepared to provide facilities for competent authority inspection during manufacture and use and to demonstrate to any cognizant competent authority that:* *a) the manufacturing methods and materials used are in accordance with the approved design specifications; and* *b) all packagings are periodically inspected and, as necessary, repaired and maintained in good condition so that they continue to comply with all relevant requirements and specifications, even after repeated use* *Where competent authority approval is required, such approval must take into account and be contingent upon the adequacy of the quality assurance programme.*

The design, engineering, manufacture, testing, documentation, use, maintenance and inspection of the packagings and the transport of radioactive material are regulated in the

- quality assurance programme of the ANF /8/.

With regard to manufacture, construction supervision and the tests to be carried out, the following technical directive is taken into account:

- TRV 006, VkBl. 1991, p. 233, /9/ Technical Directive on Quality Assurance (QA) Measures and Quality Monitoring (QM) for Packaging for the Transport of Radioactive Material.

The ANF-50 shipping container is manufactured in accordance with the manufacturing specification ANFG-11.103 (005) /R4/ examined and approved by an independent expert.

Container instruction ANFG-11.101 (24) /R5/ is definitive for the handling and maintenance of ANF-50 shipping containers.

In-service inspections of ANF-50 shipping containers are carried out in accordance with the container instruction ANFG-11.101 (25) /R8/.

Tests in the context of production and In-service inspections are carried out by BAM experts or experts commissioned by BAM.

5 Activity limits

5.1 Restrictions on the contents of packages

ADR/RID: 2.2.7.7.1.1 **IMDG Code: 2.7.7.1.1** **TS-R-1 (ST-1, Revised) No. 407**	*The quantity of radioactive material in a package must not exceed the relevant limits for the package type as specified below.*
ICAO TI: 2;7.7.1.1	*The quantity of radioactive material in a package must not exceed the relevant limits for the package type as specified below:*
ADR/RID: 2.2.7.7.1.4	***Type A packages***
ADR/RID: 2.2.7.7.1.4.1 **IMDG Code: 2.7.7.1.4.1** **TS-R-1 (ST-1, Revised) No. 413**	*Type A packages must not contain activities greater than the following:* *a) for special form radioactive material –* A_1*; or* *b) for all other radioactive material –* A_2*.*
ADR/RID: 2.2.7.7.1.4.2 **IMDG Code: 2.7.7.1.4.2** **TS-R-1 (ST-1, Revised) No. 414**	*For mixtures of radionuclides whose identities and respective activities are known, the following condition must apply to the radioactive contents of a Type A package:* $\sum_i \frac{B(i)}{A_1(i)} + \sum_j \frac{C(j)}{A_2} \leq 1$ *where* *B(i) is the activity of radionuclide i as special form radioactive material and* $A_1(i)$ *is the* A_1 *value for radionuclide i; and* *C(j) is the activity of radionuclide j as other than special form radioactivity material and* $A_2(j)$ *is the* A_2 *value for radionuclide j.*
ICAO TI 2,7.7.1.4	***Type A packages***
ICAO TI: 2;7.7.1.4.1	*Type A packages must not contain activities greater than the following:* *a) for special form radioactive material –* A_1*; or* *b) for all other radioactive material –* A_2*.*

ICAO TI: 2;7.7.1.4.2	*For mixtures of radionuclides whose identities and respective activities are known, the following condition must apply the radioactive contents of a Type A package:* $\sum_i \frac{B(i)}{A_1(i)} + \sum_j \frac{C(j)}{A_2} \leq 1$ *where* *B(i) is the activity of radionuclide i as special form radioactive material and $A_1(i)$ is the A_1 value for radionuclide i; and* *C(j) is the activity of radionuclide j as other than special form radioactivity material and $A_2(j)$ is the A_2 value for radionuclide j.*

There is no radioactive material in any special form. Therefore, the stated formula is reduced to:

$$\sum_j \frac{C(j)}{A_2} \leq 1$$

Table 2 (column $C(j)/A_2(j)$) in Section 3.1 shows that the requirement is met.

Due to the procedure specified in the quality assurance programme /8/ and observing the container instruction /R5/ for each transport it is ensured that the stated limit values are not exceeded.

5.2 Activity values

ADR/RID: 2.2.7.7.2.1 **IMDG Code: 2.7.7.2.1** **TS-R-1 (ST-1, Revised) No. 401**	*The following basic values for the individual radionuclides are given in Table 2.2.7.7.2.1:* *a) A_1 and A_2 in TBq;* *b) Activity concentration for exempt material in Bq/g; and* *c) Activity limits for exempt consignments in Bq.* Note: The table 2.2.7.7.2.1 is not quoted here owing to its size.
ICAO TI: 2;7.7.2.1	*The following basic values for individual radionuclides are given in Table 2-13:* *a) A_1 and A_2 in TBq;* *b) Activity concentration for exempt material in Bq/g; and* *c) Activity limits for exempt consignments in Bq.* Note: The "Table 2-13" is not quoted here owing to its size.

Re (b), (c): Not applicable. The package contains fissile material. It does not contain any exempt material and is not transported as an exempt consignment.

ADR/RID: 2.2.7.7.2.2 **IMDG Code: 2.7.7.2.2** **TS-R-1 (ST-1, Revised) No. 402**	*For individual radionuclides which are not listed in Table 2.2.7.7.2.1 the determination of the basic radionuclide values referred to in 2.2.7.7.2.1 shall require competent authority approval or, for international carriage, multilateral approval. Where the chemical form of each radionuclide is known, it is permissible to use the A_2 value related to its solubility class as recommended by the International Commission on Radiological Protection, if the chemical forms under both normal and accident conditions of carriage are taken into consideration. Alternatively, the radionuclide values in Table 2.2.7.7.2.2 may be used without obtaining competent authority approval.*

Table 2.2.7.7.2.2
Basic radionuclide values for unknown radionuclides or mixtures

Radioactive contents	*A_1 (TBq)*	*A_2 (TBq)*	*Activity concentration for exempt material (Bq/g)*	*Activity limit values for exempt consignment (Bq)*
Only beta or gamma emitting nuclides are known to be present	*0.1*	*0.02*	*1×10^1*	*1×10^4*
Only alpha emitting nuclides are known to be present	*0.2*	*9×10^{-5}*	*1×10^{-1}*	*1×10^3*
No relevant data are available	*0.001*	*9×10^{-5}*	*1×10^{-1}*	*1×10^3*

ICAO TI: 2;7.7.2.2

For individual radionuclides which are not listed in Table 2-13, the determination of the basic radionuclide values referred to in 7.7.2.1 must require competent authority approval or, for international transport, multilateral approval. Where the chemical form of each radionuclide is known, it is permissible to use the A_2 value related to its solubility class as recommended by the International Commission on Radiological Protection, if the chemical form under both normal and accident conditions of transport are taken into consideration. Alternatively, the radionuclide values in Table 2-14 may be used without obtaining competent authority approval.

Table 2-14. Basic radionuclide values for unknown radionuclides or mixtures

Radioactive contents	*A_1* (TBq)	*A_2* (TBq)	*Activity concentration for exempt material* (Bq/g)	*Activity limit for an exempt consignment* (Bq)
Only beta- or gamma-emitting nuclides are known to be present	*0.1*	*0.02*	$1x10^{1}$	$1x10^{4}$
Only alpha-emitting nuclides are known to be present	*0.2*	$9x10^{-5}$	$1x10^{-1}$	$1x10^{3}$
No relevant data are available	*0.001*	$9x10^{-5}$	$1x10^{-1}$	$1x10^{3}$

Not applicable, as the radionuclide values to be observed are given in Table 2.2.7.7.2.1 (ICAO TI: Table 2-13).

ADR/RID: 2.2.7.7.2.3

IMDG Code: 2.7.7.2.3

TS-R-1 (ST-1, Revised) No. 403

In the calculations of A_1 and A_2 for a radionuclide not in Table 2.2.7.7.2.1, a single radioactive decay chain in which the radionuclides are present in their naturally occurring proportions, and in which no daughter nuclide has a half-life either longer than 10 days or longer than that of the parent nuclide, must be considered as a single radionuclide; and the activity to be taken into account and the A_1 or A_2 value to be applied must be those corresponding to the parent nuclide of that chain. In the case of radioactive decay chains in which any daughter nuclide has a half-life either longer than 10 days or greater than that of the parent nuclide, the parent and such daughter nuclides must be considered as mixtures of different nuclides.

ICAO TI: 2;7.7.2.3

In the calculations of A_1 und A_2 for a radionuclide not in Table 2-13, a single radioactive decay chain in which the radionuclides are present in their naturally occurring proportions, and in which no daughter nuclide has a half-life either longer than 10 days or longer than of the parent nuclide, must be considered as a single radionuclide; and the activity to be taken into account and the A_1 or A_2 value to be applied must be that corresponding to the parent nuclide of the chain. In the case of radioactive decay chains in which any daughter nuclide has a half-life either longer than 10 days or greater than that of the parent nuclide, the parent and such daughter nuclides must be considered as mixtures of different nuclides.

Not applicable, as the radionuclide values to be observed are given in Table 2.2.7.7.2.1 (ICAO TI: Table 2-13).

ADR/RID: 2.2.7.7.2.4 **IMDG Code: 2.7.7.2.4** **TS-R-1 (ST-1, Revised) No. 404**	*For mixtures of radionuclides, the determination of the basic radionuclide values referred to in 2.2.7.7.2.1 may be determined as follows:* $X_m = \frac{1}{\sum_i \frac{f(i)}{X(i)}}$ *where:* *f(i) is the fraction of activity or activity concentration of radioactive nuclide i in the mixture;* *X(i) is the appropriate value of A_1 or A_2, or the activity concentration for exempt material or the activity limit for an exempt consignment as appropriate for the radionuclide i; and* *X_m is the derived value of A_1 or A_2, or the activity concentration for exempt material or the activity limit for an exempt consignment in case of a mixture.*
ICAO TI: 2;7.7.2.4 **TS-R-1 (ST-1, Revised) No. 404**	*For mixtures of radionuclides, the determination of the basic radionuclide values referred to in 7.7.2.1 may be determined as follows:* $X_m = \frac{1}{\sum_i \frac{f(i)}{X(i)}}$ *where:* *f(i) is the fraction of activity or activity concentration of radioactive nuclide i in the mixture;* *X(i) is the appropriate value of A_1 or A_2, or the activity concentration for exempt material or the activity limit for an exempt consignment as appropriate for the radionuclide i; and* *X_m is the derived value of A_1 or A_2, or the activity concentration for exempt material or the activity limit for an exempt consignment in case of a mixture.*

A_2 is determined in Section 3 of this safety analysis.

ADR/RID: 2.2.7.7.2.5 **IMDG Code: 2.7.7.2.5** **TS-R-1 (ST-1, Revised) No. 405**	*When the identity of each radionuclide is known but the individual activities of some of the radionuclides are not known, the radionuclides may be grouped and the lowest radionuclide value, as appropriate, for the radionuclides in each group may be used in applying the formulas in 2.2.7.7.2.4 and 2.2.7.7.1.4.2. Groups may be based on the total alpha activity and the total beta/gamma activity when these are known, using the lowest radionuclide values for the alpha emitters or beta/gamma emitters, respectively.*

ICAO TI: 2;7.7.2.5	*When the identity of each radionuclide is known but the individual activities of some of the radionuclides are not known, the radionuclides may be grouped and the lowest radionuclide value, as appropriate, for the radionuclides in each group may be used in applying the formulas in 2;7.7.1.4.2 and 2;7.7.2.4. Groups may based on the total alpha activity and the total beta/gamma activity when these are known, using the lowest radionuclide values for the alpha emitters or beta/gamma emitters, respectively.*

Not applicable, as the individual activities are assumed to be known (see Section 3 of this report).

ADR/RID: 2.2.7.7.2.6 **IMDG Code: 2.7.7.2.6** **TS-R-1 (ST-1, Revised) No. 406**	*For individual radionuclides or for mixtures of radionuclides for which relevant data are not available, the values shown in Table 2.2.7.7.2.2 must be used.*
ICAO TI: 2;7.7.2.6	*For individual radionuclides or for mixtures of radionuclides for which relevant data are not available, the values shown in Table 2-14 must be used.*

Not applicable, as all the relevant data required are known.

6 Special regulations for the packaging of Class 7 material

6.1 General

ADR/RID: 4.1.9.1.3 **IMDG Code: 4.1.9.1.3** **TS-R-1 (ST-1, Revised) No. 503**	*A package must not contain any other items except such articles and documents as are necessary for the use of the radioactive material. This requirement must not preclude the carriage of low specific activity material or surface contaminated objects with other items. The transport of such articles and documents in a package, or of low specific activity material or surface contaminated objects with other items may be permitted provided that there is no interaction between them and the packaging or its radioactive contents that would reduce the safety of the package.*
ICAO TI: 4;9.1.3	*A package must not contain any other items except such articles and documents as are necessary for the use of the radioactive material. This requirement must not preclude the transport of low specific activity material or surface contaminated objects with other items. The transport of such articles and documents in a package, or of low specific activity material or surface contaminated objects with other items may be permitted provided that there is no interaction between them and the packaging or its radioactive contents that would reduce the safety of the package.*

Apart from the inventory described in Section 3 of this safety analysis, the package contains no other objects.

ADR/RID: 4.1.9.1.1 **IMDG Code: 4.1.9.1.1**	*Radioactive material, packagings and packages must meet the requirements of Chapter 6.4. The quantity of radioactive material in a package must not exceed the limits specified in 2.2.7.7.1.*
ICAO TI: 4;9.1.1	*Radioactive material, packagings and packages must meet the requirements of Part 6, Chapter 7. The quantity of radioactive material in a package must not exceed the limits specified in 2.7.7.1.*

The requirements in respect of the radioactive material, packagings and packages to be transported correspond to the regulations in Chapter 6.4 (ICAO TI: 6;7). The verification is provided in Section 7 of this safety analysis.

The quantity and type of radioactive material is described in Section 3 of this safety analysis. The limit values in accordance with Para. 2.2.7.7.1 (ICAO TI: 2;7.7.1) are not exceeded (also see Section 5.1 of this safety analysis).

Due to the procedure specified in the quality assurance programme /8/ and observing the container instruction /R5/ for the preparation and performance of transports it is ensured that the limit values are observed.

ADR/RID: **4.1.9.1.2** **IMDG Code:** **4.1.9.1.2** **TS-R-1** **(ST-1, Revised)** **No. 508**	*The non-fixed contamination on the external surfaces of any package must be kept as low as practicable and, under routine conditions of transport, must not exceed the following limits:* *a) 4 Bq/cm² for beta and gamma emitters and low toxicity alpha emitters;* *b) 0.4 Bq/cm² for all other alpha emitters.* *These limits are applicable when averaged over any area of 300 cm² of any part of the surface.*
ICAO TI: **4;9.1.2**	*The non-fixed contamination on the external surfaces of any package must be kept as low as practicable and, under routine conditions of transport, must not exceed the following limits:* *a) 4 Bq/cm² for beta and gamma emitters and low toxicity alpha emitters;* *b) 0.4 Bq/cm² for all other alpha emitters.* *These limits are applicable when averaged over any area of 300 cm² of any part of the surface.*

The package contains fissile material that is no radioactive material in any special form.

Qualified staff are employed to decontaminate contaminated parts.

Due to the procedure specified in the quality assurance programme /8/ and observing the container instruction /R5/ as well as the regulations covering the method of transportation for each transport it is ensured that the stated limits are not exceeded.

The verifications for the sections specified in the quotations affecting the criticality safety are provided in Section 6.3 of this safety analysis.

6.2 Determination of the transport index (TI) and criticality safety index (CSI)

6.2.1 Determination of the transport index (TI)

<table>
<tr>
<td>ADR/RID:
2.2.7.6.1.1

IMDG Code:
2.7.6.1.1

TS-R-1
(ST-1, Revised)
No. 526</td>
<td>The transport index (TI) for a package, overpack or container, or for unpackaged LSA-I or SCO-I, must be the number derived in accordance with the following procedure:

a) Determine the maximum radiation level in units of millisieverts per hour (mSv/h) at a distance of 1 m from the external surfaces of the package, overpack, container, or unpackaged LSA-I or SCO-I. The value determined must be multiplied by 100 and the resulting number is the transport index.

For uranium and thorium ores and their concentrates, the maximum radiation level at any point 1 m from the external surface of the load may be taken as:

0.4 mSv/h for ores and physical concentrates of uranium and thorium;

0.3 mSv/h for chemical concentrates of thorium;

0.02 mSv/h for chemical concentrates of uranium, other than uranium hexafluoride;

b) For tanks, containers and unpackaged LSA-I and SCO-I, the value determined in step (a) above must be multiplied by the appropriate factor from Table 2.2.7.6.1.1;

c) The value obtained in steps (a) and (b) above must be rounded up to the first decimal place (e.g. 1.13 becomes 1.2), except that a value of 0.05 or less may be considered as zero.

Table 2.2.7.6.1.1 – Multiplication factors for tanks, containers and unpackaged LSA-I and SCO-I

<table>
<tr><th>Size of load [a)]</th><th>Multiplication factor</th></tr>
<tr><td>Size of load ≤ 1 m^2</td><td>1</td></tr>
<tr><td>1 m^2 < size of load ≤ 5 m^2</td><td>2</td></tr>
<tr><td>5 m^2 < size of load ≤ 20 m^2</td><td>3</td></tr>
<tr><td>20 m^2 < size of load</td><td>10</td></tr>
</table>

a). Largest cross-sectional area of the load being measured.</td>
</tr>
</table>

<table>
<tr><td>ICAO TI:
2;7.6.1.1</td><td>The transport index (TI) for a package, overpack or freight container, must be the number derived in accordance with the following procedure:

a) Determine the maximum radiation level in units of millisieverts per hour (mSv/h) at a distance of 1 m from the external surface of the package, overpack, or freight container. The value determined must be multiplied by 100 and the resulting number is the transport index. For uranium and thorium ores and their concentrates, the maximum radiation level at any point 1 m from the external surface of the load may be taken as:

0.4 mSv/h for ores and physical concentrates of uranium and thorium;
0.3 mSv/h for chemical concentrates of thorium;
0.02 mSv/h for chemical concentrates of uranium, other than uranium hexafluoride;

b) For freight containers, the value determined in step a) above must multiplied by the appropriate factor from Table 2-11;.

c) The value obtained in steps a) and b) above must be rounded up to the first decimal place (e. g. 1.13 becomes 1.2) except that a value of 0.05 or less may be considered as zero.

Table 2-11. Multiplication factors for freight containers

<table>
<tr><td>Size of load *)</td><td>Multiplication factor</td></tr>
<tr><td>Size of load ≤ 1 m²
1 m² < size of load ≤ 5 m²
5 m² < size of load ≤ 20 m²
20 m² < size of load</td><td>1
2
3
10</td></tr>
</table>

a). Largest cross-sectional area of the load being measured.</td></tr>
</table>

The transport index TI is determined on the basis of dose rate measurements prior to the transport operation in accordance with the container instruction /R5/ and under consideration of the quality assurance programme /8/. An estimation of the transport index TI is made in Section 6.2.3.

6.2.2 Determination of the criticality safety index (CSI)

6.2.2.1 Determination of the criticality safety index of package configurations under normal transport conditions

ADR/RID: 2.2.7.6.2.1 **IMDG Code: 2.7.6.2.1** **TS-R-1 (ST-1, Revised) No. 528**	*The criticality safety index (CSI) for packages containing fissile material must be obtained by dividing the number 50 by the smaller of the two values of "N" derived in 6.4.11.11 and 6.4.11.12 (i.e. CSI = 50/N). The value of the criticality safety index may be zero, provided that an unlimited number of packages is subcritical (i.e. N is effectively equal to infinity in both cases).*

ICAO TI: 2;7.6.2.1	*The criticality safety index (CSI) for packages containing fissile material must be obtained by dividing the number 50 by the smaller of the two values off N derived in 6;7.10.11 and 6;7.10.12 (i. e. CSI = 50/N). The value of the criticality safety index may be zero, provided that an unlimited number of packages is subcritical (i. e. N is effectively equal to infinity in both cases).*
ADR/RID: 6.4.11.11 **IMDG Code: 6.4.11.11** **TS-R-1 (ST-1, Revised) No. 681**	*For normal conditions of transport, a number "N" must be derived, such that five times "N" must be sub-critical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:* *(a) there must not be anything between the packages, and the package arrangement must be reflected on all sides by at least 20 cm of water; and* *(b) the state of the packages must be their assessed or demonstrated condition if they had been subjected to the tests in accordance with 6.4.15.*

The verifications for the requirements specified in ICAO TI 6;7.14 are provided in Section 7 and Section 8 of this report.

N = 125 is selected.

A criticality safety index CSI = 0.4 was determined in the criticality safety analysis /R7/.

For normal transport conditions, criticality safety was demonstrated for a package configuration of at least 625 ANF-50 shipping containers /R7/.

6.2.2.2 Assessing package configurations under accident transport conditions

ADR/RID: 6.4.11.12 **IMDG Code: 6.4.11.12** **TS-R-1 (ST-1, Revised) No. 682**	*For accident conditions of transport a number "N" must be derived, such that two times "N" must be sub-critical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:* *(a) hydrogenous moderation between packages, and the package arrangement reflected on all sides by at least 20 cm of water; and* *(b) the tests in accordance with 6.4.15 followed by whichever of the following is the more limiting:* *(i) the tests specified in 6.4.17.2 b) and, either 6.4.17.2 c) for packages having a mass not greater than 500 kg and an overall density not greater than 1 000 kg/m^3 based on the external dimensions, or 6.4.17.2 a) for all other packages; followed by the test specified in 6.4.17.3 and completed by the tests specified in 6.4.19.1 - 6.4.19.3; or* *(ii) the test in accordance with 6.4.17.4; and* *(c) where any part of the fissile material escapes from the containment system following the tests specified in 6.4.11.12 b), it must be assumed that fissile material escapes from each package in the array and all of the fissile material must be arranged in the configuration and moderation that results in the maximum neutron multiplication with close reflection by at least 20 cm of water.*

ICAO TI: 6;7.10.12	*A number "N" must be derived, such that two times "N" must be subcritical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:* *(a) hydrogenous moderation between packages, and the package arrangement reflected on all sides by at least 20 cm of water; and* *(b) the tests specified in 6;7.14 followed by whichever of the following is the more limiting:* *(i) the tests specified in 6;7.16.2 b) and, either 6;7.16.2 c) for packages having a mass not greater than 500 kg and an overall density not greater than 1000 kg/m³ based on the external dimensions, or 6;7.16.2 a) for all other packages; followed by the test specified in 6;7.14.3 and completed by the testes specified in 6;7.18.1 to 6;7.18.3; or* *(ii) the test specified in 6;7.16.4; and* *(c) where any part of the fissile material escapes from the containment system following the tests specified in 6;7.10.12 b), it must be assumed that fissile material escapes from each package in the array and all of the fissile material must be arranged in the configuration and moderation that results in the maximum neutron multiplication with close refection by at least 20 cm of water.*

For accident transport conditions, criticality safety was demonstrated for a package configuration of 250 ANF-50 shipping containers /R7/.

6.2.3 Limits on the transport index (TI), criticality safety index (CSI) and radiation levels for packages and overpacks

ADR/RID: 2.2.7.8.1 **IMDG Code: 2.7.8.1** **TS-R-1 (ST-1, Revised) No. 530**	*Except for consignments under exclusive use, the transport index of any package or overpack must not exceed 10, nor must the criticality safety index of any package or overpack exceed 50.*
ICAO TI: 2;7.8.1	*Except for consignments under exclusive use, the transport index of any package or overpack must not exceed 10, nor must the criticality safety index of any package or overpack exceed 50.*

The package contains fissile material. The material is transported in a type A package. The transport index is determined prior to each transport operation taking account of the container instruction /R5/, the quality assurance programme /8/ and the relevant regulations covering the method of transportation. The package is classified and the transport operation carried out observing the relevant regulations.

The criticality safety index CSI is set out in /R7/ and is CSI = 0.4.

ADR/RID: 2.2.7.8.2 **TS-R-1 (ST-1, Revised) No. 531**	*Except for packages or overpacks transported under exclusive use in accordance with the conditions specified in 7.5.11, CV33 (3.5) (a), the maximum radiation level at any point on any external surface of a package or overpack must not exceed 2 mSv/h.*
IMDG Code: 2.7.8.2	*With the exception of packages and overpacks that are transported by rail or road according to 7.1.14.7(a) under exclusive use or under exclusive use and on the basis of a special agreement by ship in accordance with 7.1.14.9, the maximum radiation level at any point on any external surfaces of a package or an overpack must not exceed 2 mSv/h.*
ICAO TI: 2;7.8.2	*Except for packages and overpacks transported under exclusive use and special arrangement under the conditions specified in 7;2.9.5.3, the maximum radiation level at any point on any external surface of a package or overpack must not exceed 2 mSv/h.*
ICAO TI: 7;2.9.5.3	*Packages or overpacks having a surface radiation level greater than 2 mSv/h must not be transported by air except by special arrangement.*
ADR/RID: 2.2.7.8.3 **IMDG Code: 2.7.8.3** **TS-R-1 (ST-1, Revised) No. 532**	*The maximum radiation level at any point on any external surface of a package under exclusive use or of an overpack under exclusive use must not exceed 10 mSv/h.*
ICAO TI: 2;7.8.3	*The maximum radiation level at any point on any point on any external surface of a package or overpack under exclusive use must not exceed 10 mSv/h.*
ADR/RID: 7.5.11, Special reg. CV 33 (3.5) **IMDG Code: 7.1.14.7** **TS-R-1 (ST-1, Revised) No. 572**	*For consignments under exclusive use, the radiation level must not exceed:* *a) 10 mSv/h at any point on the external surface of any package or overpack, and may only exceed 2 mSv/h provided that:* *(i) the vehicle is equipped with an enclosure which, during routine conditions of carriage, prevents the access of unauthorized persons to the interior of the enclosure; and* *(ii) provisions are made to secure the package or overpack so that its position within the vehicle enclosure remains fixed during routine conditions of transport, and* *(iii) there is no loading or unloading during the shipment;* *b) 2 mSv/h at any point on the outer surfaces of the vehicle, including the upper and lower surfaces, or, in the case of an open vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load, and on the lower external surface of the vehicle; and* *c) 0.1 mSv/h at any point 2 m from the vertical planes represented by the outer lateral surfaces of the vehicle, or, if the load is carried in an open vehicle, at any point 2 m from the vertical planes projected from the outer edges of the vehicle.*

The package contains fissile material. The material is transported as type A package. The transport index is determined prior to each transport operation taking account of the container instruction /R5/, the quality assurance programme /8/ and the relevant regulations covering the method of transportation. The package is classified and the transport operation carried out observing the relevant regulations. The expected dose rate for the conservative uranium composition is estimated.

The following Figure 1 shows the nominal position of the pellets relative to the surface of the ANF-50 shipping container.

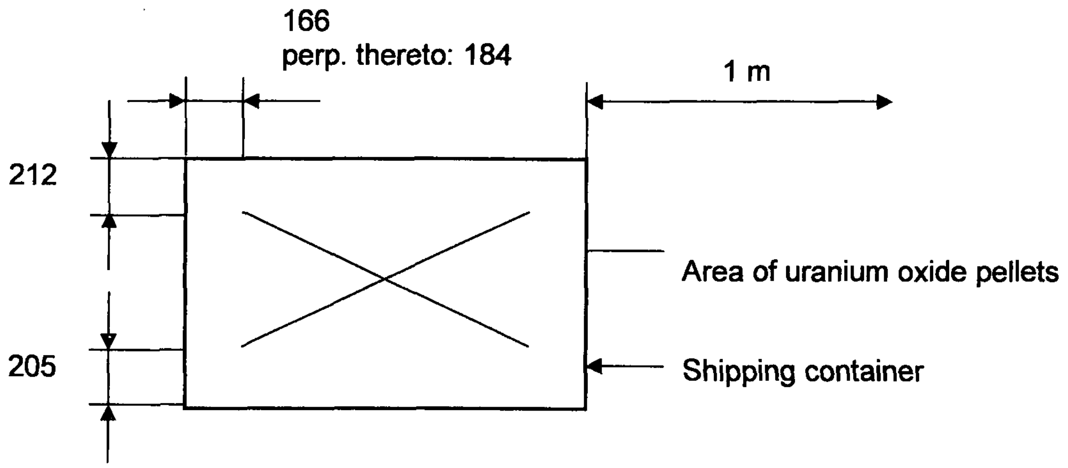


Figure 1: Cross section of the ANF-50 shipping container

Measurements taken on a pellet container of the ANF-50 shipping container filled with ERU pellets were used to illustrate the typical dose rates used to determine the transport index TI. The measurements performed on a pellet container of the ANF-50, loaded with pellets of known uranium composition, had the results summarized in Table 4. Furthermore, information relevant to the type A package of the ANF-50 as well as correction factors are given in Table 4.

List of correction factors:

- factor F_1: consideration of the permissible uranium mass,
- factor F_2: structure consideration of daughter nuclides until they achieve a stable configuration (10 years). Measurements were performed approx. 0.7 years after the last separation of radioactive daughter nuclides. 03
- factor F_3: consideration of different uranium qualities,

	Uranium oxide pellets of batch D31473 in ANF-50 No. S165	ASTM C 996-04 (conservative uranium composition for a type A-package ANF-50)	Comment
Measured γ local dose rate in contact	58 µSv/h	---	Distance to the area with the highest γ local dose rate (base)
Measured γ local dose rate at a distance of 1 m	0.8 µSv/h	---	1 m distance to the area with the highest γ local dose rate (base)
Mass of uranium oxide in the container	43.5 kg	52 kg	F_1 = 1.20
Uranium age	0.7 a	10 a	F_2 = 1.99
Uranium composition in mass %	U-232: 7.20E-8 U-234: 5.00E-2 U-235: 4.51E+0 U-236: 3.48E-1 U-238: 9.51E+1	U-232: 1.00E-8 U-234: 5.50E-2 U-235: 5.00E+0 U-236: 5.00E-2 U-238: 9.49E+1	F_3 = 0.46

03

Table 4: Measurements on a pellet container of the ANF-50 for determining the maximum dose rate in contact and at a distance of 1 m

The expected dose rate is estimated below.

Multiplying the measured values with the correction factors specified in the table results in a dose rate of 64 mSv/h to be expected for contact and a maximum dose rate of 0.88 mSv/h to be expected at a distance of 1 m.

Thus, a TI = 0.1 can be expected per package.

It is planned to transport several packages on one vehicle.

The current dose rates are to be measured prior to each transport operation in accordance with the valid container instruction /R5/ and assessed taking the regulations covering the method of transportation applied for into account. If appropriate, suitable measures can be taken to ensure that the limits are adhered to.

ADR/RID: 2.2.7.8.4 **IMDG Code: 2.7.8.4** **TS-R-1 (ST-1, Revised) No. 533**	*Packages and overpacks must be assigned to either category I-WHITE, II-YELLOW or III-YELLOW in accordance with the conditions specified in Table 2.2.7.8.4 and with the following requirements:* a) *for a package or overpack, both the transport index and the surface radiation level conditions must be taken into account in determining which is the appropriate category. Where the transport index satisfies the condition for one category but the surface radiation level satisfies the condition for a different category, the package or overpack must be assigned to the higher category. For this purpose, category I-WHITE must be regarded as the lowest category;* b) *the transport index must be determined following the procedures specified in 2.2.7.6.1.1 and 2.2.7.6.1.2;* c) *if the surface radiation level is greater than 2 mSv/h, the package or overpack must be carried under exclusive use and under the provisions of 7.5.11, CV33 (3.5) (a);* d) *a package transported under a special arrangement must be assigned to category III-YELLOW;* e) *an overpack which contains packages carried under special arrangement must be assigned to category III-YELLOW.*

Table 2.2.7.8.4 - Categories of packages and overpacks

Conditions		*Category*
Transport index (TI)	*Maximum radiation level at any point on external surface*	
0[a)]	*Not more than 0.005 mSv/h*	*I-WHITE*
More than 0, but not more than 1[a)]	*More than 0.005 mSv/h, but not more than 0.5 mSv/h*	*II-YELLOW*
More than 1, but not more than 10	*More than 0.5 mSv/h, but not more than 2 mSv/h*	*III-YELLOW*
More than 10	*More than 2 mSv/h, but not more than 10 mSv/h*	*III-YELLOW*[b)]

[a)] *If the measured TI is not greater than 0.05, the value quoted may be zero in accordance with 2.2.7.6.1.1(c).*

[b)] *Must also be carried under exclusive use.*

ICAO TI: 2;7.8.4

Packages and overpacks must be assigned to either category I-White, II-YELLOW or III-YELLOW in accordance with the conditions specified in Table 2-15 and with the following requirements:

a) for a package or overpack, both the transport index and the surface radiation level conditions must be taken into account in determining which is the appropriate category. Where the transport index satisfies the condition for one category but the surface radiation level satisfies the condition for a different category, the package or overpack must be assigned to the higher category. For this purpose, category I-WHITE must be regarded as the lowest category;

b) the transport index must be determined following the procedures specified in 2;7.6.1.1 and 2;7.6.1.2;

c) if the surface radiation level is greater than 2 mSv/h, the package or overpack must be transported under exclusive use and under the provisions of 7;2.9.5.3; as appropriate;

d) a package transported under a special arrangement must be assigned to category III-YELLOW;

e) an overpack which contains packages transported under special arrangement must be assigned to category III-YELLOW.

Table 2-15. Categories of packages and overpacks

Conditions		
Transport index (TI)	*Maximum radiation level at any point on external surface*	*Category*
*0**	*Not more than 0.005 mSv/h*	*I-WHITE*
*More than 0 but not more than 1**	*More than 0.005 mSv/h but not more than 0.5 mSv/h*	*II-YELLOW*
More than 1but not more than 10	*More than 0.5 mSv/h but not more than 2 mSv/h*	*III- YELLOW*
More than 10	*More than 2 mSv/h but not more than 10 mSv/h*	*III- YELLOW***

* *If the measured transport index is not greater than 0.05, the value quoted may be zero in accordance with 2;7.6.1.1 c).*

** *Must be transported under exclusive use and special arrangement.*

The transport index is determined in accordance with the container instruction /R5/ taking the quality assurance programme /8/ and the relevant regulations covering the method of transportation into account and the package or packages are classified and transported according to the result.

7 Requirements for packagings and packages

7.1 Requirements for the construction, testing and approval of packages and material of Class 7

7.1.1 General Requirements

ADR/RID: **6.4.2.**	*General Requirements*
ICAO TI: **6;7.1**	*General Requirements*
ADR/RID: **6.4.2.1** **IMDG Code:** **6.4.2.1** **TS-R-1 (ST-1, Revised) No. 606**	*The package must be so designed in relation to its mass, volume and shape that it can be easily and safely carried. In addition, the package must be so designed that it can be properly secured in or on the conveyance during transport.*
ICAO TI: **6;7.1.1**	*The package must be so designed in relation to its mass, volume and shape that it can be easily and safely transported. In addition, the package must be so designed that it can be properly secured in the aircraft during transport.*

Due to its shape and stackability the package should be safely and easily fastened on the means of transport with the aid of lashing straps. The ANF-50 shipping container is handled in accordance with the handling instruction /R5/.

ADR/RID: **6.4.2.2** **IMDG Code:** **6.4.2.2** **TS-R-1 (ST-1, Revised) No. 607**	*The design must be such that any lifting attachments on the package will not fail when used in the intended manner and that, if failure of the attachments should occur, the ability of the package to meet other requirements of this Annex would not be impaired. The design must take account of appropriate safety factors to cover snatch lifting.*
ICAO TI: **6;7.1.2**	*The design must be such that any lifting attachments on the package will not fail when used in the intended manner and that, if failure of the attachment should occur, the ability of the package to meet other requirements of these Instructions* (ICAO TI) *would not be impaired. The design must take account of appropriate safety factors to cover snatch lifting.*

There are no special attachments on the package. Handling is carried out in accordance with the container instruction /R5/ using a fork-lift truck or a crane. For handling using a crane, the shipping container is attached to the crane hook by means of round slings.

ADR/RID: 6.4.2.3 **IMDG Code: 6.4.2.3** **TS-R-1 (ST-1, Revised) No. 608**	*Attachments or other devices on the outer surface of the package that could be used to lift it must be designed either to support its mass in accordance with the regulations in subsection 6.4.2.2 or to be removable during transport or otherwise rendered incapable of being used.*
ICAO TI: 6;7.1.3	*Attachments and any other features on the outer surface of the package which would could be used to lift it must be designed either to support its mass in accordance with the requirements of 6;7.1.2 or must be removable or otherwise rendered incapable of being used during transport.*

The package may only be handled in the manner described in the container instruction /R5/. The competent functional unit of the owner of the shipping containers must ensure in accordance with the quality assurance programme /8/ that other users receive the necessary instructions and observe them. The user of the shipping containers has to register at the BfS and has to confirm that he/she received the container instructions for the handling and recurring testing.

In the strength verification /R10/ it is verified that the structure of the ANF-50 shipping container is adequately dimensioned for the potential loads during handling and transportation.

ADR/RID: 6.4.2.4 **IMDG Code: 6.4.2.4** **TS-R-1 (ST-1, Revised) No. 609**	*As far as practicable, the packaging must be so designed and finished that the external surfaces are free from protruding features and can be easily decontaminated.*
ICAO TI: 6;7.1.4	*As far as practicable, the packaging must be designed and finished so that the external surface are free from protruding features and can be easily decontaminated.*

The structure of the packaging was designed in such a way that protruding components were avoided as far as possible. The external components of the packaging are made of stainless steel; the surfaces can therefore be easily decontaminated.

ADR/RID: 6.4.2.5 **IMDG Code: 6.4.2.5** **TS-R-1 (ST-1, Revised) No. 610**	*As far as practicable, the outer layer of the package must be so designed as to prevent the collection and the retention of water.*
ICAO TI: 6;7.1.5	*As far as practicable, the outer layer of the package must be designed so as to prevent the collection and the retention of water.*

The accumulation of water is prevented by the smooth and level surfaces of the outsides of the package. Water can easily drain off the smooth and planar outsides of the container.

ADR/RID: 6.4.2.6 **IMDG Code: 6.4.2.6** **TS-R-1 (ST-1, Revised) No. 611**	*Any features added to the package at the time of transport which are not part of the package must not reduce its safety.*
ICAO TI: 6;7.1.6	*Any features added to the package at the time of transport which are not part of the package must not reduce its safety.*

No parts belong to the package other than those described in this safety analysis.

No parts are transported in the package other than the inventory defined in Section 3 of this safety analysis.

ADR/RID: 6.4.2.7 **IMDG Code: 6.4.2.7** **TS-R-1 (ST-1, Revised) No. 612**	*The package must be capable of withstanding the effects of any acceleration, vibration or vibration resonance which may arise under routine conditions of carriage without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole. In particular, nuts, bolts and other securing devices must be so designed as to prevent them from becoming loose or being released unintentionally, even after repeated use.*
ICAO TI: 6;1.7.7	*The package must be capable of withstanding the effects of any acceleration, vibration or vibration resonance, which may arise under routine conditions of transport without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole. In particular, nuts, bolts and other securing devices must be designed so as to prevent them from becoming loose or being released unintentionally, even after repeated use.*

The bolted connection to attach the lid for case cover and protective cover as well as the screw fittings of the pellet container cover are tightened using a controlled tightening torque (in accordance with the container instruction /R5/). This ensures that the screws do not come loose during routine transport. The screw material A5-70 as per DIN EN ISO 3506-2 has adequate strength properties ($R_{P0.2(20°C)}$ = 450 N/mm^2) /R10/.

ADR/RID: 6.4.2.8 **IMDG Code: 6.4.2.8** **TS-R-1 (ST-1, Revised) No. 613**	*The materials of the packaging and any components or structures must be physically and chemically compatible with each other and with the radioactive contents. Account must be taken of their behaviour under irradiation.*
ICAO TI: 6;7.1.8	*The material of the packaging and any components or structure must be physically and chemically compatible with each other and with the radioactive contents. Account must be taken of their behaviour under irradiation.*

All components which could come into contact with the radioactive contents are made of stainless steel. The materials used for the components of the packaging are physically and chemically compatible with each another and with the radioactive contents described in

Section 3 of this safety analysis. There also exists sufficient operating experience with similar shipping containers.

ADR/RID: 6.4.2.9 **IMDG Code: 6.4.2.9** **TS-R-1 (ST-1, Revised) No. 614**	*All valves through which the radioactive contents could otherwise escape must be protected against unauthorized operation.*
ICAO TI: 6;7.1.9	*All valves through which the radioactive contents could otherwise escape must be protected against unauthorized operation.*

There are no valves on the package.

ADR/RID: 6.4.2.10 **IMDG Code: 6.4.2.10** **TS-R-1 (ST-1, Revised) No. 615**	*The design of the package must take into account ambient temperatures and pressures that are likely to be encountered in routine conditions of transport.*
ICAO TI: 6;7.1.10	*The design of the package must take into account ambient temperatures and pressures that are likely to be encountered in routine conditions of transport.*

No special ambient temperatures and pressures occur during routine transport. The sufficient strength of the shipping container is demonstrated in the design calculation. The required safety coefficients are observed /R10/.

ADR/RID: 6.4.2.11 **IMDG Code: 6.4.2.11** **TS-R-1 (ST-1, Revised) No. 616**	*For radioactive material having other dangerous properties the package design must take into account those properties; see 2.1.3.5.3 and 4.1.9.1.5.*
ICAO TI: 6;7.1.11	*For radioactive material having other dangerous properties, the package design must take into account those properties (see Part 2, Introductory Chapter, 2;3.1, 2;3.2 and 4;9.1.5).*

Other than radioactivity, the inventory of the package possesses no other dangerous properties.

7.1.1.1 Requirements for packages for air transport

ICAO TI: 6;7.2.	*Additional Requirements for packages transported by air*
ICAO TI: 6;7.2.1 **TS-R-1 (ST-1, Revised) No. 617**	*The temperature of the accessible surfaces must not exceed 50 °C at an ambient temperature of 38 °C with no account taken for insolation.*

The package does not contain any contents or components conveying thermal energy so that the temperature on the surface depends on the ambient temperature and insolation only.

ICAO TI: 6;7.2.2 **TS-R-1 (ST-1, Revised) No. 618**	*Packages must be designed so that, if they were exposed to ambient temperatures ranging from -40 °C to +55 °C, the integrity of the containment would not be impaired.*

The ANF-50 shipping container is designed for the temperature range from -40 °C to +70 °C. The materials - basically stainless steels of the material numbers 1.4301, 1.4306, 1.4404, 1. 4541, 1.4550, 1.4571 - have been selected correspondingly. In the required temperature range, the steels have an adequate viscosity /10/ and the elastic limit decreases only insignificantly above 20 °C /11/, /12/. The applicable data have been taken into account for designing.

The materials of the pellet container parts ensuring the containment system have been selected from the above mentioned steels. The seal between lid and enclosure (O-ring) consists of EPDM. The seals of the screw fittings of the clevis are made of polyamide (PA). In the event of a decreasing pressure difference, the seals are loaded statically and are not subject to impact loading. The seal materials are designed for the temperature range from -40 °C to +70 °C /R6/.

ICAO TI: 6;7.2.3 **TS-R-1 (ST-1, Revised) No. 619**	*Packages containing radioactive material must be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than maximum normal operating pressure plus 95 kPa.*

The specimen of a pellet container was subjected to a pressure test in a pressure tank filled with water, with an overpressure of 150 kPa (corresponds to an immersion depth of 15 m) /R14/. No changes in geometry and no leak-in of water have been established. Due to their design, the seals seal in the case of an overpressure from the outside as well as from the inside in the event. The test carried out can therefore also be taken for verification of conformity to the requirement as per ICAO TI 6;7.2.3. In addition to this test, a further pressure test was carried out at Framatome ANP GmbH at a later date. In that, a pellet container (No. 221) was equipped with a pressure connection and a water pressure of 150 kPa (1.5 bar) was applied on the inside. It was determined that, at a test pressure of 150 kPa over a test period of 5 hours, the overpressure remained constant and no water leaked out /R14/. It is thus verified that the seal between lid and enclosure as well as the seal of the screw fittings of the clevis on the lid meet the requirements. It is ensured that the pellet container does not leak at a pressure difference of 95 kPa.

7.1.2 Requirements for Type A packages

ADR/RID: 6.4.7.	*Requirements for Type A packages*
ICAO TI: 6;7.6.	*Requirements for Type A packages*
ADR/RID: 6.4.7.1	*Type A packages must be designed to meet the general requirements of 6.4.2 and 6.4.7.2 to 6.4.7.17.*
IMDG Code: 6.4.7.1 **TS-R-1 (ST-1, Revised) No. 633**	*Type A packages must be designed to meet the general requirements of 6.4.2 and 6.4.7.2 to 6.4.7.17 and in the case of air transport the requirements of 6.4.3.*
ICAO TI: 6;7.6.1	*Type A packages must be designed to meet the requirements of 7.1, 7.2 and 7.6.2 to 7.6.17*
ADR/RID: 6.4.7.2 **IMDG Code: 6.4.72** **TS-R-1 (ST-1, Revised) No. 634**	*The smallest overall external dimension of the package must not be less than 10 cm.*
ICAO TI: 6;7.6.2	*The smallest overall external dimension of the package must not be less than 10 cm.*

In accordance with the classification of the inventory, the package is designed in accordance with the general requirements applicable to type A packages (see Section 7.1.1 of this safety analysis).

The smallest external dimension of the package is greater than 10 cm (see Section 2.1.4 of this safety analysis).

ADR/RID: 6.4.7.3 **IMDG Code: 6.4.7.3** **TS-R-1 (ST-1, Revised) No. 635**	*The outside of the package must incorporate a feature such as a seal, which is not readily breakable and which, while intact, will be evidence that it has not been opened.*
ICAO TI: 6;7.6.3	*The outside of the package must incorporate a feature such as a seal, which is not readily breakable and which, while intact, will be evidence that it has not been opened.*

Within the framework of the loading process, the packages are leaded /R5/. After the completion of transport, the undamaged lead seal shows that the package has not been opened during transport.

ADR/RID: 6.4.7.4 **IMDG Code: 6.4.7.4** **TS-R-1 (ST-1, Revised) No. 636**	*Any tie-down attachments on the package must be designed so that, under normal and accident conditions of transport, the forces in those attachments must not impair the ability of the package to meet the requirements of the ADR.*
ICAO TI: 6;7.6.4	*Any tie-down attachments on the package must be designed so that, under normal and accident conditions of transport, the forces in those attachments must not impair the ability of the package to meet the requirements of these instructions.*
ADR/RID: 6.4.7.5 **IMDG Code: 6.4.7.5** **TS-R-1 (ST-1, Revised) No. 637**	*The design of the package must take into account temperatures ranging from -40°C to +70°C for the components of the packaging. Attention must be given to freezing temperatures for liquids and to the potential degradation of packaging materials within the given temperature range.*
ICAO TI: 6;7.6.5	*The design of the package must take into account temperatures ranging from -40°C to +70°C for the components of the packaging. Attention must be given to freezing temperatures for liquids and to the potential degradation of packaging materials within the given temperature range.*

There are no special tie-down attachments on the package. In Section 8 it is verified that the package meets with the requirements under normal as well as under accident transport conditions.

In the strength calculation for the ANF-50 shipping container /R10/, the load-bearing parts are verified for a temperature of 70°C.

The characteristic strength values increase for austenitic steels as the temperature drops, so that the results of the computational verifications can be regarded as covering this.

The toughness data for the materials do not change in the temperature range considered, so that the characteristic values ascertained at 70°C can be regarded as covering this. It is thus verified that the package is designed safely for the temperature range of -40°C to +70°C.

There are no liquids transported.

ADR/RID: 6.4.7.6 **IMDG Code: 6.4.7.6** **TS-R-1 (ST-1, Revised) No. 638**	*The design and manufacturing techniques must be in accordance with national and international standards, or other requirements, acceptable to the competent authority.*

ICAO TI: **6;7.6.6**	*The design and manufacturing techniques must be in accordance with national and international standards, or other requirements, acceptable to the competent authority.*

This safety analysis verifies that the design of the ANF-50 shipping container meets the requirements. The manufacture is carried out in accordance with the specification /R4/ approved by the competent authority. This specification defines the manufacturing requirements, materials, the design test and the creation of documentation, taking into account the relevant national and international standards and requirements. This ensures that all relevant standards and requirements are observed.

ADR/RID: **6.4.7.7** **IMDG Code:** **6.4.7.7** **TS-R-1** **(ST-1, Revised)** **No. 639**	*The design must include a containment system securely closed by a positive fastening device which cannot be opened unintentionally or by a pressure which may arise within the package.*
ICAO TI: **6;7.6.7**	*The design must include a containment system securely closed by a positive fastening device which cannot be opened unintentionally or by a pressure which may arise within the package.*
ADR/RID: **6.4.7.8** **IMDG Code:** **6.4.7.8** **TS-R-1** **(ST-1, Revised)** **No. 640**	*Special form radioactive material may be considered as a component of the containment system.*
ICAO TI: **6;7.6.8**	*Special form radioactive material may be considered as a component of the containment system.*
ADR/RID: **6.4.7.9** **IMDG Code:** **6.4.7.9** **TS-R-1** **(ST-1, Revised)** **No. 641**	*If the containment system forms a separate unit of the package, it must be capable of being securely closed by a positive fastening device which is independent of any other part of the packaging.*
ICAO TI: **6;7.6.9**	*If the containment system forms a separate unit of the package, it must be capable of being securely closed by a positive fastening device which is independent of any other part of the packaging.*

ADR/RID: 6.4.7.10 **IMDG Code: 6.4.7.10** **TS-R-1 (ST-1, Revised) No. 642**	*The design of any component of the containment system must take into account, where applicable, the radiolytic decomposition of liquids and other vulnerable materials and the generation of gas by chemical reaction and radiolysis.*
ICAO TI: 6;7.6.10	*The design of any component of the containment system must take into account, where applicable, the radiolytic decomposition of liquids and other vulnerable materials and the generation of gas by chemical reaction and radiolysis.*
ADR/RID: 6.4.7.11 **IMDG Code: 6.4.7.11** **TS-R-1 (ST-1, Revised) No. 643**	*The containment system must retain its radioactive contents under reduction of ambient pressure to 60 kPa.*
ICAO TI: 6;7.6.11	*The containment system must retain its radioactive contents under reduction of ambient pressure to 60 kPa.*
ADR/RID: 6.4.7.12 **IMDG Code: 6.4.7.12** **TS-R-1 (ST-1, Revised) No. 644**	*All valves, other than pressure relief valves, must be provided with an enclosure to retain any leakage from the valve.*
ICAO TI: 6;7.6.12	*All valves, other than pressure relief valves, must be provided with an enclosure to retain any leakage from the valve.*
ADR/RID: 6.4.7.13 **IMDG Code: 6.4.7.13** **TS-R-1 (ST-1, Revised) No. 645**	*A radiation shield, which encloses a component of the package specified as a part of the containment system, must be designed so as to prevent the unintentional release of that component from the shield. Where the radiation shield and such component within it form a separate unit, the radiation shield must be capable of being securely closed by a positive fastening device, which is independent of any other packaging structure.*
ICAO TI: 6;7.6.13	*A radiation shield, which encloses a component of the package specified as a part of the containment system, must be designed so as to prevent the unintentional release of that component from the shield. Where the radiation shield and such component within it form a separate unit, the radiation shield must be capable of being securely closed by a positive fastening device, which is independent of any other packaging structure.*

The containment system is formed by the pellet container. The pellet container is a separate unit of the package. The containment system is established by screwing the container lid with the container. During transport, the pellet container is inside the case for pellet box of the shipping frame (see also Section 2).

Radiolytic decomposition can be ruled out since only solids (uranium oxide in the form of pellets, scrap or powder) are transported. The materials used for the components of the pellet container are physically and chemically compatible with each another and with the radioactive contents described in Section 3 of this safety analysis. There also exists sufficient operating experience with similar pellet containers.

The specimen of a pellet container was subjected to a pressure test in a pressure tank filled with water, with an overpressure of 150 kPa (corresponds to an immersion depth of 15 m) /R14/. No changes in geometry and no leak-in of water have been established. Due to their design, the seals seal in the case of an overpressure from the outside as well as from the inside in the event. The test carried out can therefore also be taken for verification of conformity to the requirement as per ICAO TI 6;7.2.3. In addition to this test, a further pressure test was carried out at Framatome ANP GmbH at a later date. In that, a pellet container (No. 221) was equipped with a pressure connection and a water pressure of 150 kPa (1.5 bar) was applied on the inside. It was determined that, at a test pressure of 150 kPa over a test period of 5 hours, the overpressure remained constant and no water leaked out /R14/. It is thus verified that the seal between lid and enclosure as well as the seal of the screw fittings of the clevis on the lid meet the requirements. It is ensured that the pellet container does not leak at a pressure difference of 60 kPa.

There are no valves on the pellet container.

ADR/RID 6.4.7.13 (ICAO TI 6;7.6.13) is not applicable. There is no radiation shield as separate unit.

ADR/RID: 6.4.7.14 **IMDG Code: 6.4.7.14** **TS-R-1 (ST-1, Revised) No. 646**	*A package must be designed so that if it were subjected to the tests specified in 6.4.15, it would prevent:* *a) loss or dispersal of the radioactive contents; and* *b) loss of shielding integrity which would result in more than a 20% increase in the radiation level at any external surface of the package.*
ICAO TI: 6;7.6.14	*A package must be designed so that if it were subjected to the tests specified in 7.14, it would prevent:* *a) loss or dispersal of the radioactive contents; and* *b) loss of shielding integrity which would result in more than 20 per cent increase in the radiation level at any external surface of the package.*

The verifications for the tests in accordance with ADR/RID Section 6.4.15 (ICAO TI 6;7.14) are provided in Section 8.2.4 of this report.

ADR/RID: 6.4.7.15 **IMDG Code: 6.4.7.15** **TS-R-1 (ST-1, Revised) No. 647**	*The design of a package intended for liquid radioactive material must make provision for ullage to accommodate variations in the temperature of the contents, dynamic effects and filling dynamics.*
ICAO TI: 6;7.6.15	*The design of a package intended for liquid radioactive material must make provision for ullage to accommodate variations in the temperature of the contents, dynamic effects and filling dynamics.*

There are no liquids transported in the package.

7.1.3 Requirements for packages containing fissile material

ADR/RID: 6.4.11.1 **IMDG Code: 6.4.11.1** **TS-R-1 (ST-1, Revised) No. 671**	*Fissile material must be transported so as to:* *a) Maintain undercriticality during normal and accident conditions of carriage; in particular, the following contingencies must be considered:* *(i) water leaking into or out of packages;* *(ii) the loss of efficiency of built-in neutron absorbers or moderators;* *(iii) rearrangement of the contents either within the package or as a result of loss from the package;* *(iv) reduction of spaces within or between packages;* *(v) packages becoming immersed in water or buried in snow; and* *(vi) temperature changes; and* *b) meet the requirements:* *(i) of 6.4.7.2 for packages containing fissile material;* *(ii) prescribed elsewhere in ADR which pertain to the radioactive properties of the material; and* *(iii) specified in 6.4.11.3 to 6.4.11.12, unless excepted by 6.4.11.2.*
ICAO TI: 6;7.10.1	*Fissile material must be transported so as to:* *a) maintain undercriticality during normal an accident conditions of transport; in particular, the following contingencies must be considered:* *(i) water leaking into or out of package;* *(ii) the loss of efficiency of built-in neutron absorbers or moderators;* *(iii) rearrangement of the contents either within the package or as a result of loss from the package;* *(iv) reduction of spaces within or between packages;* *(v) packages becoming immersed in water or buried in snow; and* *(vi) temperature changes; and* *b) meet the requirements:*

	(i) of 6;7.6.2 for packages containing fissile material; *(ii) prescribed elsewhere in these instructions and which pertain to the radioactive properties of the material; and* *(iii) specified in 6;7.10.3 to 6;7.10.12, unless excepted by 6;7.10.2.*

Sufficient undercriticality under normal and accident shipping conditions is proven in the criticality safety analysis for the ANF-50 shipping container /R7/ taking into account the hazardous options stated in the requirements.

ADR/RID: 6.4.11.2 **IMDG Code: 6.4.11.2** **TS-R-1 (ST-1, Revised) No. 672**	*Fissile material meeting one of the provisions (a) to (d) of this paragraph is excepted from the requirement to be carried in packages that comply with 6.4.11.3 to 6.4.11.12 as well as the other requirements of ADR that apply to fissile material. Only one type of exception is allowed per consignment.* *a) A mass limit per consignment such that:* $\frac{\text{mass of uranium} - 235(g)}{X} + \frac{\text{mass of other fissile material } (g)}{Y} < 1$ *where X and Y are the mass limits defined in Table 6.4.11.2, provided that either:* *(i) each individual package contains not more than 15 g of fissile material;* *(ii) the fissile material is a homogenous hydrogenous solution or mixture where the ratio of fissile nuclides to hydrogen is less than 5 per cent by mass; or* *(iii) there is not more than 5 g of fissile material in any 10 L volume of material.* *Neither beryllium nor deuterium in hydrogeneous material enriched in deuterium must be present in quantities exceeding 1 % of the applicable consignment mass limits provided in Table 6.4.11.2.* *b) Uranium enriched in uranium-235 to a maximum of 1% by mass, and with a total plutonium and uranium-233 content not exceeding 1% of the mass of uranium-235, provided that the fissile material is distributed essentially homogeneously throughout the material. In addition, if uranium-235 is presentin metallic, oxide or carbide forms, it must not form a lattice arrangement;* *c) Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2% by mass, with a total plutonium and uranium-233 content not exceeding 0.002% of the mass of uranium, and with a minimum nitrogen to uranium atomic ratio (N/U) of 2;* *d) Packages containing, individually, a total plutonium mass not more than 1 kg, of which not more than 20% by mass may consist of plutonium-239, plutonium-241 or any combination of those radionuclides.*

Table 6.4.11.2 - Consignment mass limits for exceptions from the requirements for packages containing fissile material

Fissile material	*Fissile material mass (g) mixed with substances having an average hydrogendensity less than or equal to water*	*Fissile material mass (g) mixed with substances having an average hydrogendensity greater than water*
Uranium-235 (X)	*400*	*290*
Other fissile materials (Y)	*250*	*180*

ICAO TI: 6;7.10.2

Fissile material meeting one of the provisions in a) to d) below is excepted from the requirements to be transported in packages that comply with 6;7.10.3 to 6;7.10.12, as well as the other requirements of these Instructions that apply to fissile material. Only one type of exception is allowed per consignment:

a) *A mass limit per consignment such that:*

$$\frac{\text{mass of uranium} - 235(g)}{X} + \frac{\text{mass of other fissile material }(g)}{Y} < 1$$

where X and Y are the mass limits defined in Table 6-5, provided that:

- (i) *each individual package contains not more than 15 g of fissile material;*
- (ii) *the fissile material is a homogenous hydrogenous solution or mixture where the ratio of fissile nuclides to hydrogen is less than 5 per cent by mass; or*
- (iii) *there is not more than 5 g of fissile material in any 10 L volume of material.*

Neither beryllium nor deuterium in hydrogeneous material enriched in deuterium must be present in quantities exceeding 1 % of the applicable consignment mass limits provided in Table 6-5.

b) *Uranium enriched in uranium-235 to a maximum of 1 per cent by mass, and with a total plutonium and uranium-233 content not exceeding 1 per cent of the mass of uranium-235, provided that the fissile material is distributed essentially homogeneously throughout the material. In addition, if uranium-235 is present in metallic, oxide or carbide forms, it must not form a lattice arrangement;*

c) *Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2 per cent by mass, with a total plutonium and uranium-233 content not exceeding 0,002 per cent of the mass of uranium, and with a minimum nitrogen to uranium atomic ratio (N/U) of 2;*

d) *Packages containing, individually, a total plutonium mass not more than 1 kg, of which not more than 20 per cent by mass may consist of plutonium-239, plutonium-241 or any combination of those radionuclides.*

	Table 6-5. Consignment mass limits for exceptions from the requirements for packages containing fissile material		
	Fissile material	*Fissile material mass (g) mixed with substances having an average hydrogen density less than or equal to water*	*Fissile material mass (g) mixed with substances having an average hydrogen density greater than water*
	Uranium-235 (X)	*400*	*290*
	Other fissile material (Y)	*250*	*180*

The content of the package does not satisfy any of the conditions cited under Para. 6.4.11.2 (ICAO TI 6;7.10.2), so that the package has to satisfy the requirements in subsections 6.4.11.3 to 6.4.11.12 (ICAO TI 6;7.10.3 to ICAO TI 6;7.10.12) and also the other requirements of these regulations that apply to fissile material.

7.1.3.1 Description of contents for assessing packages containing fissile materials

ADR/RID: 6.4.11.3 **IMDG Code: 6.4.11.3** **TS-R-1 (ST-1, Revised) No. 673**	*Where the chemical or physical form, isotopic composition, mass or concentration, moderation ratio or density, or geometric configuration is not known, the assessments of subsections 6.4.11.7 to 6.4.11.12 must be performed assuming that each parameter that is not known has the value which gives the maximum neutron multiplication consistent with the known conditions and parameters in these assessments.*
ICAO TI: 6;7.10.3	*Where the chemical or physical form, isotopic composition, mass or concentration, moderation ratio or density, or geometric configuration is not known, the assessments of 7.10.7 to 7.10.12 must be performed assuming that each parameter that is not known has the value which gives the maximum neutron multiplication consistent with the known conditions and parameters in these assessments .*

This requirement is not relevant, as all necessary parameters are known.

ADR/RID: 6.4.11.4 **IMDG Code: 6.4.11.4** **TS-R-1 (ST-1, Revised) No. 674**	*For irradiated nuclear fuel the assessments of subsections 6.4.11.7 to 6.4.11.12 must be based on an isotopic composition demonstrated to provide:* *a) the maximum neutron multiplication during the irradiation history; or* *b) a conservative estimate of the neutron multiplication for the package assessments. After irradiation but prior to shipment, a measurement must be performed to confirm the conservatism of the isotopic composition.*

ICAO TI: 6;7.10.4	*For irradiated nuclear fuel the assessments of 6;7.10.7 to 6;7.10.12 must be based on an isotopic composition demonstrated to provide:* *a) the maximum neutron multiplication during the irradiation history; or* *b) a conservative estimate of the neutron multiplication for the package assessment must be performed to confirm the conservatism of the isotopic composition.*

Irradiated nuclear fuel is not involved in terms of the above-stated requirements.

7.1.3.2 Geometry and temperature requirements

ADR/RID: 6.4.11.5 **IMDG Code: 6.4.11.5** **TS-R-1 (ST-1, Revised) No. 675**	*The package, after being subjected to the tests specified in 6.4.15, must prevent the entry of a 10 cm cube.*
ICAO TI: 6;7.10.5	*The package, after being subjected to the tests specified in 6;7.14, must prevent the entry of a 10 cm cube.*

Verification of the integrity of the package was provided by the tests in accordance with 6.4.15 (ICAO TI 6;7.14) on four specimens of the ANF-50 shipping container and is covered in Section 8.2.4. It was determined that the entry of a cube with a side length of 10 cm into the specimens of the ANF-50 shipping container subjected to the tests, specified in Section 6.4.15, was not possible.

ADR/RID: 6.4.11.6 **IMDG Code: 6.4.11.6** **TS-R-1 (ST-1, Revised) No. 676**	*The package must be designed for an ambient temperature range of -40 °C to +38 °C unless the competent authority specifies otherwise in the certificate of approval for the package design.*
ICAO TI: 6;7.10.6	*The package must be designed for an ambient temperature range of -40°C to +38°C unless the competent authority specifies otherwise in the certificate of approval for the package design.*

In the strength calculation for the ANF-50 shipping container /R10/, the load-bearing parts are verified for a temperature of 70°C.

The characteristic strength values increase for austenitic steels as the temperature drops, so that the results of the computational verifications can be regarded as covering this.

The toughness data for the materials do not change in the temperature range considered, so that the characteristic values ascertained at +70°C can be regarded as covering this. It is thus verified that the package is designed safely for the temperature range of -40°C to +38°C (see also Section 7.1.1.1).

7.1.3.3 Assessing a package in isolation

ADR/RID: 6.4.11.7 **IMDG Code: 6.4.11.7** **TS-R-1 (ST-1, Revised) No. 677**	*For a package in isolation, it must be assumed that water can leak into or out of all void spaces of the package, including those within the containment system. However, if the design incorporates special features to prevent such leakage of water into or out of certain void spaces, even as a result of error, absence of leakage may be assumed in respect of those void spaces. Special features must include the following:* *a) multiple high standard water barriers, each of which would remain watertight if the package were subject to the tests prescribed in 6.4.11.12 (b), a high degree of quality control in the manufacture, maintenance and repair of packagings and tests to demonstrate the closure of each package before each shipment; or* *b) for packages containing uranium hexafluoride only:* *(i) packages where, following the tests prescribed in 6.4.11.12 (b), there is no physical contact between the valve and any other component of the packaging other than at its original point of attachment and where, in addition, following the test prescribed in 6.4.17.3 the valves remain leaktight; and* *(ii) a high degree of quality control in the manufacture, maintenance and repair of packagings coupled with tests to demonstrate closure of each package before each shipment.*
ICAO TI: 6;7.10.7	*For a package in isolation, it must be assumed that water can leak into or out of all void spaces of the package, including those within the containment system. However, if the design incorporates special features to prevent such leakage of water into or out of certain void spaces, even as a result of error, absence of leakage may be assumed in respect of those void spaces. Special features must include the following:* *a) multiple high standard water barriers, each of which would remain watertight if the package were subject to the tests prescribed in 7.10.12b), a high degree of quality control in the manufacture, maintenance and repair of packagings and tests to demonstrate the closure of each package before shipment; or* *b) for packages containing uranium hexafluoride only:* *(i) packages where, following the tests prescribed in 6;7.10.12b), there is no physical contact between the valve and any other component of the packaging other than is original point of attachment and where, in addition, following the test prescribed in 6;7.16.3, the valves remain leaktight; and* *(ii) a high degree of quality control in the manufacture, maintenance and repair of packagings coupled with tests to demonstrate closure of each package before each shipment.*

ADR/RID: 6.4.11.8 **IMDG Code: 6.4.11.8** **TS-R-1 (ST-1, Revised) No. 678**	*It must be assumed that the confinement system must be closely reflected by at least 20 cm of water or such greater reflection as may additionally be provided by the surrounding material of the packaging. However, when it can be demonstrated that the confinement system remains within the packaging following the tests prescribed in 6.4.11.12 (b), close reflection of the package by at least 20 cm of water may be assumed in 6.4.11.9 (c).*
ICAO TI: 6;7.10.8	*It must be assumed that the confinement system must be closely reflected by at least 20 cm of water or such greater reflection as may additionally be provided by the surrounding material of the packaging. However, when it can be demonstrated that the confinement system remains within the packaging following the tests prescribed in 6;7.10.12b), close reflection of the package by at least 20 cm of water may be assumed in 6;7.10.c).*
ADR/RID: 6.4.11.9 **IMDG Code: 6.4.11.9** **TS-R-1 (ST-1, Revised) No. 679**	*The package must be subcritical under the conditions of 6.4.11.7 and 6.4.11.8 with the package conditions that result in the maximum neutron multiplication consistent with:* *a) routine conditions of transport (incident free);* *b) the tests specified in 6.4.11.11 (b);* *c) the tests specified in 6.4.11.12 (b).*
ICAO TI: 6;7.10.9	*The package must be subcritical under the conditions of 7.10.8 and 7.10.17, with the package conditions that result in the maximum neutron multiplication consistent with:* *a) routine conditions of transport (incident free);* *b) the tests specified in 6;7.10.11b);* *c) the tests specified in 6;7.10.12b).*

Verification of the integrity of the package was provided for the ANF-50 shipping container with the specimens 1 to 4 and is covered in Section 8.3.4.

Sufficient undercriticality for a single package is proven in the criticality safety analysis /R7/ assuming that water can leak into and also drain off all cavities of the package. The undercriticality is proven for all load strategies for a single ANF-50 shipping container during routine, normal and accident transport conditions.

There is no uranium hexafluoride transported in the package.

Furthermore, it is established that:

- The survey report on the deformation of the ANF-50 shipping container / specimens 1 to 4 based on the drop tests shows that neither the volume nor any distances on which the criticality assessment is based on were changed excessively /R11/.
- The leak-in of water was assumed in the criticality analysis. No excessive increase in neutron multiplication occurs.
- No change in the arrangement of the radioactive contents occurred that result in an excessive increase in neutron multiplication.

7.1.3.4 Requirements for air transport

ICAO TI: 6;7.10.10 **TS-R-1 (ST-1, Revised) No. 680**	*a) The package must be subcritical under conditions consistent with the Type C package tests specified in 6;7.19.1 assuming reflection by at least 20 c of water but no water-in leakage.* *b) In the assessment of 6;7.10.9, allowance must not be made for special features of 6;7.10.7 unless, following the Type C package tests specified in 6;7.19.1 and subsequently, the water-in leakage test of 6;7.18.3, leakage of water into or put of the void spaces is prevented.*
ICAO TI 6;7.18.3 **TS-R-1 (ST-1, Revised) No. 733**	*The specimen must be immersed under a head of water of at least 0.9 m for a period of not less than eight hours and in the attitude for which maximum leakage is excepted.*
ICAO TI 6;7.19.1 **TS-R-1 (ST-1, Revised) No. 734**	*Specimens must be subjected to the effects of each of the following test sequences in the orders specified:* *a) The tests specified in 7.16.2a), 7.16.2c), 7.19.2 and 7.19.3; and* *b) The tests specified in 7.19.4* *Separate specimens are allowed to be used for each of the sequences in a) and b).*
ICAO TI 6;7.16.2 **TS-R-1 (ST-1, Revised) No. 727**	*Mechanical test: the mechanical test consists of three different drop tests. Each specimen must be subjected to the applicable drops as specified in 6;7.7.7 or 6;7.19.12. The order in which the specimen is subjected to the drops must be such that, on completion of the mechanical test, the specimen must have suffered such damage as will lead to the maximum damage in the thermal test which follows:* *a) For drop I, the specimen must drop onto the target so as to suffer the maximum damage, and the height of the drop measured from the lowest point of the specimen to the upper surface of the target must be 9 m. The target must be as defined in 6;7.13;* *b) For drop II, the specimen must drop so as to suffer the maximum damage onto a bar rigidly mounted perpendicularly on the target. The height of the drop measured from the intended point of impact of the specimen to the upper surface of the bar must be 1 m. The bar must be of solid mild steel of circular section, (15.0 ± 0.5 cm) in diameter and 20 cm long unless a longer bar would cause greater damage, in which case a bar of sufficient length to cause maximum damage must be used. The upper end of the bar must be flat and horizontal with its edges rounded off to a radius of not more than 6 mm. The target on which the bar is mounted must be as described in 6;7.13.* *c) For drop III, the specimen must be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass must consist of a solid mild steel plate 1 m by 1 mm and must fall in horizontal attitude. The height of the drop must be measured from the underside of the plate to the highest point of the specimen. The target on which the specimen tests must be as defined in 6;7.13.*

ICAO TI 6;7.19.2 **TS-R-1 (ST-1, Revised) No. 735**	*Puncture/tearing test: the specimen must be subjected to the damaging effects of a solid probe made of mild steel. The orientation of the probe to the surface of the specimen must be positioned so as to cause maximum damage at the conclusion of the test sequence specified in 7.19.1a)* *a) The specimen, representing a package having a mass less than 250 kg, must be placed on a target and subjected to a probe having a mass of 250 kg and falling from a height of 3 m above the intended impact point. For this test, the probe must be a 20 cm diameter cylindrical bar with the striking end forming a frustum of a right circular cone with the following dimensions: 30 cm height and 2.5 cm diameter at the top with its edge rounded off to a radius of not more than 6 mm. The target on which the specimen is placed must be as specified in 6;7.13;* *b) For packages having a mass of 250 kg or more, the base of the probe must be placed on a target and the specimen dropped onto the probe. The height of the drop, measured from the point of impact with the specimen to the upper surface of the probe must be 3 m. For this test, the probe must have the same properties and dimensions as specified in a) above, except that length a mass of the probe must be such as to incur maximum damage to the specimen. The target on which the base of the probe is placed must be as specified in 6;7.13.*
ICAO TI 6;7.19.3 **TS-R-1 (ST-1, Revised) No. 736**	*Enhanced thermal test: the conditions for this test must be as specified in 7.16.3, except that the exposure to the thermal environment must be for a period of 60 minutes.*
ICAO TI 6;7.19.4 **TS-R-1 (ST-1, Revised) No. 737**	*Impact test: the specimen must be subject to an impact on a target at a velocity of not less than 90 m/s, at such an orientation as to suffer maximum damage. The target must be as defined in 7.13, except that the target surface may be at any orientation as long as the surface is normal to the specimen path.*

Except for the test 6;7.16.2 c), none of the tests requested in 6;7.19.1 was performed with the specimens 1 to 4 of the ANF-50 shipping container. Further tests performed on the specimens 1 to 4 of the ANF-50 shipping container are described and commented in Section 8.3.

For the verification of criticality safety, it was assumed that, due to the requirements in accordance with 6;7.10.10, the package was damaged in such a way that the content is no longer enclosed in the confinement system and has taken on the best arrangement for neutron multiplication. For this case, the proof of sufficient undercriticality was carried out in the criticality safety analysis /R7/. In that, the undercriticality for a released, unmoderated and reflected uranium oxide pellet mass of 55 kg is proven. Undercriticality is also proven for a mass of 21 kg of released and reflected uranium oxide powder. This uranium oxide powder mass is clearly higher than the intended transport mass of 14.5 kg of uranium oxide powder, the safe undercriticality is thus sufficiently fulfilled.

7.1.3.5 Assessing package configurations under normal transport conditions

ADR/RID: 6.4.11.11 **IMDG Code: 6.4.11.11** **TS-R-1 (ST-1, Revised) No. 681**	*For normal conditions of transport, a number "N" must be derived, such that five times "N" must be sub-critical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:* *a) there must not be anything between the packages, and the package arrangement must be reflected on all sides by at least 20 cm of water; and* *b) the state of the packages must be their assessed or demonstrated condition if they had been subjected to the tests specified in 6.4.15.*
ICAO TI: 6;7.10.11	*A number "N" must be derived, such that five times "N" must be subcritical for the arrangement and package conditions that provide the maximum neutron multiplication consists with the following:* *a) there must not be anything between the packages, and the package arrangement must be reflected on all sides by at least 20 cm of water; and* *b) the state of the packages must be their assessed or demonstrated condition if they had been subjected to the tests specified in 6;7.14.*

The undercriticality is to be proven for an array of at least 625 ANF-50 shipping containers. Sufficient undercriticality is proven for an array of 9 x 9 x 9 (corresponds to 729) ANF-50 shipping containers in the criticality safety analysis /R7/. In the verification, the partial flooding and flooding of the shipping containers with water is assumed. The undercriticality for an array of ANF-50 shipping containers loaded with pellets on pellet trays is proven for normal transport conditions. The undercriticality for an array of ANF-50 shipping containers loaded with pellets as bulk goods and with pellet scrap or uranium oxide powder is also proven for normal transport conditions.

The tests for resistance under normal transport conditions were carried out in accordance with Section 6.4.15 (ICAO TI 6;7.14). Verifications for that are provided in Section 8.3.4.

7.1.4 Assessing package configurations under accident transport conditions

ADR/RID: 6.4.11.12 **IMDG Code: 6.4.11.12** **TS-R-1 (ST-1, Revised) No. 682**	*For accident conditions of transport, a number "N" must be derived, such that two times "N" must be sub-critical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:* *a) hydrogenous moderation between packages, and the package arrangement reflected on all sides by at least 20 cm of water; and* *b) the tests specified in 6.4.15 followed by whichever of the following is the more limiting:* *(i) the tests specified in 6.4.17.2 b) and, either 6.4.17.2 c) for packages having a mass not greater than 500 kg and an overall density not greater than 1 000 kg/m³ based on the external dimensions, or 6.4.17.2 a) for all other packages; followed by the test specified in 6.4.17.3 and completed by the tests specified in 6.4.19.1 to 6.4.19.3; or* *(ii) the test specified in 6.4.17.4 and* *c) where any part of the fissile material escapes from the containment system following the tests specified in 6.4.11.12 (b), it must be assumed that fissile material escapes from each package in the array and all of the fissile material must be arranged in the configuration and moderation that results in the maximum neutron multiplication with close reflection by at least 20 cm of water.*
ICAO TI: 6;7.10.12	*A number "N" must be derived, such that two times "N" must be subcritical for the arrangement and package conditions that provide the maximum neutron multiplication consistent with the following:* *a) hydrogenous moderation between packages, and the package arrangement reflected on all sides by at least 20 cm of water; and* *b) the tests specified in 6;7.14 followed by whichever of the following is the more limiting:* *(i) the tests specified in 6;7.16.2b) and, either 6;7.16.2c) for packages having a mass not greater than 500 kg and an overall density not greater than 1000 kg/m³ based on the external dimensions, or 6;7.16.2a) for all other packages; followed by the test specified in 6;7.16.3 and completed by the tests specified in 6;7.18.1 to 6;7.18.3; or* *(ii) the tests specified in 6;7.16.4; and* *c) where any part of the fissile material escapes from the containment system following the tests specified in 6;7.10.12b), it must be assumed that fissile material escapes from each package in the array and all of the fissile material must be arranged in the configuration and moderation that results in the maximum neutron multiplication with close reflection by at least 20 cm of water.*

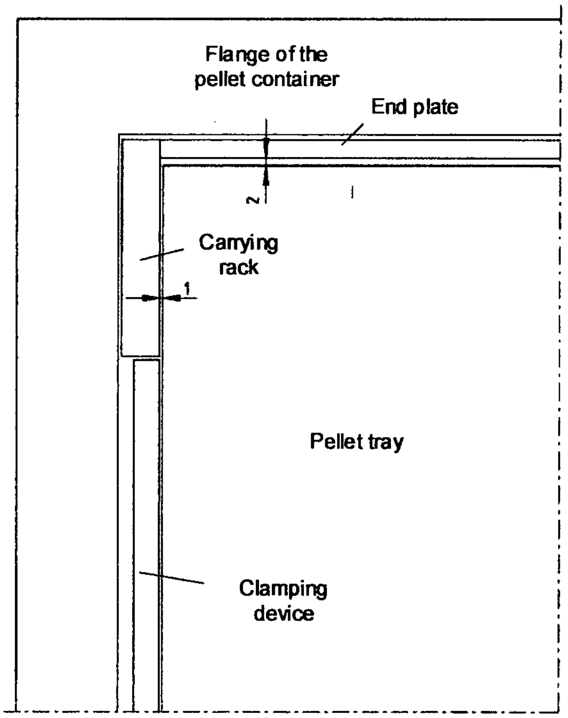
The ANF-50 shipping container was tested in accordance with the requirements of the regulations as to determine the resistance under accident transport conditions. The results are stated in /R14/. With all specimens, the pellet containers with lid remained dimensionally stable; with respect to the even surface, a slight curvature to the outside was detected for the side walls and the pellet container lid.

The pellets were replaced by lead rods for the tests. Pellets have a lower viscosity than lead so that breaking or coming off in splinters cannot be ruled out. Here, especially the pellet scrap at the edge of the pellet trays is important. If it is so small that it can penetrate the gaps shown in Figure 2, a spreading of the scrap into the space behind cannot be ruled out.

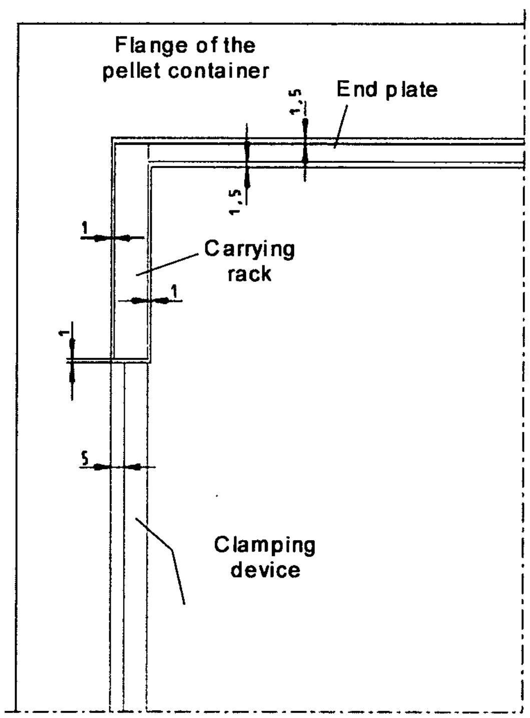
Tests were performed to determine the behaviour of the pellets under pressure load. In the first test, a column of four pellets was arranged between two pellet tray sections and loaded with a pressure of 5000 N. The pellet trays were deformed in the test, the pellets were not damaged. The test arrangement is shown in Figure 3.

In a further test, the pellets were loaded radially between two prisms. The prisms had the same geometric form as the pellet trays, the load was 5000 N. At this load, the pellets were not damaged either. A single pellet was loaded with 5000 N also between the prisms. This pellet also did not reveal any damage. The prisms did not show any remaining deformations.

The geometric examination shows that only very small pellet scrap can enter the space above the pellet trays. The result of the load test of the pellets shows that damage to the pellets under accident transport conditions is improbable and thus the entry of pellet scrap into the spaces above the pellet trays can be ruled out.



Gap between pellet container and pellet tray to the space between the top pellet tray and the clamping device (top view)



Gap between pellet container and clamping device to the space above the clamping device (top view)

Figure 2: Illustration of the gap in the pellet container

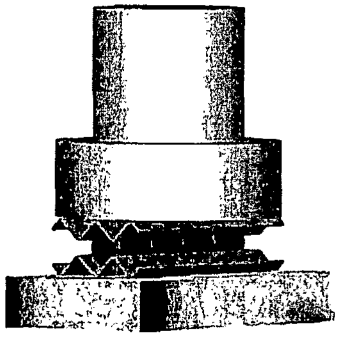


Figure 3: Load test on pellets between pellet trays

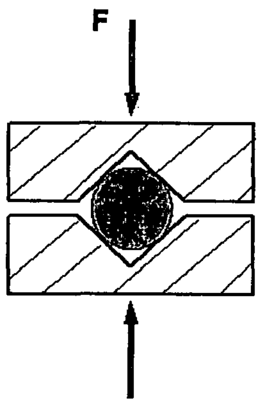


Figure 4: Load test on pellets between prisms

The undercriticality is to be proven for an array of 250 ANF-50 shipping containers. Sufficient undercriticality is proven for an array of 6 x 6 x 8 (corresponds to 288) ANF-50 shipping containers in the criticality safety analysis /R7/. In the verification, the partial flooding and flooding of the shipping containers with water is assumed.

The undercriticality for an array of ANF-50 shipping containers loaded with pellets on pellet trays is proven for accident transport conditions. The undercriticality for an array of ANF-50 shipping containers loaded with pellets as bulk goods and with pellet scrap or uranium oxide powder is also proven for accident transport conditions.

The verifications for the tests for resistance compared with normal transport conditions are provided in Section 8.3.4 of this safety analysis.

The mass of the package is smaller than 500 kg. The total density relative to the outer dimensions is approx. 570 kg/m³. Verifications are provided in Section 8.3.5 of this safety analysis.

Verifications are not required for Paras. 6.4.19.1 to 6.4.19.3 (ICAO TI 6;7.18.1 to 6;7.18.3), as the leak-in of water is assumed in the criticality safety analysis /R7/.

Re 6.4.11.12b) (ICAO TI 6;7.10.12b)): The tests to demonstrate resistance under normal transport conditions and under accident transport conditions provided verification of the preservation of the containment system (see Section 8.3.4 and 8.3.5).

8 Test methods

8.1 Verification procedures

ADR/RID: 6.4.12. **IMDG Code: 6.4.12.**	*Test methods and verification procedures*
ICAO TI: 6;7.11	*Test Procedures*
ADR/RID: 6.4.12.1 **IMDG Code: 6.4.12.1** **TS-R-1 (ST-1, Revised) No. 701**	*Demonstration of compliance with the performance standards required in 2.2.7.3.3, 2.2.7.3.4, 2.2.7.4.1, 2.2.7.4.2, and 6.4.2 to 6.4.11 must be accomplished by any of the methods listed below or by a combination thereof:* *a) Performance of tests with specimens representing LSA-III material, or special form radioactive material, or with prototypes or samples of the packaging, where the contents of the specimen or the packaging for the tests shall simulate as closely as practicable the expected range of radioactive contents and the specimen or packaging to be tested must be prepared as presented for carriage;* *b) Reference to previous satisfactory demonstrations of a sufficiently similar nature;* *c) Performance of tests with models of appropriate scale incorporating those features which are significant with respect to the item under investigation when engineering experience has shown results of such tests to be suitable for design purposes. When a scale model is used, the need for adjusting certain test parameters, such as penetrator diameter or compressive load, must be taken into account;* *d) Calculation, or reasoned argument, when the calculation procedures and parameters are generally agreed to be reliable or conservative.*
ICAO TI: 6;7.11.1	*Demonstration of compliance with the performance standards required in 2;7.3.3, 2;7.3.4, 2;7.4.1, 2;7.4.2, 2;7.10.1, 2;7.10.2 and 6;7.1 to 6;7.10 must be accomplished by any of the methods listed below or by a combination thereof:* *a) Performance of tests with specimens representing LSA-III material, or special form radioactive material, or low dispersible radioactive material or with prototypes or samples of the packaging, where the contents of the specimens or the packaging for the tests must simulate, as closely as practicable, the excepted range of radioactive contents and the specimens or packaging to be tested must be prepared as presented for transport;* *b) Reference to previous satisfactory demonstrations of a sufficiently similar nature;*

	c) *Performance of tests with models of appropriate scale incorporating those features which are significant with respect to the item under investigation when engineering experience has shown results of such tests to be suitable for design purposes. When a scale model is used, the need for adjusting certain test parameters, such as penetrator diameter or compressive load, must be taken into account;* d) *Calculation, or reasoned argument, when the calculation procedures and parameters are generally agreed to be reliable or conservative.*

Verification that the ANF-50 shipping container meets the requirements for a Type 2 package for fissile material has been provided by way of tests using the specimens 1 to 4 of the ANF-50 shipping container. The specimens were produced in accordance with the records that had been subjected to preliminary review, which are listed in cover sheet No. DBL-4435 /R12/. The drawing numbers for the specimens and series containers are compared in the following table.

Specimen drawings	Sample drawings
W 4435	AD-003750-001
---	AD-003751-001
0ZB0381100	AD-003753-001
0ZB0381101	AD-003754-001
W 4435-1	AD-003755-001
W 4435-1-1	AD-003756-001
W 4435-2	AD-003757-001
W 4435-3	AD-003758-001
W 4435-4	AD-003759-001
W 4435-5	AD-003760-001
W 4435-6	AD-003761-001
W 4435-7	AD-003762-001

ADR/RID: 6.4.12.2 **IMDG Code: 6.4.12.2** **TS-R-1 (ST-1, Revised) No. 702**	*After the specimen, prototype or sample has been subjected to the tests, appropriate methods of assessment must be used to assure that the requirements for the test procedures have been fulfilled in compliance with the performance and acceptance standards prescribed in 2.2.7.3.3, 2.2.7.3.4, 2.2.7.4.1, 2.2.7.4.2, and 6.4.2 to 6.4.11.*

ICAO TI: 6;7.11.2	*After the specimen, prototype or sample has been subjected to the tests, appropriate methods of assessment must be used to assure that the requirements for the test procedures have been fulfilled in compliance with the performance and acceptance standards prescribed in 2;7.3.3, 2;7.3.4, 2;7.4.1, 2;7.4.2, 2;7.10.1, 2;7.10.2 and 6;7.1 to 6;7.10.*

The test methods are explained in the respective test reports (/R7/, /R11/, /R13/, /R14/, /R15/, /R16/, /R17/).

8.2 Package tests

8.2.1 Preparation of specimens for the test

ADR/RID: 6.4.12.3 **IMDG Code: 6.4.12.3** **TS-R-1 (ST-1, Revised) No. 713**	*All specimens must be inspected before testing in order to identify and record faults or damage including the following:* *a) divergence from the design;* *b) defects in manufacture;* *c) corrosion or other deterioration; and* *d) distortion of features.* *The containment system of the package must be clearly specified. The external features of the specimen must be clearly identified so that reference may be made simply and clearly to any part of such specimen.*
ICAO TI: 6;7.11.3	*All specimens must be inspected before testing in order to identify and record faults or damage including the following:* *a) divergence from the design;* *b) defects in manufacture;* *c) corrosion or other deterioration; and* *d) distortion of features.* *The containment system of the package must be clearly specified. The external features of the specimen must be clearly identified so that reference may be made simply and clearly to any part of such a specimen.*

Test specimens 1 to 4 of the ANF-50 shipping container were examined and measured prior to the tests and the results were recorded /R11/.

The parts are positioned and labeled in the drawings in accordance with the summary drawing /R2/.

The containment system of the ANF-50 shipping container is described in Section 2.3 of this safety analysis.

8.2.2 Testing the integrity of the containment system and shielding and evaluating the criticality safety

ADR/RID: 6.4.13 **IMDG Code: 6.4.13** **TS-R-1 (ST-1, Revised) No. 716**	*After each of the applicable tests specified in 6.4.15 to 6.4.21:* *a) faults and damage must be identified and recorded;* *b) it must be determined whether the integrity of the containment system and shielding has been retained to the extent required in 6.4.2 to 6.4.11 for the package under test; and* *c) for packages containing fissile material, it must be determined whether the assumptions and conditions used in the assessments required by 6.4.11.1 to 6.4.11.12 for one or more packages are valid.*
ICAO TI: 6;7.12	*After each of the applicable tests specified in 6;7.14 to 6;7.20:* *a) faults and damages must be identified and recorded;* *b) it must be determined whether the integrity of the containment system and shielding has been retained to the extent required in 7.1 to 7.10 for the package under test; and* *c) it must be determined, for packages containing fissile material, whether the assumptions and conditions used in assessments required by 6;7.10.1 to 6;7.10.12 for one or more packages in valid.*

Defects of and damages to the specimens were ascertained. The results are documented in /R11/ and /R14/.

It is demonstrated in the verification of the local dose rate for the ANF-50 shipping container /R15/ that the shielding effect following the tests ADR/RID 6.4.15.4 and 6.4.15.5 (ICAO TI 6;7.14.4 and 6;7.14.5) is reduced by less than 20 % as required.

The specimens were opened following all drop tests. Before the screw fittings were undone, the release torque and existing tightening torque of the screw fittings were ascertained. Adequate torques were established at all the relevant screw fittings /R14/. Verification of the integrity of the containment system is thus provided.

The requirements for a Type A package and packages with fissile material are met in accordance with the comments in Section 7.1.3 and 7.1.4 of this safety analysis.

8.2.3 Target for drop tests

ADR/RID: 6.4.14 **IMDG Code: 6.4.14** **TS-R-1 (ST-1, Revised) No. 717**	*The target for the drop tests specified in 2.2.7.4.5 a), 6.4.15.4, 6.4.16 a), 6.4.17.2, 6.4.17.2, and 6.4.20.2 must be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen.*

ICAO TI: 6;7.13	*The target for the drop tests specified in 2;7.4.5 a), 6;7.14.4, 6;7.15 a), 6;7.16.2 and 6;7.19.2 must be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase the damage to the specimen.*

The drop tests were carried out on the drop test facility at BAM. The foundation conforms to the requirements and is described in /R14/.

8.2.4 Tests for demonstrating ability to withstand normal conditions of carriage

ADR/RID: 6.4.15.	*Tests for demonstrating ability to withstand normal conditions of transport*
ICAO TI: 6;7.14.	*Tests for demonstrating ability to withstand normal conditions of transport.*
ADR/RID: 6.4.15.1 **IMDG Code: 6.4.15.1** **TS-R-1 (ST-1, Revised) No. 719**	*The tests are: the water spray test, the free drop test, the stacking test and the penetration test. Specimens of the package must be subjected to the free drop test, the stacking test and the penetration test, preceded in each case by the water spray test. One specimen may be used for all the tests, provided that the requirements of 6.4.15.2 are fulfilled.*
ICAO TI: 6;7.14.1	*The tests are: the water spray test, the free drop test, the stacking test and the penetration test. Specimens of the package must be subjected to the free drop test, the stacking test and the penetration test, preceded in each case by the water spray test. One specimen may be used for all tests, provided that the requirements of 6;7.14.2 are fulfilled.*
ADR/RID: 6.4.15.2 **IMDG Code: 6.4.15.2** **TS-R-1 (ST-1, Revised) No. 720**	*The time interval between the conclusion of the water spray test and the succeeding test must be such that the water has soaked in to the maximum extent, without appreciable drying of the exterior of the specimen. In the absence of any evidence to the contrary, this interval must be taken to be two hours if the water spray is applied from four directions simultaneously. No time interval must elapse, however, if the water spray is applied from each of the four directions consecutively.*
ICAO TI: 6;7.14.2	*The time interval between the conclusion of the water spray test and the succeeding test must be such that the water has soaked in to the maximum extent, without appreciable drying of the exterior of the specimen. In the absence of any evidence to the contrary, this interval must be taken to be two hours if the water spray test is applied from four directions simultaneously. No time interval must elapse, however, if the water spray is applied from each of the four directions consecutively.*

Water spray test:

ADR/RID: 6.4.15.3 **IMDG Code: 6.4.15.3** **TS-R-1 (ST-1, Revised) No. 721**	*Water spray test: the specimen must be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm per hour for at least one hour.*
ICAO TI: 6;7.14.3	*Water spray test: the specimen must be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm per hour for at least one hour.*

Carrying out the water spray test is not relevant to criticality behaviour, as the leak-in of water was assumed in the criticality safety analysis /R7/.

The surfaces of the ANF-50 shipping container consist completely of austenitic steel plate. The case for pellet box and the lid for the pellet box are screwed to one another. A groove in the flange of the pellet box, which is closed by the container cover, contains an O-ring, so that no water can enter the pellet container. The container materials used are not changed by the water, nor are container parts adversely affected. The water spray test was not carried out, therefore.

Free drop test:

ADR/RID: 6.4.15.4 **IMDG Code: 6.4.15.4** **TS-R-1 (ST-1, Revised) No. 722**	*Free drop test: The specimen must drop onto the target so as to suffer maximum damage in respect of the safety features to be tested.* *a) The height of drop measured from the lowest point of the specimen to the upper surface of the target must be not less than the distance specified in Table 6.4.15.4 for the applicable mass. The target must be as defined in 6.4.14.* *b) For rectangular fibreboard or wood packages not exceeding a mass of 50 kg, a separate specimen must be subjected to a free drop onto each corner from a height of 0.3 m;* *c) For cylindrical fibreboard packages not exceeding a mass of 100 kg, a separate specimen must be subjected to a free drop onto each of the quarters of each rim from a height of 0.3 m.* ***Table 6.4.15.4 Free drop distance for testing packages to normal conditions of transport***

Package mass (kg)					*Free drop distance (m)*
		Package mass	<	*5000*	*1.2*
5000	≤	*Package mass*	<	*10000*	*0.9*
10000	≤	*Package mass*	<	*15000*	*0.6*
15000	≤	*Package mass*			*0.3*

ICAO TI: 6;7.14.4

Free drop test: the specimen must drop onto the target so as to suffer maximum damage in respect of the safety features to be tested.

a) The height of the drop measured from the lowest point of the specimen to the upper surface of the target must be not less than the distance specified in Table 6-6 for the applicable mass. The target must be as defined in 6;7.13;

b) For rectangular fibreboard or wood packages not exceeding a mass of 50 kg, a separate specimen must be subjected to a free drop onto each corner from a height of 0.3 m;

c) For cylindrical fibreboard packages not exceeding a mass of 100 kg, a separate specimen must be subjected to a free drop onto each of rim from a height of 0.3 m.

Table 6-6. Free drop distance for testing packages to normal conditions of transport

Package mass (kg)	*Free drop distance (m)*
Package mass < 5000	*1.2*
5000 ≤ Package mass < 10000	*0.9*
10000 ≤ Package mass < 15000	*0.6*
15000 ≤ Package mass	*0.3*

In line with the maximum mass of the package of 248 kg, a drop test is to be carried out with a free drop height of 1.2 m.

Drop test as per 6.4.15.4 a) (ICAO TI 6;7.14.4 a))

The impact positions and angle of impact for the drop tests using the specimens 1 to 4 of the ANF-50 shipping container are described in /R13/.

The drop height was set at 1.3 m, to cover the maximum permissible package mass.

The verification to 6.4.15.4 a) (ICAO TI 6;7.14.4a)) was provided by the drop test with the specimens 1 to 4 at BAM and documented in the test report /R14/.

The damage to the outer shell of the package resulting from the drop test with a free drop height of 1.3 m was slight.

The containment system of the pellets formed by the pellet container was still intact after the drop test.

It was verified that the loss or spread of radioactive contents or a reduction in the shielding effect, leading to an increase in the dose rate of more than 20% at any point on the outside of the package, is thus excluded /R14/.

Drop test as per Para. 6.4.15.4 b) (ICAO TI 6;7.14.4 b)):

The test is not relevant owing to the design of the package (metal).

Drop test as per Para. 6.4.15.4 c) (ICAO TI 6;7.14.4 c)):

The test is not relevant owing to the design of the package (metal).

Stacking test:

ADR/RID: 6.4.15.5 **IMDG Code: 6.4.15.5** **TS-R-1 (ST-1, Revised) No. 723**	*Stacking test: Unless the shape of the packaging effectively prevents stacking, the specimen must be subjected, for a period of 24 h, to a compressive load equal to the greater of the following:* *a) the equivalent of 5 times the mass of the actual package; and* *b) the equivalent of 13 kPa multiplied by the vertically projected area of the package.* *The load must be applied uniformly to two opposite sides of the specimen, one of which must be the base on which the package would typically rest.*
ICAO TI: 6;7.14.5	*Stacking test: unless the shape of the packaging effectively prevents stacking, the specimen must be subjected, for a period of 24 hours, to a compressive load equal to the greater of the following:* *a) the equivalent of 5 times the mass of the actual package; and* *b) the equivalent of 13 kPa multiplied by the vertically projected area of the package.* *The load must be applied uniformly to two opposite sides of the specimen, one of which must be the base on which the package would typically rest.*

Determining condition:

a) Total mass of the loaded ANF-50 shipping container: 248 kg

⇒ This gives the equivalent of five times the mass of: 1,240 kg

b) The vertically projected face of the container comes to approx. 0.507 m^2

⇒ This gives an equivalent mass of: 660 kg

It is decisive that the stacking test corresponds to a).

The verification was produced by calculation and documented in /R13/. It was verified that the package conforms to the requirements.

The pellets or the scrap / powder box loaded with pellet scrap, abraded pellet material, or uranium oxided powder in the interior of the packaging are not affected by stacking. The loss or spread of radioactive contents or a reduction in the shielding effect, leading to an increase in the dose rate of more than 20% at any point on the outside of the package, is thus excluded.

Penetration test:

ADR/RID: 6.4.15.6 **IMDG Code: 6.4.15.6** **TS-R-1 (ST-1, Revised) No. 724**	*Penetration test: The specimen must be placed on a rigid, flat, horizontal surface which will not move significantly while the test is being carried out.* *a) A bar of 3.2 cm in diameter with a hemispherical end and a mass of 6 kg must be dropped and directed to fall, with its longitudinal axis vertical, onto the centre of the weakest part of the specimen, so that, if it penetrates sufficiently far, it will hit the containment system. The bar must not be significantly deformed by the test performance.* *b) The height of drop of the bar measured from its lower end to the intended point of impact on the upper surface of the specimen must be 1 m.*
ICAO TI: 6;7.14.6	*Penetration test: the specimen must be placed on a rigid, flat, horizontal surface which will not move significantly while the test is being carried out.* *a) A bar of 3.2 cm in diameter with a hemispherical end and a mass of 6 kg must be dropped and directed to fall, with its longitudinal axis vertical, onto the centre of the weakest part of the specimen, so that, if it penetrates sufficiently far, it will hit the containment system* *b) The height of the drop of the bar measured from its lower end to the intended point of impact on the upper surface of the specimen must be 1 m.*

The penetration test was carried out with a bar of 3.2 cm in diameter, with a hemispherical end and a mass of 6 kg. In the test, the bar was dropped vertically from a height of 1.2 m onto the surface of the case for pellet box.

Of the components that are accessible from outside, the lining plates of the side walls of the case for pellet box have the smallest thickness. The thickness is 1.5 mm. The lining plate did not show any significant damage after the penetration test /R14/.

8.2.5 Tests for demonstrating ability to withstand accident transport conditions

ADR/RID: 6.4.17.1 **IMDG Code: 6.4.17.1** **TS-R-1 (ST-1, Revised) No. 726**	*The specimen must be subjected to the cumulative effects of the tests specified in 6.4.17.2 and 6.4.17.3, in that order. Following these tests, either this specimen or a separate specimen must be subjected to the effect(s) of the water immersion test(s) as specified in 6.4.17.4 and, if applicable, 6.4.18.*
ICAO TI: 6;7.16.1	*The specimen must be subjected to the cumulative effects of the tests specified in 6;7.16.2 and 6;7.16.3, in that order. Following these tests, either this specimen or a separate specimen must be subjected to the effect(s) of the water immersion tests(s) as specified in 6;7.16.4 and, if applicable, 6;7.17.*

Conformity to the requirements has been demonstrated in the relevant Sections. Verification of conformity to the requirement as per 6.4.18 (ICAO TI 6;7.17) is not necessary, as this requirement refers to packages type B(U) and type B(M) with a content of more than 10^5 A_2 and for type C.

Mechanical test:

ADR/RID: 6.4.17.2 **IMDG Code: 6.4.17.2** **TS-R-1 (ST-1, Revised) No. 727**	*Mechanical test: The mechanical test consists of three different drop tests. Each specimen must be subjected to the applicable drops as specified in 6.4.8.7 or 6.4.11.12. The order in which the specimen is subjected to the drops must be such that, on completion of the mechanical test, the specimen shall have suffered such damage as will lead to the maximum damage in the thermal test which follows.* a) *For drop I, the specimen must drop onto the target so as to suffer the maximum damage, and the height of the drop measured from the lowest point of the specimen to the upper surface of the target must be 9 m. The target must be as defined in 6.4.14.* b) *For drop II, the specimen must drop so as to suffer the maximum damage onto a bar rigidly mounted perpendicularly on the target. The height of the drop measured from the intended point of impact of the specimen to the upper surface of the bar must be 1 m. The bar must be of solid mild steel of circular section, (15.0 cm Â± 0.5 cm) in diameter and 20 cm long unless a longer bar would cause greater damage, in which case a bar of sufficient length to cause maximum damage must be used. The upper end of the bar must be flat and horizontal with its edges rounded off to a radius of not more than 6 mm. The target on which the bar is mounted must be as described in 6.4.14.* c) *For drop III, the specimen must be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass must consist of a solid mild steel plate 1 m by 1 m and must fall in a horizontal attitude. The height of the drop must be measured from the underside of the plate to the highest point of the specimen. The target on which the specimen rests must be as defined in 6.4.14.*
ICAO TI: 6;7.16.2	*Mechanical test: the mechanical test consists of three different drop tests. Each specimen must be subjected to the applicable drops as specified in 6;7.7.7 or 6;7.10.12. The order in which the specimen is subjected to the drops must be such that, on completion of the mechanical test, the specimen must have suffered such damage as will lead to the maximum damage in the thermal test which follows:* a) *For drop I, the specimen must drop onto the target so as to suffer the maximum damage, and the height of the drop measured from the lowest point of the specimen to the upper surface of the target must be 9 m. The target must be as defined in 6;7.13;* b) *For drop II, the specimen must drop so as to suffer the maximum damage onto a bar rigidly mounted perpendicularly on the target. The height of the drop measured from the intended point of impact of the specimen to the upper surface of the bar must be 1 m. The bar must be solid mild steel of circular section, (15.0 ± 0.5 cm) in diameter and 20 cm long unless a longer bar would cause greater damage, in which case a bar of sufficient length to cause maximum damage must be used. The upper end of the bar must be flat and horizontal with its edges rounded off to a radius of not more than 6 mm. The target on which the bar is*

	mounted must be as described in 6;7.13. c) *For the drop III, the specimen must be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass must consist of a solid mild steel plate 1 m by 1 m and must fall in horizontal attitude. The height of the drop must be measured from the underside of the plate to the highest point of the specimen. The target on which the specimen rests must be as defined in 6;7.13.*

Drop tests II and III were carried out in accordance with the test programme /R13/.

Drop test I is not required for the present packing, as the mass of the package is smaller than 500 kg.

Following the drop tests, specimens 1 to 4 were inspected and measured and the results documented /R11/, /R14/.

The criticality safety analysis /R7/ is based on the outcomes of survey report /R11/.

Thermal test:

ADR/RID:
6.4.17.3

IMDG Code:
6.4.17.3

TS-R-1
(ST-1, Revised)
No. 728

Thermal test: The specimen must be in thermal equilibrium under conditions of an ambient temperature of 38 °C, subject to the solar insolation conditions specified in Table 6.4.8.5 and subject to the design maximum rate of internal heat generation within the package from the radioactive contents. Alternatively, any of these parameters are allowed to have different values prior to and during the test, providing due account is taken of them in the subsequent assessment of package response.

The thermal test must then consist of:

a) *Exposure of a specimen for a period of 30 minutes to a thermal environment which provides a heat flux at least equivalent to that of a hydrocarbon fuel/air fire in sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and an average temperature of at least 800 °C, fully engulfing the specimen, with a surface absorptivity coefficient of 0.8 or that value which the package may be demonstrated to possess if exposed to the fire specified, followed by.*

b) Exposure of the specimen to an ambient temperature of 38 °C, subject to the solar insolation conditions specified in Table 6.4.8.5 and subject to the design maximum rate of internal heat generation within the package by the radioactive contents for a sufficient period to ensure that temperatures in the specimen are everywhere decreasing and/or are approaching initial steady state conditions. *Alternatively, any of these parameters are allowed to have different values following cessation of heating, providing due account is taken of them in the subsequent assessment of package response.*

During and following the test the specimen must not be artificially cooled and any combustion of materials of the specimen must be permitted to proceed naturally.

Table 6.4.8.5 – Insolation data

Case	*Form and location of surface*	*Insolation for 12 hours per day (W/m^2)*
1	*Flat surfaces transported horizontally - downwards facing*	*0*
2	*Flat surfaces transported horizontally - upward facing*	*800*
3	*Surfaces transported vertically*	*200[a]*
4	*Other downwards facing (not horizontal)*	*200[a]*
5	*All other surfaces*	*400[a]*

[a)] *alternatively, a sine function may be used, with an absorption coefficient adopted and the effects of possible reflection of neighbouring objects neglected.*

ICAO TI: 6;7.16.3

Thermal test: the specimen must be in thermal equilibrium under conditions of an ambient temperature of 38 °C, subject to the solar insolation conditions specified in Table 6-4 and subject to the design maximum rate o internal heat generation within the package from the radioactive contents. Alternatively, any of these parameters are allowed to have different values prior to and during the test, provided due account is taken of them in the subsequent assessment of package response. The thermal test must then consists of:

a) Exposure the specimen for a period of 30 minutes to a thermal environment which provides a heat flux at least equivalent to that of a hydrocarbon fuel/air fire in sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and an average temperature of at least 800 °C, fully engulfing the specimen, with a surface absorptivity coefficient of 0.8 or that value which the package may be demonstrated to possess if exposed to the fire, followed by;

b) Exposure of the specimen to an ambient temperature of 38 °C, subject to the solar insolation conditions specified in Table 6-4 and subject to the design maximum rate of internal heat generation within the package by the radioactive contents for a sufficient period to ensure that temperatures in the specimen are everywhere decreasing and/or are approaching initial steady state conditions. Alternatively, any of these parameters are allowed to have different values following cessation of heating, provided due account is taken of them in the subsequent assessment of package response.

During and following the test, the specimen must not be artificially cooled and any combustion of material of the specimen must be permitted to proceed naturally.

Table 6-4. Insulation data

Case	*Form and location of surface*	*Insolation for 12 hours per day (W/m²)*
1	*Flat surfaces transported horizontally – downwards facing*	*0*
2	*Flat surfaces transported horizontally – upward facing*	*800*
3	*Surfaces transported vertically*	*200**
4	*Other downwards facing (not horizontal)*	*200**
5	*All other surfaces*	*400**

** alternatively, a sine function may be used, with an absorption coefficient adopted and the effects of possible refection fro neighbouring objects neglected.*

A thermal test was not carried out. To assess the effects of the thermal test, the temperature gradient up to the pellets in the pellet container was determined by calculation /R16/. To do this, the ANF-50 shipping container not subjected to any test was looked at for preliminary observation. Once the results of the required preceding tests for demonstrating ability to withstand accident transport conditions had been obtained, they were integrated into the calculations.

A pellet temperature of approx. 162 °C was ascertained for an ANF-50 shipping container, not subjected to any test, with a minimum load and a pellet temperature of approx. 147 °C for a shipping container with a maximum load.

Pellet temperatures of approx. 1 °C higher are yielded for an ANF-50 shipping container subjected to the tests for demonstrating ability to withstand accident transport conditions as per the relevant traffic regulations.

The oxidation characteristics of UO_2 pellets and of Gd_2O_3/UO_2 pellets were investigated in the laboratory at a temperature of 240 °C.

The oxidation characteristics of the pellets are determined by:

- pellet density
- grain size
- surface / volume ratio
- Gd_2O_3 content.

The pellets were selected for the tests with reference to the basic pellet parameters.

The precise test conditions and results of the tests are shown in /R17/.

Heating in accordance with the test conditions has no unfavourable effects with regard to criticality. The release of fuel can likewise be ruled out.

ADR/RID: 6.4.17.4 **IMDG Code: 6.4.17.4** **TS-R-1 (ST-1, Revised) No. 729**	*Water immersion test: The specimen must be immersed under a head of water of at least 15 m for a period of not less than eight hours in the attitude which will lead to maximum damage. For demonstration purposes, an external gauge pressure of at least 150 kPa must be considered to meet these conditions.*
ICAO TI: 6;7.16.4	*Water immersion test: the specimen must be immersed under a head of water of at least 15 m for a period of not less than eight hours in the attitude which will lead to maximum damage. For demonstration purposes, an external gauge pressure of at least 150 kPa must be considered to meet these conditions.*

The specimen of a pellet container was subjected to the water immersion test. Impermeability under the test conditions was verified /R14/.

8.2.6 Water leakage test for packages containing fissile material

ADR/RID: 6.4.19.1 **IMDG Code: 6.4.19.1** **TS-R-1 (ST-1, Revised) No. 731**	*Packages for which water in-leakage or out-leakage to the extent which results in greatest reactivity has been assumed for purposes of assessment under 6.4.11.7 to 6.4.11.12 must be excepted from the test.*
ICAO TI: 6;7.18.1	*Packages for which water in-leakage or out-leakage to the extent which results in the greatest reactivity has been assumed, for purposes of assessment under 6;7.10.7 to 6;7.10.12, must be excepted from the test.*
ADR/RID: 6.4.19.2 **IMDG Code: 6.4.19.2** **TS-R-1 (ST-1, Revised) No. 732**	*Before the specimen is subjected to the water leakage test specified below, it must be subjected to the tests in 6.4.17.2 (b), and either 6.4.17.2 (a) or (c) as required by 6.4.11.12, and the test specified in 6.4.17.3.*
ICAO TI: 6;7.18.2	*Before the specimen is subjected to the water leakage test specified below, it must be subjected to the tests in 6;7.19.2b) and either 6;7.16.2a) or c) as required by 6;7.10.12 and the test specified in 6;7.16.3.*
ADR/RID: 6.4.19.3 **IMDG Code: 6.4.19.3** **TS-R-1 (ST-1, Revised) No. 733**	*The specimen must be immersed under a head of water of at least 0.9 m for a period of not less than 8 hours and in the attitude for which maximum leakage is expected.*
ICAO TI: 6;7.18.3	*The specimen must be immersed under a head of water of at least 0.9 m for a period of not less than eight hours and in the attitude for which maximum leakage is expected.*

The leak-in of water was assumed in the criticality safety analysis /R7/. Carrying out the water immersion test is therefore not necessary.

9 Deviations from the specimen and improvements applied to the real ANF-50 series shipping container

Experience was accumulated during construction, handling and in the drop tests with the ANF-50 shipping container specimens and improvements for the design of the series container derived from this.

These improvements are implemented on the series container compared with the specimen, without new drop tests being carried out. The modifications of the specimen to give the series container have been designed so that the deformation on the specimen also covers the series container in respect of criticality safety analysis.

The improvements to the specimen for the series container are described in /R18/. The influence of the modifications on the results of the drop tests were assessed /R18/.

10 References

	References
/1/	GGVSE Ordinance governing the domestic and cross-border conveyance of dangerous goods by road and railway (Gefahrgutverordnung Straße und Eisenbahn – GGVSE)
/2/	ADR - 2005 European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) of 30 September 1957, Appendices A and B.
/3/	RID - 2005 Requirements of the Ordinance for the international conveyance of dangerous goods by rail (RID), Appendices A and B.
/4/	Ordinance governing the conveyance of dangerous goods with seagoing vessels (Gefahrgutverordnung See – GGVSee)
/5/	IMDG Code, 2002 edition, Amendment 31-02 and 1st corrigendum 2003 International Maritime Dangerous Goods Code.
/6/	IAEA, Safety Standards Series No. TS-R-1 (ST-1, Revised) Regulations for the Safe Transport of Radioactive Material 1996 Edition (Revised)
/7/	Technical Instructions for the Safe Transport of Dangerous Goods by Air 2005-2006 Edition, Doc 9284, AN/905 Approved and published by decision of the Council of ICAO
/8/	Quality assurance programme for the design, construction, manufacture, testing, documentation, maintenance, inspection as well as the use and for all operations during transport and transport-related interim stops of packaging for the transport of radioactive material, Quality assurance programme ANFG-11.107 (02)
/9/	Technical Directive on Measures for Quality Assurance (QA) and Quality Monitoring (QM) for Packaging for the Transport of Radioactive Material (TRV 006), VkBl. 1991 p. 233
/10/	AD-Merkblatt W10 Materials for low temperatures – Ferrous materials May 2000 edition

	References
/11/	DIN EN 10088-2 Stainless steels Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes August 1995 edition
/12/	DIN 17458, replaced by: DIN EN 10216-5 Seamless steel tubes for pressure purposes Technical delivery conditions – Stainless steel tubes November 2004 edition

The references in this safety analysis identified with /RX/ refer to the safety report No. ANFG-11.105 (05) and are included in the list of appendices (/RX/ corresponds to register X in the list of appendices).

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The English translation of the criticality safety analysis **ANFG-5.061 (11) Rev. 2** is equivalent to the German original of the criticality safety analysis **ANFG-5.060 (11) Rev. 2.**

Criticality safety analysis for the transport approval of ANF-50 shipping containers

[signature]	07 December 2004
Prepared: Dr. B. Bendick	Date
[signature]	09. December 2004
Released: R. Witten	Date

Reasons for creating the 2nd revision:

1. A new analysis model has been created for pellets as bulk goods. Pellets as bulk goods and pellet chips are modelled as spheres in a hexagonal array. Using this approach, all variants of pellet chips and pellets as bulk goods are covered.

2. In respect of the construction material, the manganese component has been removed without replacement. Manganese is a weak absorber. The manganese component in the construction material actually used amounts to max. 1% wt. and is therefore less than the manganese component in the stainless steel (SS304) used in the Standard Library of the SCALE Code.

3. The density of the insulating material has been increased from 0.3 g/cm^3 to 0.531 g/cm^3.

4. The array size of the damaged ANF-50 shipping container size has been reduced from 6 x 6 x 9 (324 x ANF-50 shipping containers) to 6 x 6 x 8 (288 x ANF-50 shipping containers) For the Transport Index of 0.4 an array size of 250 ANF-50 shipping containers is sufficient.

5. All tables and results graphics have been modified.

6. The incorrect dimensional data in the figures has been corrected. The input sheets were without errors.

7. The text was modified in accordance with the new model assumptions and results.

The changes are not marked in the report.

Table of contents

Summary

This criticality safety analysis verifies that the ANF-50 shipping container remains subcritical at a Transport Index of 0.4. Loads and part loads with pellets on pellet trays, pellets as bulk goods and pellet chips of up to 14.5 kg and uranium oxide powder up to 14.5 kg with a max. enrichment of 5 wt.-% ^{235}U are investigated. In respect of the pellets the permitted diameter is between 7.0 mm and 10.0 mm; for the pellet chips all chip sizes are permitted. In terms of moderation, the ANF-50 shipping container has no restrictions. The calculations also conservatively cover pellets and uranium oxide powder with neutron poisons (e.g. gadolinium).

The enrichment refers to the maximum enrichment that may not be exceeded, even when measurement tolerances are taken into account. A mixed load consisting of an individual ANF-50 shipping container with pellets on pellet trays, pellets as bulk goods and pellet chips / uranium oxide powder is not permitted. However, it is permissible to have an array of ANF-50 shipping containers with different loading in all ANF-50 shipping containers, but with identical loading within one ANF-50 shipping container.

1 Introduction and summary

In the present criticality safety analysis it is shown that the ANF-50 shipping container with a Transport Index of 0.4 satisfies the relevant IAEA requirements in /1/ and remains sub-critical. Loads with

- pellets up to a max.UO_2 density of 10.96 g/cm^3 on pellet trays within the diameter range between 7.0 mm and 10.0 mm,
- pellets and pellet chips without size restriction up to a max. UO_2 density of 10.96 g/cm^3 and up to a maximum mass of 14.5 kg as bulk goods,
- uranium oxide powder without density restrictions up to a maximum mass of 14.5 kg

are investigated with no restrictions in terms of moderator volume (water is used as moderator). The max. enrichment is 5% wt. ^{235}U.

In terms of the uranium oxide powder, the calculations are based on the most reactive uranium compound, i.e. uranium dioxide. This means that the calculations also cover all other uranium oxide compounds.

The pellets on pellet trays are fixed in the clamping device. Pellets as bulk goods, pellet chips and uranium oxide powder are contained in a can.

The construction material of the ANF-50 shipping container is taken into account in the calculations. The pellet trays are of particular significance. The minimum plate thickness must not be less than 0.6 mm. The maximum height of fissile material in the ANF-50 shipping container is 104.0 mm.

The structure and the relevant dimensions of the ANF-50 shipping container are shown in Figs. 1 to 9. In the event of discrepancies between the dimensions in the figures and the dimensions in the design drawings, the dimensions in the figures are binding.

2 Calculation code employed

The criticality safety calculations described below were performed with the SCALE 4.4a program system, using

- the 44-group neutron cross-section library 44GROUPNDF5 of this system derived from ENDF/BV data and
- the BONAMI-S, NITAWL-II and KENO VI program modules.

The BONAMI-S and NITAWL-II modules handle self-shielding using the Bondarenko or Nordheim method. BONAMI-S is always used here in conjunction with the NITAWL-II module which converts the problem-dependent data supplied by BONAMI-S into a cross-section working library. The KENO VI module solves the multigroup form of the Boltzmann transport equation as an eigenvalue problem by means of Monte Carlo techniques.

The SCALE-4/KENO code is verified in numerous ways by checking a wide variety of critical experiments (see /2/ to /5/).

For the validation, criticality experiments with fuel rod grids with various water fissile ratios are used. The individual results are shown in Table 9. The results lead to a slight underestimate of the calculated k_{eff} values for rod configurations.

3 Modelling of the ANF-50 shipping container with fissile material configuration

The ANF-50 shipping container consists of a shipping frame closed in the form of a grid, a receptacle and a pellet container with pellet trays or can. The receptacle is welded to the shipping frame by sheet steel corner plates. The pellet container is located inside the receptacle and can be removed from the receptacle for loading and unloading.

The ANF-50 shipping container is constructed of stainless steel and fitted with insulating plates. For the insulating plates a mixture of aluminium oxide (29%) and silicium oxide (70%) is used with a max. density of 0.531 g/cm^3 and therefore covers all lower densities of insulating plate. For the stainless steel, the stainless steel material SS304 without manganese content (manganese is a weak absorber and should not be included in the calculations) is taken from the standard library of SCALE Codes.

3.1 Shipping frame

The shipping frame of the ANF-50 shipping container is a welded construction of stainless steel tubes and stainless steel flat sections. Four vertical tubes are joined at the upper and lower ends to four horizontal tubes. The four sides are each stiffened by a diagonal tube and closed in the form of a grid by longitudinal flat sections. The bottom is stiffened by two diagonal tubes and likewise closed in the form of a grid by longitudinal flat sections. At the bottom of the vertical tubes, solid feet of the same diameter are integrated to allow stacking of the ANF-50 shipping containers in conjunction with the angles welded to the top.

Sheet steel corner plates are welded to the corners of the top for attaching the protective cover. The protective cover consists of a frame of rectangular sections, the top of which is faced with a cover plate. The protective cover is screwed to the supporting frame at the four angled brackets at the corners.

For reasons of simplicity, the calculation models only model the horizontal and vertical tubes and the feet – but as tubes rather than solid material. Stainless steel is assumed as the material. These simplifications are permissible because stainless steel is a weak neutron absorber. Further, the shipping frame is only included in the calculations for undamaged ANF-50 shipping containers.

Details regarding model dimensions are shown in Fig. 1.

3.2 Receptacle

The receptacle consists of a sandwich structure with an external and internal stainless steel cover plate. Located between the cover plates is a welded structure of austenitic tubes and rectangular tubes as well as austenitic round, angular and flat sections. The remaining cavities between the cover plates are filled as far as possible with inorganic insulating material.

The receptacle cover is also formed as a sandwich structure with an external and internal stainless steel cover plate and inorganic insulating material in between. In order to simplify the model, the cover projections were not modelled and the cover was only modelled up to the external walls of the receptacle.

The modelled details of the receptacle in different sectional views are shown in Figs. 2a to 2d and in Figs. 3 and 4. The modelled cover dimensions are shown in Fig. 5.

3.3 Pellet container

The function of the pellet container is to accommodate pellets on pellet trays in the supporting frame with clamping device, pellets as bulk goods in a can or uranium oxide powder in a can. The internal dimensions are 282 mm x 155 mm x 319 mm (width x height x length). The jacket of the pellet container consists of 2 mm thick stainless steel plate, the bottom consists of 3 mm thick stainless steel plate and the cover consists of 6 mm stainless steel plate. The cover is screwed to the 5 mm thick flange, which is welded to the pellet container jacket.

The model and dimensions used are shown in Fig. 6.

3.4 Modelling of the supporting frame with barrier plates

The function of the supporting frame is to accommodate laden and unladen pellet trays or laden / unladen cans. It consists of a baseplate, four attachment plates and the two barrier plates. The entire unit is constructed of stainless steel.

Details of the modelled dimensions are given in Fig. 7.

3.5 Modelling of the clamping device

The function of the clamping device is to fix in place the consignment of fissile material. It consists of a clamping plate, fixing screws and fixing dies. The entire unit is constructed of stainless steel.

The clamping device is connected to the supporting frame by two bars that are positioned in the bores of the supporting frame attachment plates. The various height options are achieved by the configuration of the bores in the attachment plates and ensure that the height of the fissile material consignment cannot exceed 104 mm. The four manually adjustable fixing screws enable the pellet trays or can to be pressed against each other such that the fissile material is securely fixed in place.

Details of the modelled dimensions are given in Fig. 8.

3.6 Pellet tray

The pellet trays are wave-shaped, are manufactured of stainless steel and have a minimum plate thickness of 0.6 mm. The wave shape is designed so that the pellets are arranged in a hexagonal configuration when the pellet trays are stacked.

For the calculations the pellet trays are modelled in segment form over the entire tray width. The model is designed so that the tray channels are extended as the centre-to-centre pellet distance changes. This model concept enables the centre-to-centre distance of the pellets with pellet trays to be varied in the discrete model used here.

Details are given in Fig. 9.

3.7 Modelling of the pellets on pellet trays

Pellets with a diameter range between 7.0 mm and 10.0 mm are transported on trays. The pellet density is project-dependent. There can be a theoretical maximum UO_2 density of 10.96 g/cm^3. As a conservative basis for the calculations, a maximum theoretical UO_2 density of 10.96 g/cm^3 is assumed.

The pellet trays consist of 21 parallel rows on which the pellets are positioned as columns. Depending on the loading strategy, the pellets may not butt against each other and not all pellet tray rows may be loaded with pellets.

Depending on the pellet diameter, up to 14 pellet trays can be stacked. The trays are stacked in layers so that after each pellet tray there is a pellet layer, which is offset in relation to the underlying pellet layer. The pellet trays lie directly on the pellets, therefore the stacking height depends on the pellet diameter and on the envisaged loading strategy – partial loading or full loading of the ANF-50 shipping container. However, the clamping device is designed so that the maximum height of the fissile material does not exceed 104 mm.

In the calculations under each pellet layer a pellet tray is modelled whose channels can be slightly extended in the model. To ensure that the calculations cover axial gaps in the pellet columns, dishing in the pellets and partial loading of the pellet trays, a hexagonal pellet configuration is assumed. The pellet column length is 306 mm. The centre-to-centre distance of the pellet columns is varied over the height and width of the clamping device. With this assumption, the pellet trays no longer lie on the underlying pellet layer as is the case with the real model.

3.8 Stainless steel can for uranium oxide powder, pellets as bulk goods and pellet chips

The ANF-50 shipping container is provided with a can for the transport of uranium oxide powder, pellets as bulk goods and pellet chips. For the calculations an internal can diameter of 230 mm and an internal can height of 104 mm are assumed. These dimensions are greater than the actual can dimensions and are therefore conservative.

In the calculations with uranium oxide powder the density of the uranium oxide powder is varied. The calculations with pellets as bulk goods and with pellet chips are performed in a chip model. The nuclear material is here assumed as spheres and modelled in a hexagonal configuration. The sphere diameter and the sphere centre-to-centre distance are varied.

4 Criticality safety of an individual undamaged ANF-50 shipping container

The pellet container and receptacle of the undamaged ANF-50 shipping container form the enclosure system for the pellets on pellet trays, pellets as bulk goods, pellet chips and uranium oxide powder. One ANF-50 shipping container is classified as an undamaged ANF-50 shipping container displaying no or minor, insignificant damage to the shipping frame. The minor damage that may occur under normal transportation conditions was determined in the test phase of the ANF-50 shipping container by the drop from a height of 1.3 m (1.2 m = required height). The results of the drop tests led to small dents on the shipping container frame. The enclosure system was not damaged. The damage was rated as so minor that the dimensions were not recorded. For this reason the calculations for the undamaged ANF-50 shipping container are performed using the design dimensions.

The calculations for the individual container are only performed for an ANF-50 shipping container loaded with pellets on pellet trays. For pellet scrap, pellet chips and uranium oxide powder, the loading of an individual ANF-50 shipping container is well below the safe mass so that there is no need here for individual verification.

For loading with pellets, the pellets are modelled arranged hexagonally as 306 mm long columns and over the maximum stacking height of 104 mm. The pellet column centre-to-centre distance is varied. This approach ensures that all partial loads, gaps in the pellet columns and dishing of the pellets are covered by the calculations. The complete ANF-50 shipping container is flooded. A 300 mm water reflector is modelled around the ANF-50 shipping container.

The results are included in Table 1 for pellet diameters of 7 mm and 10 mm. This shows that the multiplication factor increases with increasing pellet column centre-to-centre distance up to a maximum value and then decreases again. The maximum multiplication factor occurs with a pellet diameter of 10 mm and is 0.5970 (0.5940 + 2 * 0.0015).

Subcriticality is therefore verified for all loading strategies for a single undamaged ANF-50 shipping container.

5 Criticality safety of the undamaged shipping unit

According to IAEA Safety Series No. 6 and Safety Standards Series No. ST-1 (see Ref. /1/), adequate subcriticality is to be demonstrated under the stipulated transport conditions for the densest fully reflected configuration that can be formed from five times the number of shipping containers intended for one shipping unit.

The envisaged Transport Index is 0.4, i.e. the envisaged shipping unit contains 125 ANF-50 shipping containers. Subcriticality is therefore demonstrated for at least 625 ANF-50 shipping containers. The calculations assume an array of 9 x 9 x 9 (i.e. 729) ANF-50 shipping containers. A 300 mm thick water reflector is positioned around the configuration on all sides.

The configuration of the 729 ANF-50 shipping containers is shown in Fig. 10.

5.1 Loading with pellets on pellet trays

With regard to the loading of ANF-50 shipping containers, loading restrictions and moderator volume (water is used as the moderator) in the pellet container are not envisaged. The maximum multiplication factor for the shipping container configuration that is normally found to occur in partial loads therefore needs to be determined.

For the calculations with pellets on pellet trays, the pellets are modelled configured hexagonally as 306 mm long columns and over the maximum stacking height of 104 mm. The pellet column centre-to-centre distances are varied. This approach ensures that all partial loads, i.e. including gaps in the pellet columns and dishing in the pellets, are also included in the calculations. The pellet containers are flooded from the bottom up to and including the top pellet layer. Provided it is not occupied by construction materials, the remaining volume in the pellet containers is modelled in the parameter studies as a vacuum or as flooded with water. The interspersed moderation between the ANF-50 shipping container is varied. Water with various densities is assumed as the interspersed moderator.

The results are listed in Table 2 and are shown in Fig. 11 for pellet diameters of 7 mm, 8 mm, 9 mm and 10 mm for various pellet column centre-to-centre distances, flooding of the pellet container from the bottom up to and including the top pellet layer and vacuum between the ANF-50 shipping containers. It is shown that the multiplication values increase with increasing pellet diameter. For each pellet diameter there is an individual maximum multiplication value dependent on the pellet column centre-to-centre distance. The maximum multiplication factor occurs with a pellet diameter of 10 mm and a pellet column centre-to-centre distance of 18 mm. This factor is 0.7122 (0.7098 ± 0.0012).

For pellet diameter of 10 mm and pellet column centre-to-centre distance of 17 mm calculations are made with interspersed moderation between the ANF-50 shipping containers. In the first case the pellet containers are flooded from the bottom up to and including the top pellet layer, and in the second case over the entire internal volume. The results are listed in Table 3 and shown in Fig. 12. The results show that the multiplication factors decrease with increasing interspersed moderation density. It is also evident that flooding of the pellet containers results in multiplication factors that are lower than with partially flooded pellet containers.

Although incorrect stacking of the ANF-50 shipping containers can be ruled out because of the design, calculations are also performed for this scenario. In order to simplify the model, calculations are only performed with the pellet diameter of 10 mm, flooding of the pellet container from the bottom up to and including the top pellet layer and variation of the interspersed moderation between the ANF-50 shipping containers. Incorrect stacking is modelled by removing the shipping frame feet.

The results are shown in Table 3. As expected, the multiplication values are higher than for the calculations with shipping frame feet. The results here also show that the multiplication factors decrease with increasing interspersed moderation density. The maximum multiplication value occurs with no interspersed moderation between the ANF-50 shipping container and is 0.7363 (0.7341 + 2 * 0.0011).

Subcriticality is therefore verified for an array of undamaged ANF-50 shipping containers laden with pellets on pellet trays.

5.2 Loading with pellets and pellet chips as bulk goods in the can

Pellets as bulk goods and pellet chips are sent in the can without loading restrictions in terms of moderator volume. For reasons of model simplicity, no restriction in terms of mass is assumed for verification of subcriticality. This method is permissible because of its conservative approach. The pellets as bulk goods and the pellet chips are modelled uniformly as spheres in a hexagonal configuration. The sphere diameters and the sphere centre-to-centre distances are varied. The pellet containers are assumed to be flooded.

Table 4 gives the results for sphere diameters of 0.1 mm, 0.2 mm and 0.6 mm. Comparison of the multiplication factors shows that the multiplication factors are independent of the sphere diameter. The maximum value occurs with a water fissile ratio of 3.5 and is 0.6250 (0.6226 + 2 * 0.0012). Calculations with interspersed moderation between the ANF-50 shipping containers are not performed because the results of the calculations in Section 5.1 already show that interspersed moderation decreases the multiplication factors. Because of the low multiplication factors, no additional calculations are performed for the model scenarios of partial flooding of the pellet containers and incorrect stacking of the ANF-50 shipping containers

Subcriticality is therefore verified for an array of undamaged ANF-50 shipping containers loaded with pellets as bulk goods and for pellet chips in a can.

5.3 Loading with uranium oxide powder in the can

Uranium oxide powder of every oxidation level is sent in the can without loading restrictions in terms of moderator volume. For reasons of model simplicity, no restriction in terms of mass is assumed for verification of subcriticality. This method is permissible because of its conservative approach.

The maximum multiplication factor is determined by variation of the powder density. The most reactive uranium compound, uranium dioxide, is assumed for the calculations. This covers all other uranium oxide compounds. The uranium dioxide is filled with residual water so that a saturated uranium dioxide powder is created. In the first scenario the pellet container is modelled as a vacuum, in the second scenario it is modelled flooded up to the top edge of the can and in the third scenario it is modelled flooded over the entire internal volume. Because the multiplication factors decrease with increasing interspersed moderation (see results in Point 5.1), no calculations are performed with interspersed moderation between the ANF-50 shipping containers.

The results are shown in Table 5. The maximum multiplication factor is 0.6198 (0.6182 + 2 * 0.0008) for a uranium dioxide powder density of 2.7 g/cm^3 and flooding of the pellet containers.

Subcriticality is therefore verified for an array of undamaged ANF-50 shipping containers laden with uranium dioxide powder in a can.

6 Criticality safety of the damaged shipping unit

According to IAEA Safety Series No. 6 and Safety Standards Series No. ST-1 (see Ref. /1/), subcriticality is to be demonstrated under accident conditions for the most reactive, fully reflected array that can be formed from two times the number of shipping containers intended for one shipping unit.

The envisaged Transport Index is 0.4. Therefore, subcriticality needs to be verified for the most reactive, completely reflected array of 250 ANF-50 shipping containers under accident conditions. For the calculations an array of 6 x 6 x 8 (i.e. 288) ANF-50 shipping containers are stacked on top of each other.

As can be seen from the analysis of the tests /6/, the shipping frame is severely bent. Externally and internally the receptacle and the pellet container remain undamaged. For this reason the calculations are performed for the array of a damaged shipping unit without shipping frame. The cover overhang of the ANF-50 shipping container is not modelled. This method leads to conservative results because the damaged ANF-50 shipping containers come closer together than is possible in reality.

The investigations of fire behaviour /7/8/ show that there is no oxidation of the pellets and pellet chips and that therefore there is no disintegration into uranium oxide powder. The scenario of oxidation is therefore not included in the calculations with pellets and pellet chips. Dimensionally stable pellets and pellet chips are used in the calculations. In terms of the uranium oxide powder, the most reactive uranium oxide compound, i.e. uranium dioxide, is used in the calculations. For this reason oxidation does not need to be considered.

6.1 Loading with pellets on pellet trays

Various loading strategies are assumed in the models for pellets on pellet trays. According to previous experience, the maximum multiplication occurs in the case of partial loading. For the calculations the pellets on pellet trays are modelled arrayed hexagonally as 306 mm long columns and over the maximum stacking height of 104 mm. Calculations are performed with pellets with pellet diameters of 7 mm, 8 mm, 9 mm and 10 mm. The pellet column centre-to-centre distance is varied. This approach ensures that all partial loads, axial gaps in the pellet columns and dishing in the pellets are included in the calculations.

The drop tests /6/ have clearly shown that no pellets can penetrate into the clamping area. Because of the special design, the possibility of penetration of pellets into this area is reliably prevented. Unless occupied by technical equipment, the clamping area is therefore just modelled as a vacuum or filled with water.

The drop tests /6/ showed that the pellets cannot fall out of the pellet trays. Because of the weaker construction, more conservative calculations are performed with pellets that have fallen out of the pellet trays. A hexagonal configuration is also used for the fallen pellets. With regard to pellet diameter and pellet centre-to-centre distance, the same dimensions are assumed as on the pellet trays. The pellet containers are flooded up to the top stacking edge. Fig. 13 shows a typical pellet array.

The alignment of the individual receptacles in an ANF-50 shipping container configuration is varied over the height of the array, i.e. calculations are performed with the same stacking alignment (bottom-cover) and with alternating stacking alignment (bottom-bottom and cover-cover) (see Fig. 14). Because of the tight, gap-free array of the receptacles, interspersed moderation between the containers is not possible.

The results for alternating stacking are given in Table 6 for pellet diameters of 7 mm, 8 mm, 9 mm and 10 mm with different pellet column centre-to-centre distances, flooding of the pellet containers from the bottom up to and including the top pellet layer and with and without fallen pellets. It is evident that with increasing pellet diameter the multiplication values also increase. For each pellet diameter there is an individual maximum multiplication value dependent on the pellet column centre-to-centre distance. The inclusion of fallen pellets leads to a further increase in the multiplication factors. The maximum multiplication factor occurs with a pellet diameter of 10 mm, a pellet column centre-to-centre distance of 17 mm and fallen pellets. It is 0.9396 (0.9380 ± 0.0008).

The drop test results show that the structure of the receptacle is not damaged. In a further calculation, however, the scenario of water penetration into the gaps between receptacle and pellet container with alternate stacking alignment is investigated. The calculations are performed for a pellet diameter of 10 mm.

The results are listed in Table 7 and displayed in Fig. 15. The highest multiplication factors occur for the scenarios of alternating alignment of receptacles, fallen pellets and flooding of the pellet container up to the top edge of the fissile material. The maximum multiplication factor is 0.9325 ± 0.0008.

Subcriticality is therefore verified for a configuration of damaged ANF-50 shipping containers loaded with pellets on pellet trays.

6.2 Loading with pellets as bulk goods and pellet chips in the can

No test data are known in respect of the integrity of the can. The entire uranium oxide powder (max. 14.5 kg) can therefore enter the pellet containers from the can. The distribution of the fissile material spheres in the internal volume of the pellet container (including clamping area) is related to the water fissile ratio. With a large water fissile ratio the loading mass in the pellet container is under 14.5 kg. With a smaller water fissile ratio only a portion of the pellet containers are filled with fissile materials. This volume is modelled as a vacuum.

The calculations are performed with alternating stacking alignments (bottom-bottom and cover-cover) (see Fig. 14 in which the array of the pellets is shown). With lower water fissile ratios a free volume arises in the pellet containers. It is modelled as a vacuum. At higher water fissile ratios the uranium oxide mass is under the maximum usable mass of 14.5 kg. Because of the tight, gap-free configuration of the receptacles, interspersed moderation between the receptacles is not possible.

The results are given in Table 8 and show a maximum of multiplication factors at a water fissile ratio between 7 and 8 and are still dependent on the sphere size. The maximum is with a sphere diameter of 0.2 mm. The maximum multiplication factor is 0.9218 (0,9200 + 2 * 0,0009).

Calculations with water penetration into the gaps between pellet container and receptacle are not investigated because – as already verified for the damaged ANF-50 shipping container configuration (see Section 6.1) – they lead to a decrease in multiplication factors. Similarly, no calculations are performed with identical stacking orientation because the multiplication values decrease. No individual verification is performed at this point.

Subcriticality is therefore verified for a configuration of damaged ANF-50 shipping containers laden with pellets as bulk goods and pellet chips.

6.3 Loading with uranium oxide powder in the can

No test data is known in respect of the integrity of the can. The entire uranium oxide powder (max. 14.5 kg) can therefore run out from the can. With a uranium oxide density of 1.27 g/cm^3 the uranium oxide is distributed over the entire internal volume of the pellet containers (including clamping area). For uranium oxide densities of under 1.27 g/cm^3 the uranium oxide mass is under the maximum usable mass of 14.5 kg. For uranium oxide densities of over 1.27 g/cm^3 a free volume arises in the pellet containers which is modelled as a vacuum. The uranium oxide powder is assumed filled with water to saturation level. Uranium dioxide is used as the uranium oxide compound.

The alignment of the individual receptacles in an ANF-50 shipping container configuration is varied over the height of the configuration, i.e. calculations are performed with the same stacking alignment (bottom-cover) and with alternating stacking alignment (bottom-bottom and cover-cover) (see Fig. 14 which shows the configuration of the pellets). Because of the tight, gap-free configuration of the receptacles, interspersed moderation between the receptacles is not possible.

The results are given in Table 9 and show a steady increase of the multiplication factors up to a uranium oxide density of 1.27 g/cm^3. The maximum multiplication factor is 0.8981 (0.8963 + 2 * 0.0009) for alternating alignment of the receptacles. With identical alignment of the receptacles there is an insignificant decrease in the multiplication factors.
Calculations with water penetration in the gaps between pellet container and receptacle are not investigated because – as already verified for the damaged ANF-50 shipping container configuration (see Section 6.1) – they lead to a decrease in multiplication factors.

Subcriticality is therefore verified for a configuration of damaged ANF-50 shipping containers laden with uranium oxide powder.

Table 1: **k_{eff} in relation to pellet diameter and pellet centre-to-centre distance for an individual undamaged ANF-50 shipping container**
(see Fig. 1)
Pellet tray material included in the calculations
Pellet container flooded from bottom up to and including the top pellet layer, remaining volume in the pellet container modelled as vacuum
Pellet loading height 104 mm

Pellet centre-to-centre distance in mm	Pellet diameter 7 mm		Pellet diameter 10 mm	
	k_{eff}	σ	k_{eff}	σ
11	0.5604	0.0014	---	---
12	0.5768	0.0014	---	---
13	0.5784	0.0016	---	---
14	0.5790	0.0015	---	---
15	0.5800	0.0015	0.5690	0.0014
16	0.5578	0.0014	0.5799	0.0013
17	---	---	0.5940	0.0015
18	---	---	0.5934	0.0013
19	---	---	0.5918	0.0014

Table 2: **k_{eff} in relation to pellet diameter and pellet column centre-to-centre distance for a 9 x 9 x 9 array of undamaged ANF-50 shipping containers**

(see Fig. 11)

Vacuum between the shipping containers

Pellet tray material included in the calculations

Pellet container flooded from bottom up to and including the top pellet layer, remaining volume in the pellet containers modelled as vacuum

Pellet loading height 104 mm

Pellet centre-to-centre distance in mm	Pellet diameter 7 mm		Pellet diameter 8 mm		Pellet diameter 9 mm		Pellet diameter 10 mm	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
10	---	---	---	---	---	---	---	---
11	0.6745	0.0011	---	---	---	---	---	---
12	0.6914	0.0010	0.6663	0.0011	---	---	---	---
13	0.6948	0.0011	0.6866	0.0012	0.6673	0.0012	---	---
14	0.6889	0.0011	0.6946	0.0012	0.6915	0.0011	---	---
15	---	---	0.6990	0.0011	0.7040	0.0013	0.6863	0.0011
16	---	---	0.6892	0.0012	0.7048	0.0011	0.6985	0.0013
17	---	---	---	---	0.7010	0.0013	0.7090	0.0011
18	---	---	---	---	---	---	0.7098	0.0012
19	---	---	---	---	---	---	0.7041	0.0012

Table 3: **k_{eff} in relation to interspersed moderation for pellet diameter of 10 mm and pellet column centre-to-centre distance of 17 mm for a 9 x 9 x 9 array of undamaged ANF-50 shipping containers**

(see Fig. 12)
Pellet trays included in the calculations

Interspersed moderation in wt. % water	Correct stacking of ANF-50 shipping containers Pellet container flooded from bottom up to and including top pellet layer		Correct stacking of ANF-50 shipping containers Entire pellet container flooded		Incorrect stacking of ANF-50 shipping containers Pellet container flooded from bottom up to and including top pellet layer	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
0	0.7090	0.0011	0.6797	0.0011	0.7341	0.0011
5	0.6096	0.0010	0.6245	0.0012	0.6255	0.0012
10	0.5723	0.0010	0.6097	0.0011	0.5838	0.0012
15	0.5549	0.0011	0.6005	0.0011	0.5636	0.0011
20	0.5441	0.0010	0.5980	0.0010	0.5530	0.0010
25	0.5418	0.0011	0.5933	0.0012	0.5486	0.0012
30	0.5374	0.0011	0.5910	0.0011	0.5426	0.0010
40	0.5408	0.0011	0.5901	0.0011	0.5417	0.0011
50	0.5385	0.0011	0.5904	0.0011	0.5407	0.0010
70	0.5396	0.0010	0.5920	0.0013	0.5390	0.0012
100	0.5422	0.0013	0.5946	0.0011	0.5440	0.0013

Table 4: **k_{eff} in relation to pellet chip size and pellet chip centre-to-centre distance for a can laden with pellet chips as bulk goods for a 9 x 9 x 9 array of undamaged ANF-50 shipping containers**

Pellet chips modelled as spheres in hexagonal configuration

Can flooded without UO_2 mass restriction

Vacuum between the ANF-50 shipping containers

Pellet container flooded

Internal can dimensions: Diameter 230 mm, height 104 mm

Sphere diameter in mm	Water fissile ratio	k_{eff}	σ
0.10	1.9670	0.6065	0.0012
	2.7057	0.6193	0.0012
	3.5579	0.6221	0.0012
	4.5315	0.6203	0.0013
	5.6349	0.6075	0.0013
	6.8760	0.5956	0.0012
0.20	1.9670	0.6042	0.0011
	2.7057	0.6174	0.0012
	3.5579	0.6226	0.0012
	4.5315	0.6199	0.0011
	5.6349	0.6097	0.0010
	6.8760	0.5937	0.0013
0.60	1.9670	0.6063	0.0012
	2.7057	0.6210	0.0011
	3.5579	0.6221	0.0012
	4.5315	0.6198	0.0012
	5.6349	0.6091	0.0012
	6.8760	0.5956	0.0011

Table 5: k_{eff} in relation to UO_2 powder density for a 9 x 9 x 9 array of undamaged ANF-50 shipping containers

UO_2 powder moderated up to saturation, water volume calculated using the formula ($1-UO_2$ density/10.96 g/cm^3)

No interspersed moderation in the array

Internal can dimensions: Diameter 230 mm, height 104 mm

UO_2 powder density in g/cm^3	Pellet container modelled as vacuum		Flooding of the pellet container up to the can top edge of 104 mm		Flooding of the pellet container	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
0.9	0.4849	0.0007	0.5226	0.0008	0.5274	0.0008
1.0	0.5007	0.0007	0.5381	0.0008	0.5449	0.0008
1.7	0.5533	0.0007	0.5965	0.0008	0.6021	0.0009
1.9	0.5582	0.0008	0.6031	0.0008	0.6068	0.0008
2.1	0.5612	0.0007	0.6075	0.0008	0.6136	0.0009
2.3	0.5626	0.0008	0.6093	0.0009	0.6154	0.0008
2.5	0.5614	0.0008	0.6106	0.0007	0.6154	0.0008
2.7	0.5603	0.0007	0.6100	0.0009	0.6182	0.0008
2.9	0.5573	0.0008	0.6097	0.0008	0.6156	0.0009
3.1	0.5545	0.0008	0.6088	0.0008	0.6154	0.0008
3.5	0.5461	0.0008	0.6022	0.0009	0.6090	0.0007

Table 6: k_{eff} in relation to pellet diameter and pellet column centre-to-centre distance for a 6 x 6 x 8 array of damaged ANF-50 shipping containers

Pellet container flooded from bottom up to and including the top pellet layer, remaining volume in the pellet container modelled as vacuum

Pellet load height 104 mm, pellet tray material included in the calculations

Alternating alignment of damaged ANF-50 shipping containers

Pellet centre-to-centre distance in mm	Pellet diameter 7 mm				Pellet diameter 8 mm			
	Pellets only on pellet trays		Pellets on pellet trays and fallen pellets		Pellets only on pellet trays		Pellets on pellet trays and fallen pellets	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
10	0.8628	0.0008	0.8762	0.0008	---	---	---	---
11	0.8902	0.0008	0.9066	0.0008	---	---	---	---
12	0.9001	0.0008	0.9170	0.0008	0.8869	0.0007	0.9028	0.0008
13	0.8917	0.0008	0.9097	0.0008	0.8975	0.0009	0.9156	0.0008
14	0.8800	0.0008	0.8959	0.0008	0.8992	0.0008	0.9179	0.0007
15	---	---	---	---	0.8987	0.0008	0.9175	0.0009
16	---	---	---	---	0.8773	0.0010	0.8925	0.0008
	Pellet diameter 9 mm				Pellet diameter 10 mm			
	Pellets only on pellet trays		Pellets on pellet trays and fallen pellets		Pellets only on pellet trays		Pellets on pellet trays and fallen pellets	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
13	0.8925	0.0007	0.9051	0.0008	---	---	---	---
14	0.9078	0.0009	0.9246	0.0008	---	---	---	---
15	0.9174	0.0008	0.9367	0.0008	0.9077	0.0008	0.9245	0.0008
16	0.9063	0.0008	0.9240	0.0009	0.9148	0.0008	0.9276	0.0007
17	0.9068	0.0008	0.9262	0.0008	0.9215	0.0008	0.9380	0.0008
18	---	---	---	---	0.9109	0.0008	0.9268	0.0009
19	---	---	---	---	0.8989	0.0008	0.9169	0.0009

Table 7: k_{eff} in relation to pellet centre-to-centre distance, water penetration in the receptacles for a 6 x 6 x 8 array of damaged ANF-50 shipping containers

(see Fig. 15)

Pellet diameter 10 mm

Pellet load height 104 mm, pellet tray material included in the calculations

Pellet container flooded from bottom up to and including the top pellet layer, remaining volume in the pellet container modelled as vacuum

Pellet centre-to-centre distance in mm	Pellets only on pellet trays No water penetration in the receptacles Alternating stacking orientation of the pellet containers		Pellets on pellet trays and fallen pellets No water penetration in the receptacles Alternating stacking orientation of the pellet containers		Pellets on pellet trays and fallen pellets No water penetration in the receptacles Identical stacking orientation of the pellet containers		Pellets on pellet trays and fallen pellets Water penetration in the receptacles Alternating stacking orientation of the pellet containers	
	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ	k_{eff}	σ
15	0.9077	0.0008	0.9245	0.0008	0.9227	0.0008	0.7956	0.0009
16	0.9148	0.0008	0.9276	0.0007	0.9274	0.0008	0.8008	0.0009
17	0.9215	0.0008	0.9380	0.0008	0.9379	0.0008	0.8089	0.0008
18	0.9109	0.0008	0.9268	0.0009	0.9249	0.0008	0.7993	0.0008
19	0.8989	0.0008	0.9169	0.0009	0.9141	0.0008	0.7901	0.0008

Table 8: k_{eff} in relation to water fissile ratio for a 6 x 6 x 8 array of damaged ANF-50 shipping containers laden with pellet chips

Pellet chips modelled as spheres in hexagonal array

Pellet chips from can distributed in the pellet container
Max. uranium oxide mass in each pellet container 14.5 kg
Alternating alignment of receptacles

Sphere diameter of pellet chips in mm	Water fissile ratio	k_{eff}	σ
0.01	3.558	0.6895	0.0007
	5.635	0.8392	0.0008
	6.876	0.8961	0.0008
	8.263[1)]	0.9034	0.0009
0.25	4.532	0.7735	0.0007
	5.635	0.8380	0.0008
	6.876	0.8936	0.0009
	8.263[1)]	0.9036	0.0008
	9.804[1)]	0.8682	0.0008
2.00	4.532	0.7735	0.0008
	5.066	0.8102	0.0008
	6.876	0.8930	0.0008
	7.551[1)]	0.9200	0.0009
	8.263[1)]	0.9026	0.0008
6.00	4.360	0.7628	0.0008
	5.252	0.8127	0.0008
	6.659	0.8730	0.0008
	7.784[1)]	0.8972	0.0007
	8.509[1)]	0.8770	0.0008

[1)] = Remaining volume in the pellet containers modelled as vacuum

Table 9: **k_{eff} in relation to UO_2 powder density in the receptacles for a 6 x 6 x 8 array of damaged ANF-50 shipping containers**

UO_2 powder modelled up to saturation, water volume calculated using the formula (1-UO_2 density/10.96 g/cm^3)

Max. uranium oxide mass in each pellet container 14.5 kg

UO_2 powder density in g/cm^3	Alternating alignment of receptacles		Arrangement of receptacles in one alignment	
	k_{eff}	σ	k_{eff}	σ
1.00	0.8414	0.0009	0.8401	0.0007
1.20	0.8841	0.0009	0.8825	0.0008
1.27	0.8963	0.0009	0.8928	0.0007
1.30[1)]	0.8881	0.0007	0.8859	0.0009
1.40[1)]	0.8717	0.0009	0.8696	0.0009

[1)] = Remaining volume in the pellet containers modelled as vacuum

Table 10: Validation of k_{eff} on the basis of selected experiments from the NUREG 6361 Report of March 1997

Validation of k_{eff} based on selected experiments from the NUREG 6361 Report of March 1997											
Ser. No.	Input file name for criticality experiment	Brief description									
		Enrichment wt.-% U-235	Fuel rod centre-centre distance	Cluster	Fuel rod configuration in cluster	Cluster spacing cm	Stainless steel plate between clusters	k_{eff}	η	$\eta_{Experiment}$	η_{tot}
1	Ans33SLG	4,742	1,35	4	18x18	5	no	0,9968	0,0012	0,002	0,0023
2	bw1484c1	2,459	1,636	9	14x14	---	no	0,9949	0,0011	0,002	0,0023
3	bw1484c2	2,459	1,636	9	14x14	---	no	0,9944	0,0010	0,002	0,0022
4	bW1484SL	2,459	1,636	9	14x14	6,544	no	0,9941	0,0010	0,002	0,0022
5	nsE71SQ	4,742	1,26	1	22x22	---	no	0,9984	0,0011	0,002	0,0023
6	nse71w1	4,742	1,26	1	22x22	---	no	0,9973	0,0011	0,002	0,0023
7	nse71w2	4,742	1,26	1	22x22	---	no	0,9978	0,0010	0,002	0,0022
8	p2438SLG	2,35	2,032	3	20x16	8,39	no	0,9961	0,0008	0,002	0,0022
9	p2438ss	2,35	2,032	3	20x16	6,88	yes	0,9984	0,0010	0,002	0,0022
10	p2615ss	4,31	2,54	3	15x8	8,58	yes	0,9995	0,0012	0,002	0,0023
11	p2827SLG	2,35	2,032	3	19x16	8,31	no	0,9967	0,0011	0,002	0,0023
12	p3314ss1	4,31	1,892	4	9x12 and 9x2	2,83 and 3,38	yes	0,9995	0,0012	0,002	0,0023
13	p3314ss2	4,31	1,892	4	9x12 and 9x13	2,83 and 11,55	yes	1,0016	0,0010	0,002	0,0022
14	p3314ss3	4,31	1,892	4	9x12 and 9x5	2,83 and 4,47	yes	0,9972	0,0010	0,002	0,0022
15	p3314w1	4,31	1,892	1	14x14	---	no	0,9994	0,0012	0,002	0,0023
16	p3314w2	2,35	1,684	1	23x23	---	no	0,9979	0,0010	0,002	0,0022
17	p3602ss1	2,35	1,684	3	20x18 and 25x18	8,28	yes	1,0022	0,0010	0,002	0,0022
18	p3602ss2	4,31	1,892	3	12x16	13,75	yes	1,0022	0,0011	0,002	0,0023
19	p3926sl1	2,35	1,684	2	20x18	6,59	no	0,9956	0,0010	0,002	0,0022
20	p3926sl2	4,31	1,892	3	12x16	12,79	no	0,9989	0,0011	0,002	0,0023
21	p4267SL1	4,31	1,89	---	---	---	no	0,9974	0,0012	0,002	0,0023
22	p4267SL2	4,31	1,715	---	---	---	no	1,0004	0,0010	0,002	0,0022
23	W3269SL1	2,72	1,524	1	31x13	---	no	0,9980	0,0011	0,002	0,0023
24	W3269SL2	5,7	1,422	1	27x17	---	no	1,0038	0,0013	0,002	0,0024
25	w3269w1	2,72	1,524	1	31x31	---	no	0,9971	0,0011	0,002	0,0023
26	w3269w2	5,7	1,422	1	27x17	---	no	1,0025	0,0012	0,002	0,0023
27	W3385SL1	5,74	1,42	1	19x19	---	no	0,9996	0,0012	0,002	0,0023
28	W3385SL2	5,74	2,012	1	13x14	---	no	1,0025	0,0011	0,002	0,0023
						weighted	k_{eff}	**0,9985**			
							η	**0,00228**			

Fig 1: **Model of the shipping frame**

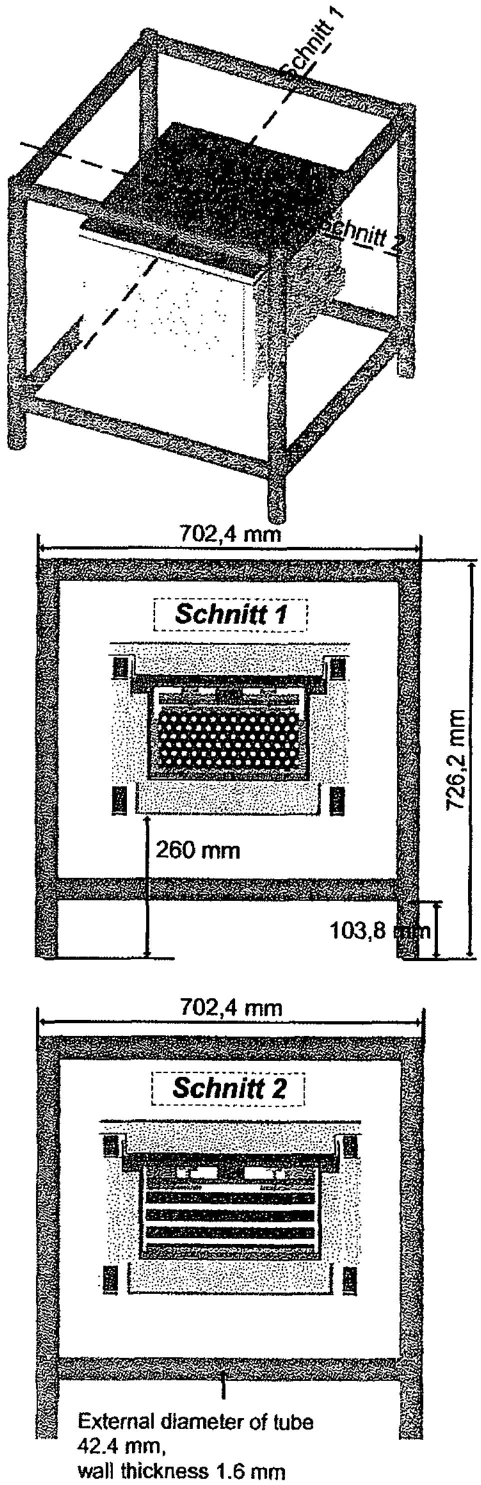


Fig 2a: **Receptacle in 3D and side view**

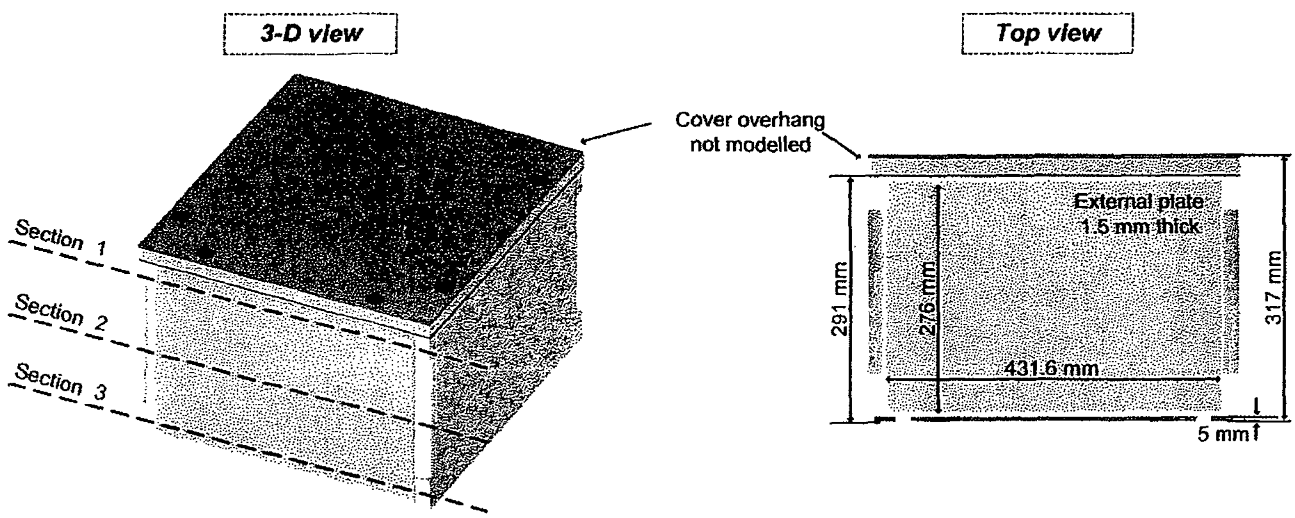


Fig 2b: **Section 1 of receptacle in 3D and side view**

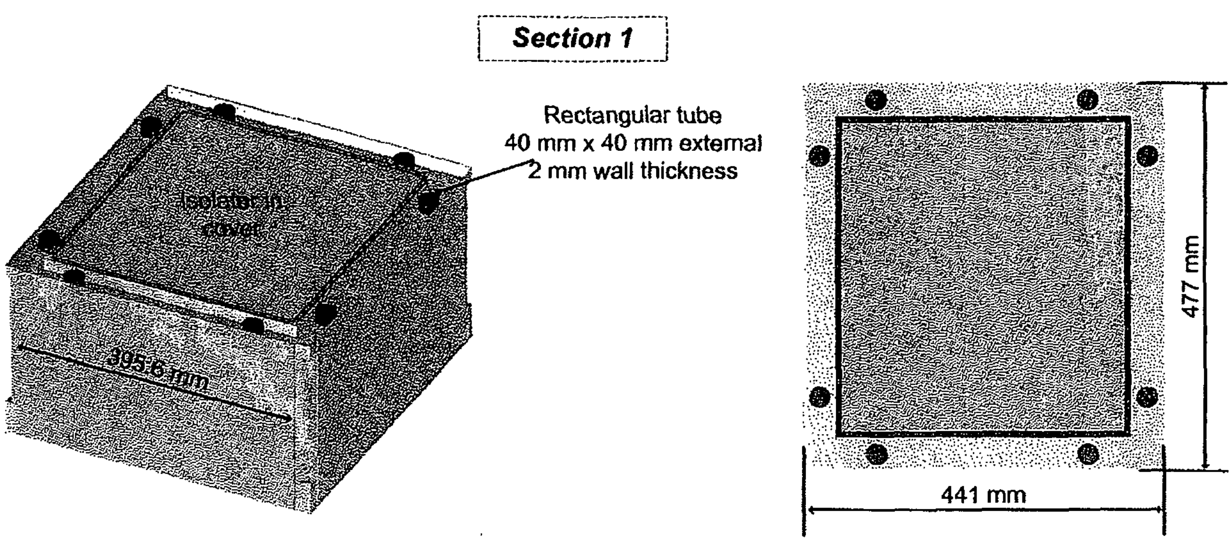


Fig. 2c: **Section 2 of receptacle in 3D and side view**

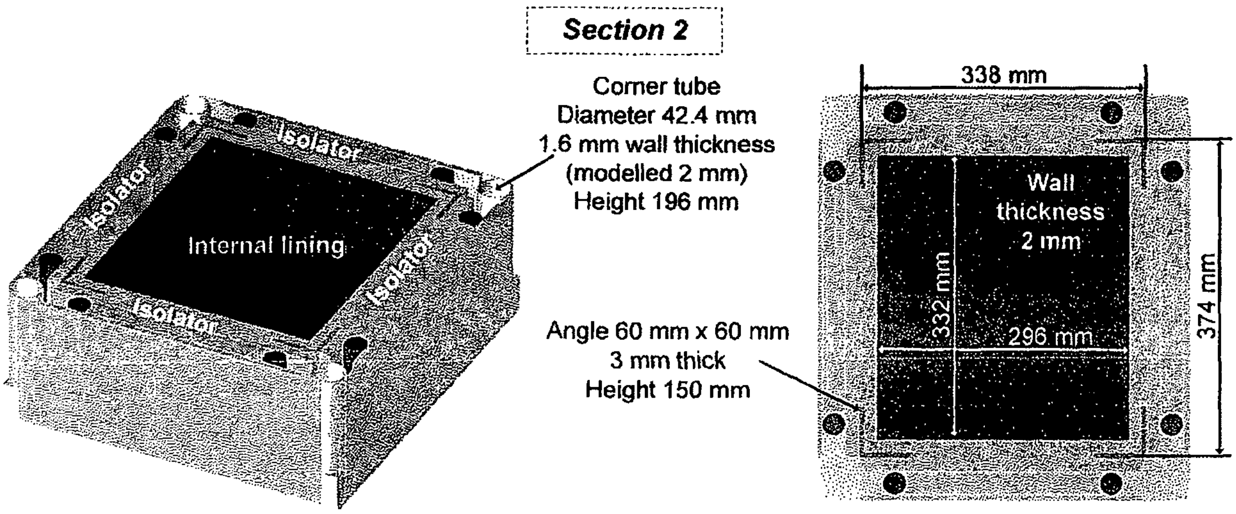


Fig. 2d: **Section 3 of receptacle in 3D and side view**

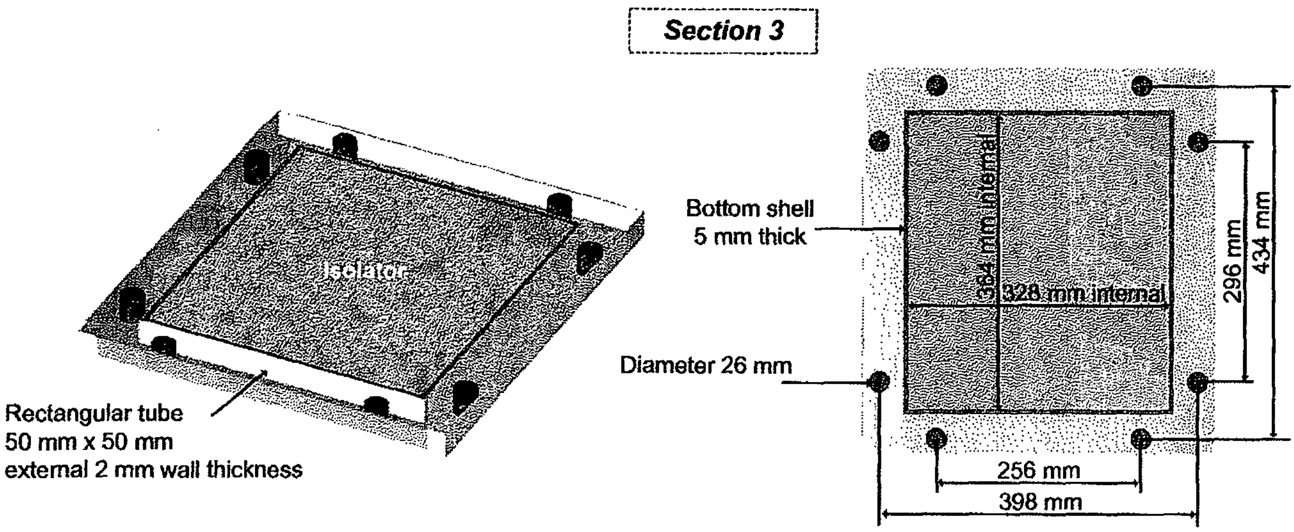


Fig 3: **Welded structure of the receptacle**

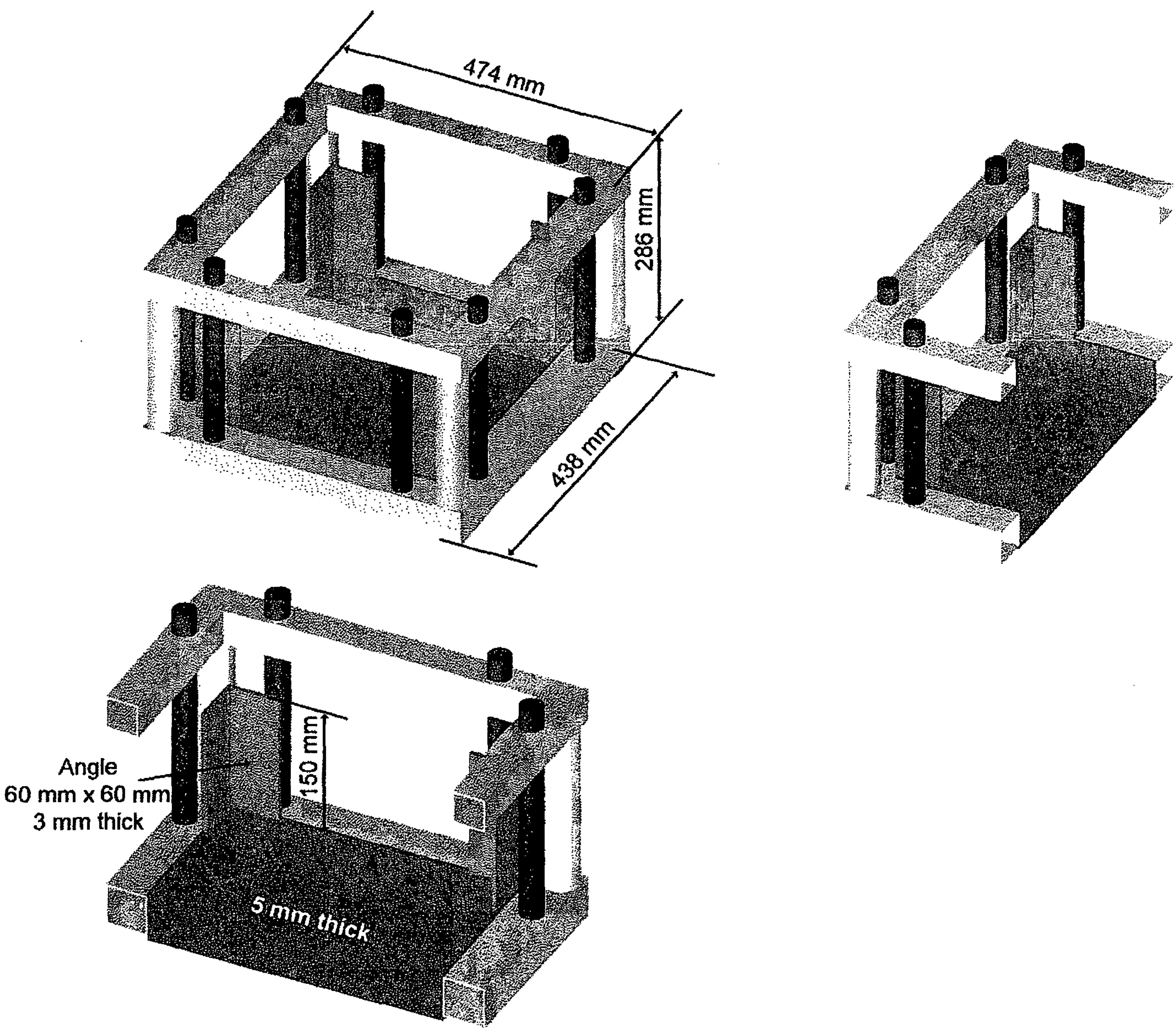


Fig 4: **Cut receptacle with isolator and internal lining**

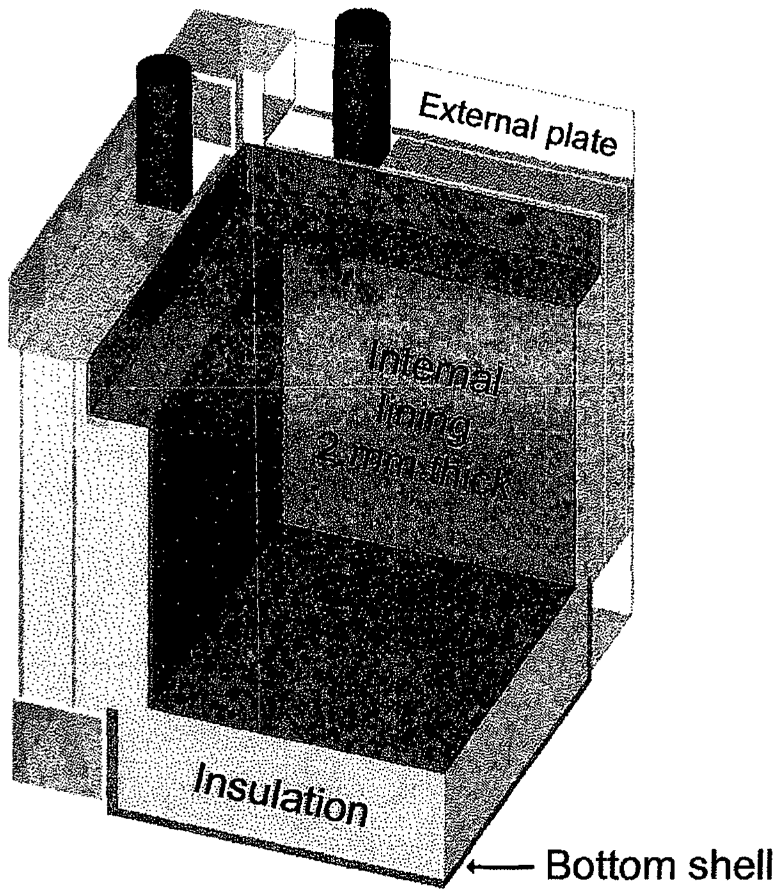


Fig 5: **Model of the cover of the receiving container**

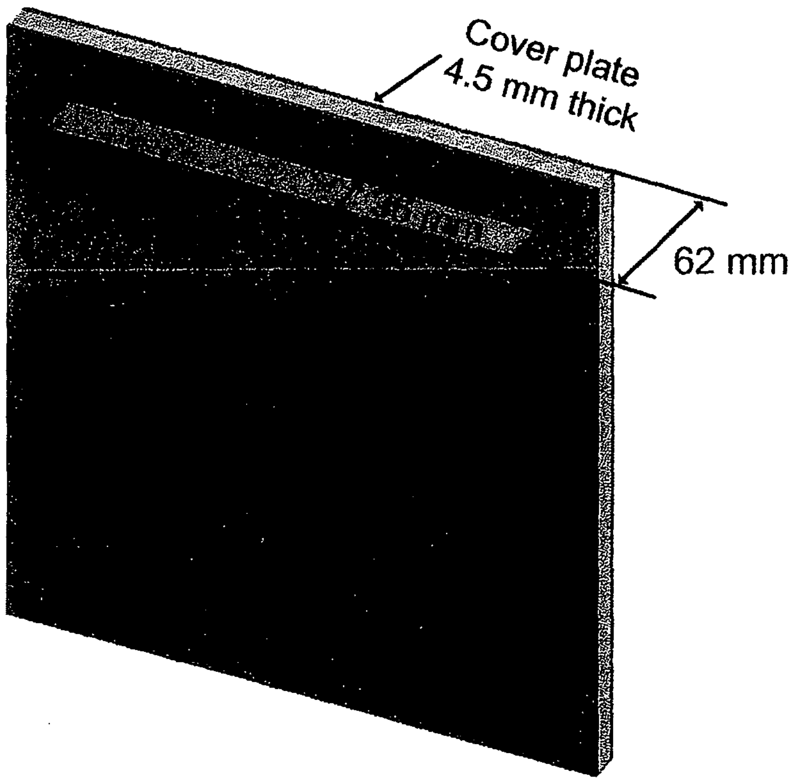


Fig 6: **Model of the pellet container laden with pellets on pellet trays**

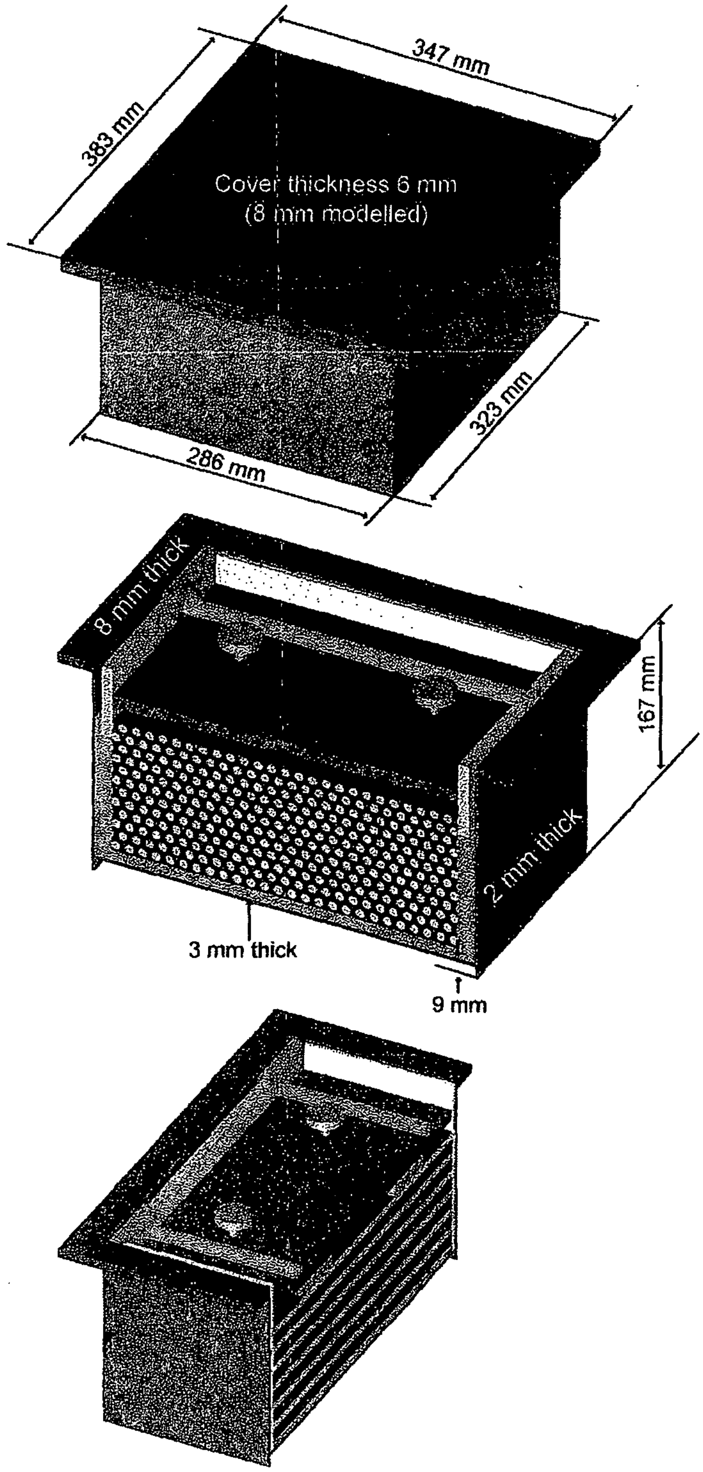


Fig 7: **Model of the supporting frame**

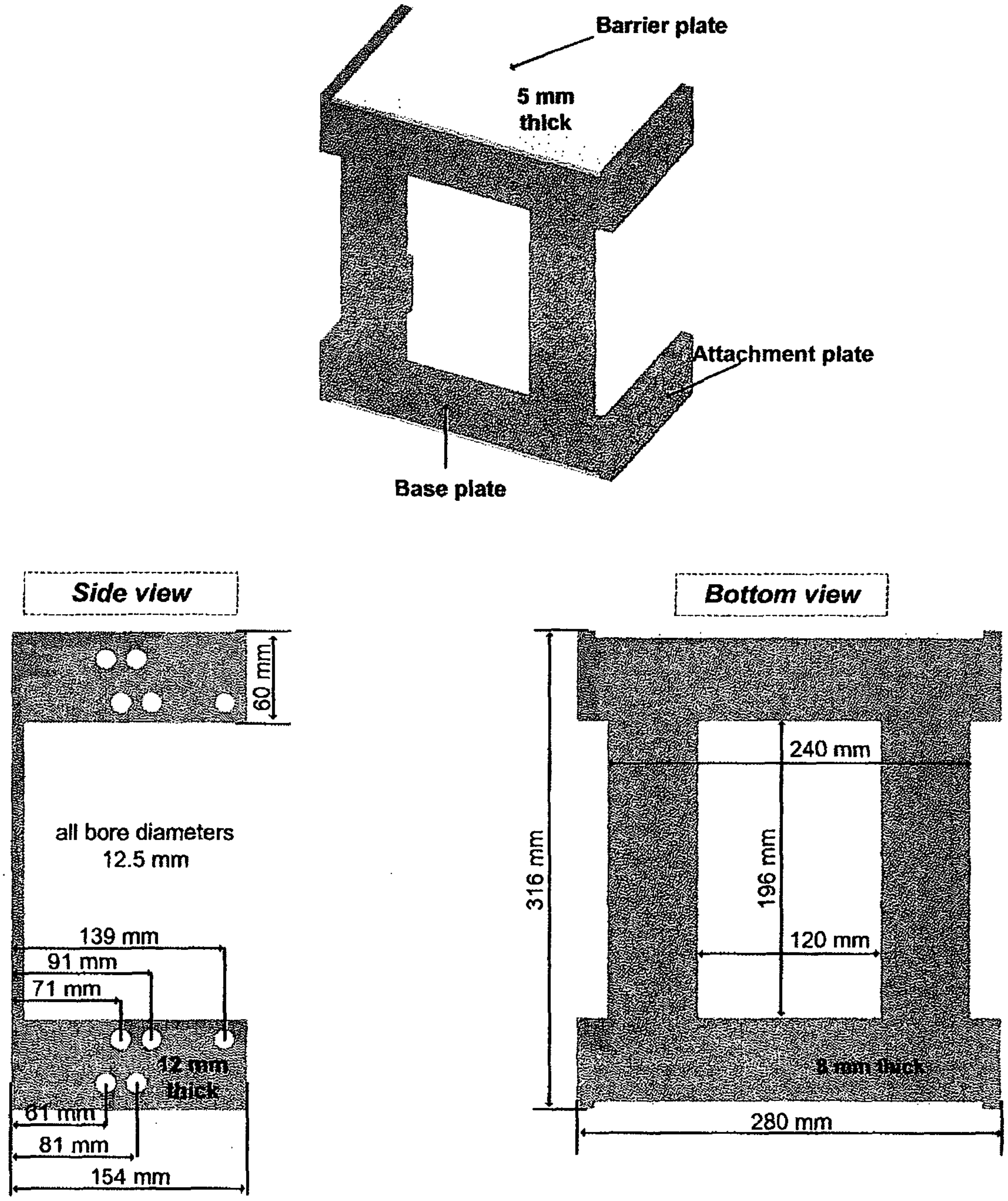


Fig 8: **Model of the clamping device**

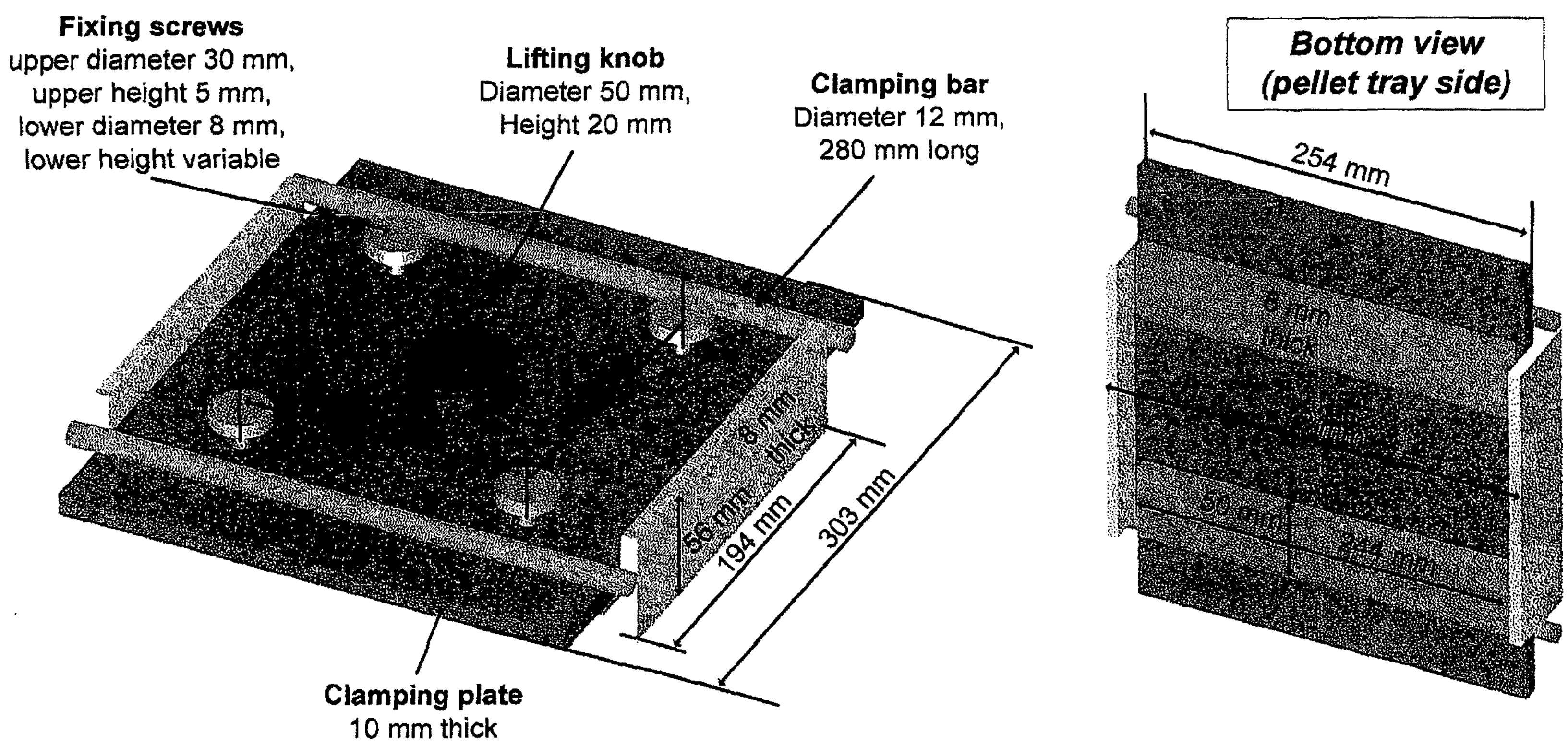


Fig 9: **Model of a pellet tray stack**

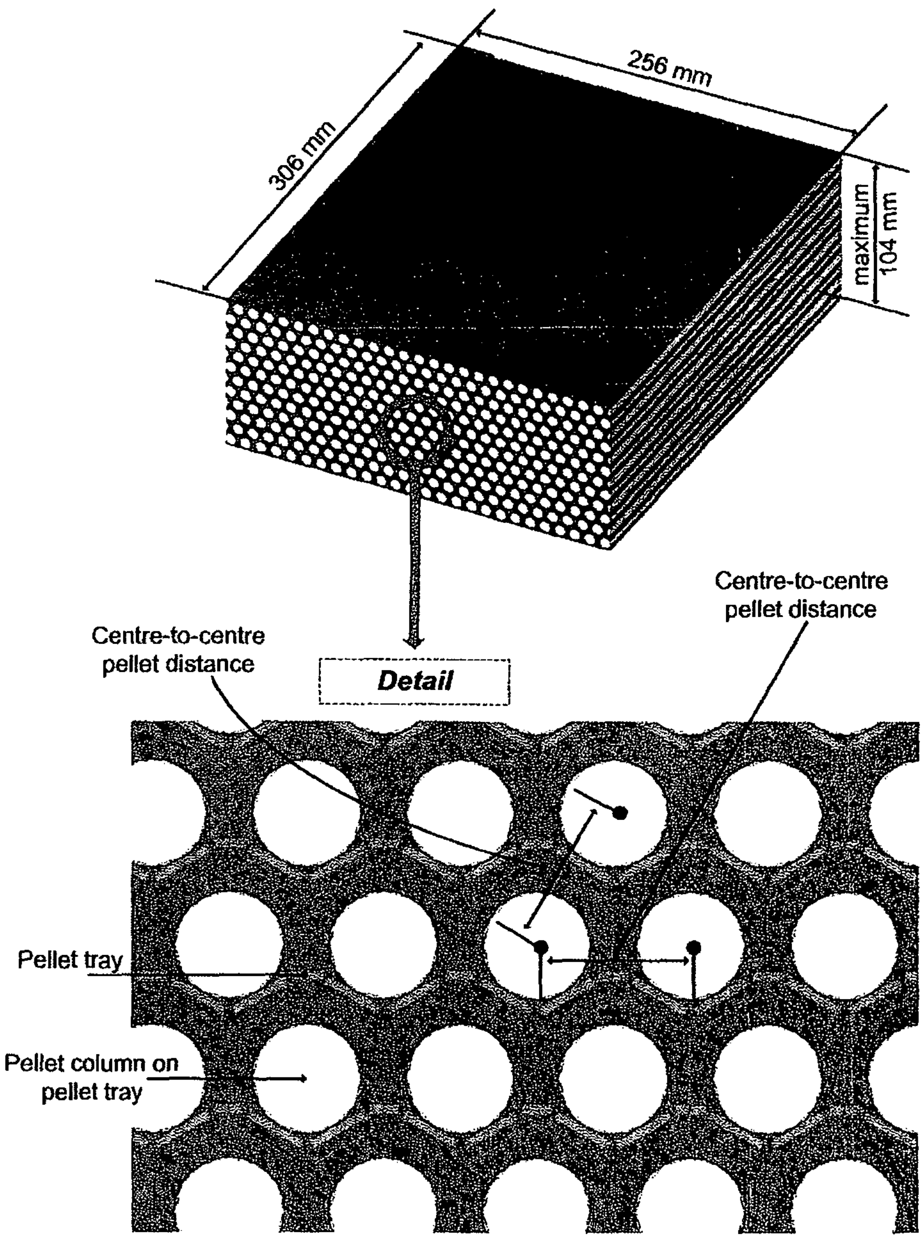


Fig 10: **Configuration of 729 undamaged ANF-50 shipping containers**

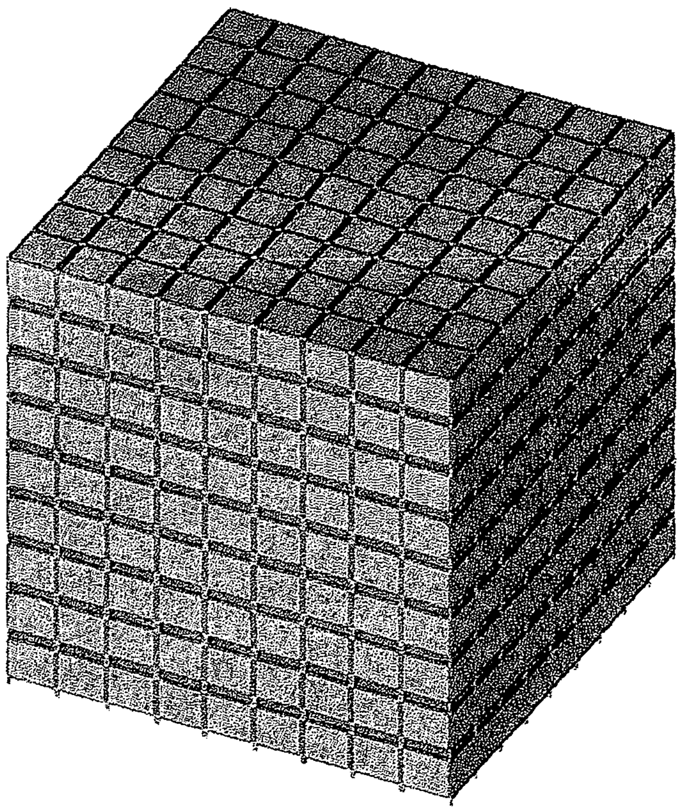


Fig 11: **k_{eff} in relation to pellet diameter and pellet centre-to-centre distance for a 9 x 9 x 9 array of undamaged ANF-50 shipping containers**

(see Table 2)

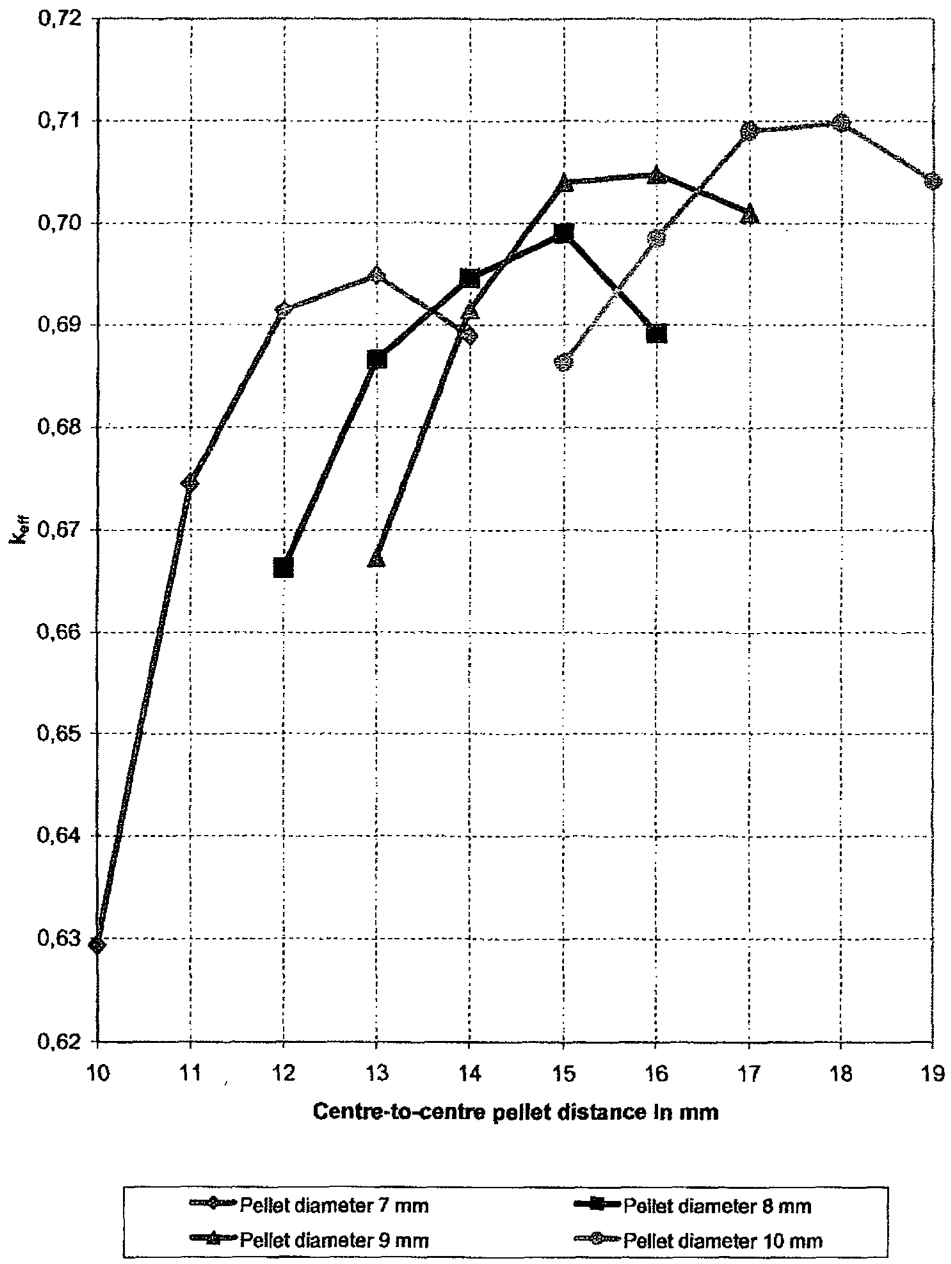


Fig 12: **k_{eff} in relation to interspersed moderation for pellet diameter of 10 mm and pellet column centre-to-centre distance of 17 mm for a 9 x 9 x 9 array of undamaged ANF-50 shipping containers**

(see Table 3)

Correct stacking of ANF-50 shipping containers

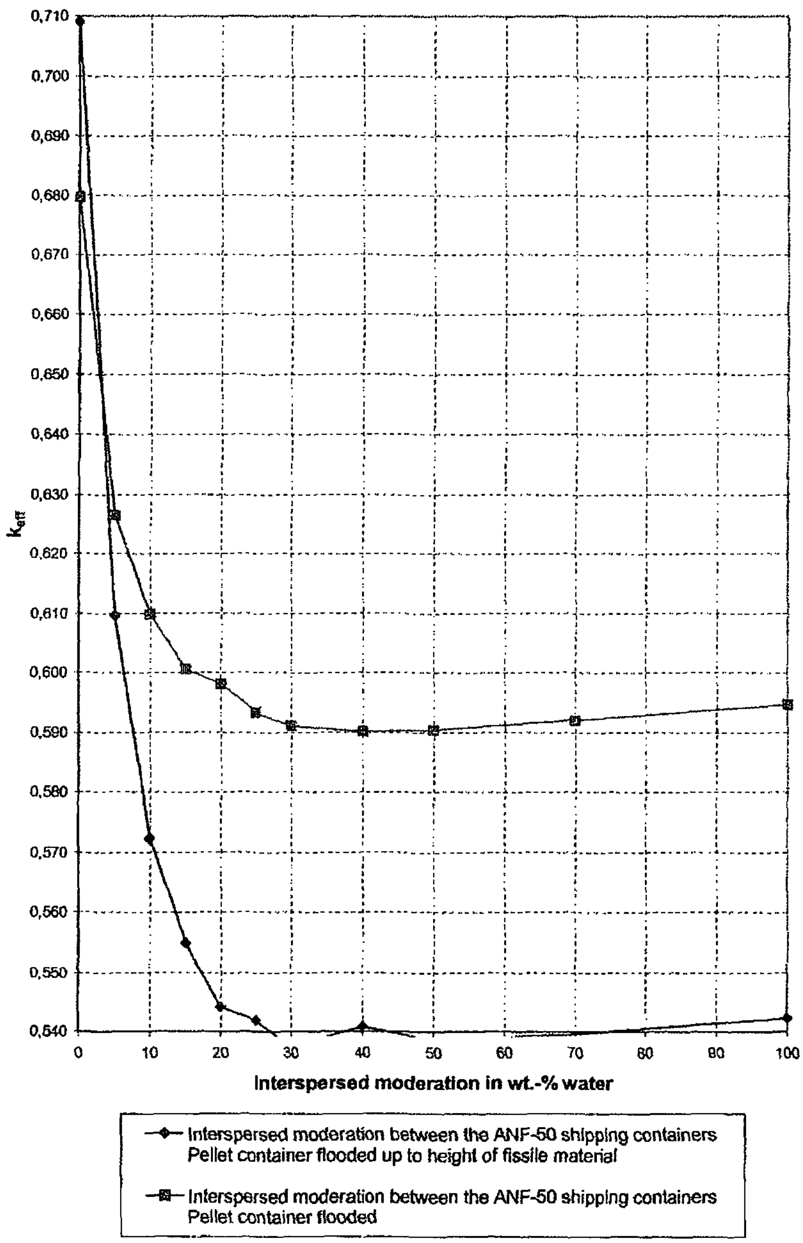


Fig 13: **Section through pellet container with fallen pellets**

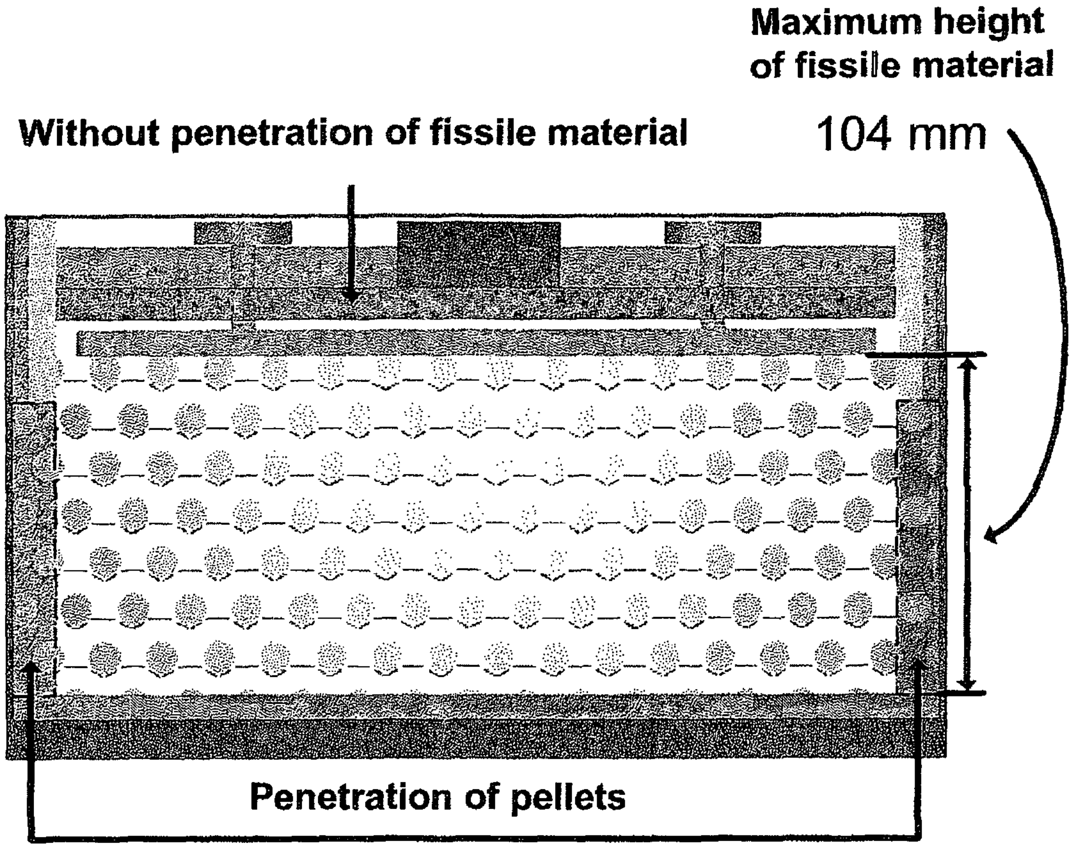


Fig 14: **Damaged ANF-50 shipping container configuration with alternating orientation (cover-bottom) of ANF-50 shipping containers over the array height**

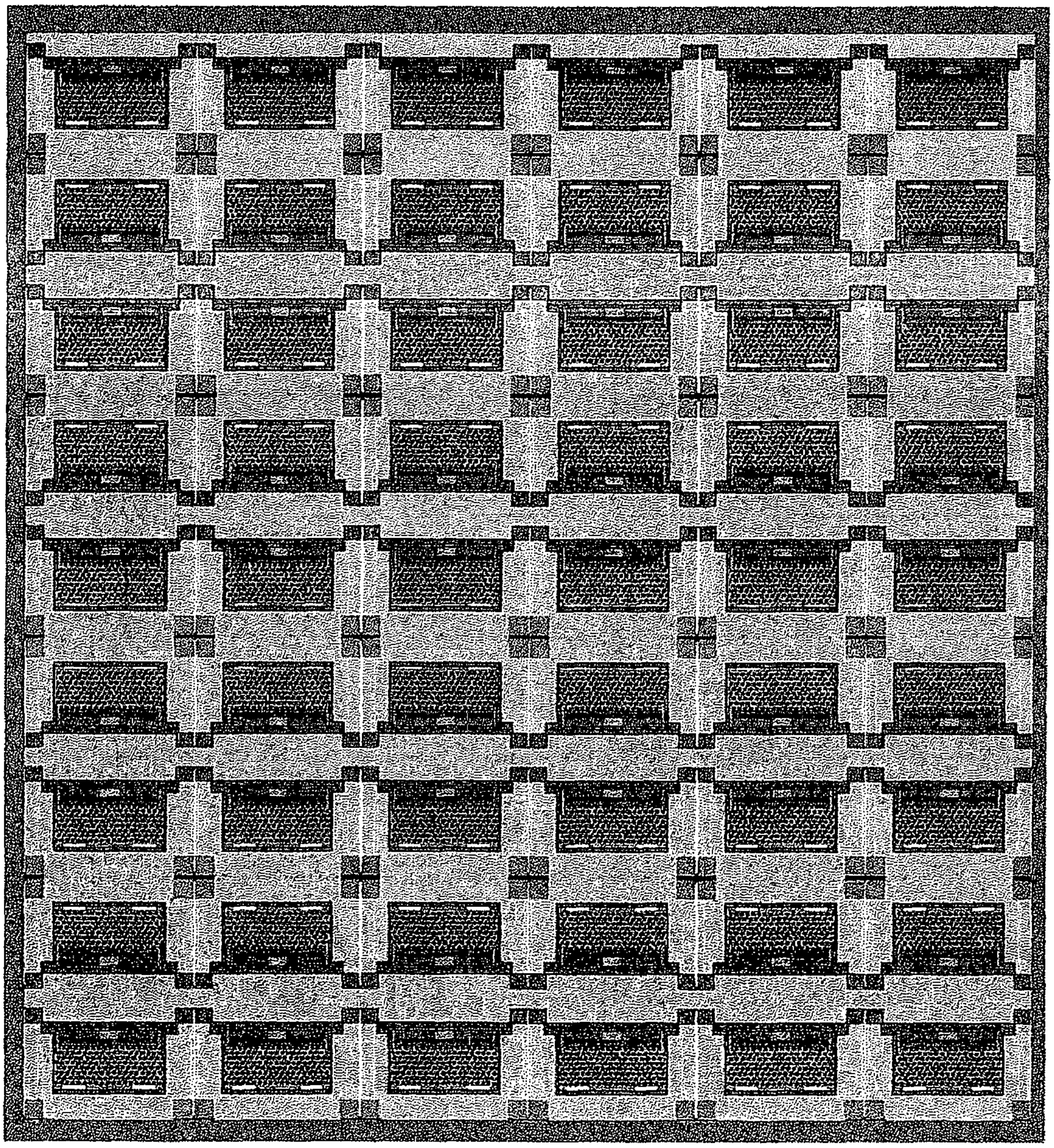
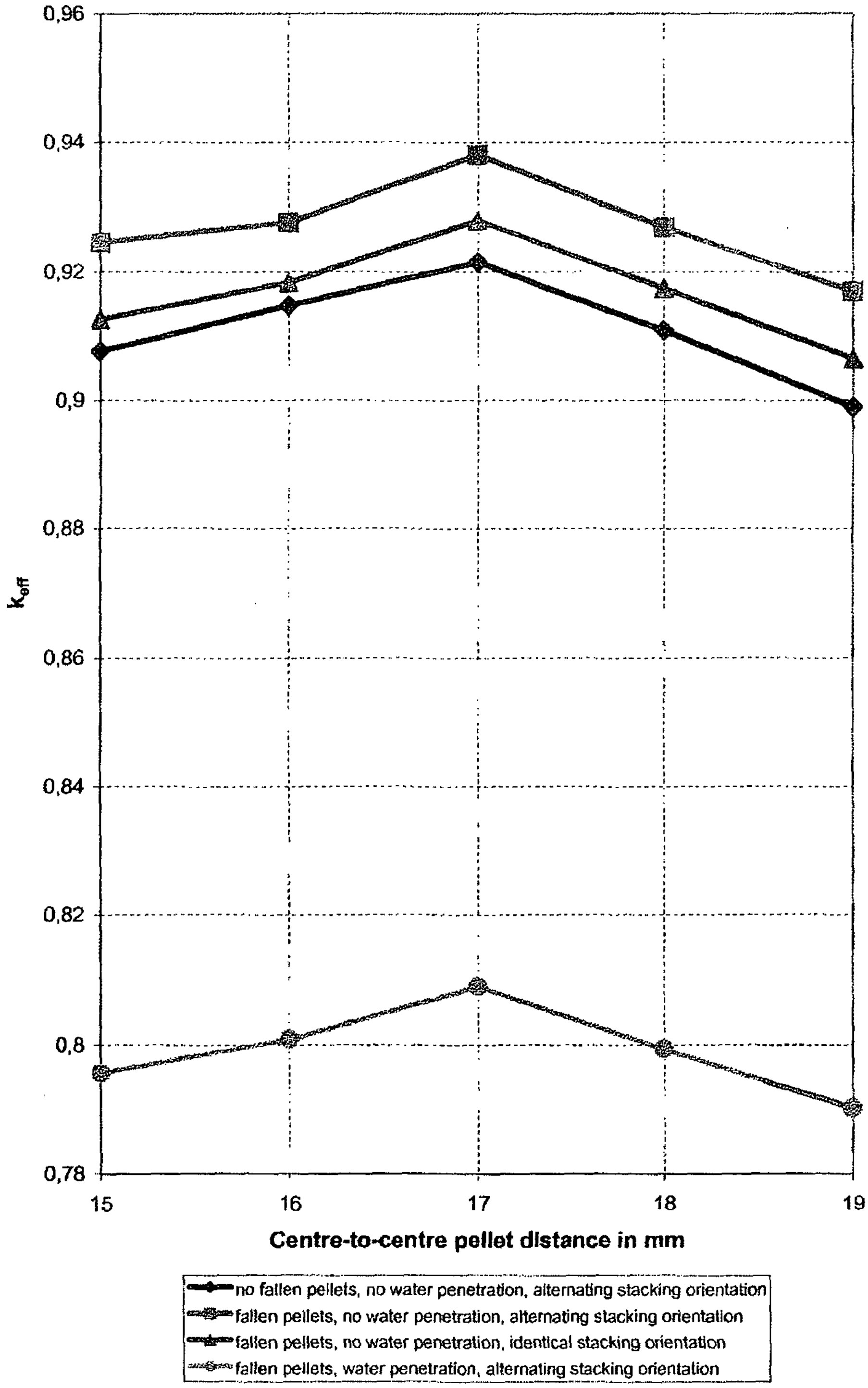


Fig 15: **k_{eff} in relation to pellet centre-to-centre distance, water penetration in the receptacles for a 6 x 6 x 9 array of damaged ANF-50 shipping containers**

(see Table 7)

Pellet diameter 10 mm



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/5/ Stephen M. Bowman, Mark D. DeHart, and Cecil V. Parks
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ANFG-11.119 (003) Rev. 0 of 12 June 2002

/7/ Calculated simulation of the IAEA thermal test for the ANF-50 pellet shipping container
Report: B-TA-3928

/8/ Laboratory tests for oxidation characteristics of UO_2 and Gd_2O_3/UO_2 pellets under conditions of the IAEA thermal test for shipping container ANF-50
Work report A1C-131344

The English translation of the criticality safety analysis **ANFG-5.061 (34) Rev. 1** is equivalent to the German original of the criticality safety analysis **ANFG-5.060 (34) Rev. 1.**

Permit for Air Transportation of the ANF-50 Shipping Container

Prepared: Dr. B. Bendick — Date: 01. Nov. 2005

Released: R. Witten — Date: 08 Nov. 2005

Exportkennzeichnung AL: 0E001 ECCN: 10CFR810.8(c)(3) Die mit „AL ungleich N" gekennzeichneten Güter unterliegen bei der Ausfuhr aus der EU der europäischen bzw. deutschen Ausfuhrgenehmigungspflicht. Die mit „ECCN ungleich N" gekennzeichneten Güter unterliegen der US-Reexportgenehmigungspflicht. Auch ohne Kennzeichen, bzw. bei Kennzeichen „AL : N" oder „ECCN : N", kann sich eine Genehmigungspflicht, unter anderem durch den Endverbleib und Verwendungszweck der Güter, ergeben	Export classification AL: 0E001 ECCN: 10CFR810.8(c)(3) Goods labeled with „AL not equal to N" are subject to European or German authorization when being exported out of the EU. Goods labeled with "ECCN not equal to N" are subject to the US reexport authorization. Even without a label, or with label "AL : N" or "ECCN : N", authorization may be required due to the final whereabouts and purpose for which the goods are to be used

Changes in this revision:

- Heading altered
- The revision was edited as an addendum for the criticality safety analysis 5.060 (11) Rev. 1. As a consequence of the revision, this report has become a report in its own right, differing from the previous revision by small editorial changes. It is not based on any new calculations.
- The uranium powder mass was reduced from 21 kg to 14.5 kg.

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0 Summary

The present criticality safety analysis demonstrates that the ANF-50 shipping container can be used for air transportation. It shows that any array of the completely released fissible material from an ANF-50 shipping container remains subcritical if the moderator materials – but no external moderator – are taken into consideration. For this purpose, 55 kg of pellets of fissible material or 21 kg of uranium oxide powder with a maximum enrichment of 5 mass percent of ^{235}U are examined. In the case of the pellets, the fission of pellets ranging in diameter between 7.00 mm and 10.0 mm into uranium oxide powder is analysed. The calculation also covers pellets and uranium oxide powder with neutron poisons (e.g. Gadolinium) without a separate calculation being made.

This enrichment is the maximum enrichment, which may not be exceeded even when taking into consideration the measuring tolerance.

1 Introduction

The ANF-50 shipping container consists of a transportation frame, which is closed in a lattice-like way, a receptacle box and a pellet container with pellet holders or a case. The receptacle box is welded to the transportation frame by means of junction plates. The pellet container or the case are inside the receptacle box and can be removed from it for filling or emptying purposes.

The ANF-50 shipping container is made of high-grade steel and is provided with insulating plates consisting of a mixture of aluminum oxide (29 %) and silicon oxide (70 %). Figure 1 shows a cross section of the ANF-50 shipping container.

The present criticality safety analysis shows that the released fissible material from an ANF-50 shipping container remains subcritical for all arrays of the fissible material, which are calculated in accordance with the regulations for air transportation /1,2/. The analysis is based on the following premises:

- a maximum UO_2 density of the pellets of 10.96 g/cm^3
- diameter range of the pellets between 7.0 mm and 10.mm
- fission of the pellets into uranium oxide powder ranging in density between 0.5 g/cm^3 and 10.96 g/cm^3 without moisture absorption
- a maximum UO_2 mass of the pellets or of the fission-induced uranium oxide powder in the ANF-50 shipping container of 55 kg
- uranium oxide powder without density or moisture limitation up to a maximum mass of 14.5 kg
- a maximum enrichment of the fissible material of 5 mass percent of ^{235}U

The calculations for the uranium oxide powder are based on the most reactive uranium compound, namely uranium dioxide (UO_2). Therefore, the calculation covers all other uranium oxide compounds as well.

The construction material of the ANF-50 shipping container is partly taken into consideration in the calculations.

2 Calculation Code Used

The criticality calculations described below are performed by means of the SCALE-4.4a /3,4/ program system using

- the 44-group neutron cross section library 44GROUPNDF5 of this system, which is derived from the ENDF/B-V data, and
- the BONAMI-S, NITAWL-II and KENO VI program modules.

The BONAMI-S and NITAWL-II modules serve for examining the self-shielding by the method of Bondarenko or Nordheim. For this purpose, the BONAMI-S module is always used in conjunction with the NITAWL-II module, which converts the problem-dependent data provided by BONAMI-S to a cross section working library. The KENO VI module solves the multi-group form of the Boltzmann transport equation as eigenvalue problem by means of Monte Carlo techniques.

There are comprehensive validations for this code.

3 Modelling of the Array of the Fissible Material and Results of the Calculation

The ANF-50 shipping container is designed for the transportation of up to 55 kg of pellets or 14.5 kg of uranium oxide powder. Under the regulations from /1/ and /2/, it has to be demonstrated that the whole content of fissible material can be released and can adopt any geometric form. Moderating construction materials from the ANF-50 shipping container are to be taken into consideration and absorbing construction materials are to be neglected.

The ANF-50 shipping container is made of high-grade steel and is provided with insulating plates. Neither of these construction materials is a moderator or an absorber. For this reason, the construction materials are taken into account in the calculation only for comparison purposes.

For the calculations, the geometric sphere is used to model the fissible material. The sphere has the smallest surface-volume ratio of all the geometric forms and consequently has the smallest neutron leakage.

The pellets are assumed to be undamaged and are modelled within the sphere as columns without gaps within them. The pellet column length depends on the position of the pellet column within the sphere. The pellet columns are hexagonally arrayed. The pellet diameter and the center-to-center distance of the pellets are varied. The radius of the sphere changes in dependency of the center-to-center distance owing to the constant pellet mass of 55 kg. A typical sphere model is displayed in figure 2. A 300-mm-thick water reflector is put around the sphere.

The geometric parameters and the calculated multiplication values are listed in table 1. As can be seen, the maximum multiplication value is reached at a pellet diameter of 10 mm with pellet contact. The value is 0.4733 (0.4715 + 2 x 0.0009). Generally, it can be seen that the k_{eff} value is not dependent on the pellet diameter. If the center-to-center distance of the pellets increases, the multiplication factor decreases.

The influence of the construction material is examined for a pellet diameter of 7 mm with pellet contact. The high-grade steel is assumed to be between fissible material and water reflector. The thickness of the high-grade steel is varied. The results are listed in table 1 and they show that the k_{eff} value decreases with increasing thickness of the steel, meaning that the calculations without construction material are conservative.

Hence, the subcriticality is demonstrated for any released, non-moderated and reflected pellet mass of 55 kg.

In a further calculation, it is assumed that the pellet mass of 55 kg splits completely into UO_2 powder. Since the less reactive U_3O_8 powder is generated in the thermal fission of the pellets, this assumption is conservative. The pellets do not contain any moisture and they are not hygroscopic. Therefore, there is no moisture assumed to be contained in the UO_2 powder in the calculations. The UO_2 powder is modelled as a sphere. The UO_2 density is varied between 0.5 g/cm^3 and the theoretical UO_2 density of 10.96 g/cm^3. The assumption of the theoretical UO_2 density for UO_2 powder is extremely conservative, since UO_2 powder cannot reach the theoretical UO_2 powder density. The sphere radius is dependent on the UO_2 density and decreases from 297 mm to 106 mm with increasing UO_2 powder density. A 300-mm-thick water reflector is assumed to surround the arrangement.

The results are displayed in table 2. As can be seen, the maximum multiplication factor is reached at the theoretical UO_2 density of 10.96 g/cm^3; its value is 0.4859 (0.4841 + 2 x 0.0009).

Hence, the subcriticality is demonstrated for any released, non-moderated and reflected UO_2 mass of 55 kg which is split into uranium oxide powder.

The ANF-50 shipping container is also envisioned to transport 14.5 kg uranium oxide powder instead of the pellets. In this case, there is no restriction as to the moisture contained. According to /6/ and /7/ the critical UO_2 mass is 37.7 kg. This is clearly above the loading mass of 14.5 kg.

Hence, the subcriticality is demonstrated for the released and reflected uranium oxide powder.

Table 1: **Multiplication factor in dependency of pellet diameter, center-to-center distance of the pellets and sphere radius**

Pellet mass: 55 kg, no moderator between the pellet columns, hexagonal array of the pellets, 300 mm water reflection

Pellet diameter in mm	Center-to-center distance of the pellets in mm	Sphere radius in mm	k_{eff}	σ
7	7	109.7	0.4701 0.4420 [1)] 0.4144 [2)]	0.0010 0.0008 [1)] 0.0008 [2)]
	9	129.7	0.4528	0.0010
	11	148.4	0.4400	0.0009
	13	165.8	0.4315	0.0009
8	8	109.7	0.4698	0.0009
	10	127.3	0.4516	0.0009
	12	143.8	0.4428	0.0009
	14	159.4	0.4324	0.0009
9	9	109.7	0.4701	0.0008
	11	125.4	0.4556	0.0009
	13	140.2	0.4443	0.0010
	15	154.3	0.4370	0.0010
10	10	109.8	0.4715	0.0009
	12	124.0	0.4561	0.0008
	14	137.3	0.4492	0.0009
	16	151.0	0.4423	0.0009

[1)] = 2 mm high-grade steel cladding between fissible material and water reflector

[2)] = 4 mm high-grade steel cladding between fissible material and water reflector

Table 2: Multiplication factor in dependency of UO_2 powder density and sphere radius

UO_2 mass: 55 kg, no moderator in the UO_2 powder, 300 mm water reflection

UO_2 density in g/cm^3	Sphere radius in mm	k_{eff}	σ
0.5	297	0.3886	0.0009
1.0	236	0.4097	0.0009
1.5	206	0.4192	0.0008
2.0	187	0.4244	0.0009
2.5	174	0.4318	0.0009
3.0	164	0.4367	0.0010
3.5	155	0.4412	0.0009
4.0	149	0.4469	0.0010
4.5	143	0.4378	0.0009
5.0	138	0.4517	0.0009
5.5	134	0.4574	0.0010
6.0	130	0.4593	0.0009
7.0	123	0.4637	0.0009
8.0	118	0.4708	0.0009
9.0	113	0.4756	0.0010
10.0	110	0.4827	0.0009
10.96	106	0.4841	0.0009

Figure 1: Cross section of the undamaged ANF-50 shipping container

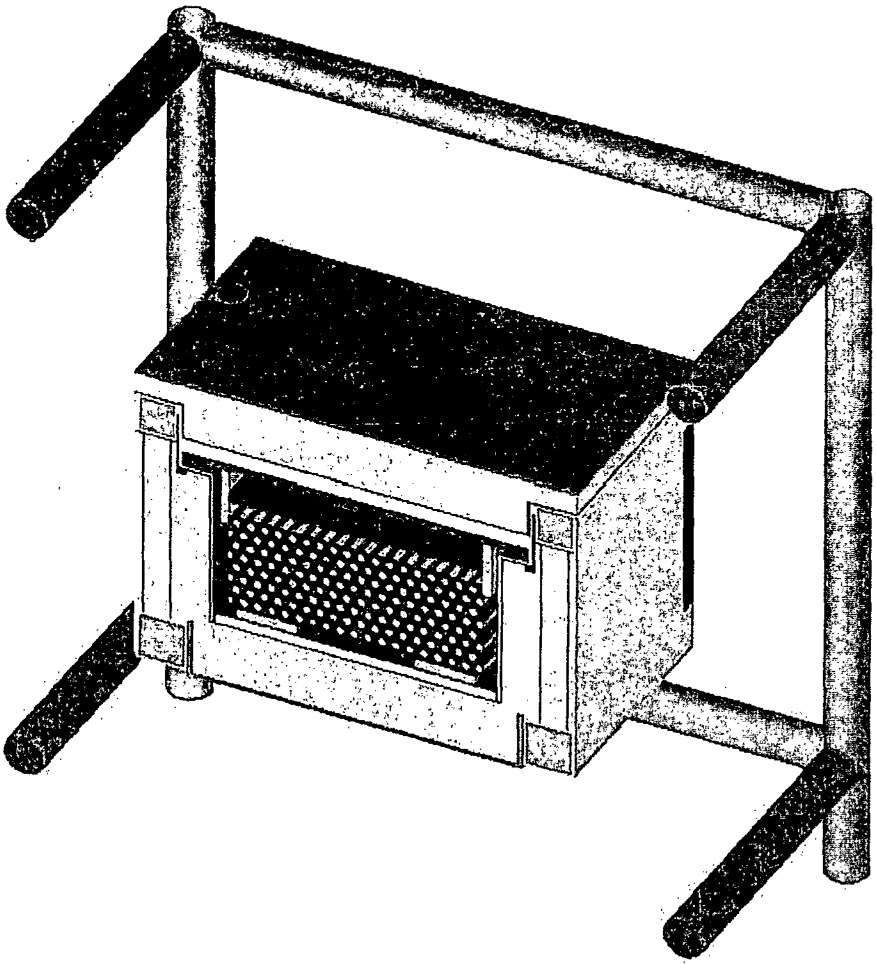
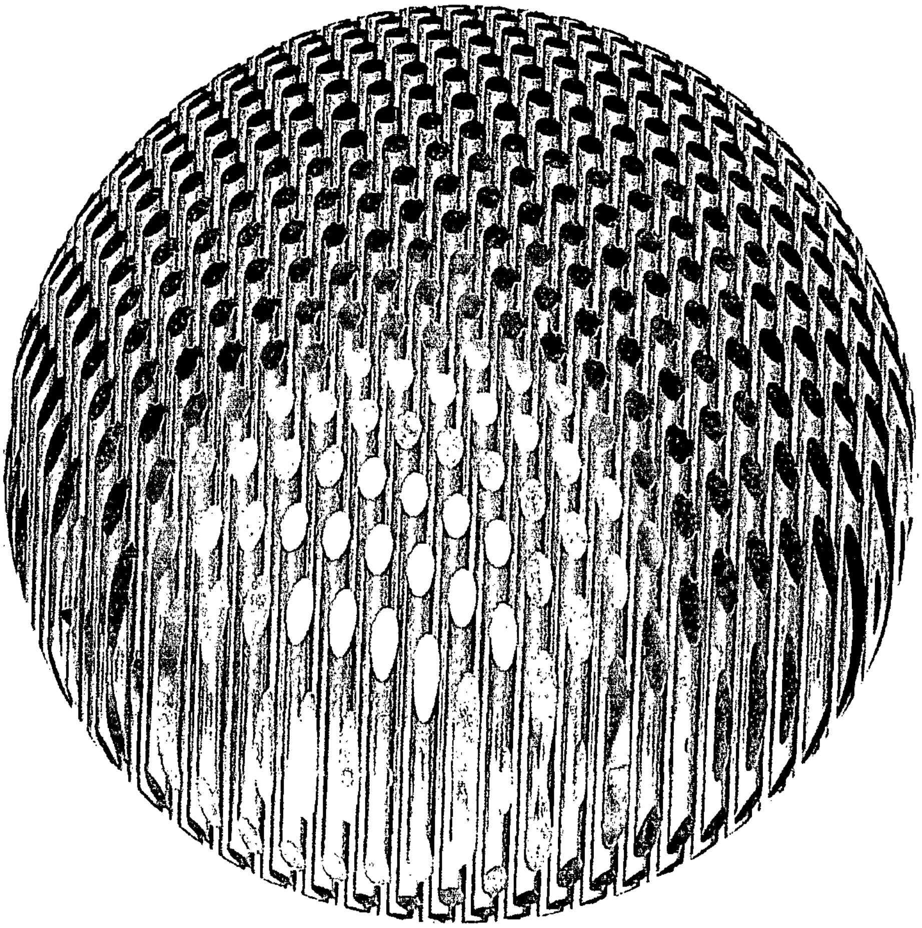


Figure 2: **Model of the pellet columns in a sphere**
Diagram without water reflector



Attachment 1: Page with typical entries

```
=csas26
kugel anf-50 tablette 9 mm, pitch 13 mm
44gr infh
uo2   1  1 293.0 92235 5.00 92238 95.00 end
' reflektorwasser
h2o   2  1 293.0 end
end comp
more data
res=1 cylinder 0.45
end more
read para tme=100 gen=603 npg=800 end para

read geom

unit 1
com='pelletsaeule'
cyli 10 0.4500 2p15.0
hexp 20 0.6500 2p15.0
media 1 1 10
media 0 1 20 -10
boundary 20

global
unit 2
com='kugel'
sphere 10 14.02
array 1 10 place 50 50 1 -50.0 -30.0 0.0
cubo   20 6p44.02
media  2 1 20 -10
boundary 20

end geom

read array

ara=1 typ=triangular nux=100 nuy=100 nuz=1
fill f1 end fill

end array

end data
end
```

4 Bibliography

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Safety Standards Series No. TS-R-1 (ST-1, Revised)

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/3/ NUREG/CR-0200
Revision 6
Volume 1, Section C4
ORNL/NUREG/CSD-2/V2/R6
CSAS: Control Module for Enhanced Criticality Safety Analysis Sequences
March 2000

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Volume 2, Section F17
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KENO-VI: A General Quadratic Version of the KENO Program
March 2000

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Kritikalitätssicherheitsanalyse für die verkehrsrechtliche Zulassung des ANF-50-Transportbehälters
(Criticality Safety Analysis for Approval under Traffic Law of ANF-50 Shipping Container)
31 March 2003

/6/ GRS
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December 1996

/7/ DIN 25403-4
Kritikalitätssicherheit bei der Verarbeitung und Handhabung von Kernbrennstoff, Teil 4: Kritikalitätsdaten für Urandioxid-Leichtwasser-Mischungen
(Criticality Safety in Processing and Handling Nuclear Fuel, Part 4: Criticality Data for Uranium Dioxide Light Water Mixtures)
October 1995

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BAM

Federal Institute for
Materials Research
and Testing

Test Report No. 10830

Drop Tests with Drop Test Specimens of ANF-50 Pellet Shipping Container

This report is an English translation of a report that was originally issued in German.
Translation checked: Pricker 10.06.03 approved and released: Jahreiß 10.06.2003

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Division III.3 Safety of Transport and Storage Containers

Test Report No. 10830

Drop Tests with Drop Test Specimens of ANF-50 Pellet Shipping Container

Reference number	III.3/ 10830
Issue	-
Applicant/ customer	ADVANCED NUCLEAR FUELS GmbH Am Seitenkanal 1 49811 Lingen/Ems
Application/order of	January 21, 2002
Received on	January 25, 2002
Subject of application/order	Qualification tests ANF-50 pellet shipping container
Date of testing	April 10, 2002 to April 12, 2002
Location of testing	BAM drop test stand in Berlin
Test report	T. Quercetti
Test performance	BAM III.31, Experimental Package Investigations H. Grünewald M. Minack T. Quercetti E. Reeck T. Reinke
Test manager	Dr. K. Müller

This Test Report consists of Pages 1 to 15 with Appendices 1 to 4.

Table of Contents

Appendices

1. Introduction

This Test Report contains the results of the drop and crush tests performed on four drop test specimens of the pellet shipping container ANF-50 (ANF Shipping Container Type 50) loaded with dummy pellets made of lead, as well as a water immersion test conducted using a pellet box (inner pellet container of ANF-50).

2. Objective of Tests

The mechanical tests for determining resistance to normal conditions of transport as well as accidents conditions arising during transport were intended to provide experimental verification that the ANF-50 shipping container meets the legal requirements applying to industrial packages of Type 2 (IP-2), as IFs, for transporting unirradiated uranium dioxide pellets.

In conjunction with this it was to be demonstrated that no configurations arise during the mechanical resistance tests with subsequent thermal test and water immersion test in which subcriticality is no longer ensured in the postulated event of water inleakage.

3. Legal Basis for Tests

The legal basis for the tests comprises the European agreements concerning the international carriage of dangerous goods by road ("ADR") and by rail ("RID") which correspond in terms of content to the recommendations of the IAEA in this regard set forth in the "Regulations for the Safe Transport of Radioactive Material" [Regulations TS-R-1 (ST-1, Revised), IAEA Vienna, 2000].

To verify adherence to the design criteria specified for packages containing fissile material, the prototypes (drop test specimens) of the ANF-50 pellet shipping container must be subjected to the following tests in respect of the safety feature to be tested – namely, maintenance of subcriticality – in accordance with [1]:

1.) Tests for demonstrating ability to withstand normal conditions of transport:
   - Water spray test (§ 721)
   - Free drop test (§ 722(a)): The test specimen shall drop onto the target from a height of 1.2 m such that it suffers the maximum possible damage in respect of the safety features to be tested.
   - Stacking test (§ 723)
   - Penetration test (§ 724): The test specimen shall be subjected to impact by a bar of 3.2 cm in diameter with a hemispherical end and a mass of 6 kg dropped from a height of 1 m onto the center of the weakest part of the test specimen.

2.) Tests for demonstrating ability to withstand accident conditions of transport:

The test specimen shall be subjected to the cumulative effects of the following tests:

- Drop test onto vertical bar (§ 727 (b)): The test specimen shall drop onto a circular solid steel bar (diam. 15.0 ± 0.5 cm) from a height of 1 m such that it suffers the maximum possible damage in respect of the safety features to be tested.
- Crush test (§ 727 (c)): The test specimen shall be positioned on an unyielding target such that it suffers the maximum possible damage in respect of the safety features to be tested - here: maintenance of subcriticality – when a mass of 500 kg is dropped onto the specimen from a height of 9 m. The mass shall consist of a solid mild steel plate measuring 1 m by 1 m and shall fall in a horizontal attitude.
- Thermal test (§ 728).

The sequence of the mechanical tests (drop test onto a vertical bar and crush test) shall be selected such that the test specimen has suffered such damage on conclusion of the mechanical tests that the maximum possible damage is incurred during the subsequent thermal test.

Further tests are as follows:

- Water immersion test (§ 729), in which the test specimen shall be immersed under a head of water of at least 15 m for a period of not less than eight hours. This depth of immersion corresponds to an external gauge pressure of at least 150 kPa.

and

- Water leakage test (§ 731 to § 733).

4. Tests

In accordance with the scope of testing specified in [1], the Federal Institute for Materials Research and Testing (BAM), Laboratory BAM-III.31, performed the 1.2-m free drop test (testing was actually performed using a drop height of 1.3 m) and the penetration test as part of the tests for demonstrating ability to withstand normal conditions of transport. The crush test and the drop test onto a vertical bar as well as a water immersion test were performed by BAM for demonstrating ability to withstand accident conditions of transport.

The tests were carried out according to the test program [2] prepared by Framatome ANP in consultation with BAM; see Appendix 2.

The water spray test, the stacking test, the thermal test and the water leakage test were not performed by BAM. This is justified in [2] as follows:

- The water spray test is not relevant for the ANF-50 shipping container due to the materials used (austenitic steel).
- The stacking test is performed as analytical verification in [2].
- The thermal test is performed analytically using a finite element (FE) mathematical model [3]. The analysis is based on the maximum damage incurred in the tests in respect of the safety features to be tested.
- The water leakage test was omitted because inleakage of water into the container leading to the maximum possible reactivity is postulated for the criticality analyses.

Pellet behavior when exposed to fire is being tested using production pellets and an enveloping temperature history in the laboratory furnace [4].

The aforementioned tests were performed on four drop test specimens of the ANF-50. Each test specimen was subjected to the same sequence of tests: a penetration test, a free drop test from 1.3 m, a crush test and a drop test onto a vertical bar. The orientation of the test specimens was changed in the crush tests, although the overall test configuration remained unchanged. Reference [2] contains a justification for specimen positioning and orientation with respect to the maximum anticipated damage.

The tests performed with the test specimens were as follows:

Test Specimen P1:

1. Penetration test with bar dropped onto side wall of case for pellet box
2. Free drop test (III.31/0928; April 10, 2002) from height of 1.3 m onto side of protective lid
3. Crush test (III.31/0928; April 11, 2002) in normal position; i.e. with container standing upright on target
4. Drop test onto vertical bar (III.31/0936; April 12, 2002) with container dropped upside down (onto protective lid) at an angle of approx. 25°
5. Additional drop test onto vertical bar (III.31/0940; April 12, 2002) with container dropped onto case for pellet box.

Test Specimen P2:

1. Penetration test with bar dropped onto side wall of case for pellet box

2. Free drop test (III.31/0929; April 10, 2002) from height of 1.3 m onto side of protective lid
3. Crush test (III.31/0933; April 11, 2002) in side position; i.e. with container lying on one side on target
4. Drop test onto vertical bar (III.31/0937; April 12, 2002) with container dropped upside down (onto protective lid) at an angle of approx. 25°

Test Specimen P3:

1. Penetration test with bar dropped onto side wall of case for pellet box
2. Free drop test (III.31/0930; April 10, 2002) from height of 1.3 m onto side of protective lid
3. Crush test (III.31/0934; April 11, 2002) in edge position; i.e. with container lying on one edge on target
4. Drop test onto vertical bar (III.31/0938; April 12, 2002) with container dropped upside down (onto protective lid) at an angle of approx. 25°

Test Specimen P4:

1. Penetration test with bar dropped onto side wall of case for pellet box
2. Free drop test (III.31/0931; April 10, 2002) from height of 1.3 m onto side of protective lid
3. Crush test (III.31/0935; April 11, 2002) in corner position; i.e. with container standing on one corner on target
4. Drop test onto vertical bar (III.31/0939; April 12, 2002) with container dropped upside down (onto protective lid) at an angle of approx. 25°

For the water immersion test, Test Specimen No. 5 – representing a pellet box (inner pellet container of ANF-50) – was subjected in a pressure vessel filled with water to a hydrostatic pressure of 150 kPa, corresponding to the external pressure prevailing at a depth of 15 meters, for a period of not less than eight hours.

5. Test Specimens

5.1 Test Specimens for Mechanical Tests

The mechanical tests were performed using the four test specimens with the factory serial numbers BW 7/ 649, BW 7/ 661, BW 7/ 748 and BW 7/ 800 for the ANF-50 shipping container.

The test specimens were constructed at Werkstätten GmbH in Nordhorn on the basis of Drawing No. W 4435 Rev. 0 and the associated subordinate drawings from existing pellet shipping containers to which, in some cases, newly fabricated components were added.

The completeness and correctness of the documentation submitted by Werkstätten GmbH for the four drop test specimens is confirmed in the inspection certificate issued by TÜV Rheinland/Berlin-Brandenburg e.V. [5].

Appendix 3-1 documents the as-delivered condition of the four test specimens (see Figs. 1 to 4); Figure 5 shows Test Specimen No. 4 after it has been opened.

The container consists of the *outer frame* with protective lid, the *case for the pellet box* with the case lid, the *pellet box* with its lid and the *pellet support structure*. The *outer frame* is a welded structure consisting of austenitic steel tubes and strips. The *case for the pellet box* is a sandwich structure with outer and inner plates made of austenitic steel. Between the plates is a welded support structure formed from austenitic channels with various cross-sectional geometries. The cavities between the plates are largely filled with inorganic insulating material (material designation KV 122). The case for the pellet box is welded along the edges of its four sides to the vertical tubes of the outer frame via sheet metal straps. The lid of the case is of a similar sandwich structure.

The *pellet box* and the lid of the box are made of austenitic sheet steel. A gasket is integrated into the flange of the pellet box. The box lid is fastened to the pellet box by means of 12 bolts. Lifting lugs are provided in the four corners of the lid for lifting the closed pellet box out of the case.

The *pellet support structure* consists of 15 *pellet trays* for storage of the pellets in layers, the *carrying rack* supporting the pellet trays, two end plates for positioning the pellet trays in the carrying rack and the clamping device for holding the stacked pellet trays together.

Dummy pellets made of lead are used to simulate the effect of the pellets' mass. These lead rods have a diameter of 9.50 ± 0.1 mm (corresponding to the maximum pellet diameter) and a length of 144^{+2} mm (two rods correspond to the width of the pellet tray and thus the maximum pellet column length).

The mass effect of the unirradiated uranium dioxide pellets is conservatively enveloped by the dummy pellets due to the density of the lead alloy ($\rho = 11.18$ kg/dm^3) compared to that of UO_2 ($\rho_{theor.} = 10.96$ kg/dm^3).

The total mass of the test specimen is approximately 229 kg:

Container (empty)	approx.	172 kg
Dummy pellets	approx.	57 kg
Total weight	approx.	229 kg

5.2 Test Specimen for Water Immersion Test

The water immersion test was performed with an empty pellet box (inner pellet container of ANF-50; Test Specimen No. 5) in order to eliminate any supporting effect on the part of the box internals.

6. Test Facility

The tests were performed at the drop test stand of the Federal Institute for Materials Research and Testing (BAM) in Berlin (BAM-Fabeckstrasse site).

6.1 Drop Tests

The BAM drop test stand was available for performance of the drop tests (see Appendix 1-1). The target in this test stand, comprising a square, reinforced concrete block measuring 6 m x 6 m x 3 m (mass = approx. 280000 kg) and a steel plate measuring 4 m x 2 m x 0.3 m (mass = approx. 18700 kg) connected to the concrete foundation by means of tie rods serving as an impact surface, meets the requirements for drop test targets according to [1].

For the drop tests onto a vertical bar, a circular bar conforming to [1] was used (material: St 52, diameter: 150 mm, length: 500 mm) (see Appendix 1-2).

An electromechanical release mechanism is used for releasing the test object. Release is entirely moment-free so that the calibrated drop position is retained on impact.

6.2 Crush Tests

The crush tests were performed using a steel plate fabricated according to the specifications in [1]. The weight of the steel plate was 520 kg and the dimensions were 1000 mm x 1000 mm x 65 mm. The electromechanical release mechanism was also used here for releasing the steel plate.

6.3 Penetration Test

A steel bar of 32 mm in diameter with a hemispherical end, a length of 1 m and a mass of 6 kg was used for the penetration test.

6.4 Water Immersion Test

The pellet box (inner pellet container of ANF-50) was subjected in a pressure vessel filled with water to a hydrostatic pressure of 150 kPa for a period of eight hours. The hydrostatic pressure acting on the outside of the test specimen corresponds to a depth of immersion of 15 m under water. The water pressure was maintained constant by a control unit and was recorded over the entire duration of the test (pressure sensor: Sensotec Super TJE, Serial No. STJE/8885-10; recorder: two-channel recorder Model DRC540, W+W Electronic AG of Basle).

7. Test Results

Test Specimens Nos. 1 to 4 were measured at Werkstätten GmbH prior to the tests as part of the in-process inspections during manufacture and after completion of the tests. Opening and measurement of the test specimens after the tests were performed in the presence of BAM. The results of these measurement are presented in [6].

7.1 Test Specimen No. 1

Appendix 4.1 of the Test Report contains the photographs showing the results of the tests for Test Specimen No. 1. The results of the measurements are documented in Appendix 2 of the Summary of Data [6].

The penetration test produced a 6-mm-deep dent in side wall P1-D of the case for the pellet box; see Appendix 4.1-1, Figures 1 and 2.

The results of the 1.3-m free drop test (App. 4.1-2, Fig, 3), the crush test (App. 4.1-3, Fig. 6), the drop test onto a vertical bar (App. 4.1-4, Fig. 9) and the additional drop test onto a vertical bar (App. 4.1-5, Fig. 11) are described below:

Outer Frame and Protective Lid

- Buckled vertical tubes from free drop test (App. 4.1-2, Figs. 4 and 5) and crush test (App. 4.1-3, Figs. 7 and 8).
- Deep dent in protective lid (App. 4.1-4, Fig. 10) from drop test onto vertical bar (III.3/0936).

Case for Pellet Box and Case Lid

- The additional drop test onto a vertical bar (III.31/0941) caused local deformation of the pellet box case. The steel section along the bottom edge is partially indented; see Appendix 4.1-5, Figures 12 and 13 as well as Appendix 2, Pages 2 – 9 in [6].

- Otherwise the pellet box case is undamaged on the outside and inside (Apps. 4.1-6 and 4.1-7, Figs. 14 to 16).
- The lid is undamaged on the outside. The heads of the bolts of the pellet box lid made small dents on the inside.

Pellet Box, Pellet Support Structure, Dummy Pellets

- No damage is visible on the *pellet box lid*; the surface can be seen to be slightly convex.
- The *pellet box* is undamaged and has retained its shape (Apps. 4.1-7 and 4.1-8, Figs. 17 to 19). The dimensions on Page 5 of Appendix 2 in [6] that were recorded before and after testing indicate slight changes (≤ 0.6 mm).
  The side walls can be seen to be slightly convex (App. 4.1-7, Fig. 17).
- The *clamping device* is loose and exhibits permanent buckling by approx. 4 mm (App. 4.1-9, Fig. 20).
- Both *end plates* exhibit slight permanent buckling.
- All *pellet trays* have remained in their original positions (App. 4.1-9, Figs. 20 and 21).
- Nearly all *dummy pellets* have moved longitudinally by approx. 8 mm in the tray grooves (App. 4.1-9, Fig. 22).

7.2 Test Specimen No. 2

Appendix 4.2 of the Test Report contains the photographs showing the results of the tests for Test Specimen No. 2. The results of the measurements are documented in Appendix 2 of the Summary of Data [6].

The penetration test (see Fig. 1 in App. 4.2-1) produced a 6-mm-deep dent in side wall P2-D of the case for the pellet box (App. 4.2-2, Fig. 2).

The results of the 1.3-m free drop test (App. 4.2-2, Fig. 3), the crush test (App. 4.2-3, Fig. 6) and the drop test onto a vertical bar (App. 4.2-4, Fig. 9) are as follows:

Outer Frame and Protective Lid

- Buckled tubes and strips from free drop test (App. 4.2-2, Figs. 4 and 5) and crush test (App. 4.2-3, Figs. 7 and 8).

- Deep dent in protective lid from drop test onto vertical bar (App. 4.2-4, Fig. 10).

Case for Pellet Box and Case Lid

- The lid is undamaged on the outside; the heads of the bolts of the pellet box lid made small dents on the inside.
- Pellet box case is undamaged on the outside and the inside (App. 4.2-5, Figs. 11 and 12).

Pellet Box, Pellet Support Structure, Dummy Pellets

- No damage was detected on the *pellet box lid.* The surface can be seen to be slightly convex.
- The *pellet box* is undamaged and has retained its shape (App. 4.2-6, Fig. 14 and App. 4.2-7, Fig. 15). Slight dimensional changes of ≤ 1 mm found after testing are documented in Appendix 3, P. 5 of [6]. Side walls can be seen to be slightly convex.
- The *clamping device* exhibits permanent buckling by approx. 4 mm (App. 4.2-8, Fig. 17).
- All *pellet trays* remained in their positions (App. 4.2-8, Figs. 18 and 19).
- The *dummy pellets* have moved longitudinally in the tray grooves (App. 4.2-8, Fig. 19) and are crushed near the bottom edge of the pellet box (App. 4.2-8, Fig. 19).

7.3 Test Specimen No. 3

Appendix 4.3 of the Test Report contains the photographs showing the results of the tests for Test Specimen No. 3. The results of the measurements are documented in Appendix 4 of the Summary of Data [6].

The penetration test (see Fig. 1 in App. 4.3-1) produced a 6-mm-deep dent in side wall P3-D of the case for the pellet box (Fig. 2, App. 4.3-1).

The results of the 1.3-m free drop test (App. 4.3-2, Fig. 3), the crush test (App. 4.3-3, Fig. 6) and the drop test onto a vertical bar (App. 4.3-4, Fig. 10) are as follows:

Outer Frame and Protective Lid

- Severely buckled tubes and strips (Apps. 4.3-3 and 4.3-4, Figs. 7 to 9) primarily from crush test.
- Deep dent in protective lid from drop test onto vertical bar (App. 4.3-5, Fig. 11).

Case for Pellet Box and Case Lid

- The lid is undamaged on the outside (App. 4.3-6, Fig. 12); the heads of the bolts of the pellet box lid made small dents on the inside.
- Pellet box case is undamaged on the outside and the inside (Apps. 4.3-6 and 4.3-7, Figs. 12 to 14).

Pellet Box, Pellet Support Structure, Dummy Pellets

- No damage was detected on the *pellet box lid*. The surface can be seen to be slightly convex.
- The *pellet box* is undamaged and has retained its shape (App. 4.3-7, Figs. 15 and 16). The dimensions on Page 5 of Appendix 4 in [6] that were recorded before and after testing are nearly the same. The side walls can be seen to be slightly convex.
- The *clamping device* exhibits permanent buckling by approx. 4 mm and one of the clamping bars has broken off (App. 4.3-8, Fig. 17).
- Both *end plates* exhibit permanent buckling.
- All *pellet trays* remained in their positions (App. 4.3-9, Fig. 19).
- Nearly all *dummy pellets* have moved longitudinally in the tray grooves (App. 4.3-9, Fig. 20).
- Some of the *dummy pellets* situated along the vertical outside edges are crushed (App. 4.3-9, Figs. 19 and 20).

7.4 Test Specimen No. 4

Appendix 4.4 of the Test Report contains the photographs showing the results of the tests for Test Specimen No. 4. The results of the measurements are documented in Appendix 5 of the Summary of Data [6].

The penetration test (see Fig. 1 in App. 4.4-1) produced a 6-mm-deep dent in side wall P4-D of the case for the pellet box (Fig. 3, App. 4.4-1).

The results of the 1.3-m free drop test (App. 4.4-2, Fig. 4), the crush test (App. 4.4-3, Fig. 6) and the drop test onto a vertical bar (App. 4.4-4, Fig. 9) are as follows:

Outer Frame and Protective Lid

- Severely buckled tubes and strips (App. 4.4-3, Figs. 7 and 8) primarily from crush test.
- Dent in protective lid from drop test onto vertical bar (App. 4.4-4, Fig. 10).

Case for Pellet Box and Case Lid

- The lid is undamaged on the outside (App. 4.4-5, Fig. 11); the heads of the bolts of the pellet box lid made small dents on the inside.
- Pellet box case is undamaged on the outside and the inside and has retained its shape (App. 4.4-5, Fig. 12).

Pellet Box, Pellet Support Structure, Dummy Pellets

- No damage is visible on the *pellet box lid*. The surface can be seen to be slightly convex.
- The *pellet box* is undamaged on the outside and the inside and has retained its shape (App. 4.4-6, Fig. 13 and App. 4.4-7, Fig. 15). The dimensions on Page 5 of Appendix 5 in [6] that were recorded before and after testing are nearly the same. The side walls can be seen to be slightly convex.
- The *clamping device* was unlatched at all four points (App. 4.4-6, Fig. 14)
- The *clamping device* exhibits permanent buckling by approx. 4 mm (App. 4.4-7, Fig. 16)
- Both *end plates* are permanently buckled outwards (App. 4.4-8, Fig. 17)
- The *pellet trays* remained in their positions (App. 4.4-8, Figs. 18 and 19).
- Nearly all *dummy pellets* have moved longitudinally in the tray grooves, with the *dummy pellets* along the outside edges of the pellet box having been crushed (App. 4.4-8, Figs. 18 and 19).

7.5 Result of Water Immersion Test

Appendix 4.5 of the Test Report contains the photographs showing the performance (Figs. 1 to 6) and results (Figs. 7 and 8) of the water immersion test.

No changes in geometry and no inleakage of water resulting from the water immersion test were discovered in the pellet boxes (inner pellet containers of ANF-50).

8. Conclusion

Four test specimens based on the ANF-50 pellet shipping container were each subjected to a sequence of tests comprising a 1.2-m free drop test, a penetration test, a crush test and a drop test onto a vertical bar to demonstrate their ability to withstand normal conditions of transport as well as accident conditions. The only difference between the four test sequences was in the orientation of the test specimen during the crush test.

The water immersion test was performed on a test specimen representing the pellet box (inner pellet container of ANF-50).

The results of the mechanical tests on the individual test specimens were similar.

Some of the tubes and strips of the *outer frame* of the test specimen suffered severe buckling, depending on the orientation of the specimen during the crush test. In large stacked configurations, deformation of this kind can be expected to result in a reduction in the distance separating the individual packages from each other.

Despite the severe deformation of the outer frame, the *pellet box cases* remained undamaged and kept their shape. The tests in which the specimen was dropped upside down onto a vertical bar resulted in denting of the protective lid; however, there was no deformation of the lid of the pellet box case.

In addition to the specified test conditions, Test Specimen No. 1 was also subjected to an "additional drop test onto a vertical bar" with the container being dropped onto the case for the pellet box. This orientation was made possible by the fact that the strips of the frame had been deformed during the preceding crush test. In the additional drop test, the vertical bar caused an indentation along part of the bottom edge of the pellet box case so that local heat input can be expected to be slightly higher compared to the original condition.

The *pellet box* and lid remained undamaged and kept their shape in all test specimens. All pellet trays stayed in position. As regards the *configuration of the contents* (dummy pellets), longitudinal movement of the dummy pellets in the grooves of the trays was identified in all test specimens. The dummy pellets situated near the bottom edges of the pellet box were crushed, meaning that individual UO_2 pellets in an actual shipping container may become severely damaged under such loading conditions.

Permanent buckling occurred in the end plates and the top plate of the *carrying rack*, resulting in a partial loss of function on the part of the top plate (Test Specimen No. 3).

All lid fasteners (for pellet box case and pellet box) remained undamaged by the tests.

The water immersion test did not lead to any inleakage of water into the pellet box or to any changes in pellet box geometry.

9. References

[1] IAEA Safety Standard Series. Regulations for the Safe Transport of Radioactive Material - 1996 Edition (revised), Regulations TS-R-1 (ST-1, Revised), IAEA 2000

[2] FRAMATOME ANP: Test Program for ANF-50 Shipping Container for Unirradiated Uranium Dioxide Pellets. Work Report No. A1C-1310729-0, Erlangen, 08.04.2002

[3] IABG: Numerical Simulation of IAEA Thermal Test for ANF-50 Pellet Shipping Container, Final Report B-TA-3928-Rev 1, Ottobrunn, October 11, 2002

[4] FRAMATOME ANP: Laboratory Tests for Oxidation Characteristics of UO_2 and Gd_2O_3/UO_2 Pellets under the Conditions of the IAEA Thermal Test for the ANF-50 Shipping Container, Work Report No. A1C-1311344-0, Erlangen, October 11, 2002

[5] TÜV Rheinland/Berlin-Brandenburg e.V.: Expert Certificate No. 620-24/0382 S. Review of Documentation for Test Specimens of ANF-50 UO_2 and ERU Pellet Shipping Container. Berlin, May 28, 2002.

[6] ANF GmbH: Measurements of ANF-50 Shipping Container (Test Specimen 1 to 4) before / after IAEA tests, Summary of Data ANFG-11.119(003), Rev. 000, Lingen, June 12, 2002

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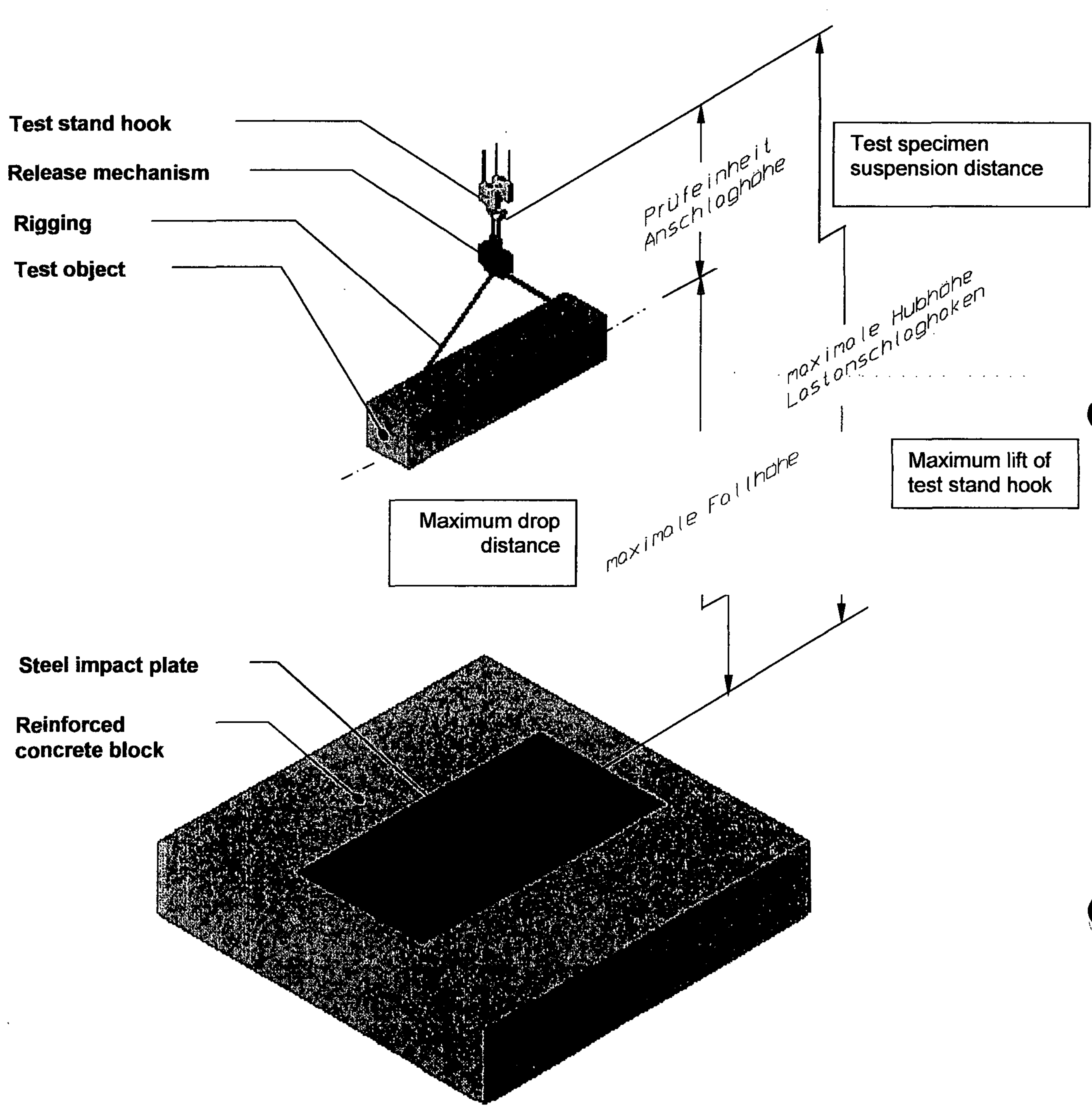
Appendix 1

Test Facility

BAM Drop Test Stand

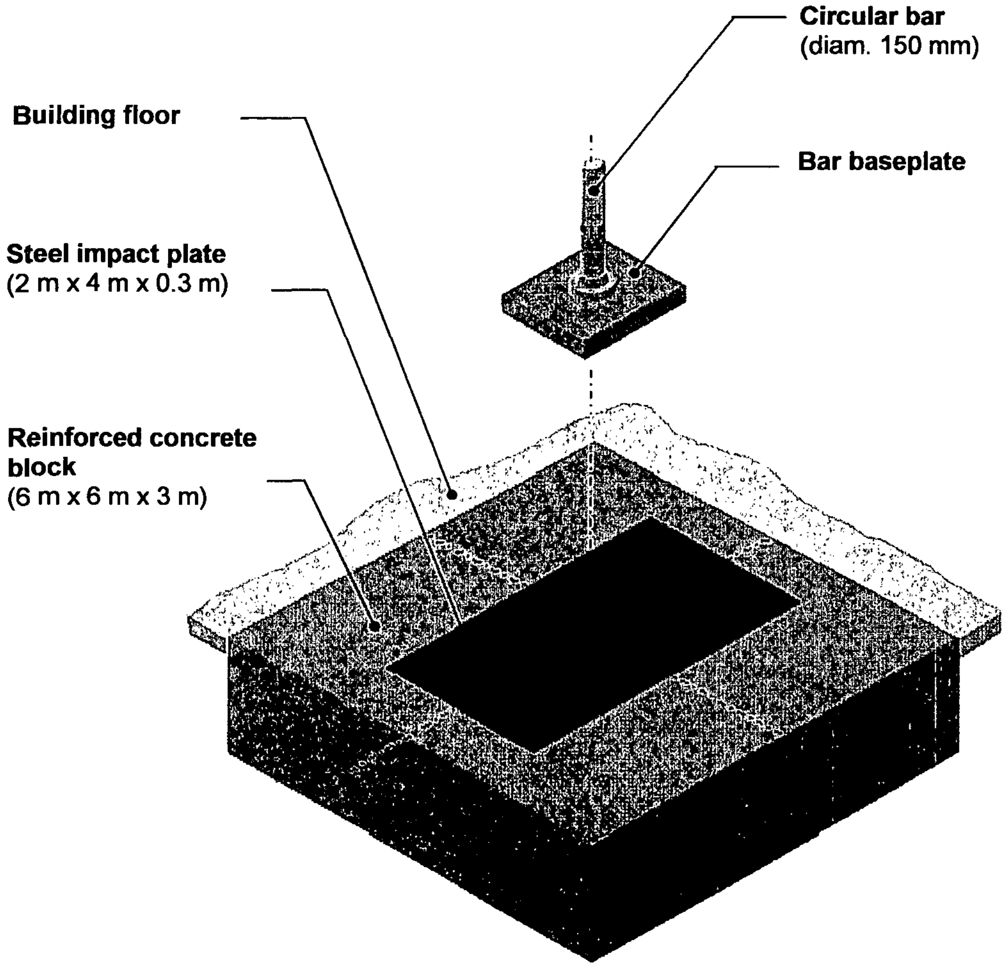
- Berlin, FB - Building 88 -



Target:	Total mass 280,000 kg (comprising 6 m x 6 m x 3 m reinforced concrete block and 4 m x 2 m x 0.3 m steel plate connected to concrete by means of tie rods).
Maximum lift:	12.5 m maximum height of lift of load attachment hook.
Total height of test unit:	Depends on test specimen dimensions and requisite rigging for selected drop position.
Maximum drop distance:	Maximum lift minus test specimen suspension distance. Where required, targets such as vertical circular bars are also placed on the block; these must be accounted for when measuring the maximum possible drop distance.

Vertical Bar on Concrete Block

- Schematic Representation -



The bar, having a diameter of 150 mm, an edge radius of r = 6 mm and a total height of 500 mm, is placed with its baseplate onto the target.

Appendix 2

Test Program

Work Report by FRAMATOME ANP
Report No. A1C-1310729-0

FRAMATOME ANP

Work Report

Ref. (Department/Year/Serial No.)
A1C-1310729-0

Place	Date
Erlangen	08.04.2002

Subject/Title
Test Program for ANF-50 Shipping Container for Unirradiated Uranium Dioxide Pellets

Author(s)	Department	Tel.	Signature
Jahreiß	FGTM	93109	

Project
All PWR and BWR projects

Signature for Release by Dept. Concerned (for Contents, Handling, Distribution)

Signature for External Release by Sales & Marketing Dept. (Not Required for Approval Documents)

Handling Instructions
Restricted

Export Classification*)

AL: N ECCN: N

Proj.-Code	UA or DCC	Contents Code	Doc. Ident. No.
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Summary*)

Pages of Text: 21 Appendices: -

The ANF-50 shipping container (ANF Shipping Container Type 50) was developed for transporting unirradiated uranium dioxide pellets. It is to be demonstrated that the shipping container satisfies the IAEA safety standards (Regulations for the Safe Transport of Radioactive Material) as well as the national and international regulations based on these standards.

This report summarizes the requisite demonstrations of compliance, describes the tests to be performed in detail, and presents justifications for the selected test parameters.

Keywords: pellet, shipment , shipping container

*) In Technical Reports add key words (max. 12) at the end of the Summary and enter Export Classification

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Framatome ANP GmbH

Revision Sheet

Page / Appendix	Change
	no changes, first edition

Table of Contents

1 Introduction

The ANF-50 shipping container (ANF Shipping Container Type 50) was developed for transporting unirradiated uranium dioxide pellets. For approval of the shipping container it must be demonstrated that it satisfies the currently applicable IAEA safety standards [1] as well as the national and international regulations based on these standards. In this process it is to be demonstrated that no configurations arise during the mechanical resistance tests with subsequent thermal test and water immersion test in which subcriticality is no longer ensured in the postulated event of water inleakage.

With the exception of the water spray test, the stacking test, the thermal test and the water leakage test, all tests required by the IAEA are to be performed using test specimens that are representative of the ANF-50 shipping container loaded with dummy pellets. The water spray test is not relevant for the ANF-50 shipping container due to the materials used. The stacking test is to be performed as an analytical verification since the stresses arising in the load-transmitting outer frame lend themselves readily to an analytical evaluation and are significantly below the elastic limit. The thermal test for the conditions specified by the IAEA is to be performed analytically using a finite element (FE) mathematical model in which the temperatures at the positions of the pellets are calculated. Pellet behavior will be tested using production pellets and an enveloping temperature history in a laboratory furnace.

The water leakage test will not be performed because inleakage of water into the container is postulated for the criticality analyses.

2 Demonstrations According to IAEA Requirements

The IAEA safety standard "Regulations for the Safe Transport of Radioactive Material" [1] specifies the methods to be used for demonstrating compliance by shipping containers.

The tests to be performed for the shipping container under consideration here are listed below. The numbers refer to the currently applicable IAEA safety standard [1].

2.1 Tests for Demonstrating Ability to Withstand Normal Conditions of Transport

The tests to be performed in accordance with [1] are given in Nos. 721 to 724.

One or more test specimens may be used for the water spray test, the free drop test, the stacking test and the penetration test.

- No. 721 Water spray test: The specimen shall be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm per hour for at least one hour.
- No. 722 (a) Free drop test: The specimen shall drop onto the target from a height of 1.2 m so as to suffer maximum damage in respect of the safety features to be tested.
- No. 723 Stacking test: The specimen shall be subjected, for a period of 24 hours, to a compressive load equal to the greater of the following:
  - a) the equivalent of five times the mass of the actual package; and
  - b) the equivalent of 13 kPa multiplied by the vertically projected area of the package.
- No. 724 Penetration test: The test specimen shall be subjected to impact by a bar of 3.2 cm in diameter with a hemispherical end and a mass of 6 kg dropped from a height of 1 m onto the center of the weakest part of the test specimen.

2.2 Tests for Demonstrating Ability to Withstand Accident Conditions of Transport

Following the tests for demonstrating ability to withstand normal conditions of transport, only one test specimen shall, according to [1], be subjected to the cumulative effects of tests Nos. 727 to 729 and Nos. 731 to 733, in that order.

- No. 727 (b) Drop test onto a vertical bar: The test specimen shall drop onto a circular solid steel bar (diam. 15.0 ± 0.5 cm) from a height of 1 m such that it suffers the maximum possible damage in respect of the safety features to be tested.
- No. 727 (c) Crush test: The test specimen shall be positioned on an unyielding target such that it suffers the maximum possible damage in respect of the safety features to be tested when a mass of 500 kg is dropped onto the specimen from a height of 9 m. The mass shall consist of a solid mild steel plate measuring 1 m by 1 m and shall fall in a horizontal attitude.
- No. 728 Thermal test: The specimen shall be in thermal equilibrium under conditions of an ambient temperature of 38°C, and shall be subjected to a heat input of 800 W/cm² on all surfaces with the exception of the base.

  The specimen shall be exposed to the thermal environment for a period of 30 minutes in sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and an average flame temperature of at least 800°C.

  After interruption of heat input, the specimen shall not be artificially cooled and any combustion of materials of the specimen shall be permitted to proceed naturally.
- No. 729 Water immersion test: The test specimen shall be immersed under a head of water of at least 15 m for a period of not less than eight hours.
- Nos. 731 to 733 Water leakage test: The specimen shall be immersed under a head of water of at least 0.9 m for a period of not less than eight hours and in the attitude for which maximum leakage is expected. The test shall only be performed if no inleakage of water is postulated in the criticality analysis.

3 Description of Shipping Container

The ANF-50 shipping container is shown with its main dimensions in Figure 1. The exact dimensions and materials used are specified in [2] and in the subordinate drawings and parts lists.

The ANF-50 shipping container consists of the outer frame with protective lid, the case for the pellet box with the case lid, the pellet box with its lid and the pellet support structure.

The outer frame is a welded structure consisting of austenitic steel tubes and strips. Four vertical tubes are connected at the top and bottom to four horizontal tubes. The four sides are each reinforced with a diagonal tube and closed by a grid of longitudinal strips. The bottom is reinforced with two diagonal tubes and is also closed by a grid of longitudinal strips. The free space between the strips is less than 10 cm. Support legs (made of solid material) having the same diameter as the vertical tubes are integrated into the bottom ends of the vertical tubes, permitting stacking of the containers on the steel angles welded to the top ends.

Gusset plates for attaching the protective lid are welded to the corners at the top. The protective lid consists of a frame of square channels, the upper side of which is closed by a cover plate. The protective lid is bolted to the outer frame at the four bent straps at the corners. With the protective lid in place, the clearance between the protective lid and the horizontal tubes on the top of the outer frame is less than 10 cm.

The case for the pellet box (Fig. 2) is a sandwich structure with an outer austenitic steel plate (sides: 1.5 mm thick, base: 5 mm thick) and an inner austenitic steel plate (2 mm thick). Between the plates is a welded support structure formed from round and rectangular austenitic steel tubes as well as austenitic steel round and angle channels and flat strips. The cavities between the plates are largely filled with inorganic insulating material. The inner and outer plates are welded to the support structure of the pellet box case. The case is welded along the edges of its four sides to the vertical tubes of the outer frame via sheet metal straps.

The lid of the case is also a sandwich structure consisting of austenitic steel plates (5 mm thick on the outside and 2 mm thick on the inside) with inorganic insulating material between the plates. To stiffen the structure, spacer sleeves are installed between the plates in the vicinity of the bolt holes. The lid of the case for the pellet box is fastened to the case with eight bolts.

The pellet box and the lid of the box are made of austenitic sheet steel. A gasket is integrated into the flange of the pellet box. The lid of the box is fastened to the pellet box by means of 10 bolts. Lifting lugs are provided in the four corners of the lid for lifting the closed pellet box out of the case.

The pellet support structure consists of 15 pellet trays for storage of the pellets in layers, the carrying rack supporting the pellet trays, two end plates for positioning the pellet trays in the carrying rack and the clamping device for holding the stacked pellet trays together. The pellet support structure is designed to accommodate up to 14 pellet trays filled with pellets. The 15th pellet tray lies on top of the uppermost pellet layer to complete the stack. Bolts are used to press the two clamping bars of the clamping device down onto the uppermost pellet tray, thus holding the entire stack of pellet trays firmly together. When less than 14 trays are filled with pellets, the empty pellet trays are placed on top of the uppermost tray and clamped together with the filled pellet trays to form a packet. The clamping device can be locked in various vertical positions in the carrying rack to ensure that the stack is properly clamped together at all times, regardless of the number of trays that are loaded with pellets (1 to 14). The pellet trays are designed to accommodate and store 22 adjacent rows of pellets with a pellet diameter of 8.05 mm to 9.50 mm. In the case of pellets with a diameter of 8.05 mm, the ANF-50 can be loaded with 14 layers of pellets, whereas the loading capacity is limited to 11 layers in the case of pellets with a diameter of 9.50 mm. Each pellet tray may only be filled with pellets of the same diameter. A lifting attachment is provided at the center of the top plate of the clamping device for lifting the pellet support structure out of the pellet box.

The mass of the ANF-50 pellet shipping container is approximately 172 kg when empty.

4 Demonstration of Compliance

4.1 Maximum Damage According to IAEA

4.1.1 Possible Damage Scenarios

The possible types of damage that could be sustained by the shipping container as a result of the IAEA test sequences are listed in the following table, ranked according to their estimated probability of occurrence. The maximum damage to the shipping container after the free drop tests, the thermal test and the water immersion test can thus comprise one form of damage as well as a combination of the listed forms of damage.

Possible Effect	Rank by Probability of Occurrence	Effect on Reactivity
Reduction of outside dimensions of shipping container, resulting in the possibility of a denser shipping container configuration	1	I
Separation of case for the pellet box from outer frame, resulting in the possibility of a denser configuration of the pellet box cases.	2	II
Oxidation of the pellets (UO_2) to powder (U_3O_8) during the thermal test.	3	II
Disruption of layered pellet configuration on or between the pellet trays.	4	III
Rupture of the pellet box and escape of pellets or pellet fragments.	5	III

Effects on reactivity in the configuration of transport containers to be examined:

Class I: Small increase in reactivity
Class II: Medium increase in reactivity
Class III: Large increase in reactivity

The presence of moderating substances or the inleakage of water is always postulated in the criticality safety analyses.

The objective of the test program is to demonstrate the kind of damage that can be sustained by the shipping container and the uranium dioxide pellets contained therein. Of special interest here is the question whether effects of Classes II and/or III actually occur.

4.1.2 Anticipated Effects

The anticipated effects on the specimens are discussed below based on experience with free drop tests as well as engineering assessments:

- The arrangement of the layers of pellets on the pellet trays can become disrupted. Whether or not this is possible depends on the integrity of the clamping device.
- The pellet support structure is efficiently protected against external effects by the surrounding pellet box as well as the case for the pellet box. Also, the outer frame protects the case positioned inside it against any major deformation. However, local deformation of the case for the pellet box, the pellet box itself and the pellet support structure is nevertheless possible.
- In the crush test, the sheet metal straps (between the outer frame and the case for the pellet box) can be pressed into the case for the pellet box and can cause local deformation of the pellet box and the pellet support structure.
- In the drop test in which the container is dropped upside down onto the vertical bar, the protective lid can become detached and the bolts of the case lid can become damaged.
- In the thermal test, no additional deformation can occur in the shipping container since the welded support structure of austenitic steel channels and plates retains its shape at 800°C. The inorganic insulating material inside the case for the pellet box and the case lid is also resistant to 800°C and will not cause any additional buildup in pressure inside the sandwich structure.

- In the thermal test, the pellets (UO_2) could oxidize to powder (U_3O_8). If the pellet box were to rupture, the powder could be washed out by water entering the box. Whether oxidation of the pellets actually takes place or not finally depends on the temperature in the interior of the pellet box.

4.1.3 Conclusions for Tests

The following conclusions are drawn based on the available experience, an engineering assessment and the analyses performed [3]:

1.) Free drop test of all four specimens upside down (onto protective lid side) in order to impose maximum loads on bolting of case lid.

2.) Crush test of the four specimens with load being applied from various directions in order to cause maximum damage in respect of criticality.

The specimens are to be positioned on the target as follows:

- Normal position, with container standing upright on target
- Side position, with container lying on one side on target
- Edge position, with container lying on one edge on target
- Corner position, with container standing on one corner on target

Drop test of all four specimens upside down (onto protective lid) onto vertical bar at an angle of approx. 25° in order to cause the maximum damage according to the current standards.

3.) The thermal test for the conditions specified by the IAEA (800°C / 30 min) is to be performed analytically using an FE model in which the temperatures at the positions of the pellets are calculated. Pellet behavior will be tested using production pellets and an enveloping temperature history in the laboratory furnace.

4.) Water immersion test on one specimen (pellet box) with gasket intact in order to cause maximum damage in respect of criticality.

4.2 Test Specimens

4.2.1 Test Specimens for Mechanical Tests

The mechanical IAEA tests will be performed with four specimens for the ANF-50 shipping container. The relevant dimensions of the shipping container are to be documented. The shipping containers will be loaded with dummy pellets.

The following masses will therefore apply during the free drop tests:

Shipping container (empty)	approx.	172 kg
Dummy pellets (diam. 9.50 mm, 22 rows, 11 layers)	approx.	57 kg
Total weight	approx.	229 kg

4.2.2 Test Specimen for Water Immersion Test

The water immersion test will be performed with an empty pellet box in order to eliminate any supporting effect on the part of the box internals. For this test it is conservatively assumed that the flange gasket will not have been destroyed during the preceding thermal test; i.e. that the pellet box will be subjected to a pressure of 150 kPa.

4.2.3 Dummy Pellets for Mechanical Tests

Dummy pellets will be used to simulate the effect of the pellets' mass in the mechanical tests. The dummy pellets will comprise lead rods with a diameter of 9.50 ± 0.1 mm (corresponding to the maximum pellet diameter) and a length of 144^{+2} mm (two rods correspond to the width of the pellet tray and thus the maximum pellet column length). In the mechanical tests the mass effect of the unirradiated uranium dioxide pellets is conservatively enveloped by the dummy pellets due to the density of the lead alloy (11.18 kg/dm^3) compared to the theoretical density of UO_2 (10.96 kg/dm^3).

4.2.4 Pellet Specimens for Thermal Test

Pellet behavior will be tested using actual production pellets. Various types of pellets (composition, geometry, microstructure and density) will be investigated, each type being represented by three specimens.

4.3 Test Facilities

4.3.1 Test Stand for Free Drop Tests

The free drop tests will be performed at the Federal Institute for Materials Research and Testing (BAM) in Berlin, Unter den Eichen 44-46. The BAM drop test stand consists of a square 4-m-thick target measuring 6 m x 6 m. The actual impact plate on the target is 4 m long, 2 m wide and 0.3 m thick. It weighs 20 tons and is firmly connected to the foundation block by means of 10 tie rods.

The free drop distance between the test stand hook and surface of the target is 12.5 m. The lifting equipment is rated for 8 tons. The hook is equipped with an electromagnetic release mechanism for releasing the test specimen or the steel plate used in the crush test.

4.3.2 Steel Plate for Crush Tests

The steel plate should have a mass of 500 kg and a surface of 1 m by 1 m. Based on a density of $\rho = 7.80$ kg/dm^3, this yields a plate thickness of 64 mm. The steel plate measures 1 m x 1 m x 65 mm and meets the specifications with its mass of 520 kg.

4.3.3 Target for Drop Tests onto Vertical Bar

The dimensions of the target (baseplate with circular bar) used for the drop tests onto the vertical bar are shown in Figure 3. The circular bar is made of steel St 52. The baseplate rests on the impact plate of the test stand, and its mass of approximately 1.8 tons prevents it from sliding or overturning.

4.3.4 Laboratory Furnace for Testing of Pellet Behavior

Pellet behavior will be tested in the fuel laboratory (controlled access area) at Framatome ANP/FGTW in Erlangen. Various production pellets will be subjected in a laboratory furnace to the thermal loads of the thermal test.

4.4 Tests According to IAEA

Approval of the ANF-50 shipping container will be based on a maximum total mass of 229 kg. The free drop tests will be performed with tests specimens (Sect. 4.2.1) having a mass of 229 kg. The maximum total mass is thus enveloped.

The stated free drop distances always refer to the minimum distance from the test specimen to the impact plate, from the steel plate to the specimen and from the specimen to the vertical bar.

The slightly larger drop distances of 9 m (30 ft) and 1 m (40 in) given in parentheses in the American code 10 CFR 71 serve solely for information purposes and are not binding for compliance with this standard.

4.4.1 No. 721 Water Spray Test

The surfaces of the shipping container are made entirely of austenitic sheet steel. The lid of the case for the pellet box fits down around the upper edges of the case and is bolted to it. The pellet box inside the case is bolted to the lid of the box, and a gasket is installed between the flange of the pellet box and the lid of the box. These two barriers – the case for the pellet box and the pellet box itself – prevent any ingress of water. It is therefore not possible for the water spray test to have any effect on the container materials used, and hence the water spray test will not be performed.

4.4.2 No. 723 Stacking Test

When loaded with uranium dioxide pellets the shipping container has a maximum total mass of 229 kg. The vertically projected area of the shipping container is calculated to be 0.712 m x 0.712 m = 0.507 m^2. The stacking test is to be performed with a compressive load equal to the greater of the following:

a) The equivalent of five times the mass of the actual package (corresponds to 11233 N).

b) The equivalent of 13 kPa multiplied by the vertically projected area of the package (corresponds to 6591 N).

In the stacking test the loads are transmitted via the four vertical tubes of the outer frame (outside diameter: 42.4 mm, wall thickness: 1.6 mm). The relevant load determined above subjects the tubes to a stress of approximately 14 N/mm^2. If the load is only transmitted via two tubes, this stress increases to around 28 N/mm^2.

For a stress of 28 N/mm^2, neither plastic deformation nor instabilities are anticipated in the load-transmitting tubes ($R_{P0.2} \approx 200$ N/mm^2). Thus demonstration of compliance for the stacking test has been provided analytically.

4.4.3 No. 724 Penetration Test

A bar with a mass of 6 kg will be dropped onto the side of the case for the pellet box from a conservative height of 1.1 m (distance from outer frame). As the outer walls of the case for the pellet box exhibit nearly the same structural strength, the result of this test can be applied to the entire shipping container. No significant damage is anticipated due to the outer sheet metal thickness of 1.5 mm.

4.4.4 No. 722 (a) Free Drop Test

The four specimens, loaded with dummy pellets, will be dropped onto their protective lids (i.e. upside down) as shown in Figure 4. The drop distance is conservative specified to be 1.3 m.

4.4.5 No. 727 (c) Crush Test

The four test specimens will be subjected to a crush test as illustrated in Figures 5 to 8. The drop height of the steel plate (1 m x 1 m, 520 kg) is 9 m. For the crush test, the specimen is welded to a support plate (1.5 m x 1.5 m x 40 mm, 702 kg) in the specified position. The support plate rests on the impact plate of the test stand target, and movement of the support plate can be ruled out due to its large mass. A vertical line through the center of mass of the steel plate should pass as closely as possible through the center of mass of the specimen.

4.4.6 No. 727 (b) Drop Test onto Vertical Bar

The four test specimens will all be dropped onto the vertical bar upside down; i.e. with their protective lids facing downwards. All test parameters are shown in Figure 9. The point of impact should be as close as possible to the center of mass of the container in order to transform as much of the kinetic energy as possible into deformation. The angle of the shipping container from the horizontal (25° across the diagonal) will maximize the damage. The drop distance is conservatively set at 1.1 m. The baseplate of the target and the surrounding concrete block shall be covered over with insulating mats in order to prevent any inadvertent secondary damage upon impact of the specimen in accordance with the IAEA regulations.

4.4.7 No. 728 Thermal Test

Demonstration of compliance for the thermal test of the ANF-50 pellet shipping container is to be provided analytically. The outer frame consisting of tubes and flat strips surrounding the case for the pellet box as well as the protective lid are not relevant for the thermal test and will not be accounted for in the analytical simulations. The numerical simulation of the thermal test is described in [3].

Pellet behavior will be tested using production pellets in a laboratory furnace, with an enveloping temperature history derived from the analytical thermal test being applied for the pellet positions.

4.4.8 No. 729 Water Immersion Test

The water immersion test will be performed with a pellet box without the pellet support structure and with an intact flange gasket. The box will be filled with loose ballast material (approx. 10 kg of steel hardware) to ensure that it sinks in the immersion tank. The test specimen will immersed under a head of water of at least 15 m for a period of not less than eight hours.

4.4.9 Nos. 731 to 733 Water Leakage Test

The inleakage of water is postulated in the criticality test; this test will therefore not be performed.

4.5 Test Performance

The tests will be performed in the sequence listed in Section 4.4.

<u>The penetration test, free drop test, crush test and drop test onto a vertical bar</u> will be performed at the Federal Institute for Materials Research and Testing (BAM) in Berlin under the responsibility of BAM. The shipping container will not be opened either between or after the drop tests at BAM. Only observations made over the course of testing will be recorded in situ. Photographic documentation shall be generated which permits identification of the external circumstances and the damage following each drop test. The test stand and all tests shall be recorded on videotape. Measurement and opening of the shipping container will be performed later at the company Werkstätten in Nordhorn. BAM shall be invited to witness the opening of the container.

Testing of pellet behavior will be performed at Framatome ANP in Erlangen under the responsibility of FGTW. Three representative specimens will be tested in the laboratory furnace for each pellet type to be investigated (as regards composition, geometry, microstructure and density). The relevant test data (enveloping temperature histories for the pellet positions derived from the preceding thermal test) shall be documented. Photographs shall be taken of the test setup and the specimens (after testing). Performance of the tests shall be confirmed by an independent workshop inspector. BAM shall be invited to witness the testing.

The water immersion test will be performed at BAM's facilities in Berlin. Photographs shall be taken both before and after the test. Measurement and opening of the pellet box will be performed later at Werkstätten in Nordhorn.

5 References

[1] Regulations for the Safe Transport of
Radioactive Material, 1996 Edition (Revised)
Safety Standards Series No. TS-R-1 (ST-1, Revised)
Requirements, IAEA, Vienna 2000

[2] ANF-50 Shipping Container
Drawing No. W 4435 from Werkstätten GmbH

[3] Numerical Simulation of IAEA Thermal Test for
ANF-50 Pellet Shipping Container
Report B-TA-3928 from IABG of February 25, 2002

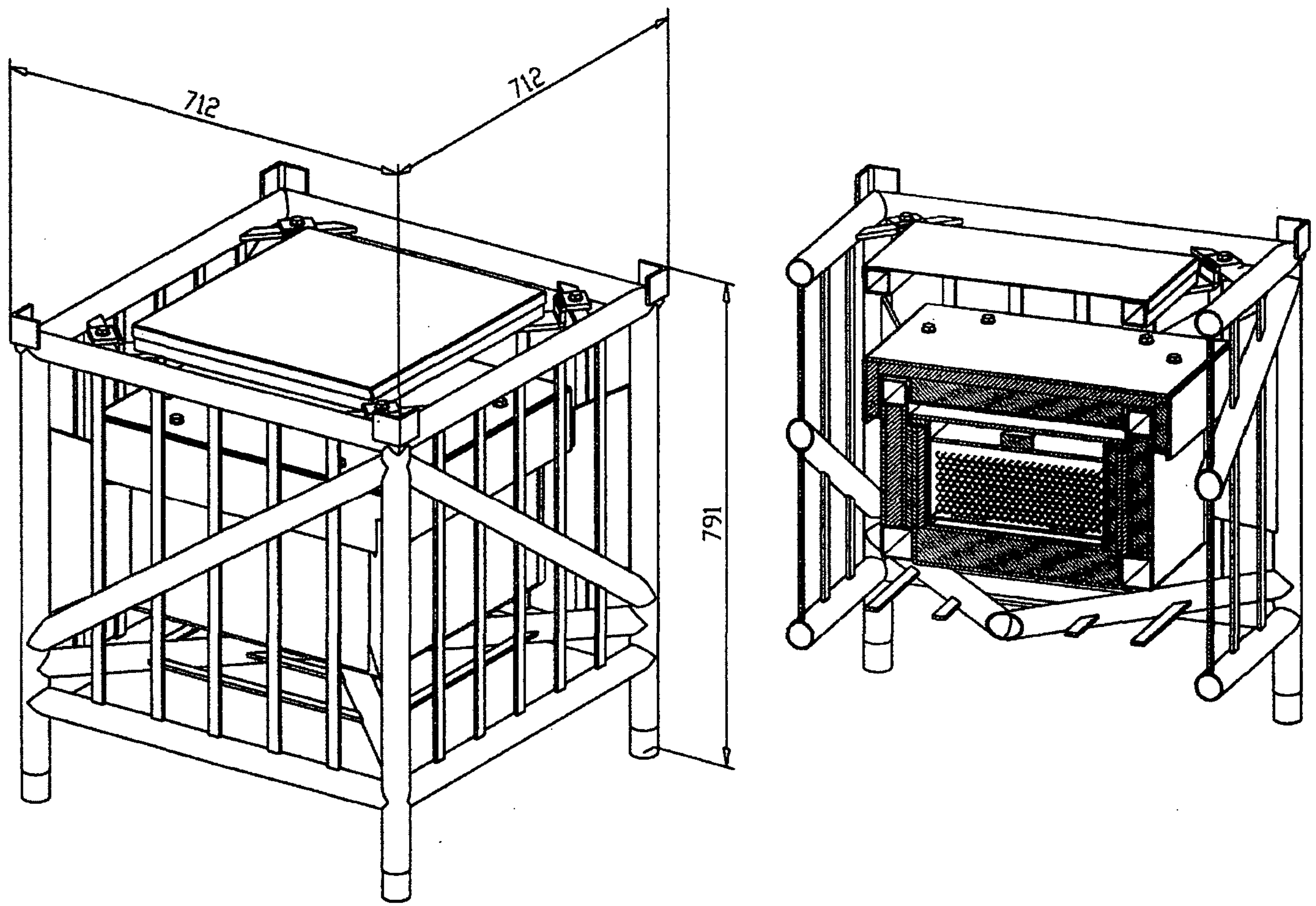


Figure 1: ANF-50 shipping container

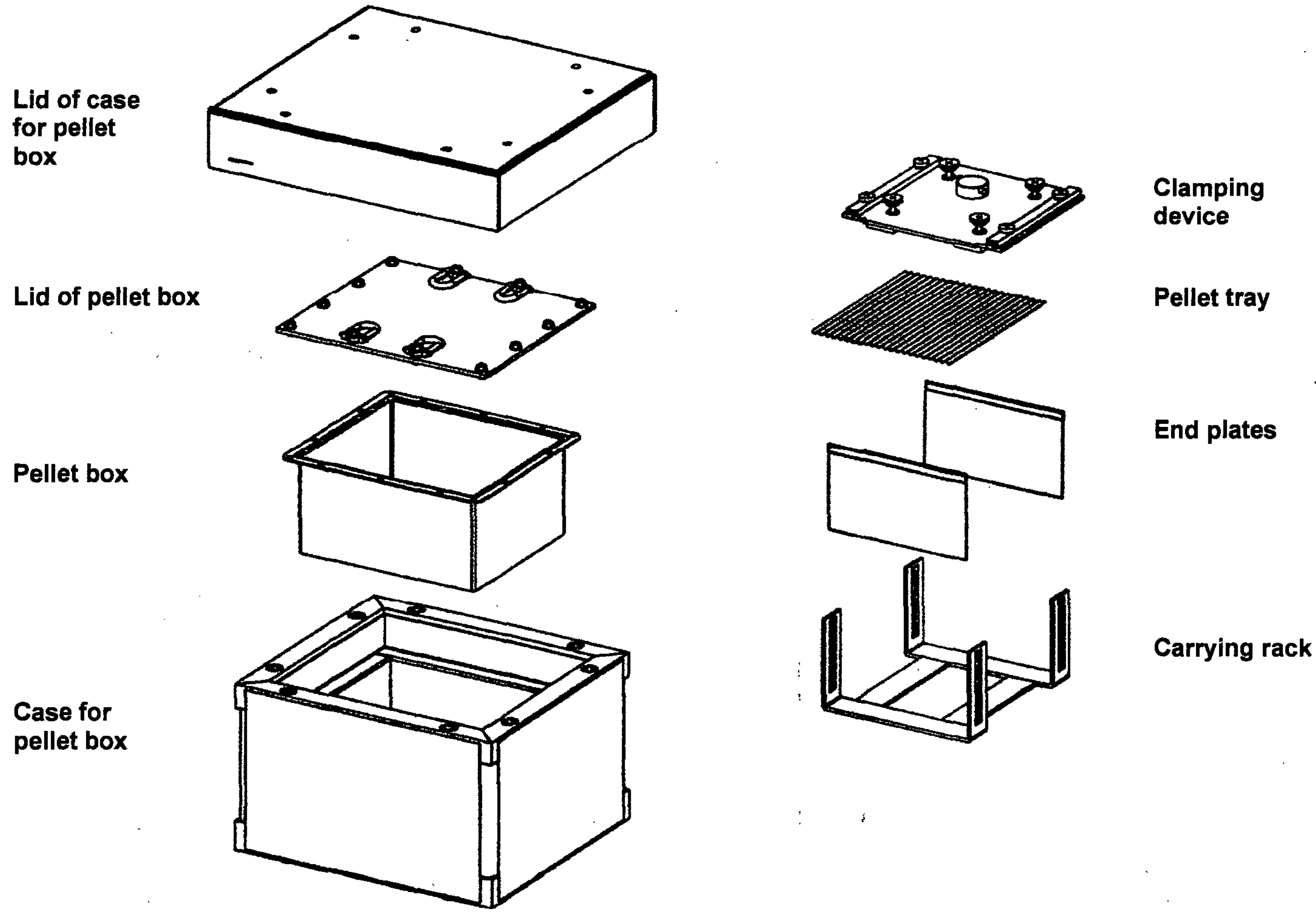


Figure 2: ANF-50 shipping container (component parts without outer frame and protective lid)

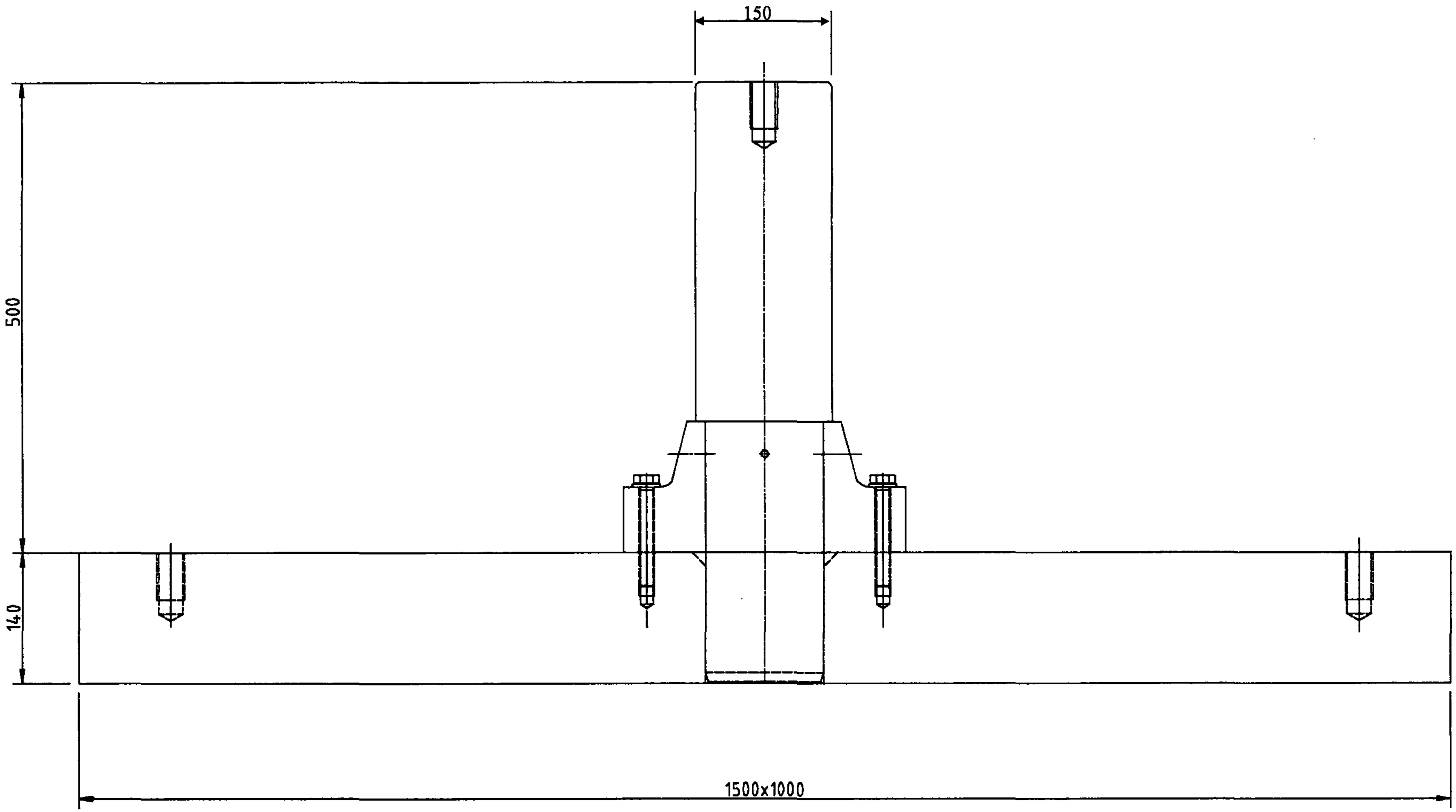


Figure 3: Target for drop test onto vertical bar (circular bar with baseplate)

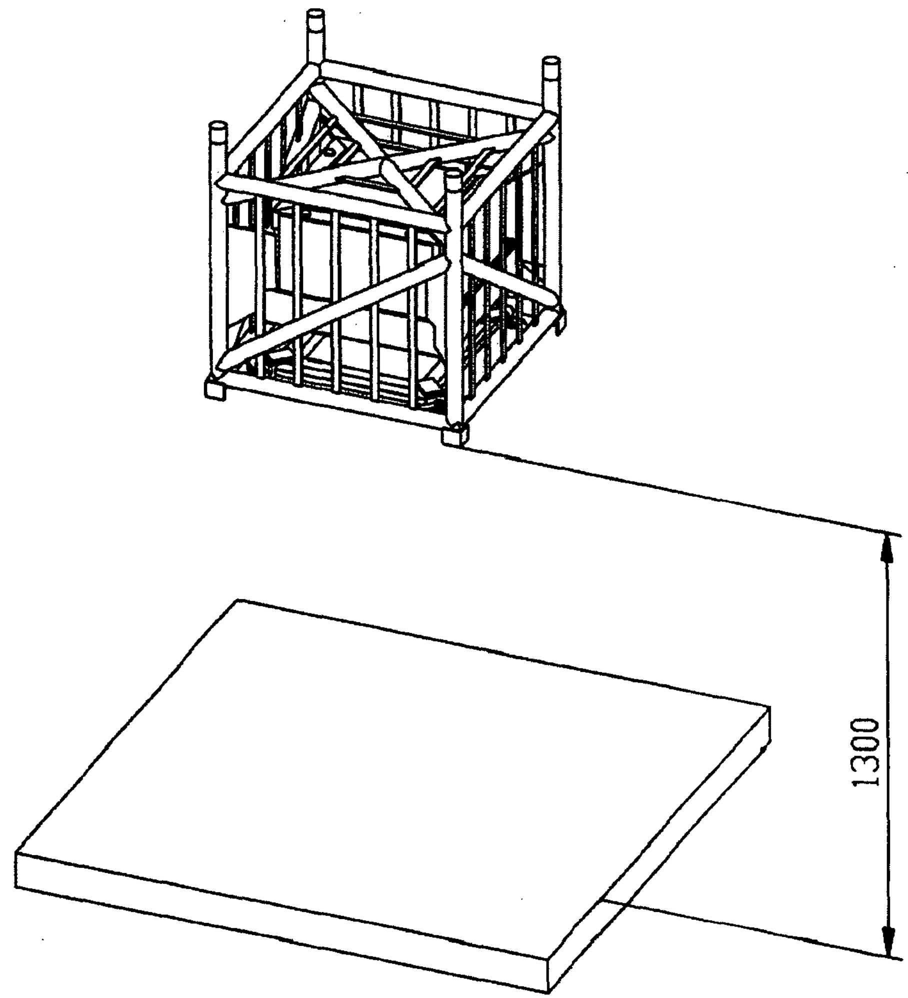


Figure 4: [1], No. 722 (a) Free drop test onto protective lid side for Test Specimens Nos. 1 to 4

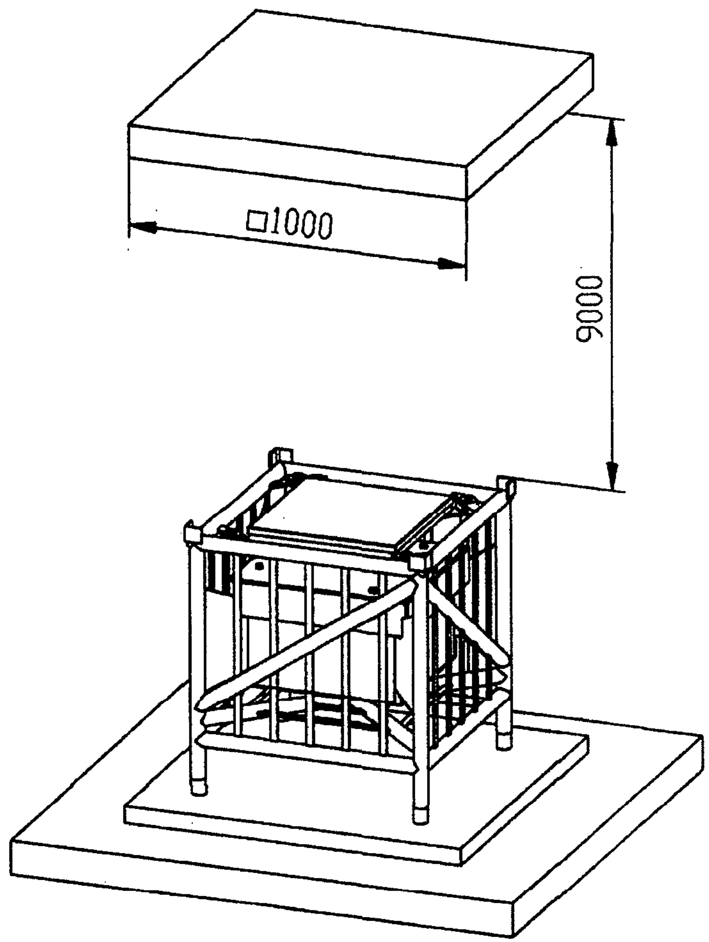


Figure 5: [1], No. 727 (c) Crush test for Test Specimen No. 1 in normal position

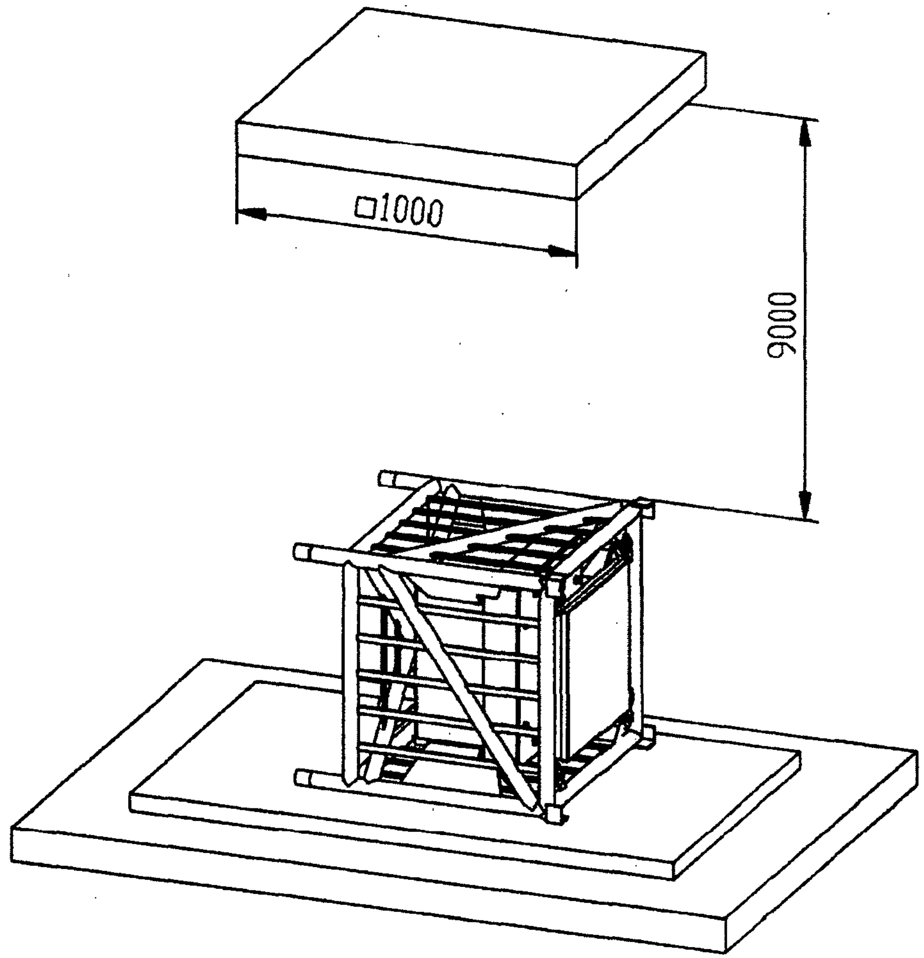


Figure 6: [1], No. 727 (c) Crush test for Test Specimen No. 2 in side position

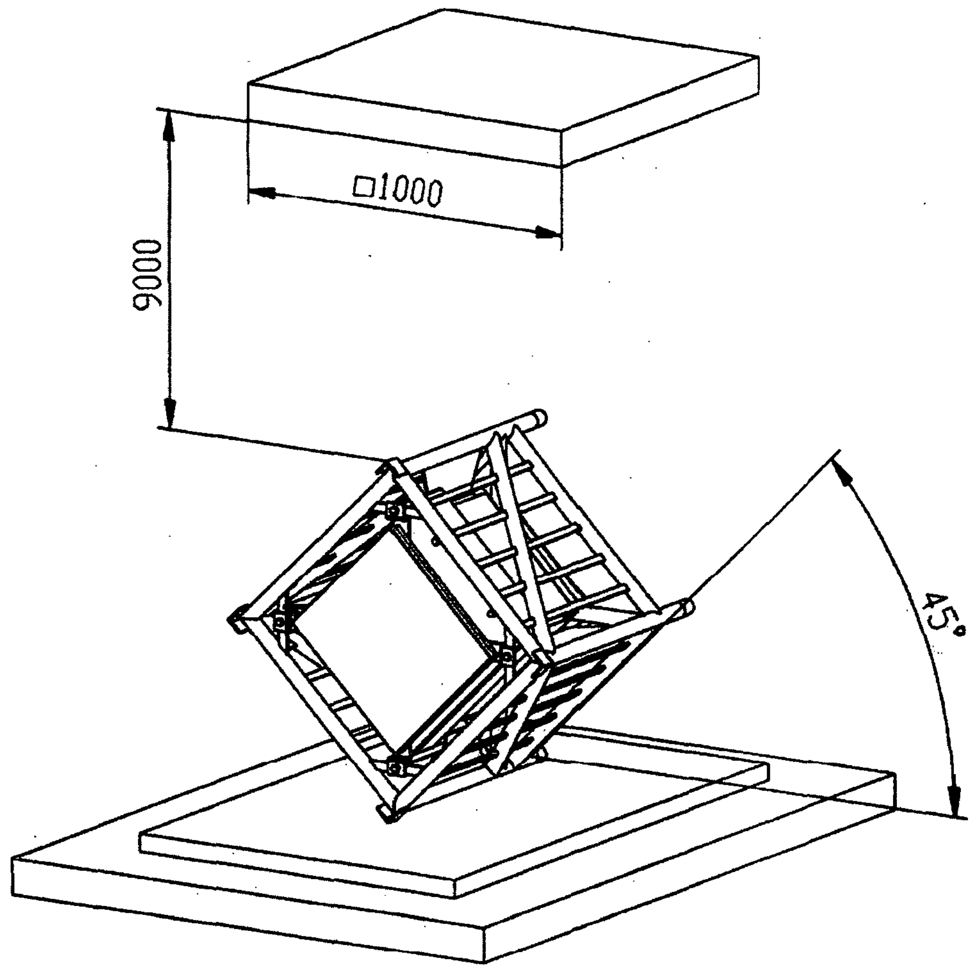
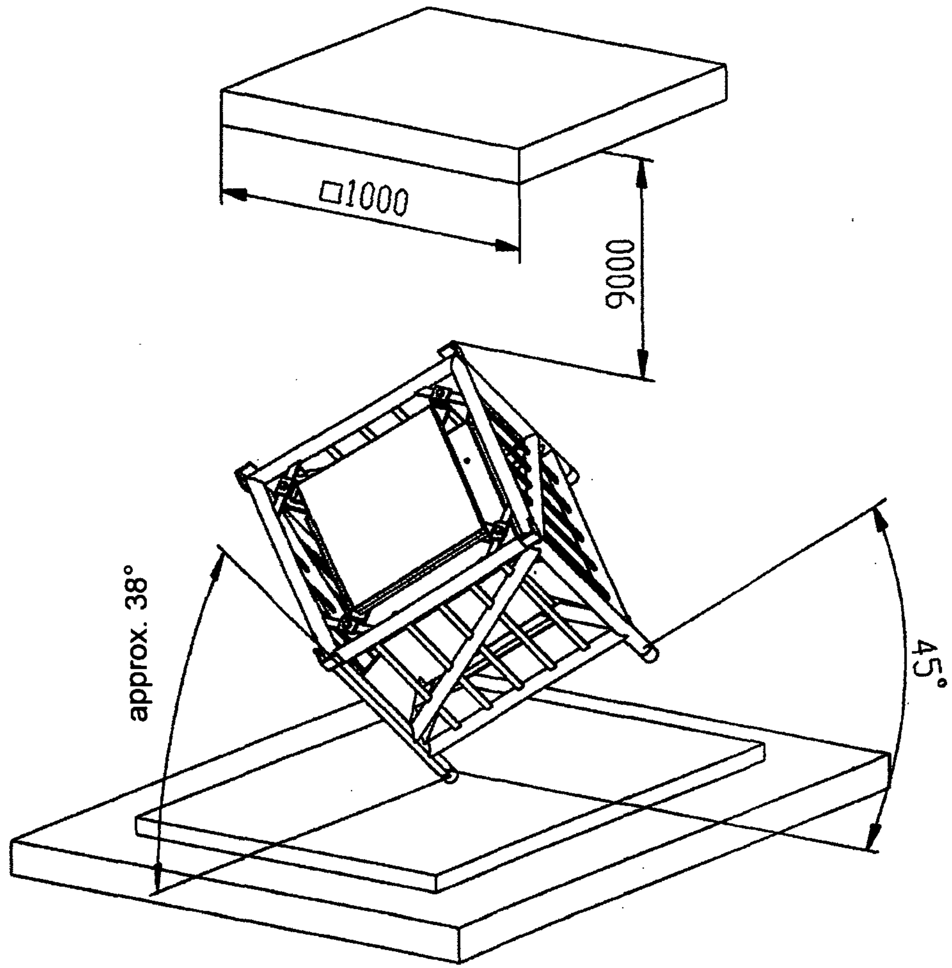


Figure 7: [1], No. 727 (c) Crush test for Test Specimen No. 3 in edge position



Bottom and top corners of outer frame form line perpendicular to impact plate

Figure 8: [1], Nr. 727 (c) Crush test for Test Specimen No. 4 in corner position

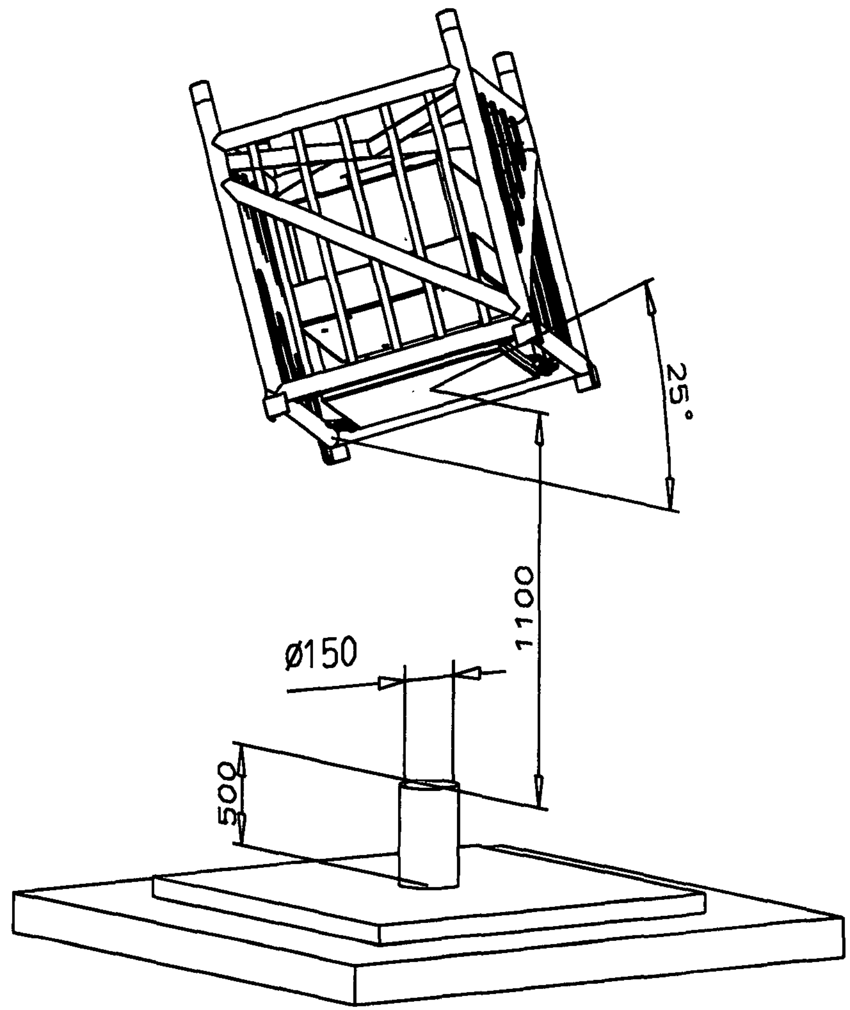


Figure 9: [1], No. 727 (b) Drop test onto vertical bar (onto protective lid) for Test Specimens Nos. 1 to 4

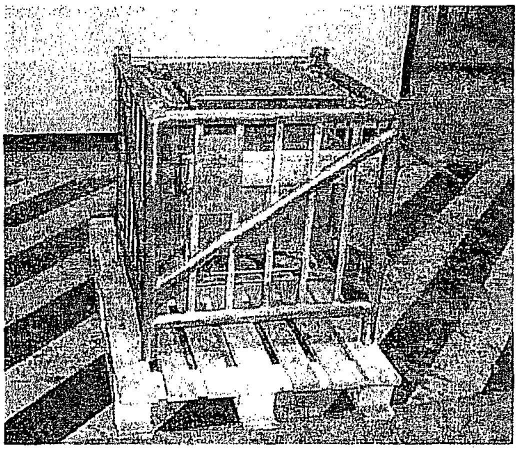


Fig. 1: Test Specimen No. 1

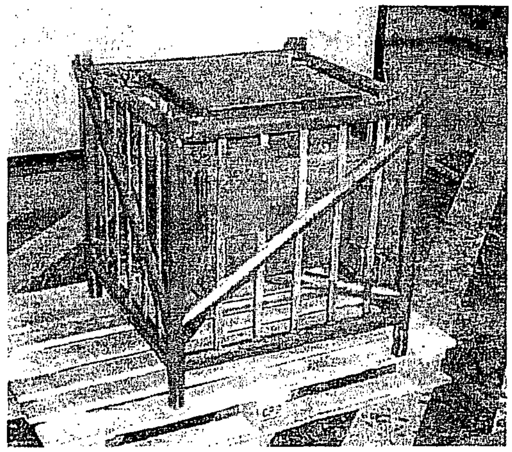


Fig. 2: Test Specimen No. 2

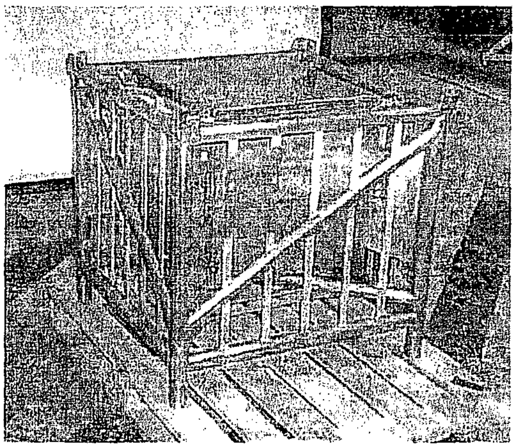


Fig. 3: Test Specimen No. 3

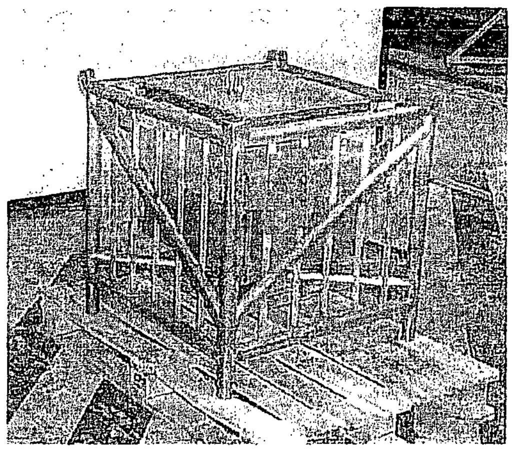


Fig. 4: Test Specimen No. 4

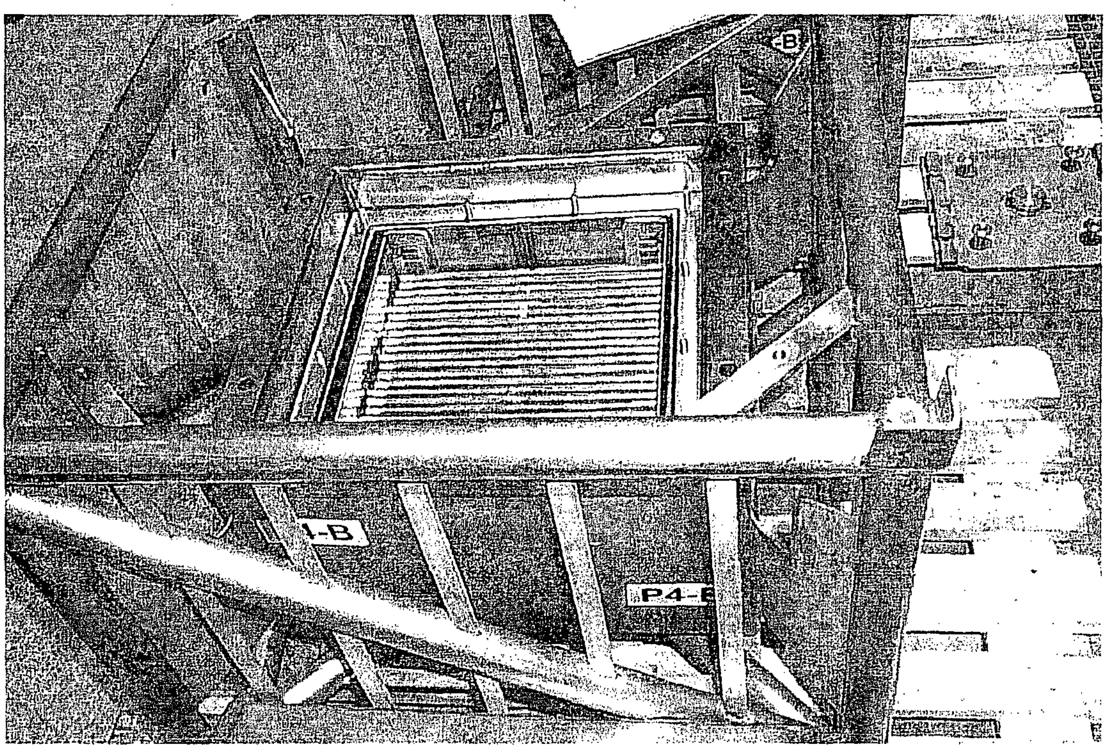


Fig. 5
Test Specimen No. 4 was opened after delivery. Picture shows uppermost layer of dummy pellets.

Appendix 4

Photographic Documentation of Tests and Test Results

Appendix 4.1	Test Specimen No. 1
Appendix 4.2	Test Specimen No. 2
Appendix 4.3	Test Specimen No. 3
Appendix 4.4	Test Specimen No. 4
Appendix 4.5	Water Immersion Test

Appendix 4.1 Test Section No. 1

Appendies 4.1-1 to 4.1-9

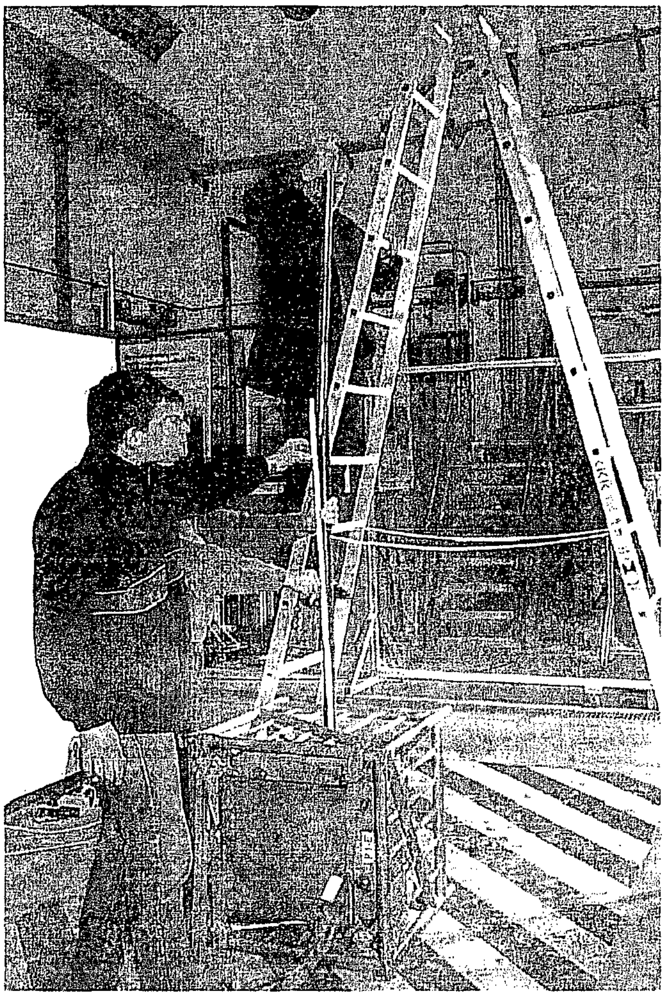


Fig. 1
Performance of penetration test before start of drop tests

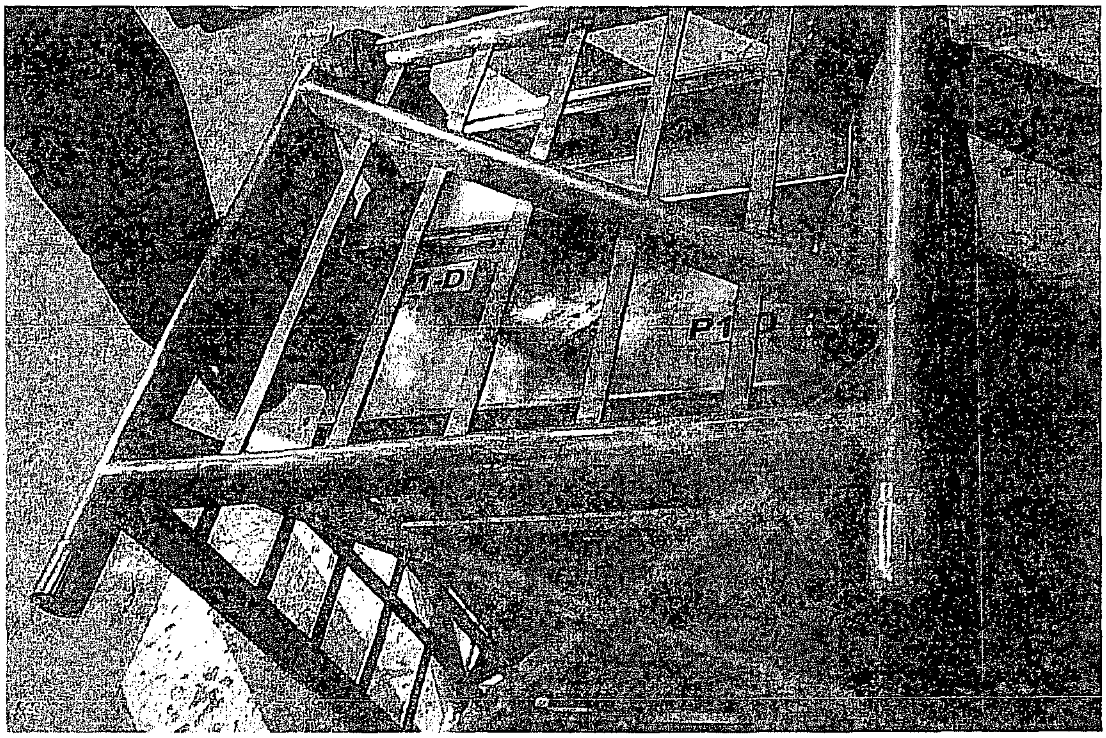


Fig. 2
Side wall P1-D of pellet box case with approx. 6-mm-deep dent

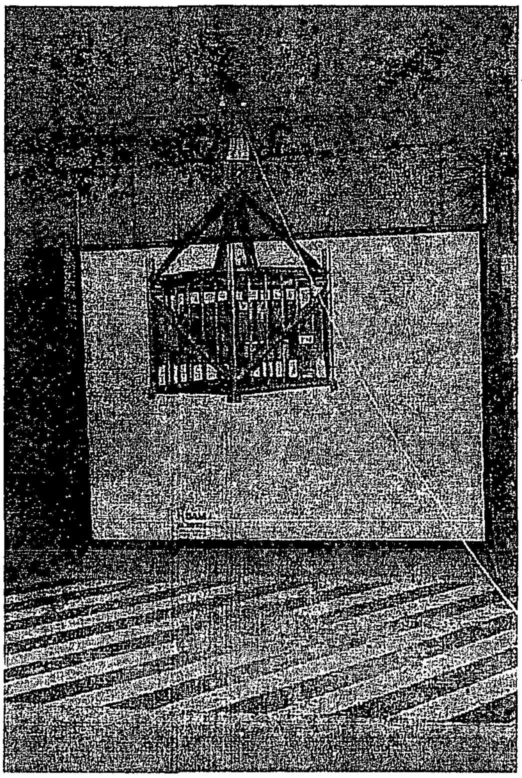


Fig. 3
Drop test III.3/0928; Test Specimen No. 1 in position for dropping, drop distance: 1.3 m

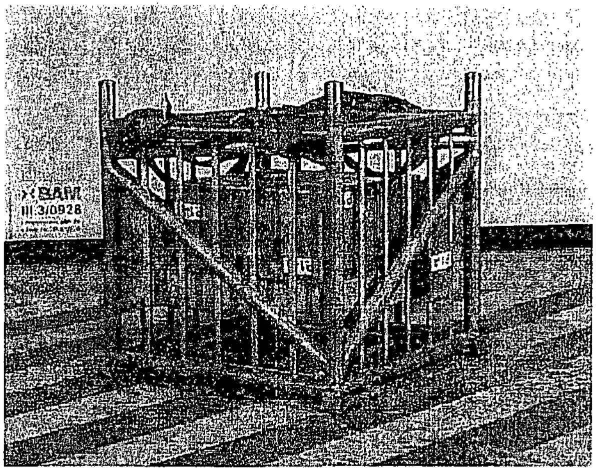


Fig. 4
Test Specimen No. 1 after free drop test III.3/0928

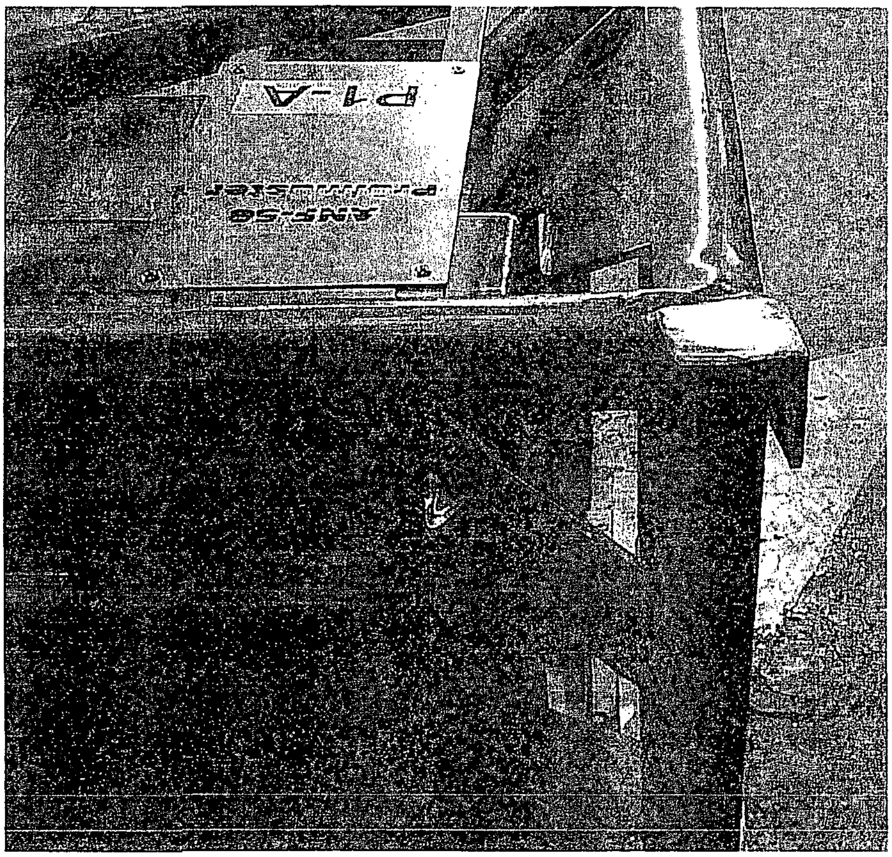


Fig. 5
Test Specimen No. 1 after drop test.
Local buckling of vertical tubes in impact area

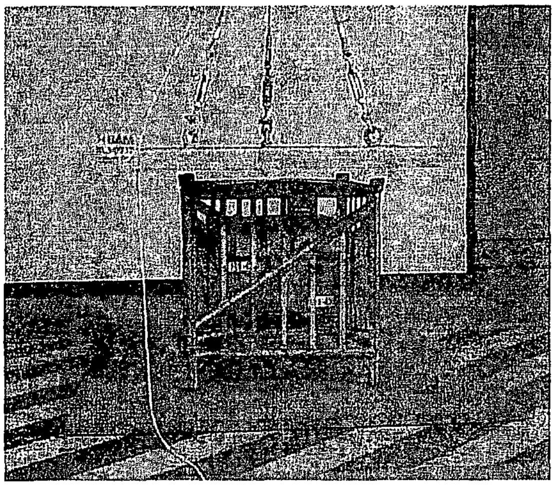


Fig. 6
Crush test III.3/0932; test specimen in normal position. Steel plate was raised to height of 9 m.

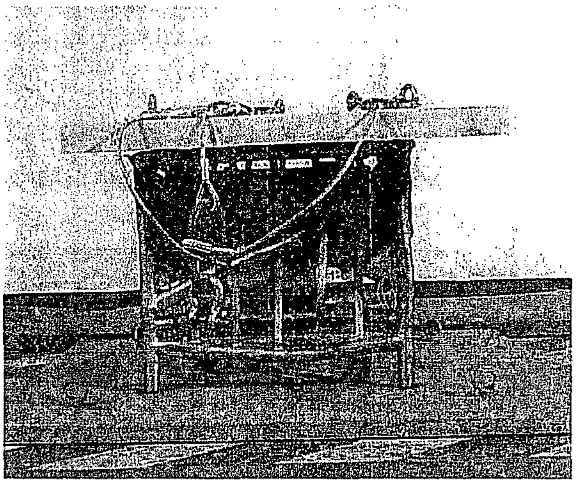


Fig. 7
Test specimen after crush test

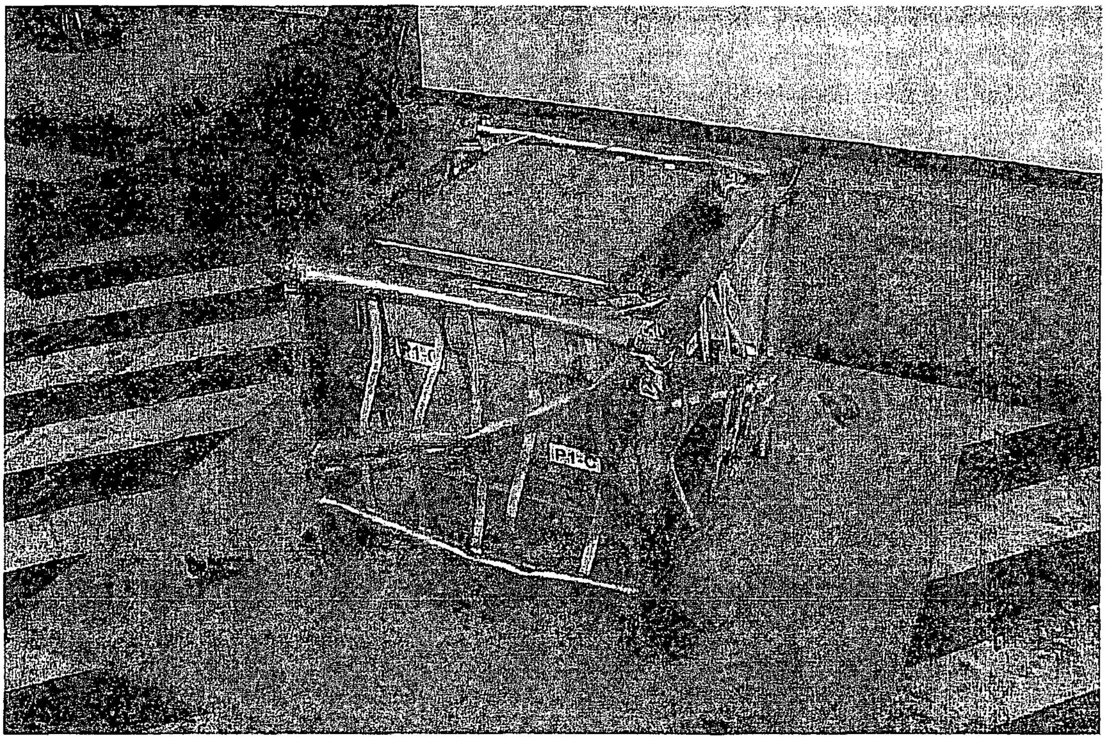


Fig. 8
Outer frame deformed; pellet box case undamaged

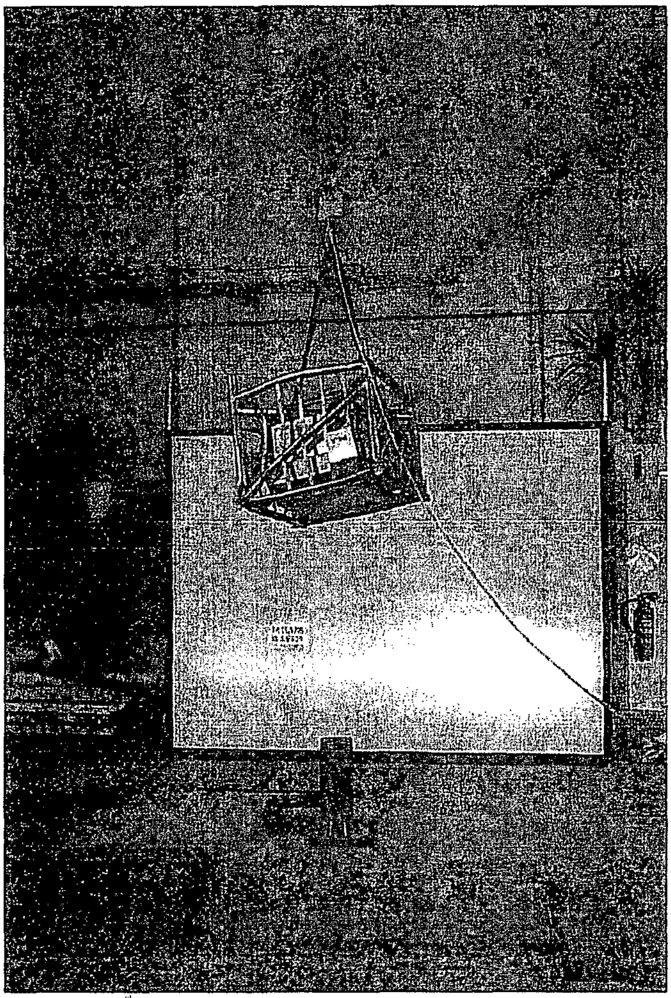


Fig. 9
Test Specimen No. 1 in dropping position.
Drop test onto vertical bar III.3/0936
Drop distance: 1.1 m
Angle: 25°

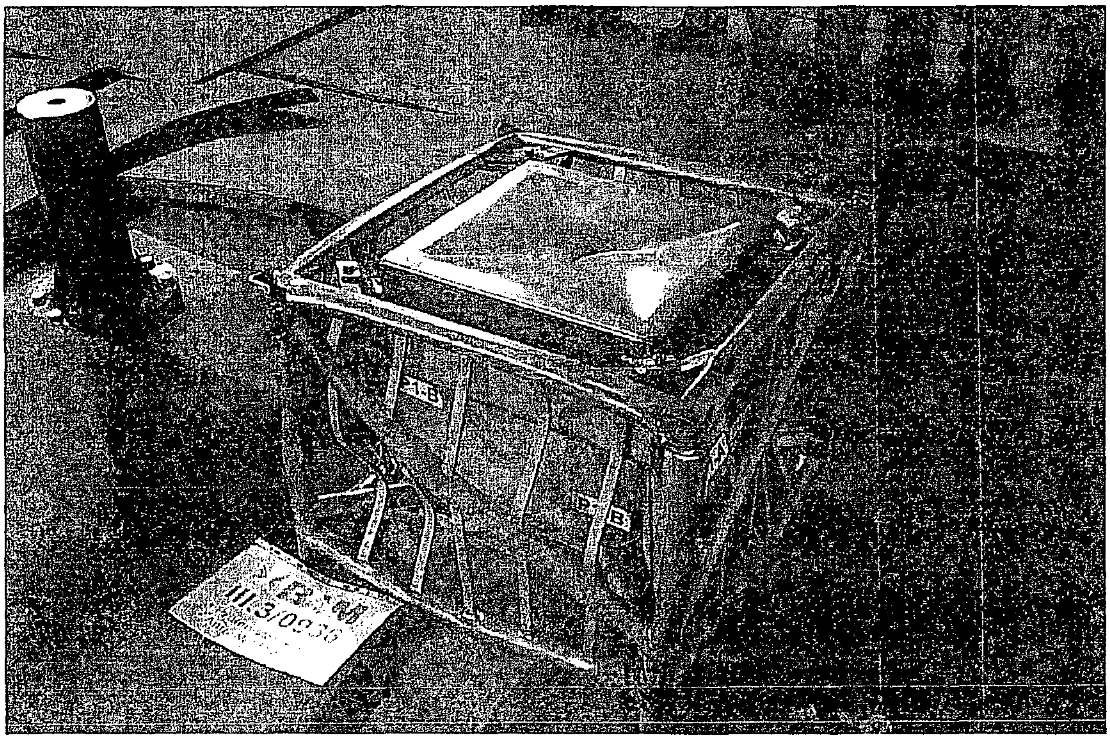


Fig. 10
Test Specimen No. 1 after drop test onto vertical bar; protective lid dented by approx. 36 mm

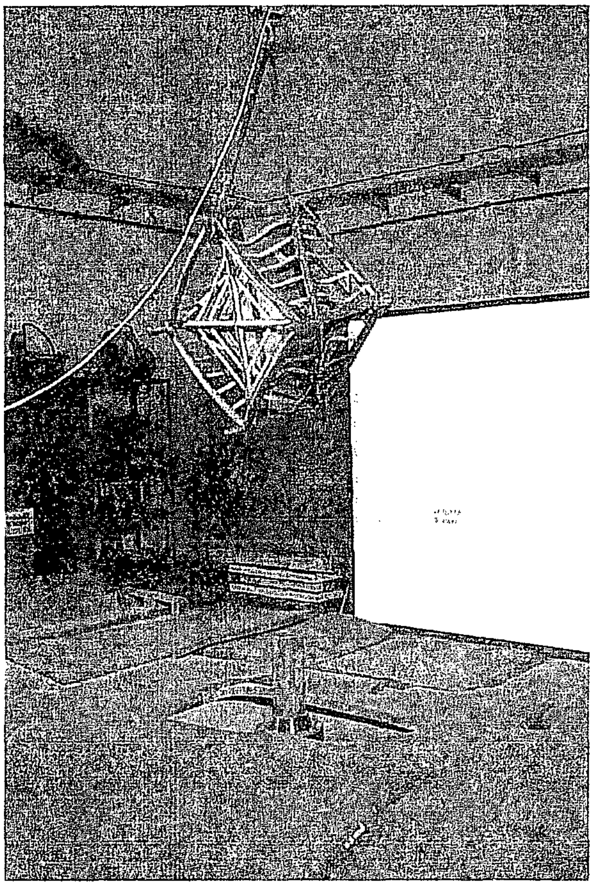


Fig. 11
Test Specimen No. 1 in dropping position for additional drop test onto vertical bar (III.3/0941)

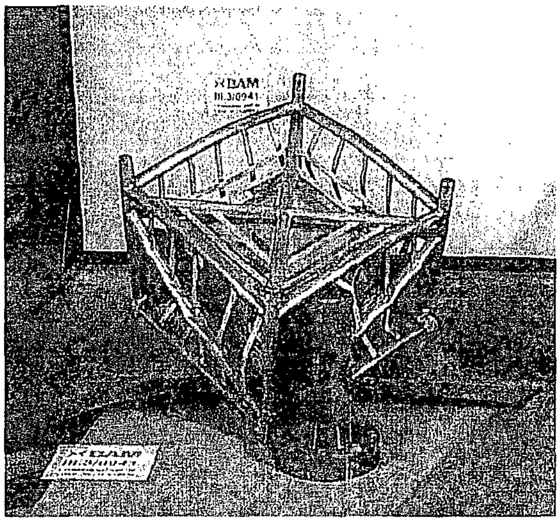


Fig. 12
Test Specimen No. 1 after additional drop test onto vertical bar III.3/0941

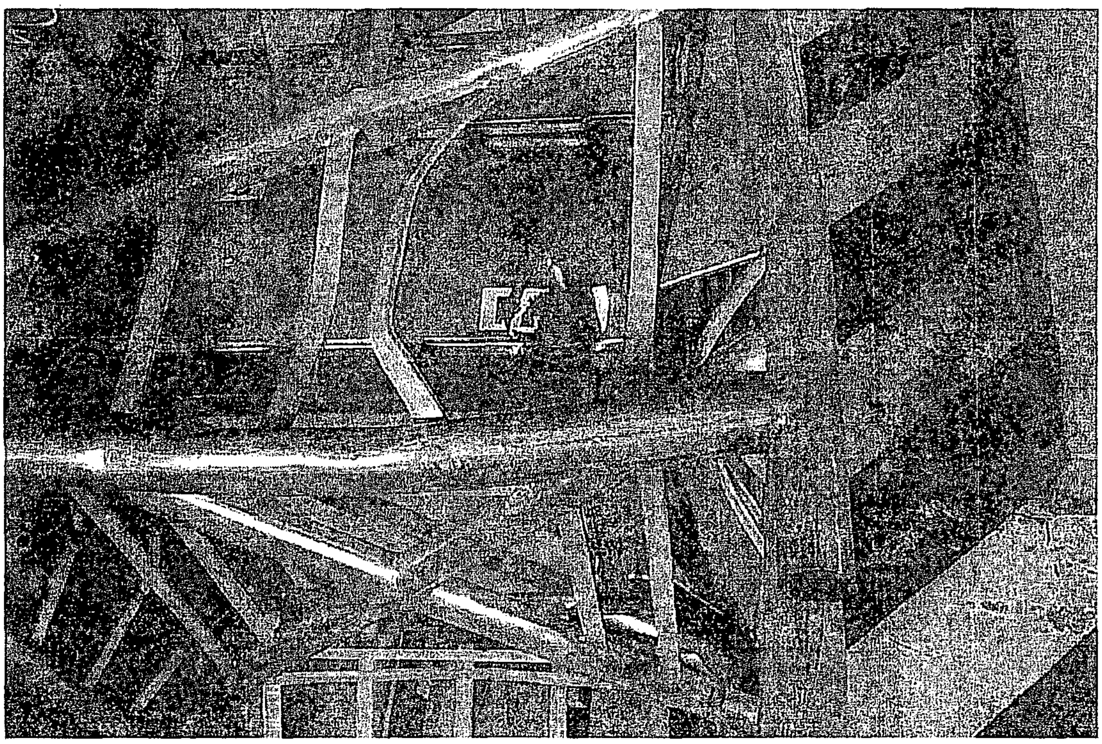


Fig. 13
Local deformation of steel section on bottom edge (pellet box case)

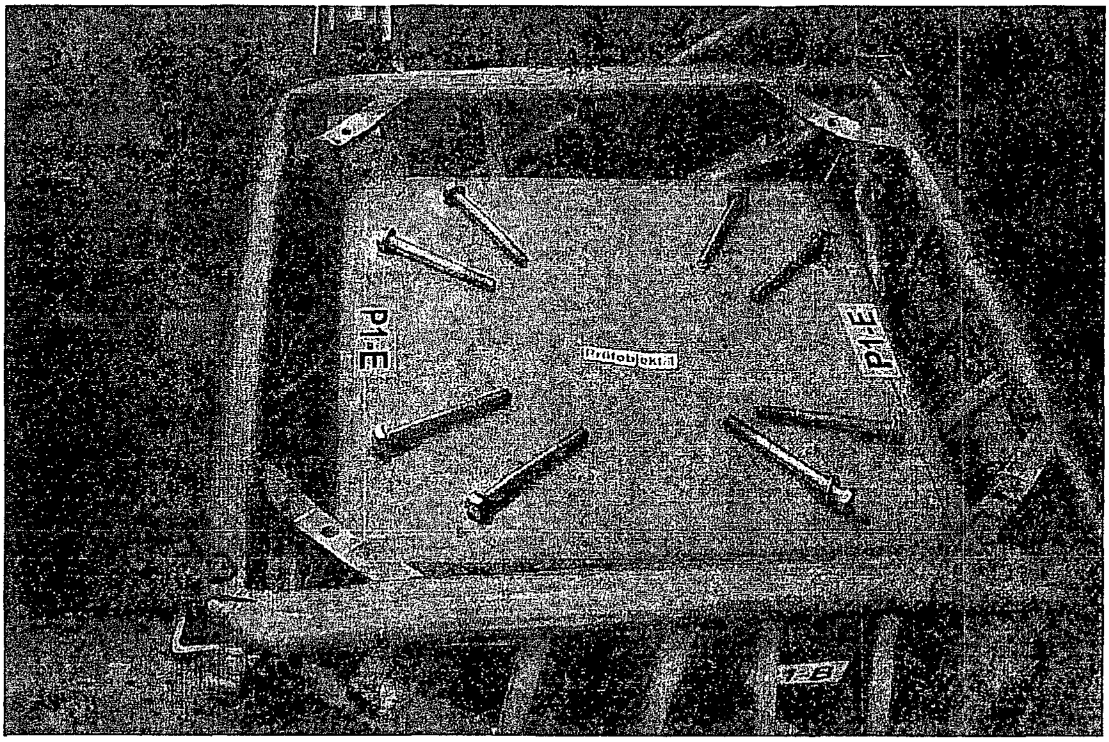


Fig. 14
Test Specimen No. 1 after completion of tests (protective lid removed)

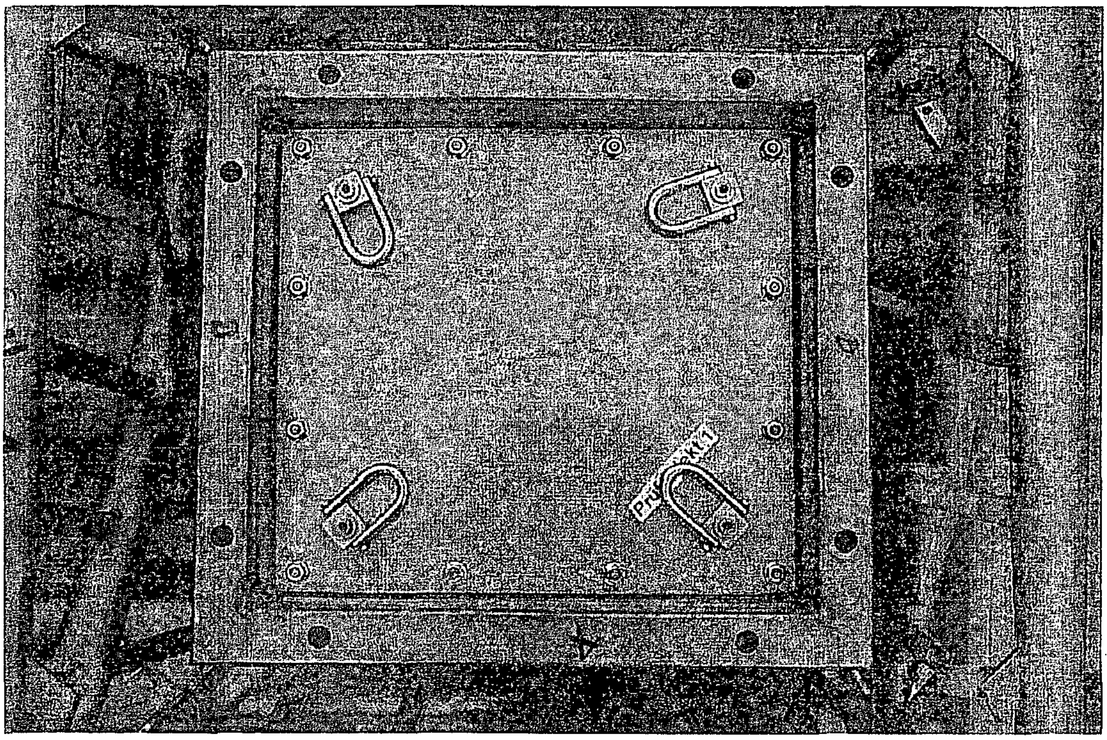


Fig. 15
Opened pellet box case showing pellet box

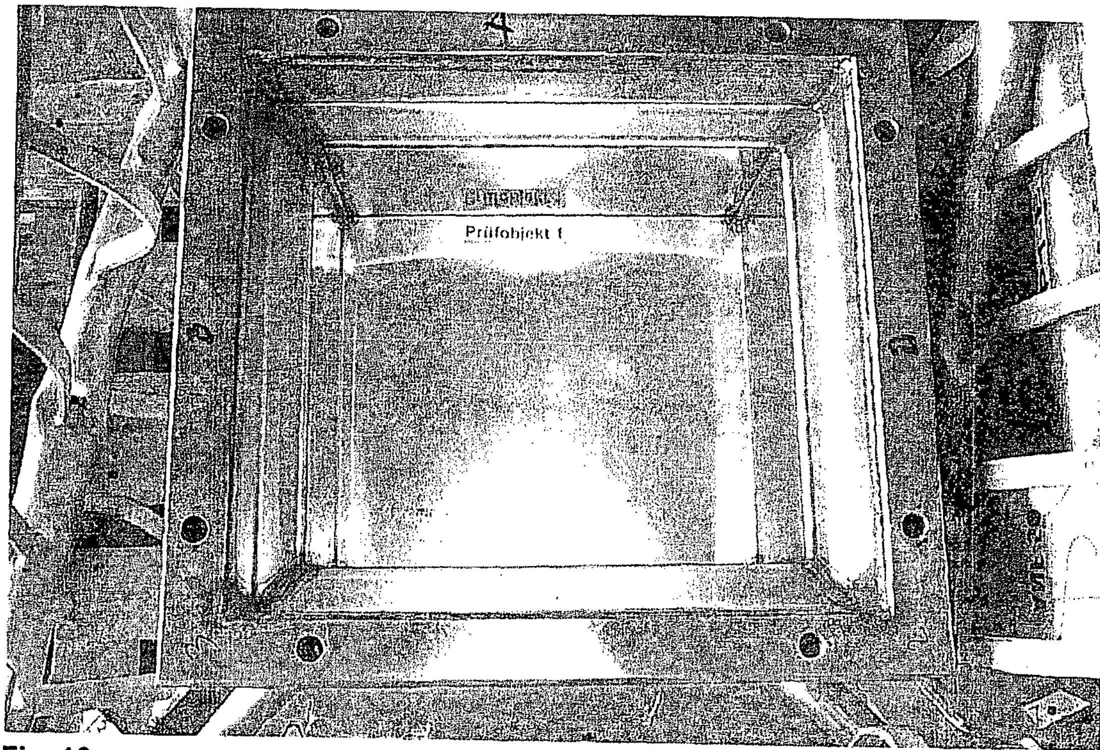


Fig. 16
Pellet box case: no visible damage

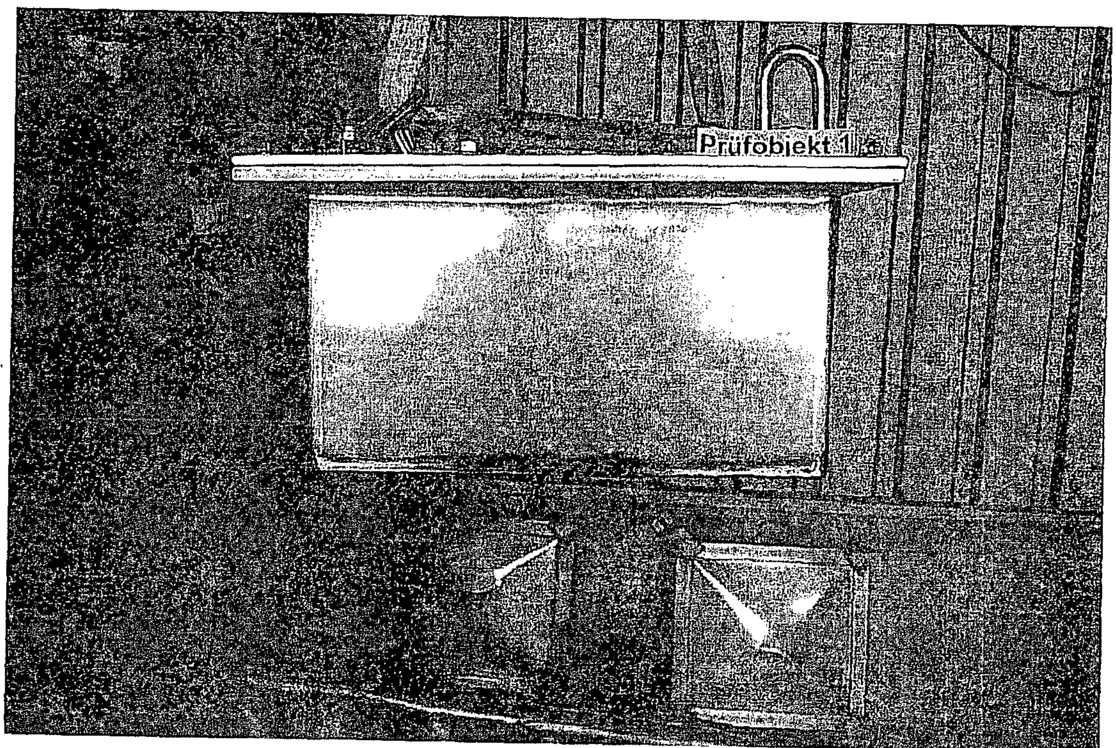


Fig. 17
Pellet box: both side walls are buckled outwards

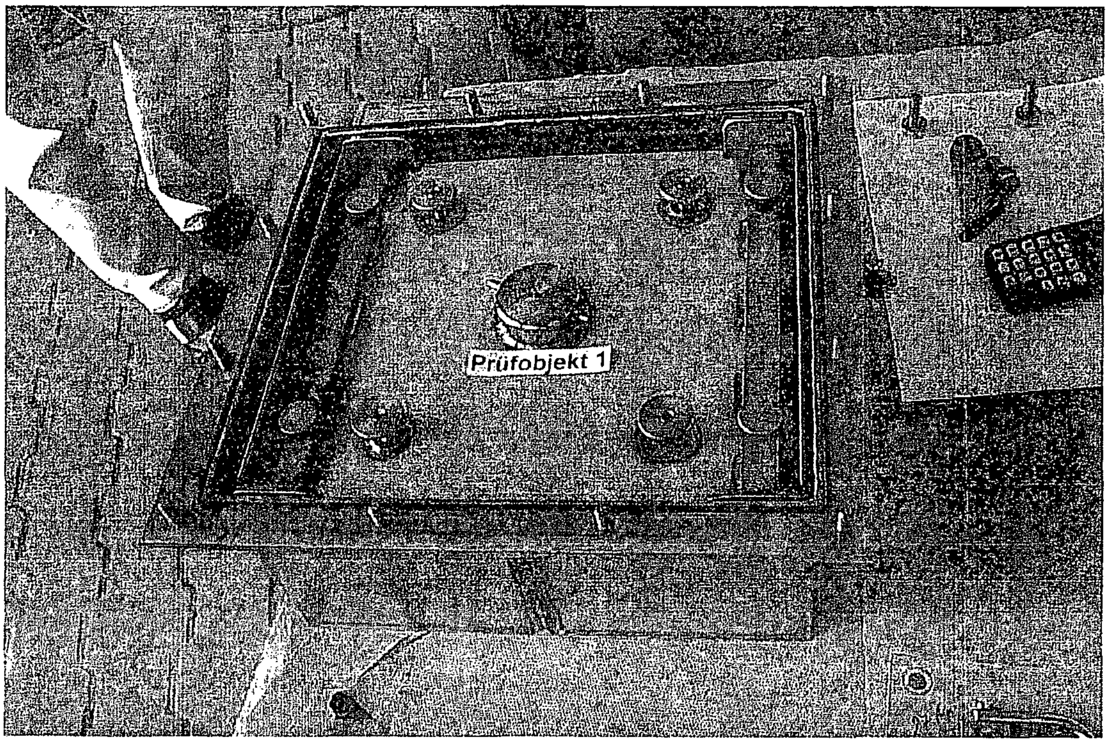


Fig. 18
Opened pellet box

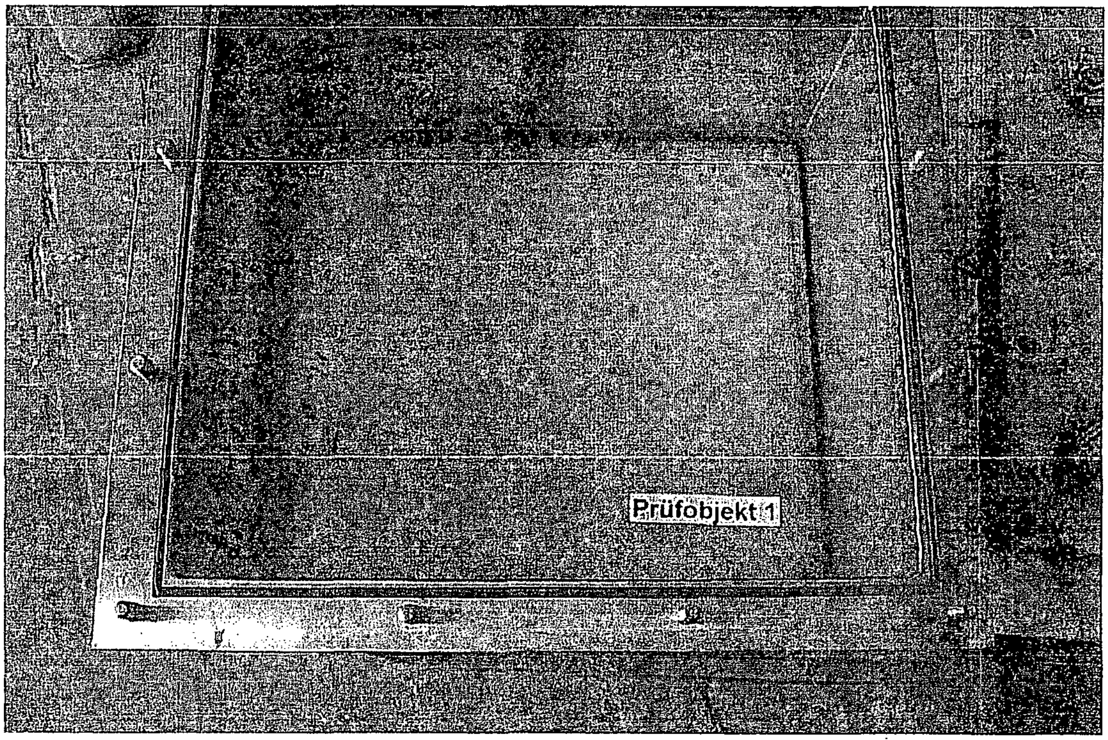


Fig. 19
Pellet box

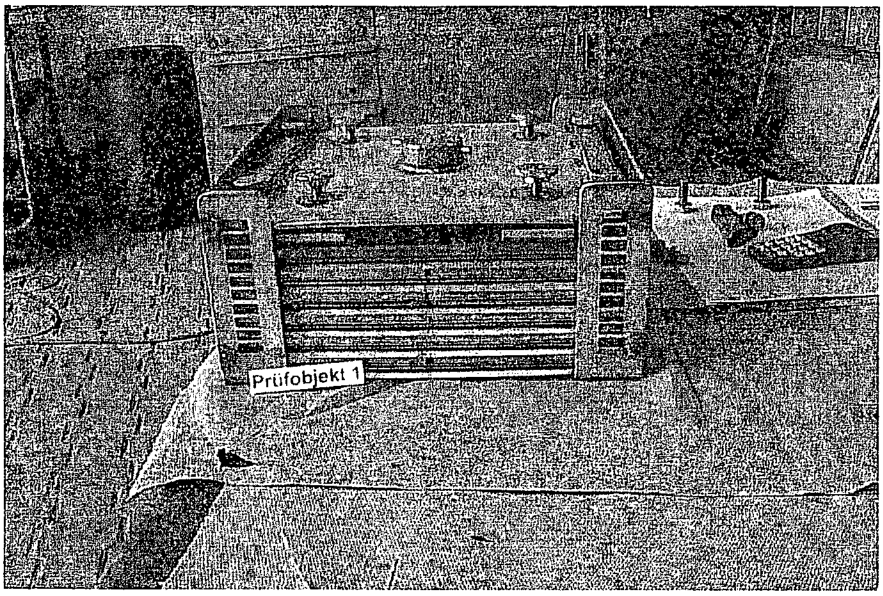


Fig. 20
Carrying rack with dummy pellets and top plate. The top plate is buckled by approx. 4 mm.
Both end plates are buckled outwards.

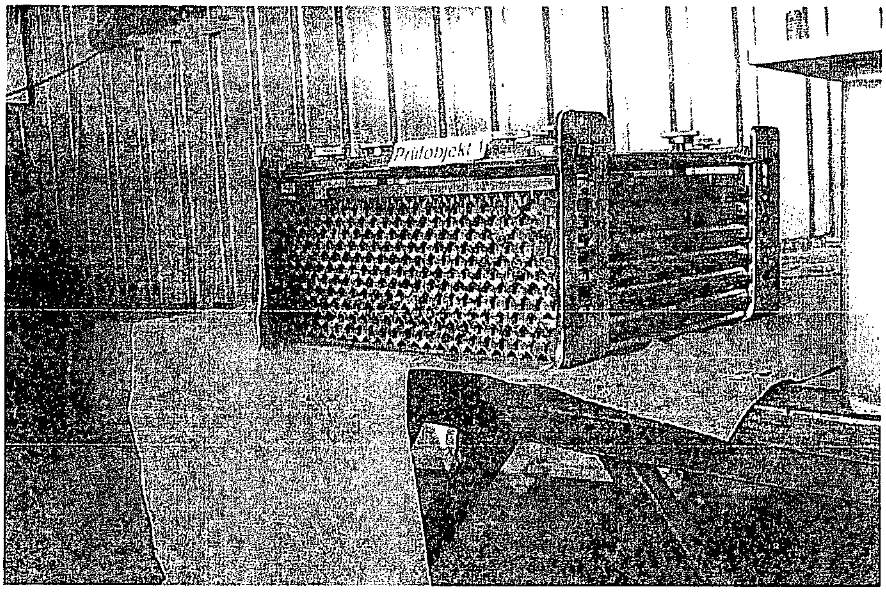


Fig. 21
View of opposite side of carrying rack

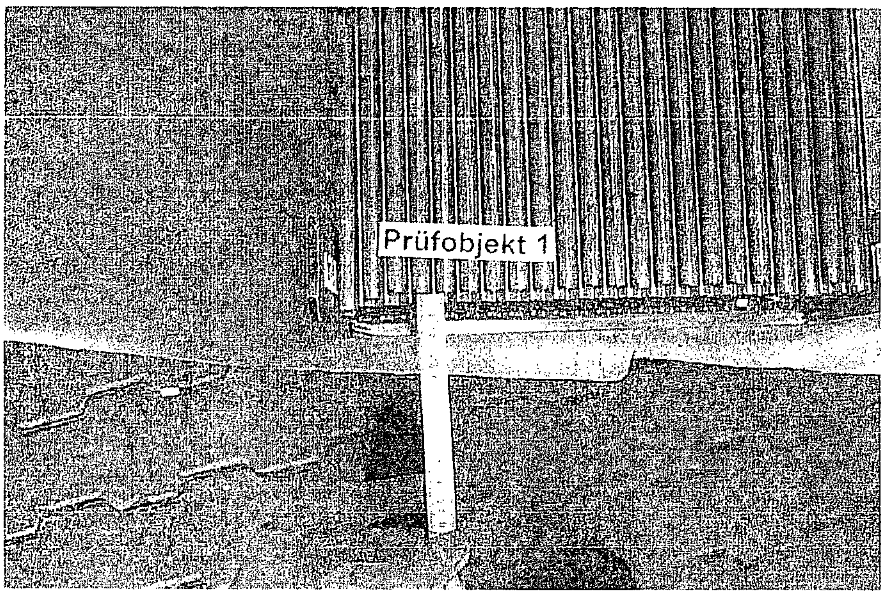


Fig. 22
Positions of dummy pellets

Appendix 4.2 Test Specimen No. 2

Appendies 4.2-1 to 4.2-8

Fig. 1
Penetration test onto side wall P2-D

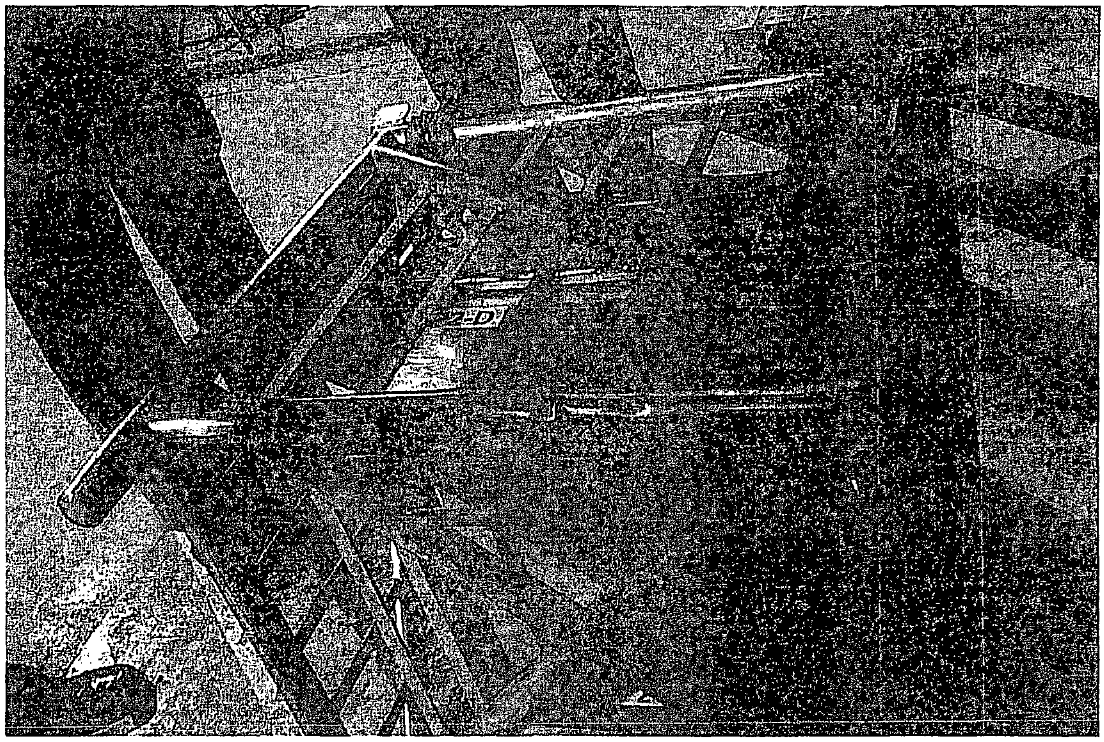


Fig. 2
Side wall P2-D of pellet box case; picture shows test bar impact point and approx. 6-mm-deep dent

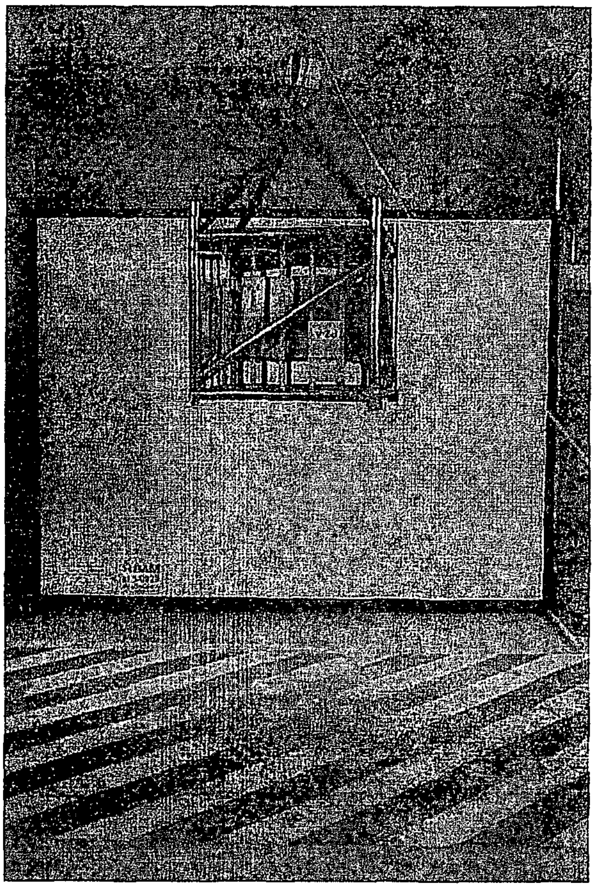


Fig. 3
Free drop test III.3/0929

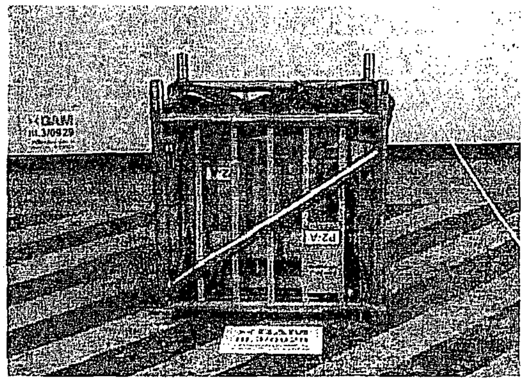


Fig. 4
Test Specimen No. 2 immediately after free drop test III.3/0929

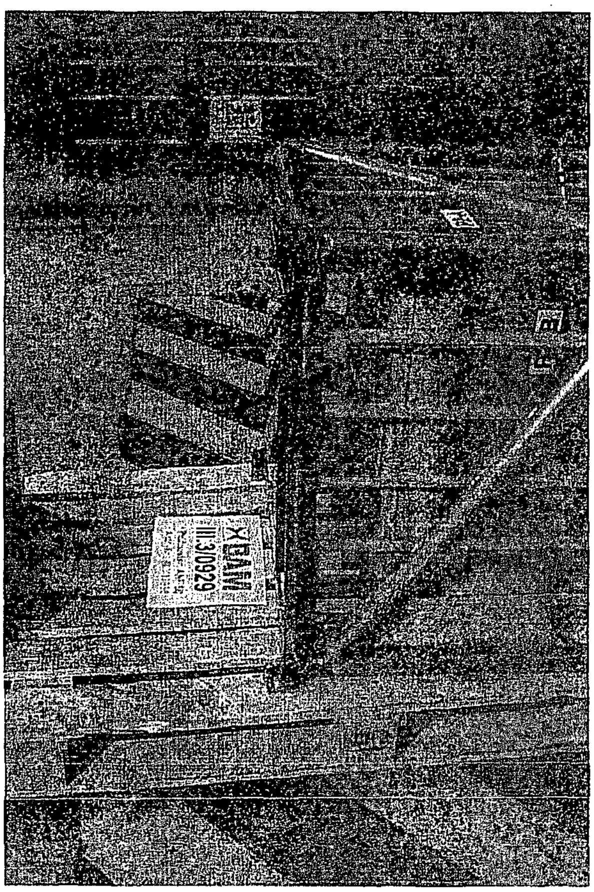


Fig. 5
Test Specimen No. 2 after free drop test. Local buckling of vertical tubes in impact area.

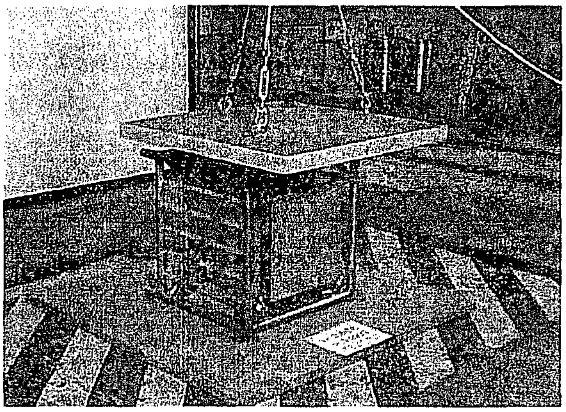


Fig. 6
Crush test III.3/0933. Test Specimen No. 2 in side position

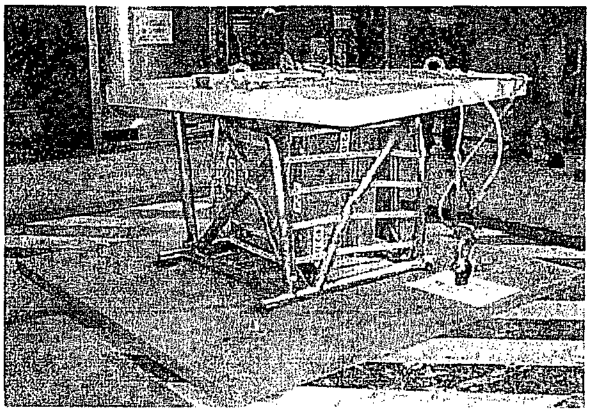


Fig. 7
Test Specimen No. 2 after crush test

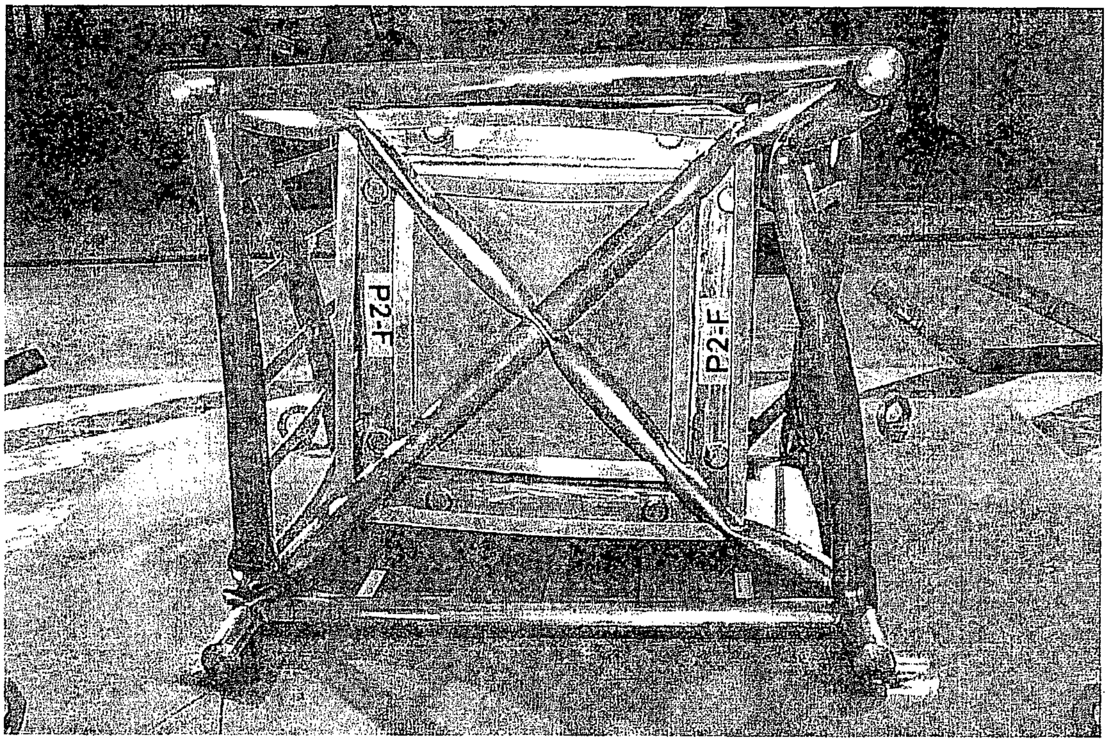


Fig. 8
Bottom view

Fig. 9
Drop test onto vertical bar III.3/0937:
Test Specimen No. 2 in dropping position
Drop distance: 1.1 m
Angle: 25°

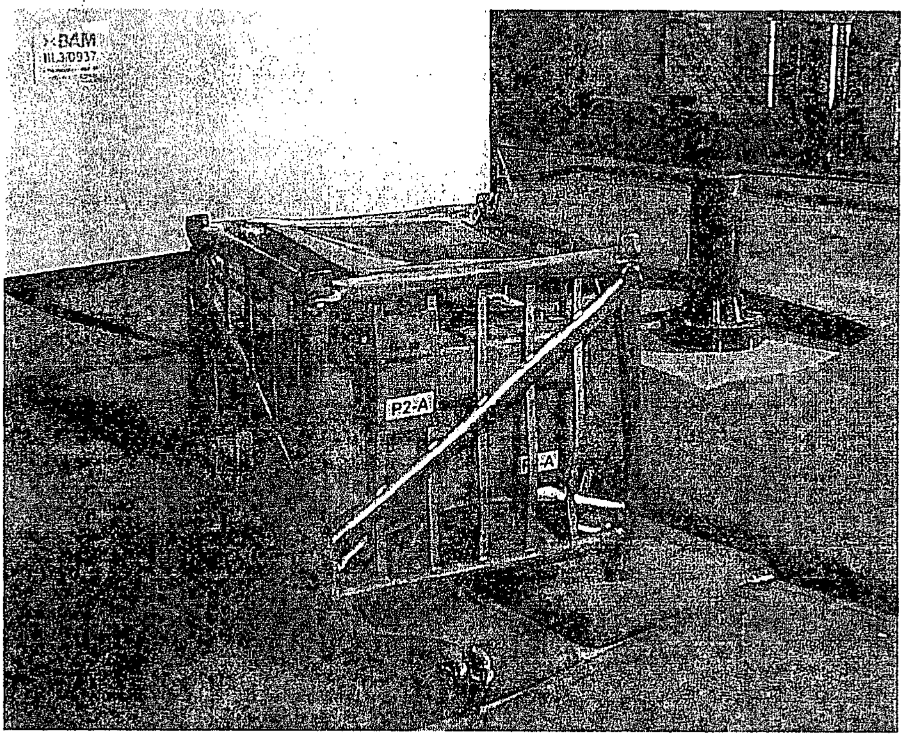


Fig. 10
Test Specimen No. 2 after drop test onto vertical bar; protective lid dented by approx. 37 mm

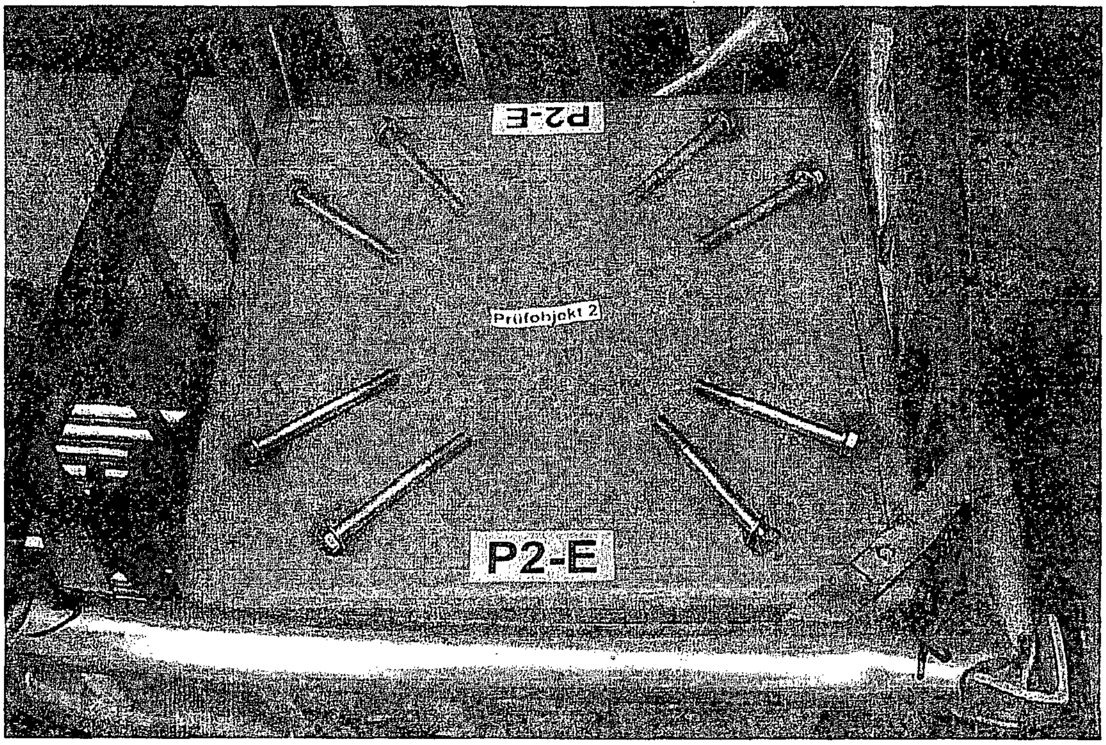


Fig. 11
Test Specimen No. 2 after completion of tests (protective lid removed)

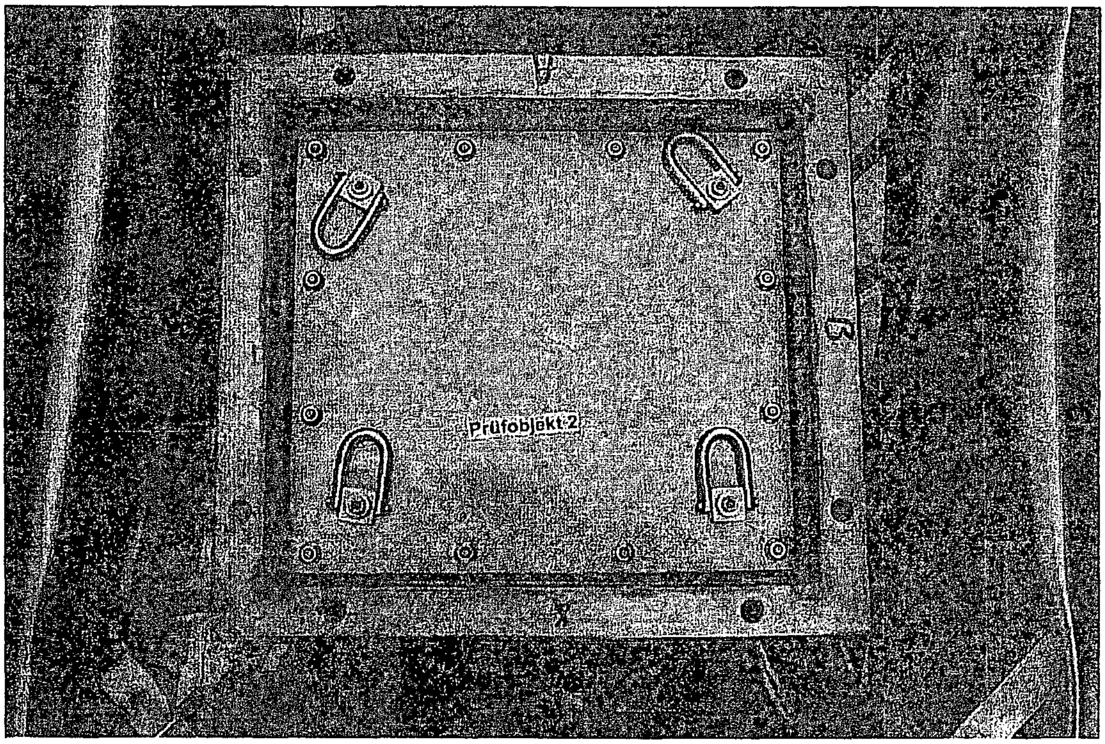


Fig. 12
Opened pellet box case showing pellet box

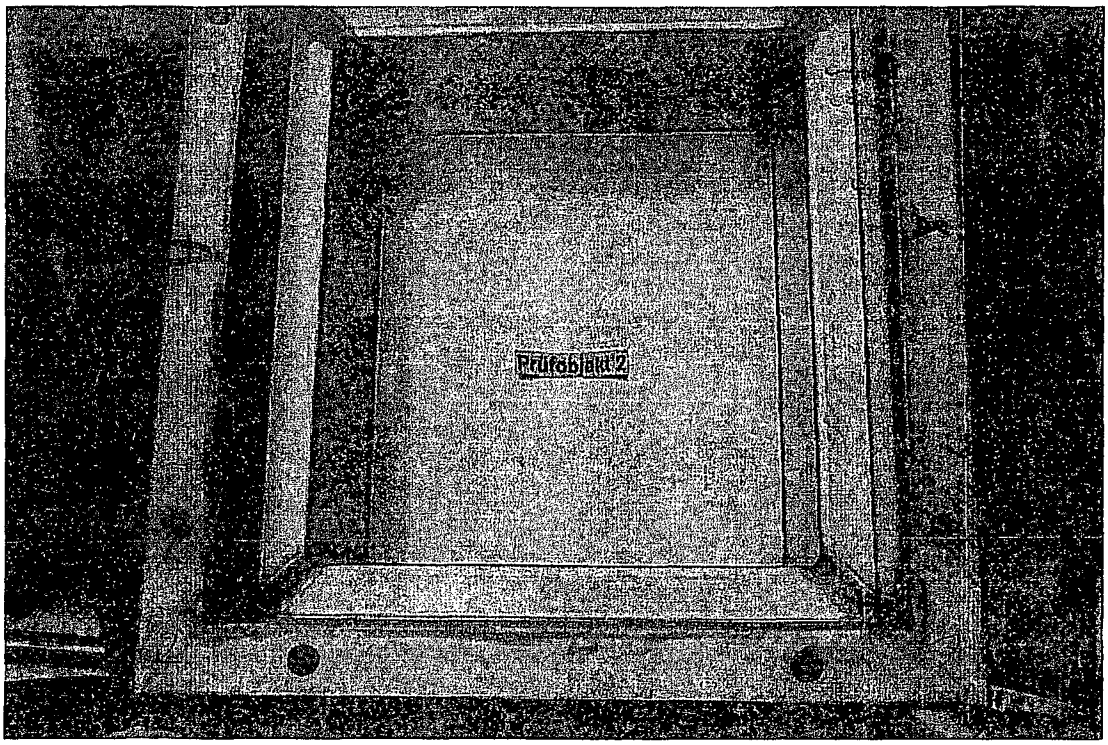


Fig. 13
Pellet box case: no visible damage

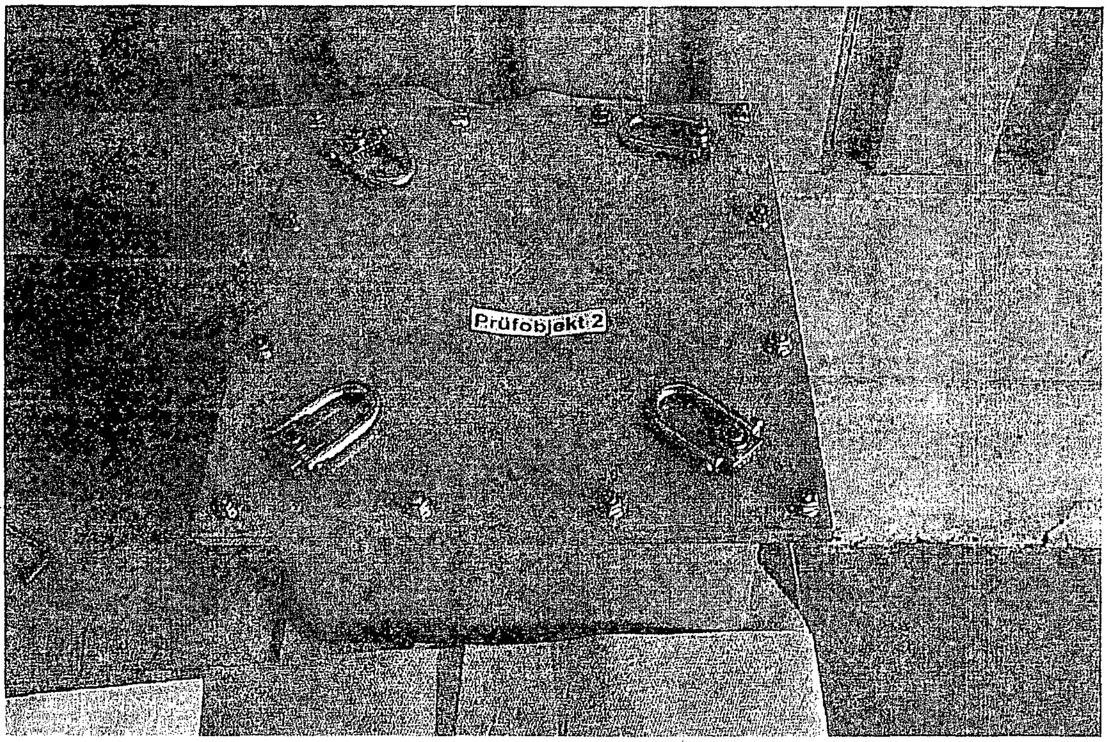


Fig. 14
Pellet box

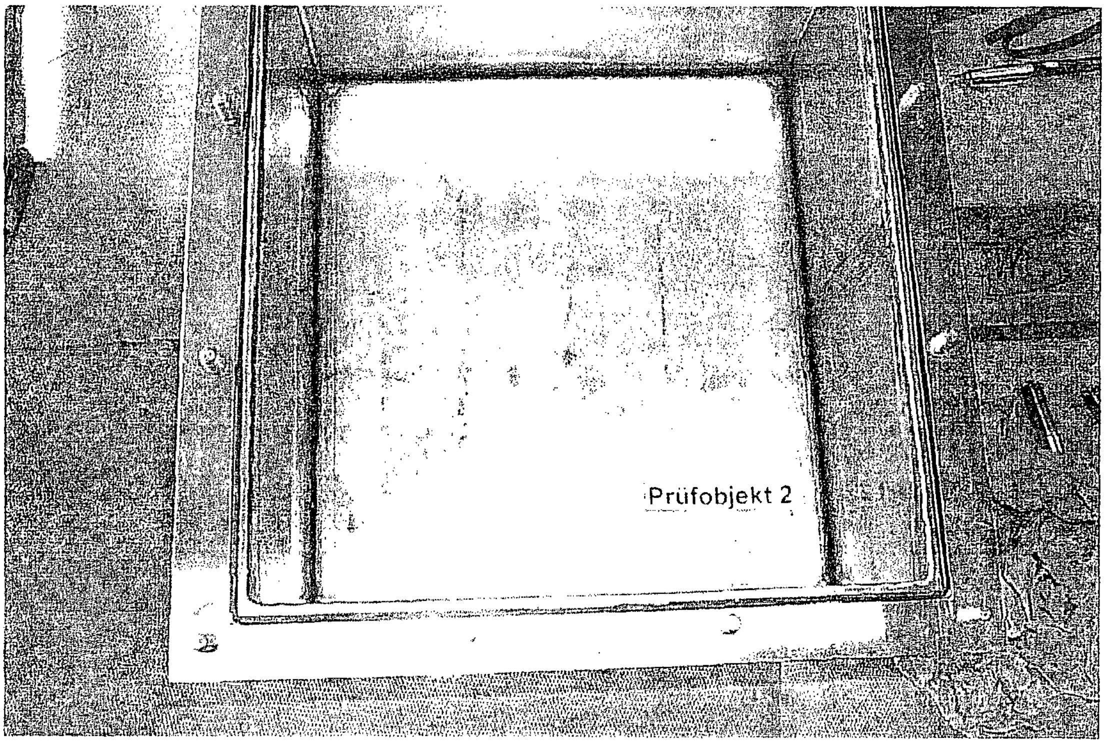


Fig. 15
Empty pellet box

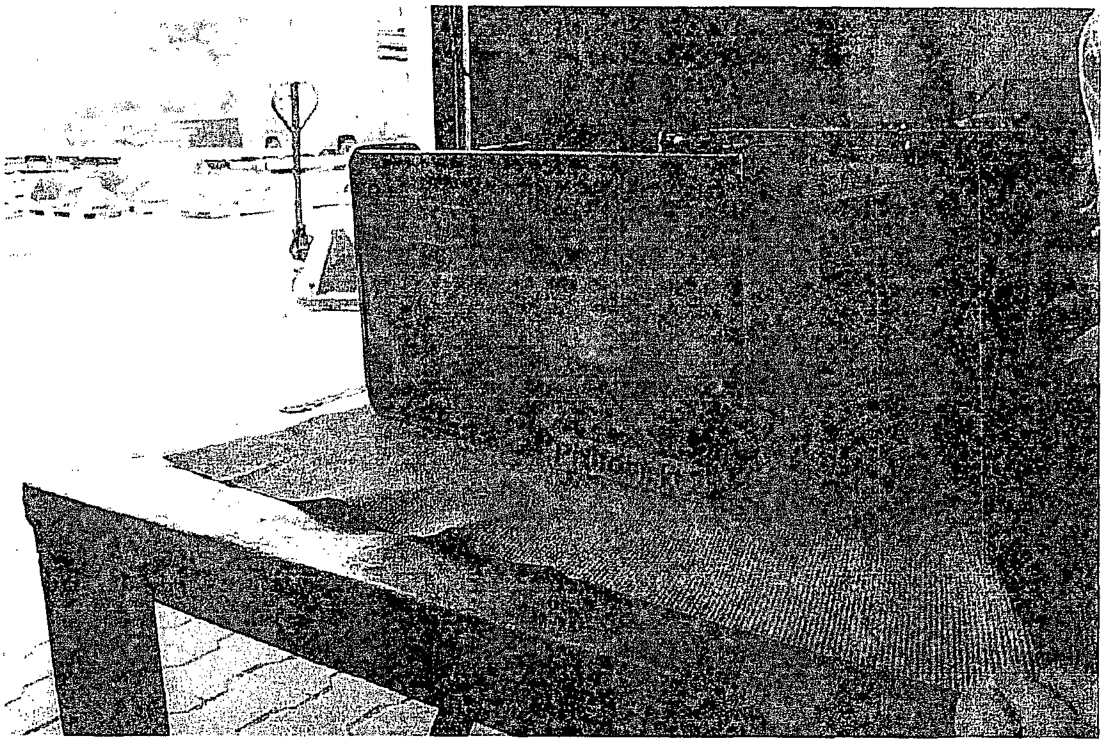


Fig. 16
Carrying rack with end plate

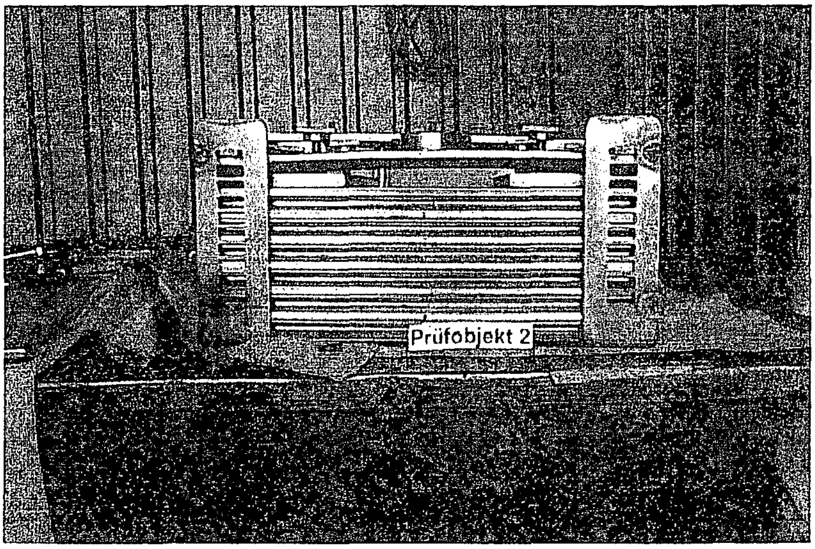


Fig. 17
Carrying rack with dummy pellets and top plate. The top plate is buckled by approx. 4 mm.

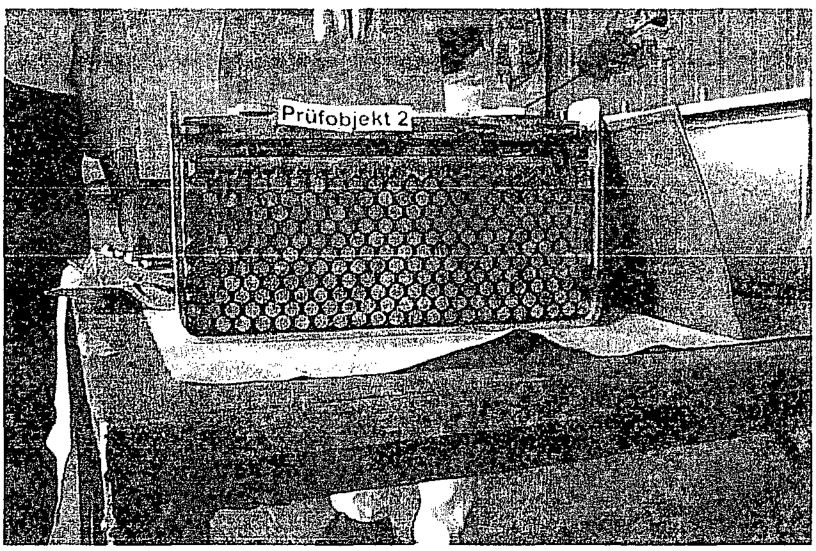


Fig. 18
Side view showing dummy pellets

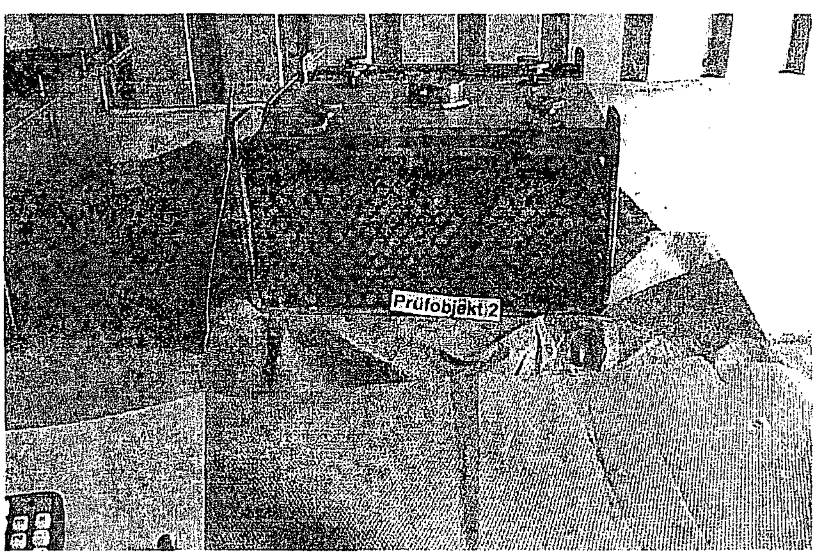


Fig. 19
View of opposite side

Appendix 4.3 Test Specimen No. 3

Appendices 4.3-1 to 4.3-9

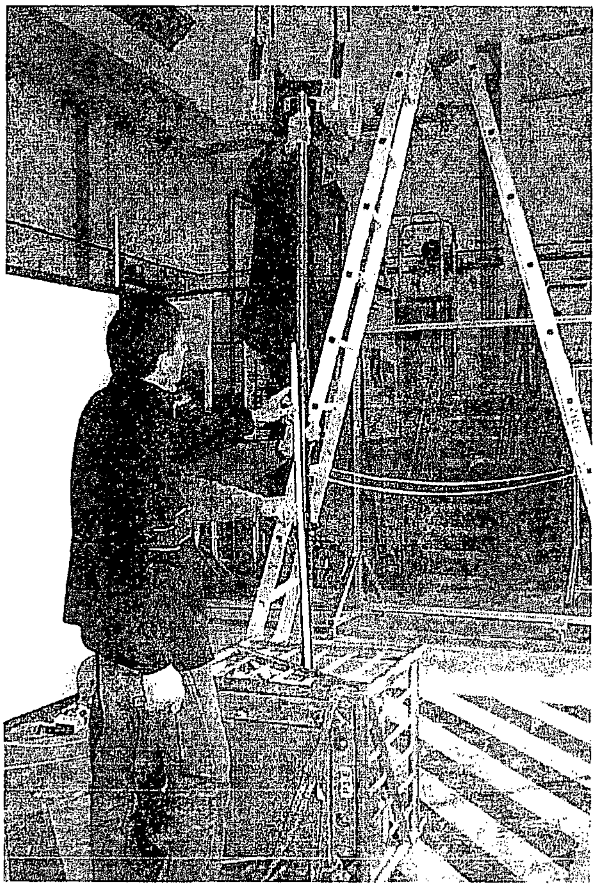


Fig 1
Performance of penetration test
before start of drop tests

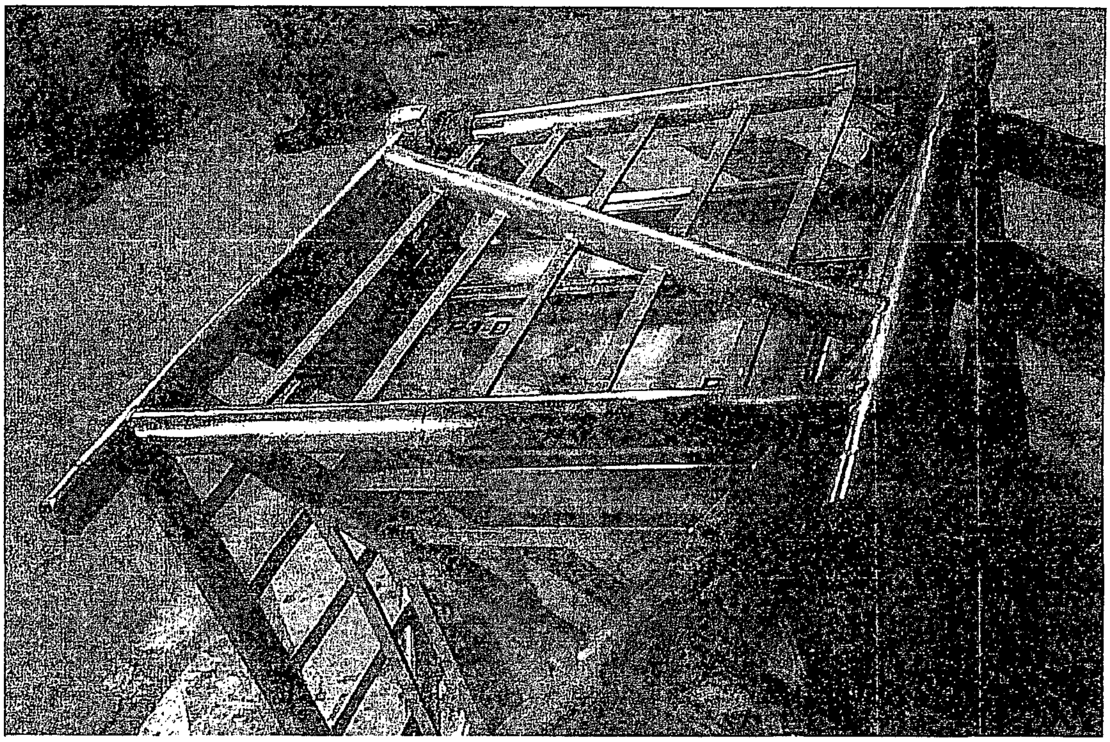
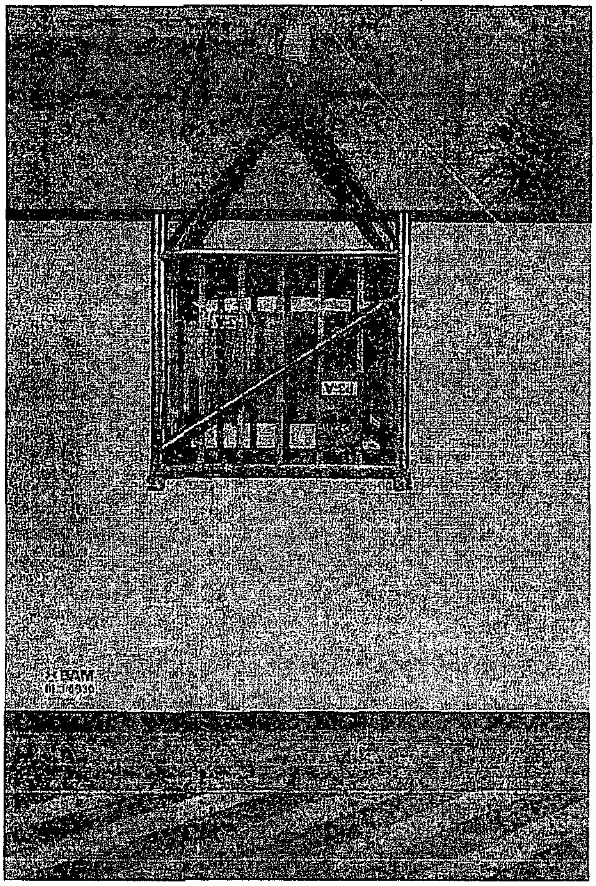


Fig 2
Side wall P3-D of pellet box case; view of test bar impact point



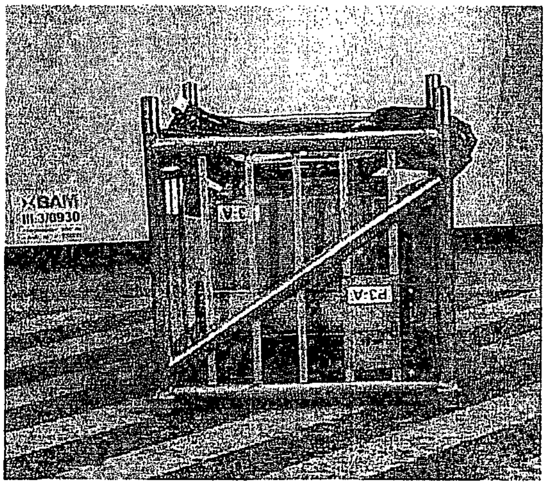


Fig4
Test Specimen No. 3 immediately after free drop test III.3/0930

Fig3
Test Specimen No. 3 in dropping position

Fig5

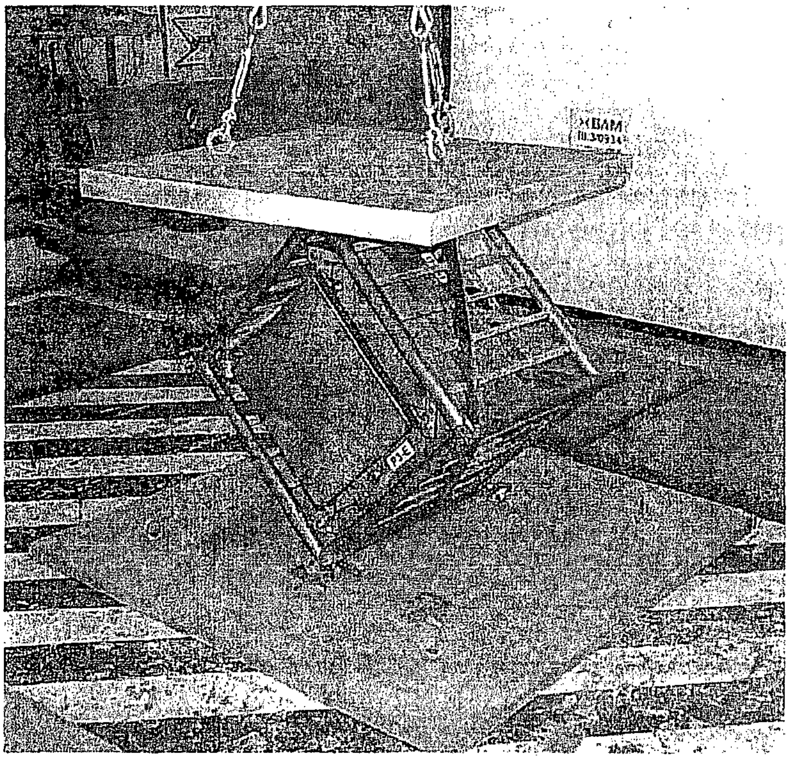


Fig6
Crush test III.3/0934; test specimen in edge position

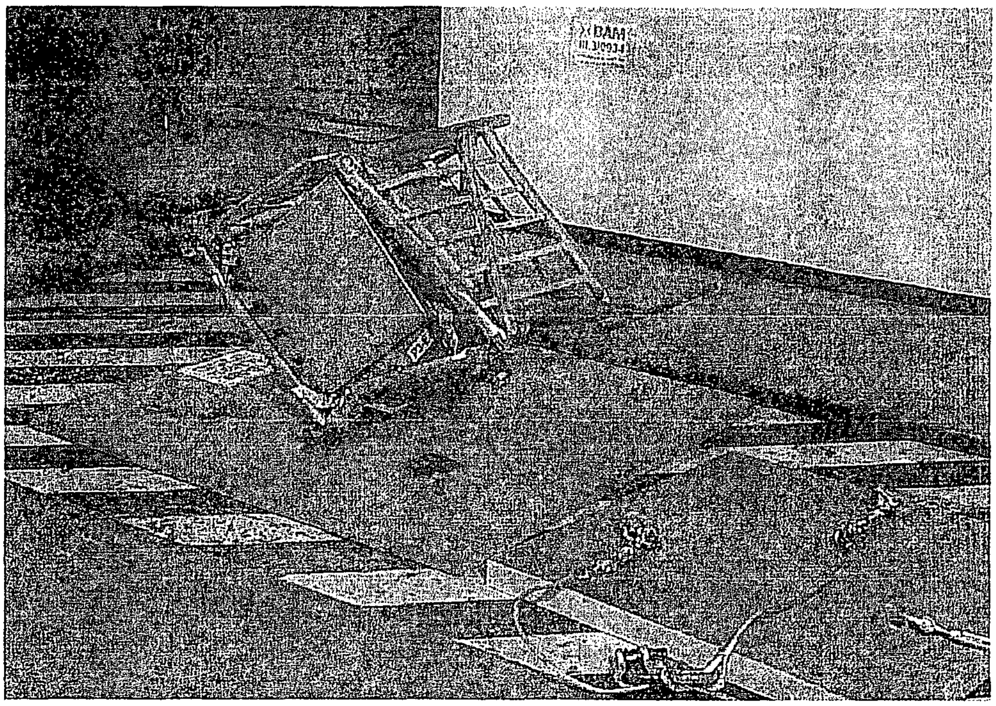


Fig7
Test specimen immediately after crush test

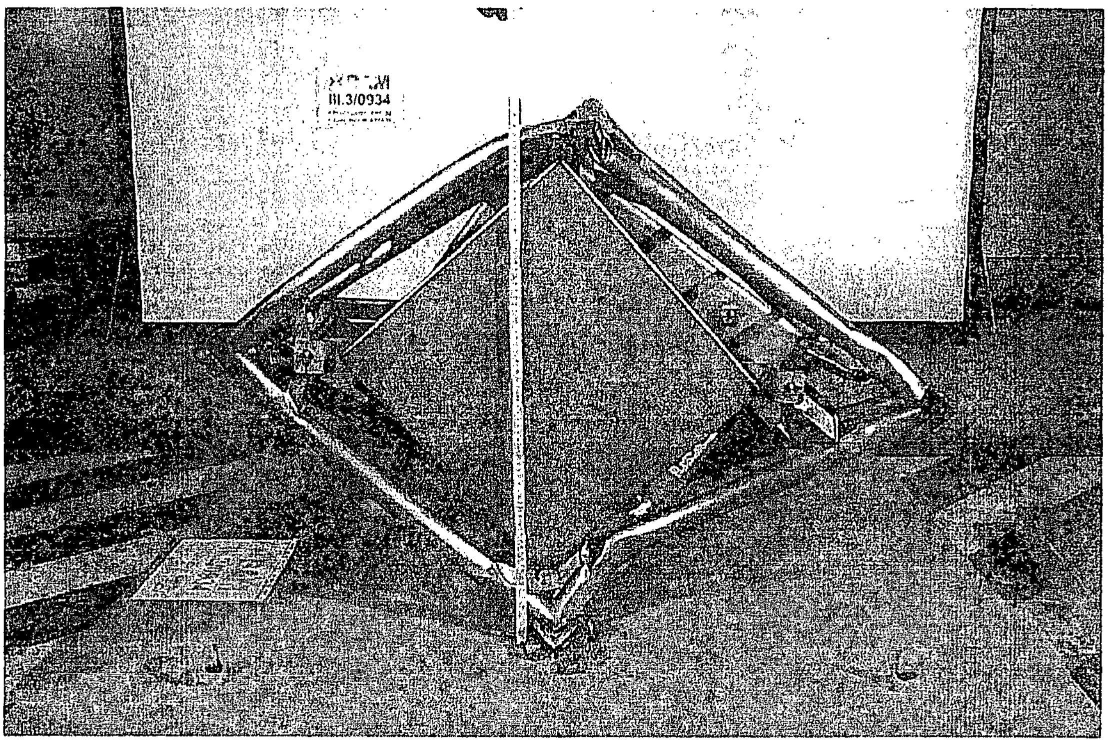


Fig8
Test Specimen No. 3: front view

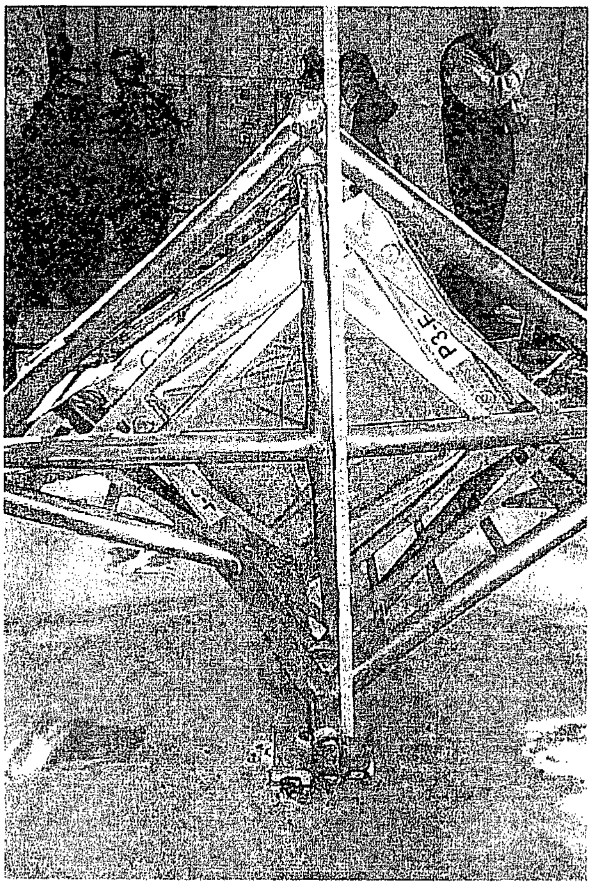


Fig9
Bottom view

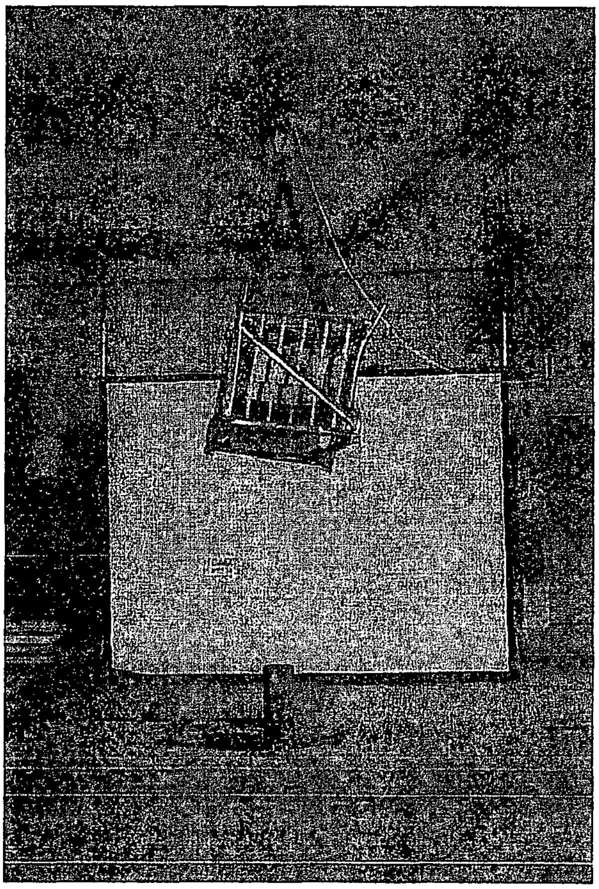


Fig10
Drop test onto vertical bar III.3/0938
Test Specimen No. 3 in dropping position
Drop distance: 1.1 m
Angle: 25°

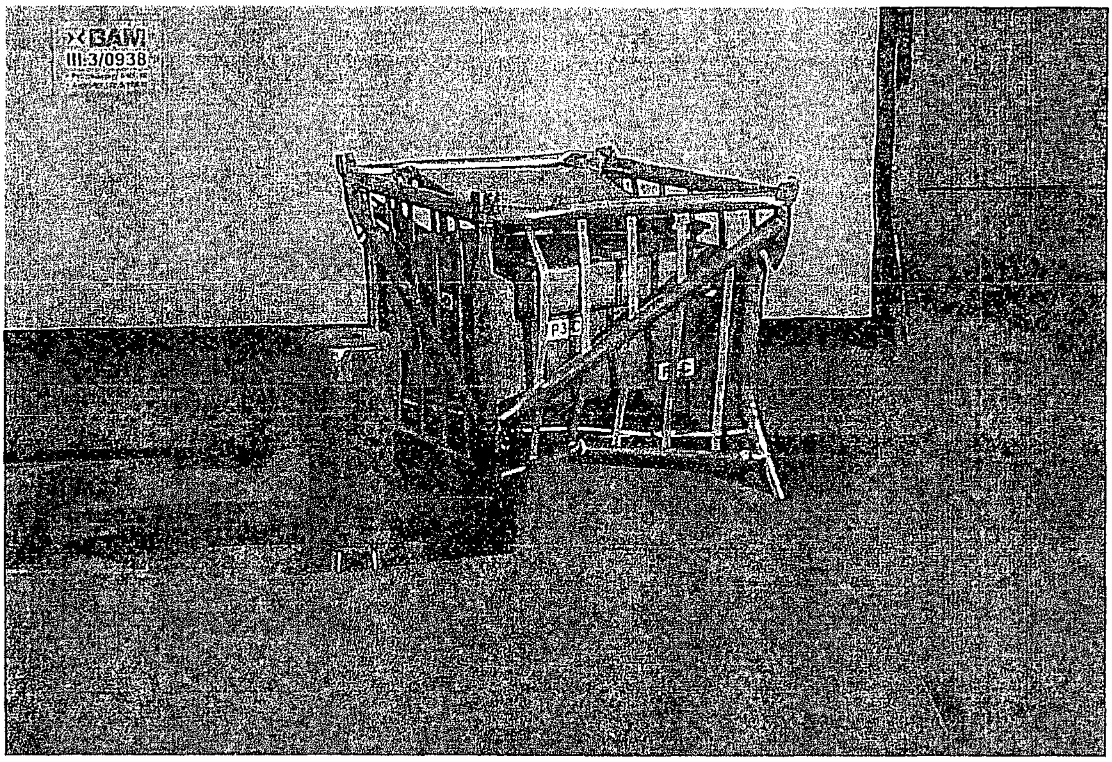


Fig11
Test specimen after drop test onto vertical bar

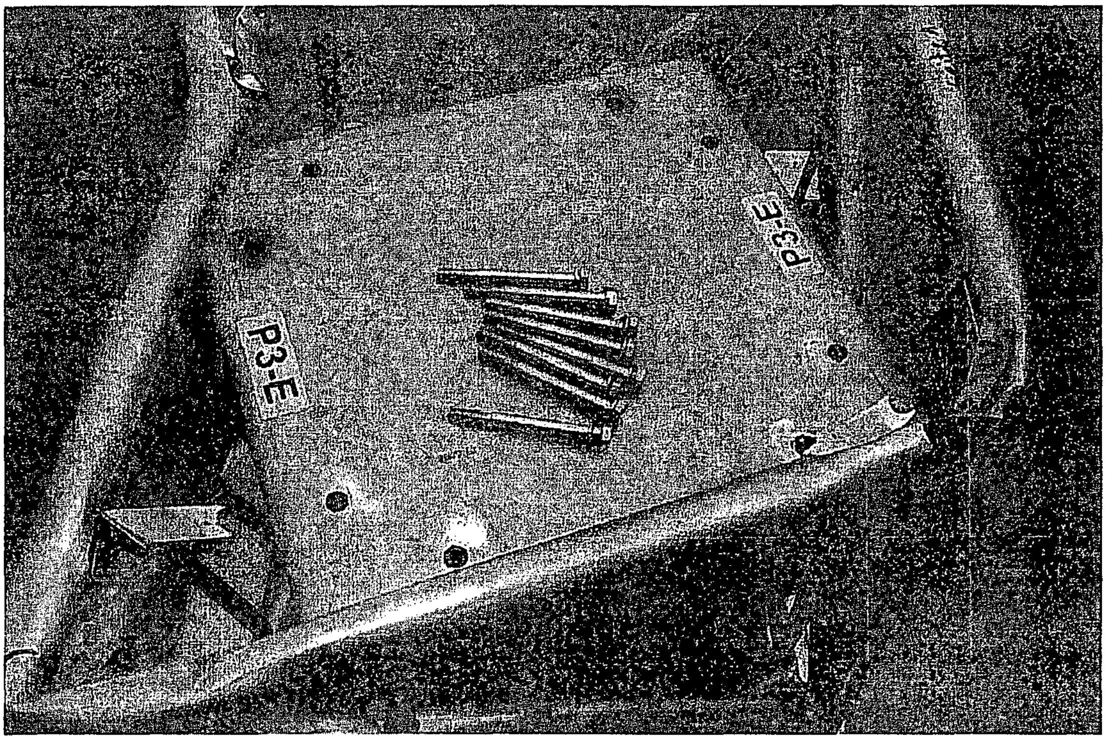


Fig12
Test Specimen No. 3 after completion of tests (protective lid removed)

Fig13
Opened pellet box case

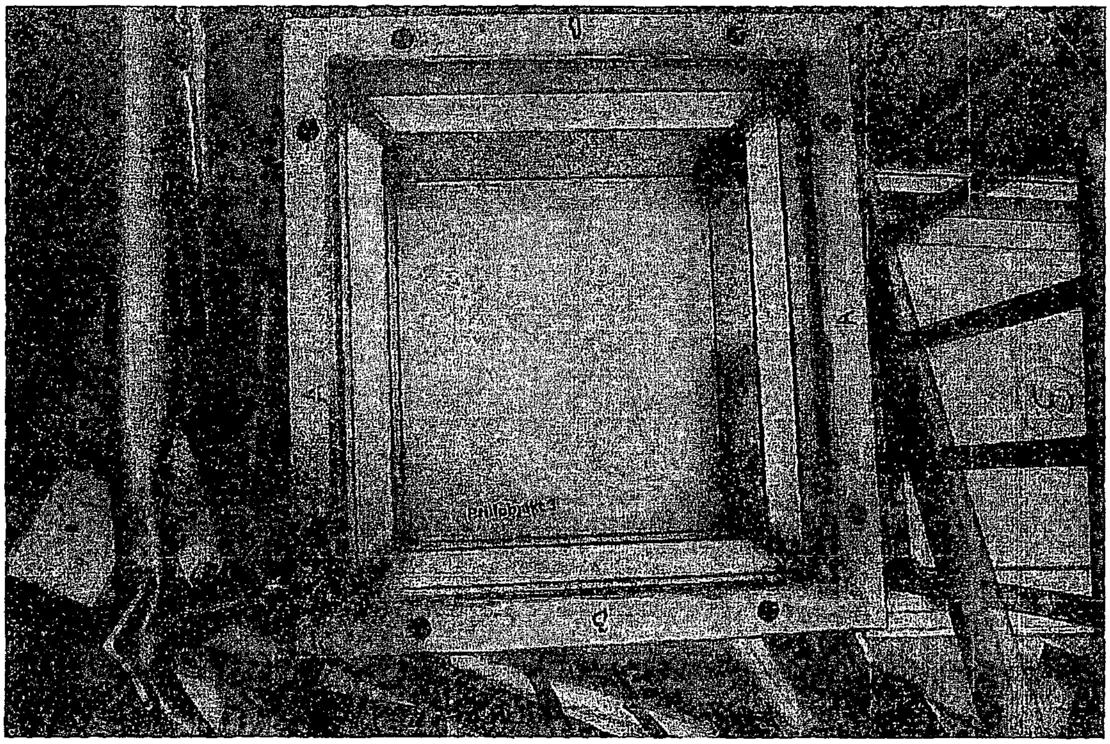


Fig14
Pellet box case

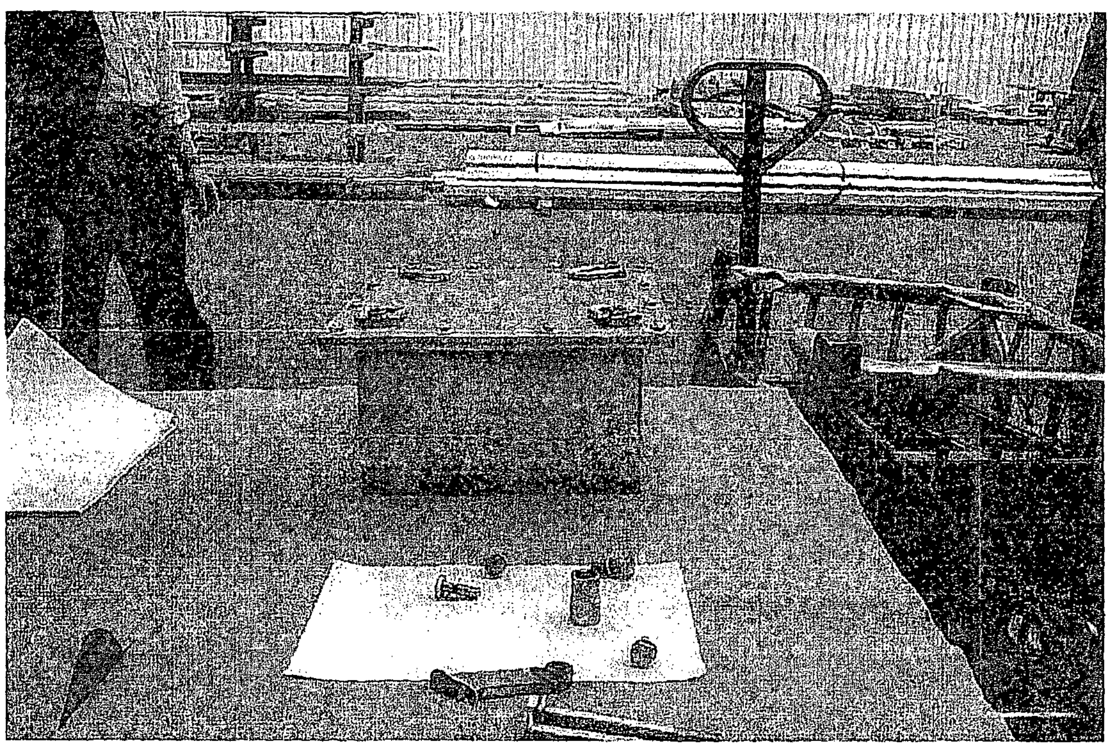


Fig15
Pellet box: side wall slightly convex

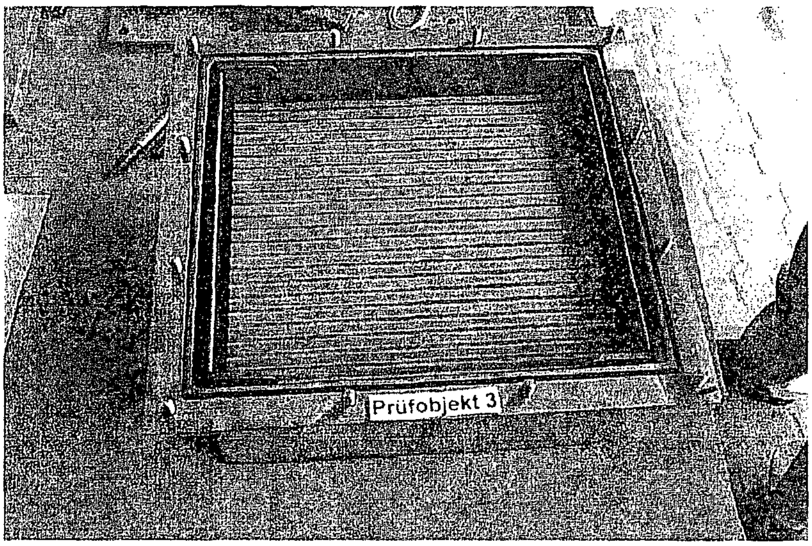


Fig16
Pellet box opened and clamping device removed

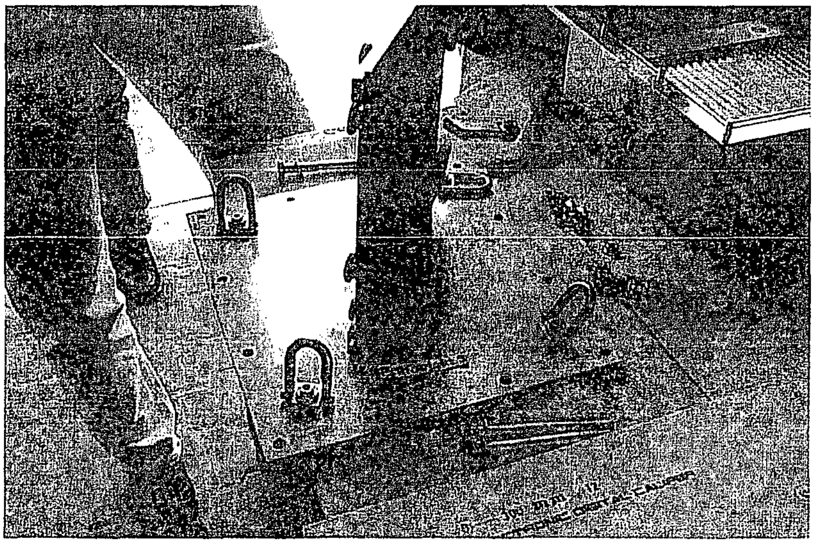


Fig17
Damaged clamping device: one of the clamping bars has broken away from the bolts. The top plate is buckled by approx. 4 mm.

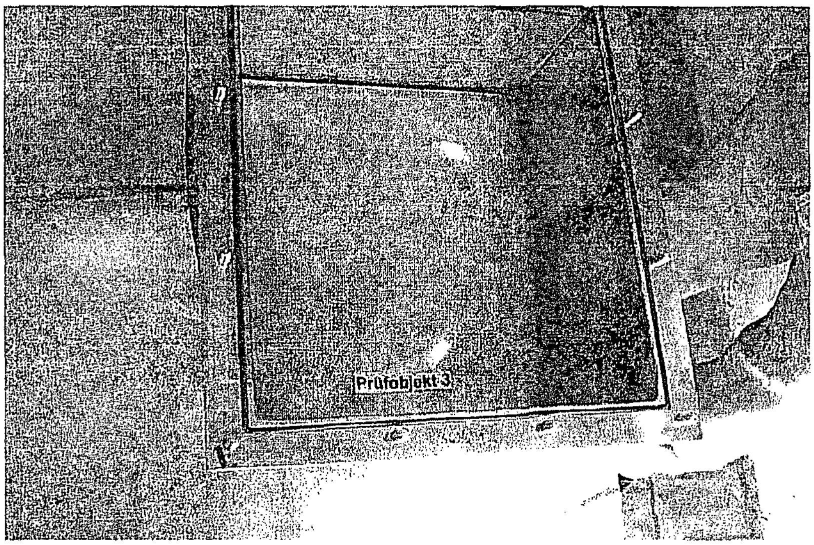


Fig18
Empty pellet box: no visible damage

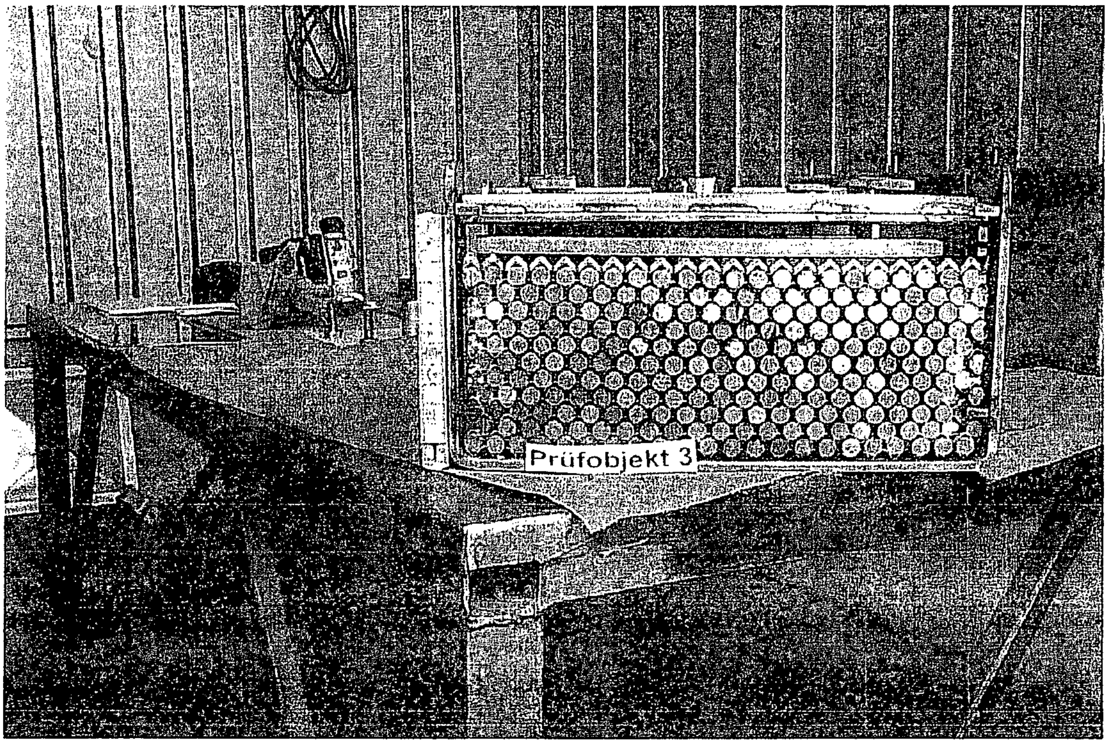


Fig 19
View of dummy pellets from one side: the dummy pellets along the two vertical outside edges are considerably crushed.

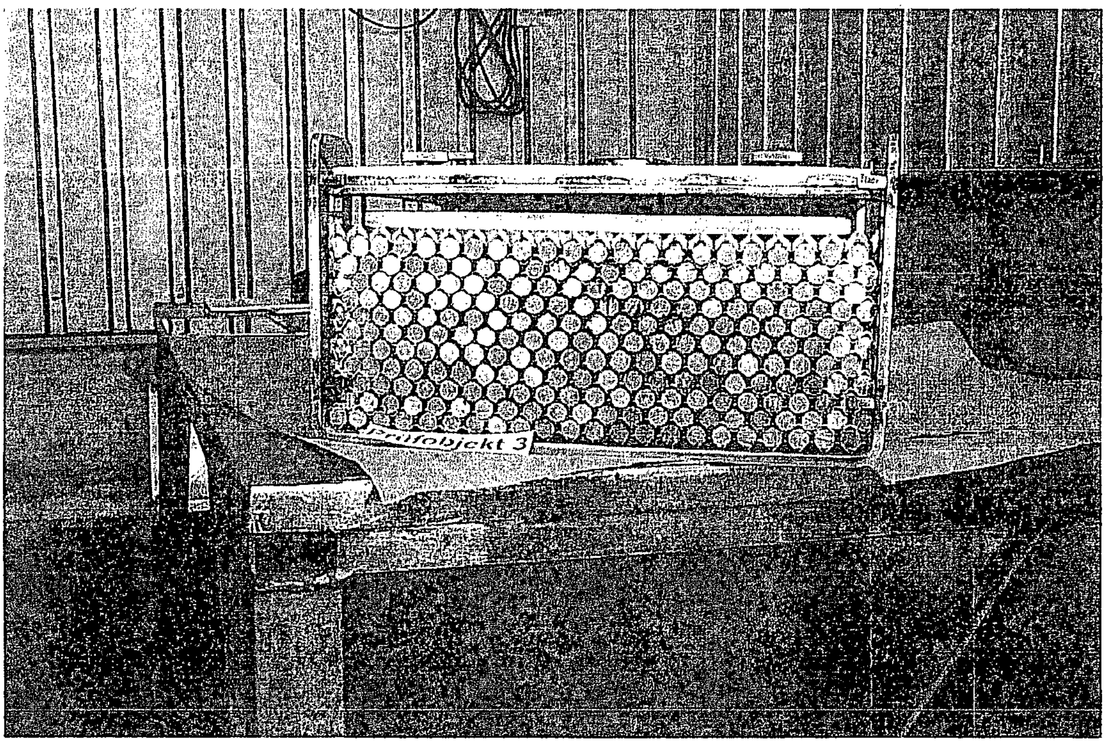


Fig 20
Opposite side: dummy pellets on vertical outside edges are severely crushed.

Appendix 4.4 Test Specimen No. 4

Appendices 4.4-1 to 4.4-8

Fig. 1
Penetration test before start of drop tests

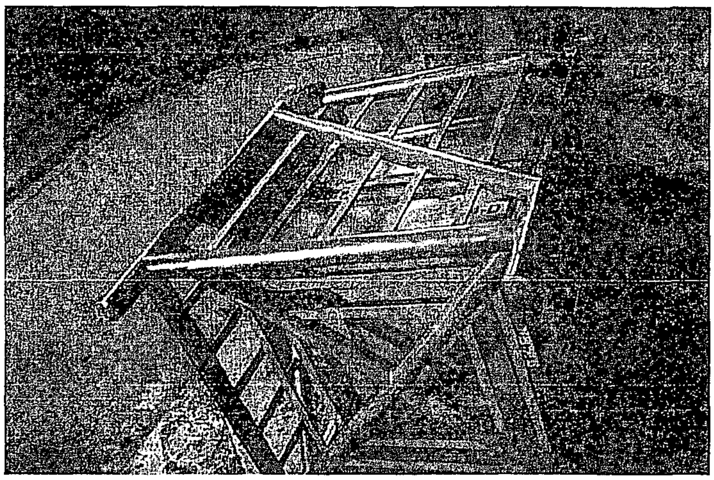


Fig. 2
Side wall P4-D of pellet box case; view of impact point of test bar

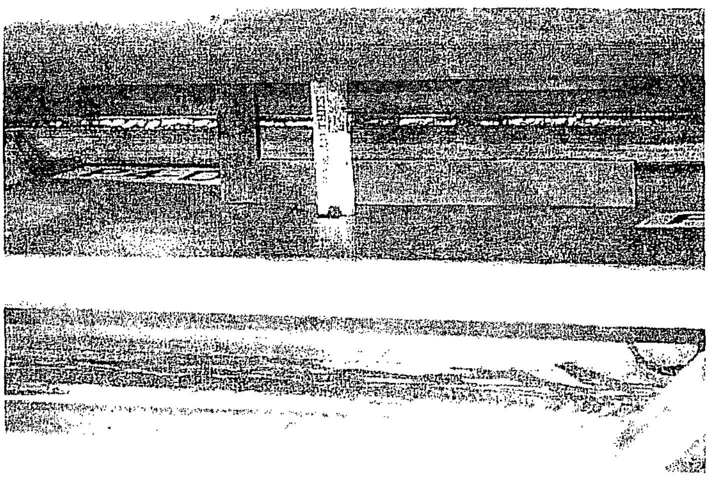


Fig. 3
Detailed view – The test bar caused a 6-mm-deep dent in side wall P4-D of the pellet box case

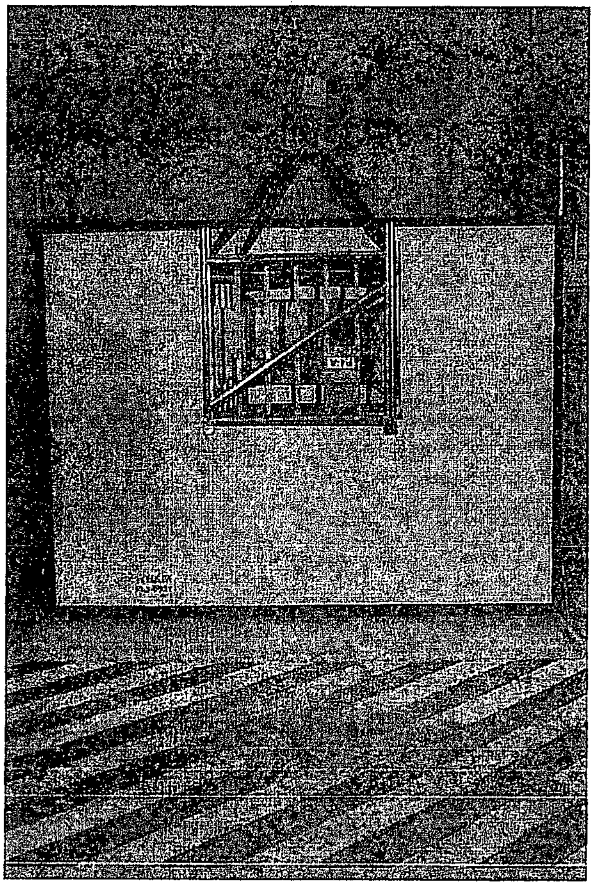


Fig. 4
Test Specimen No. 4 in dropping position,
drop distance: 1.3 m

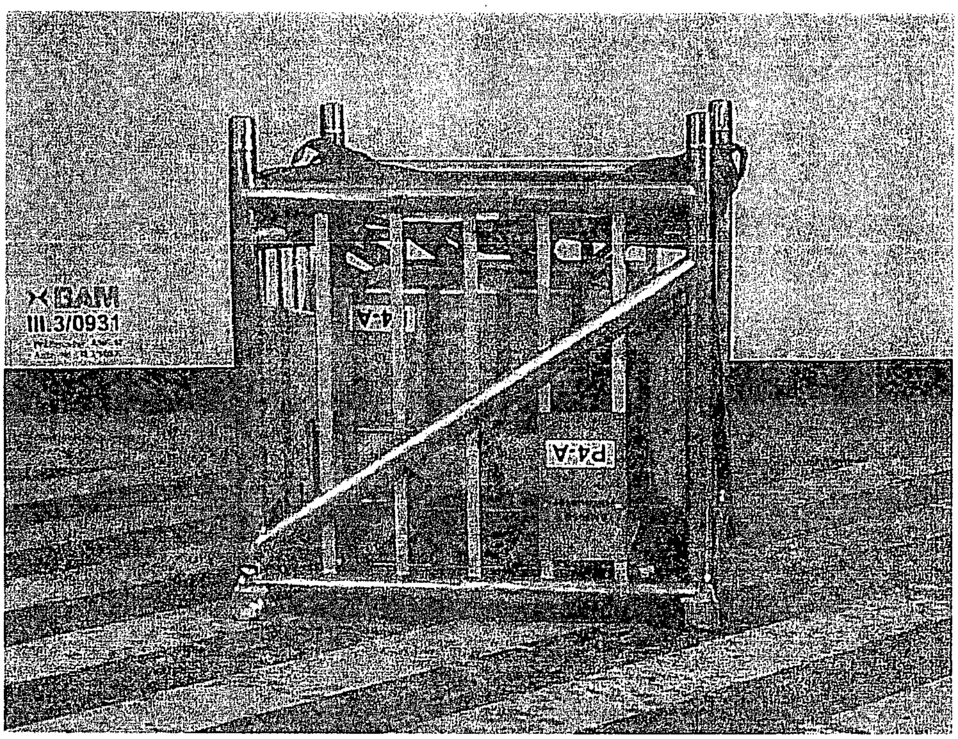


Fig. 5
Test Specimen No. 4 immediately after free drop test III.3/0931

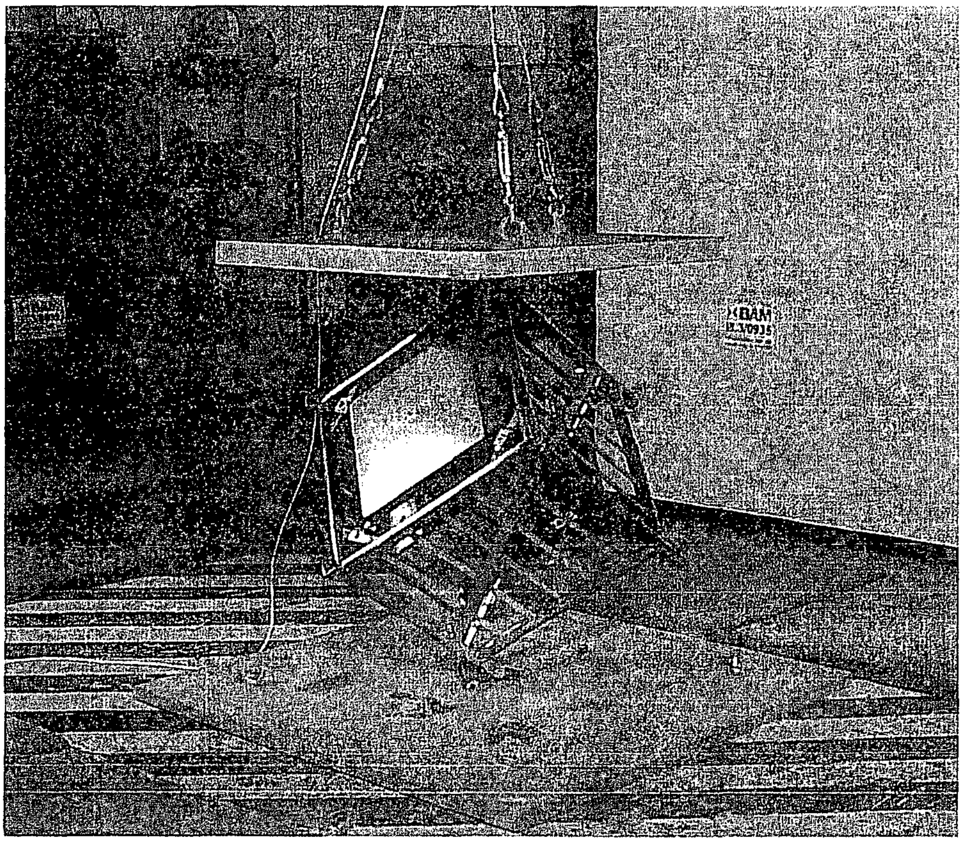


Fig. 6
The 520-kg steel plate is suspended in its dropping position above Test Specimen No. 4, which is standing on one of its corners for crush test III.3/0935.

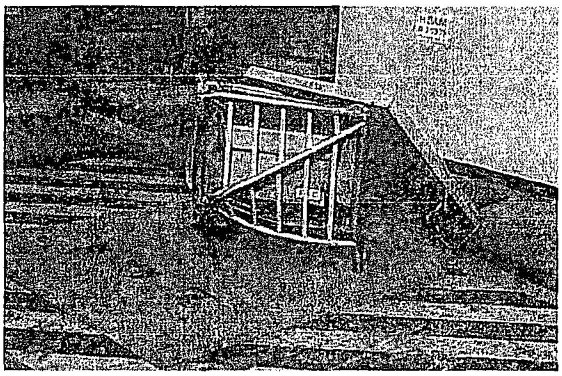


Fig. 7
Position of rest after crush test

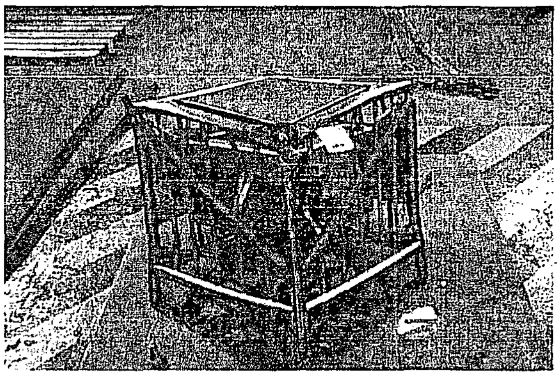


Fig. 8
View of corner impacted by steel plate

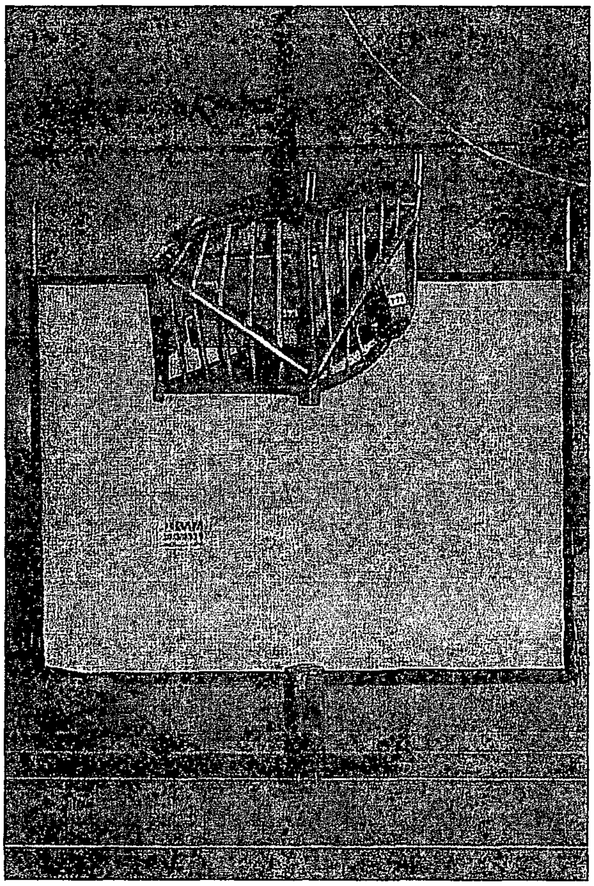


Fig. 9
Drop test onto vertical bar III.3/0939
Test Specimen No. 4 in dropping position
Drop distance: 1.1 m
Angle: 25°

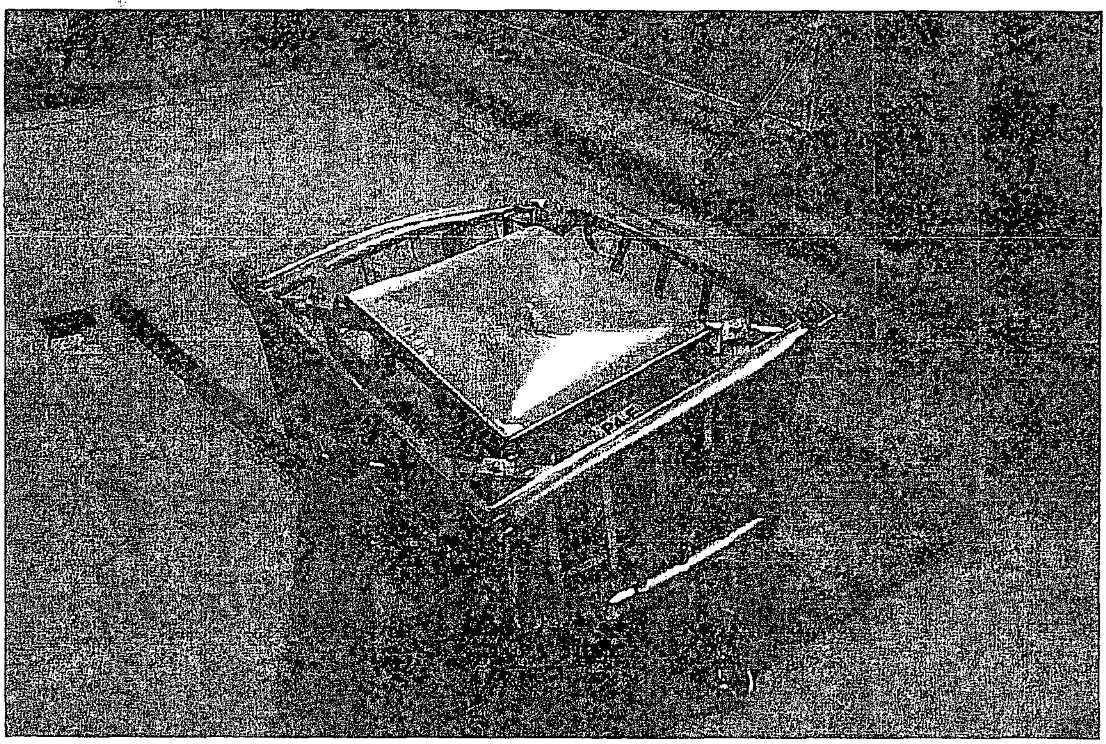


Fig. 10
View of deformed protective lid

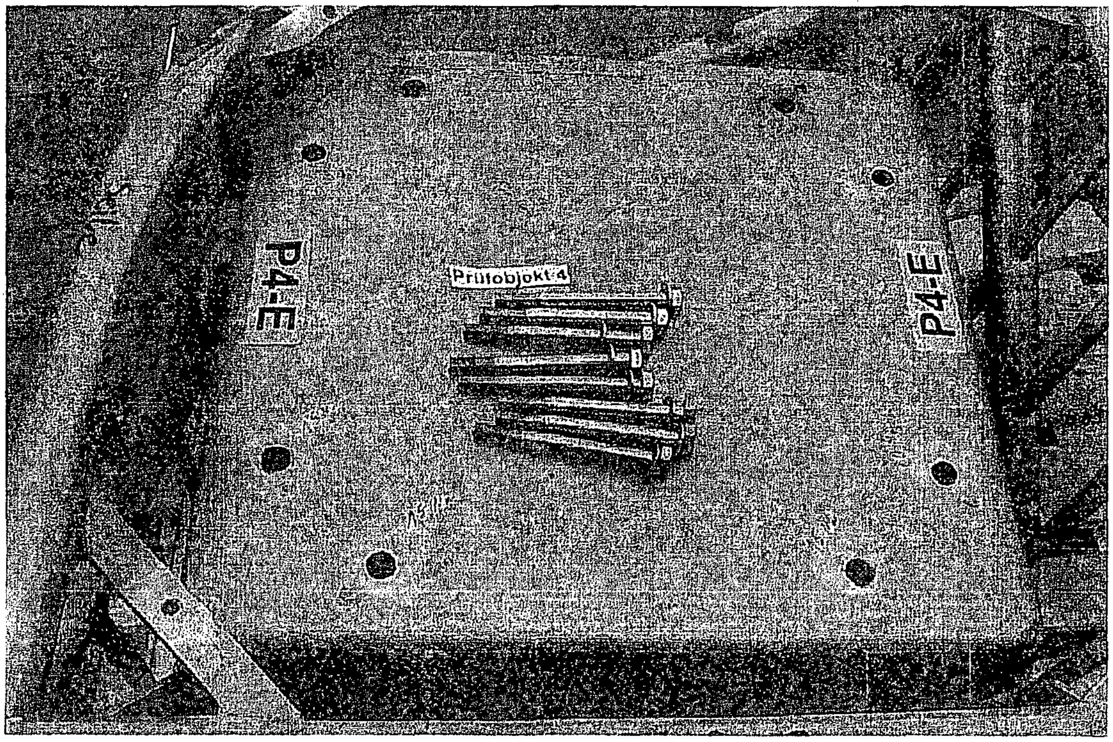


Fig. 11
Undamaged lid of pellet box case

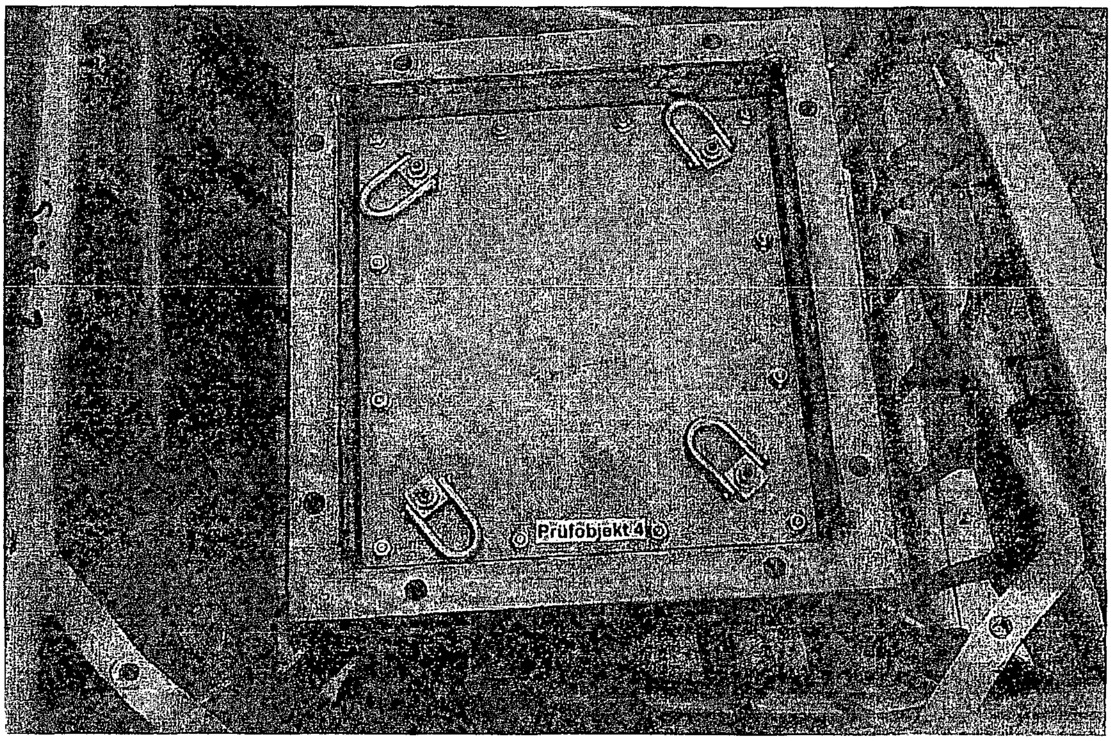


Fig. 12
Opened pellet box case

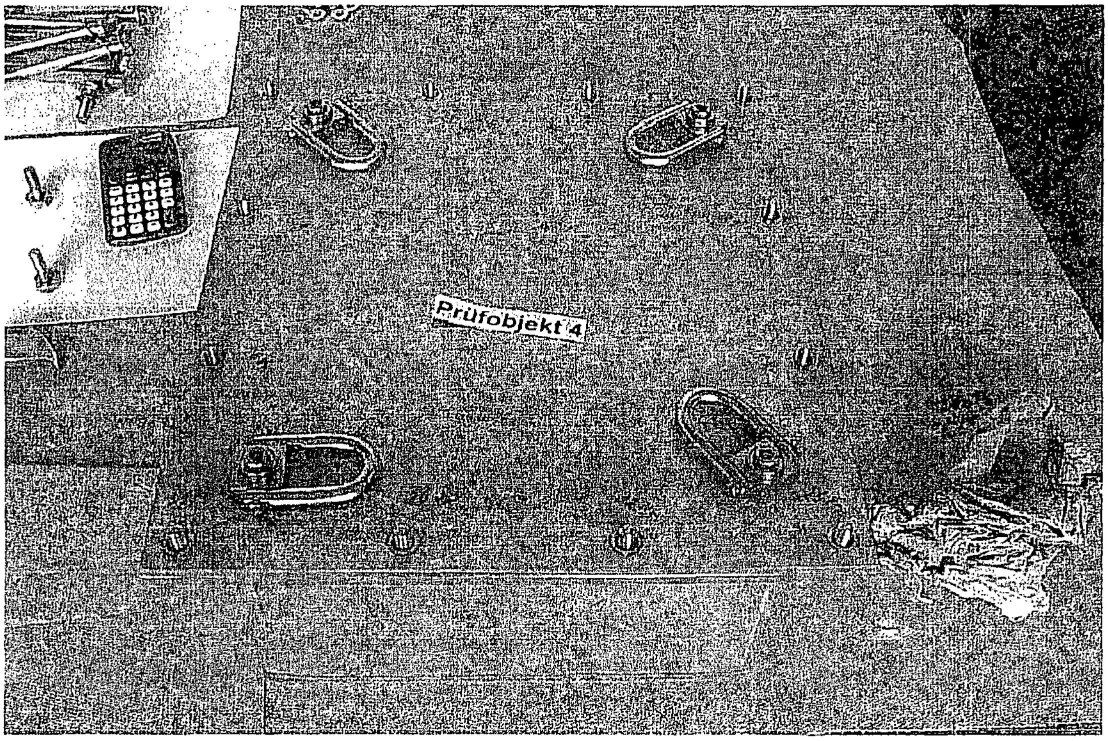


Fig. 13
View of pellet box

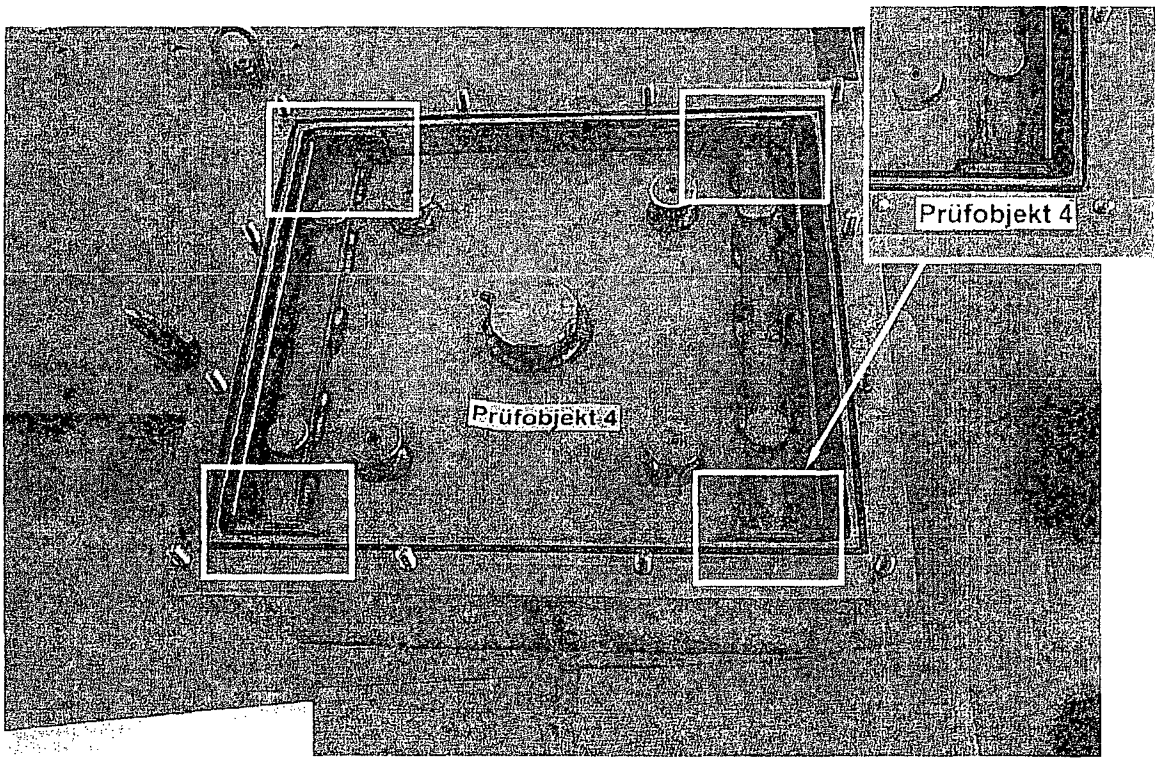


Fig. 14
Opened pellet box showing clamping device; clamping device was unlatched

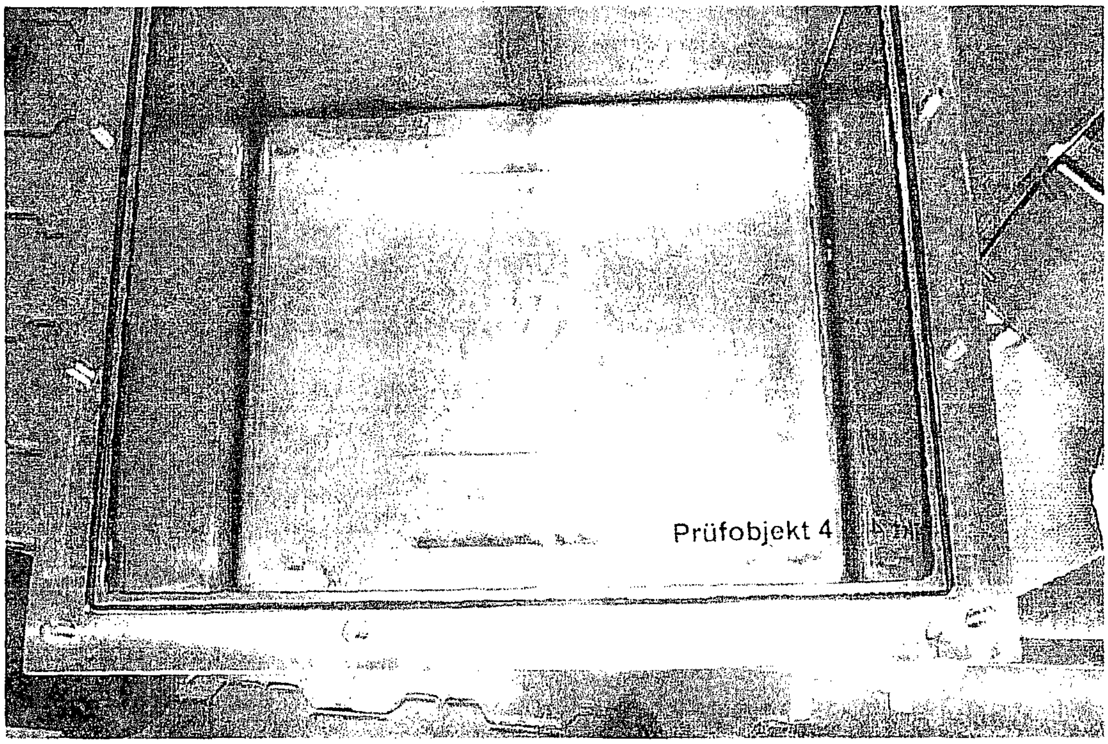


Fig. 15
Empty pellet box: no visible damage

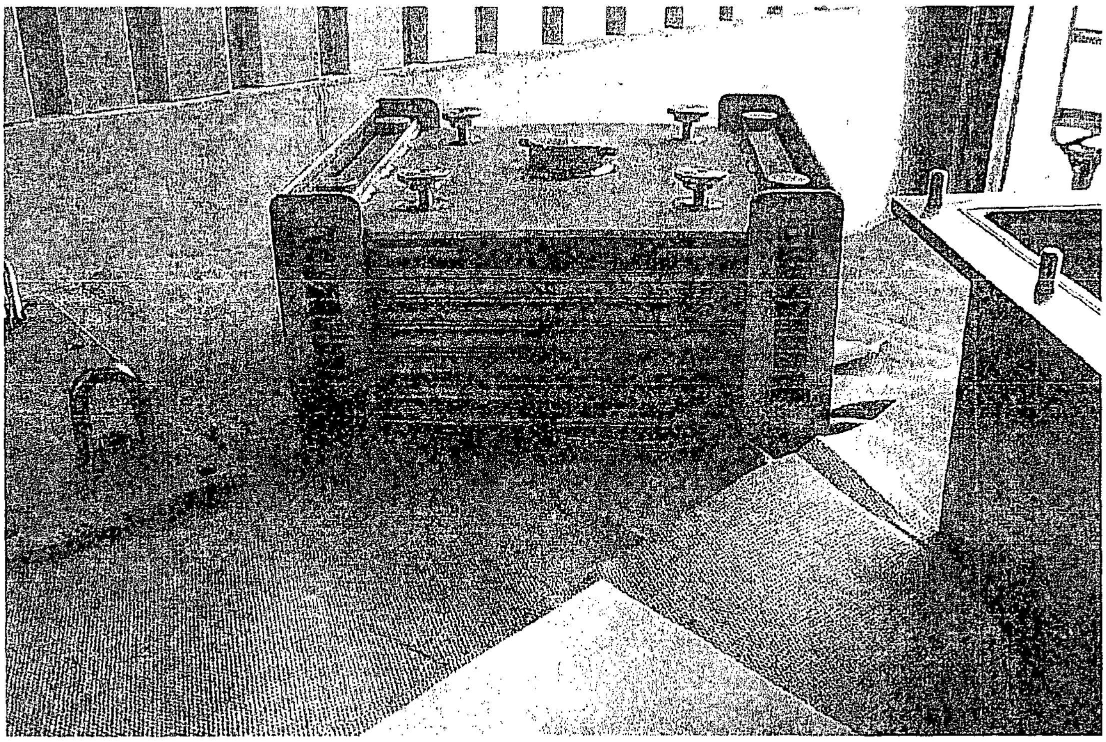


Fig. 16
Carrying rack with dummy pellets and top plate. The top plate is buckled by approx. 4 mm. The bottommost pellet tray has dented all four corners of the carrying rack. The dummy pellets and the pellet trays have moved by different amounts in the direction of load application. Both end plates are buckled outwards.

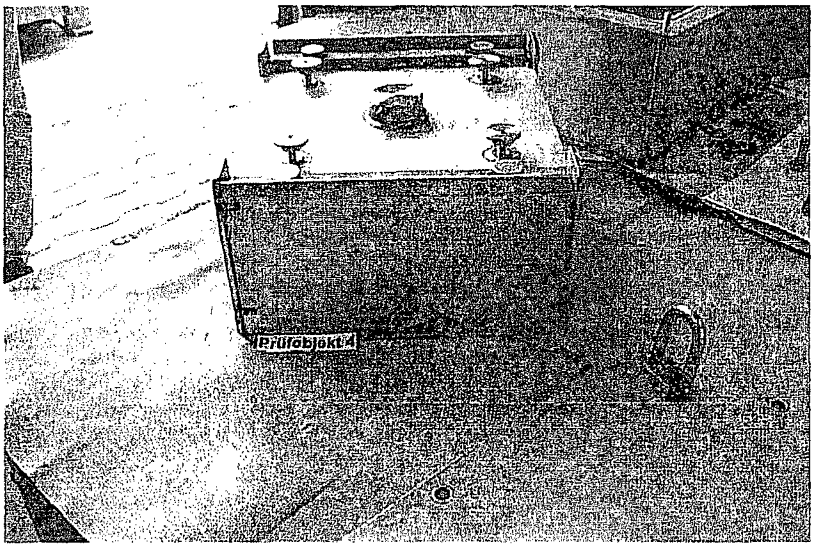


Fig. 17
Side view showing one of the buckled end plates

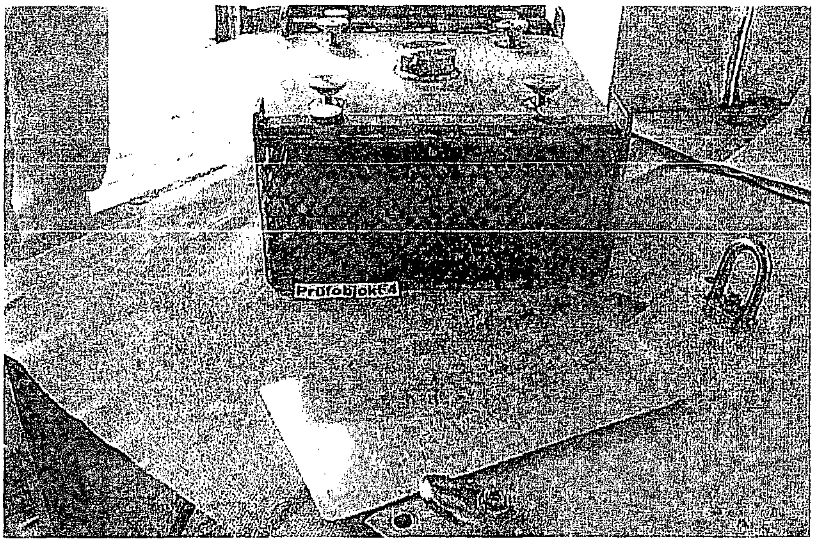


Fig. 18
Slightly deformed end plate: impressions made by dummy pellets visible on inside. Dummy pellets moved by different amounts in the loading direction.

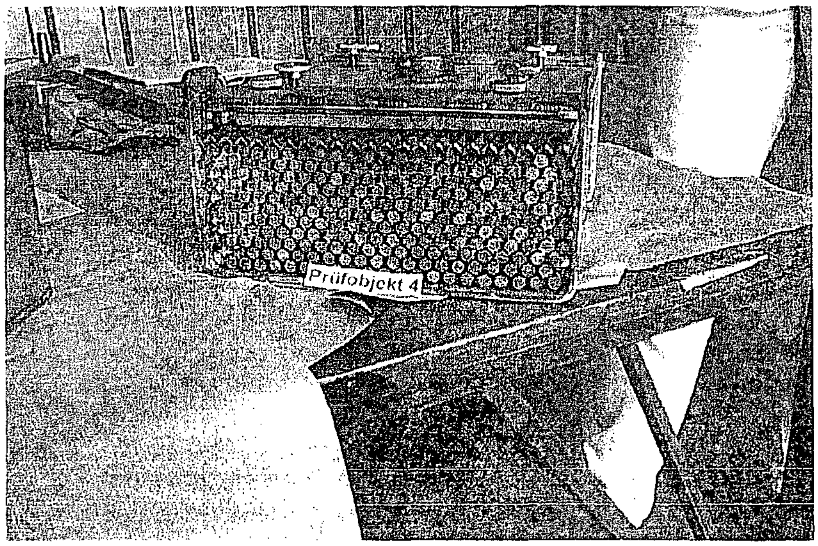


Fig. 19
View of opposite side

Appendix 4.5 Water Immersion Test

Appendices 4.5-1 to 4.5-3

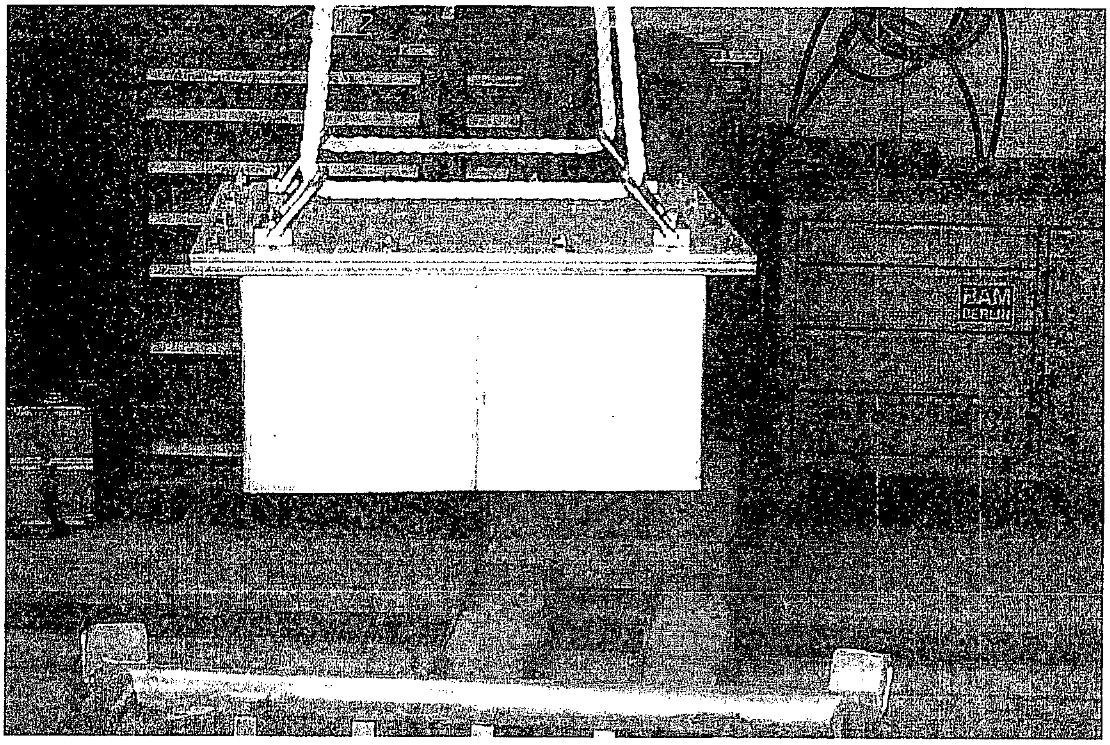


Fig1
Pellet box (inner pellet container of ANF-50) for water immersion test

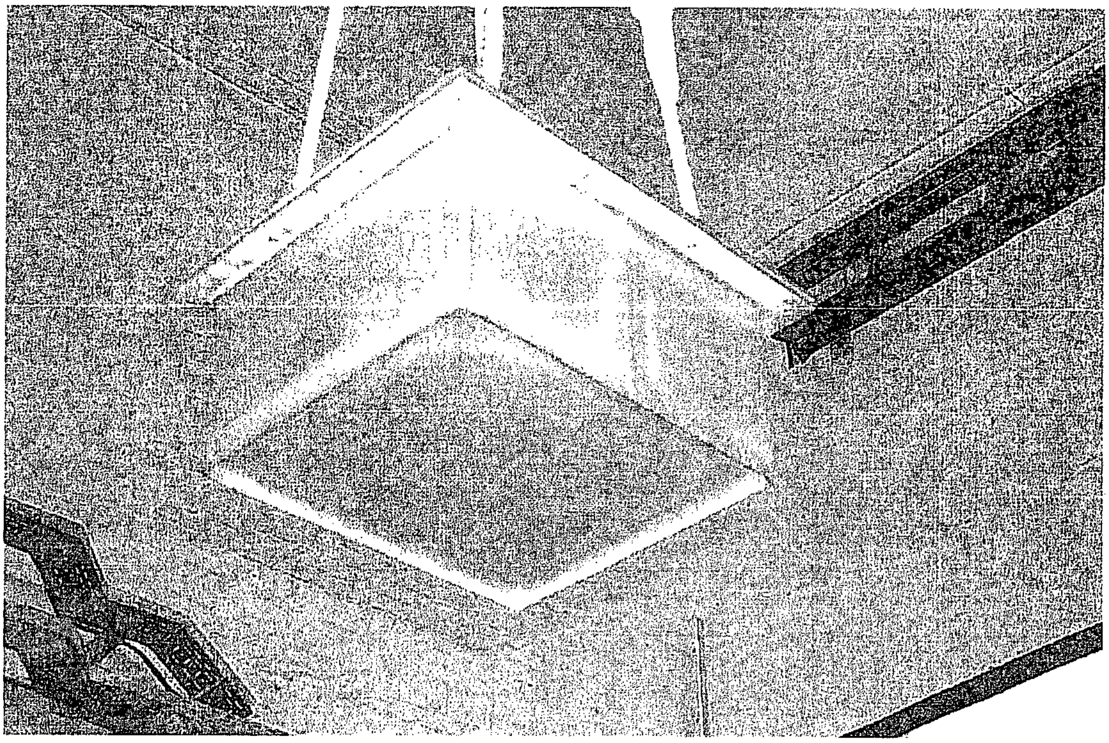
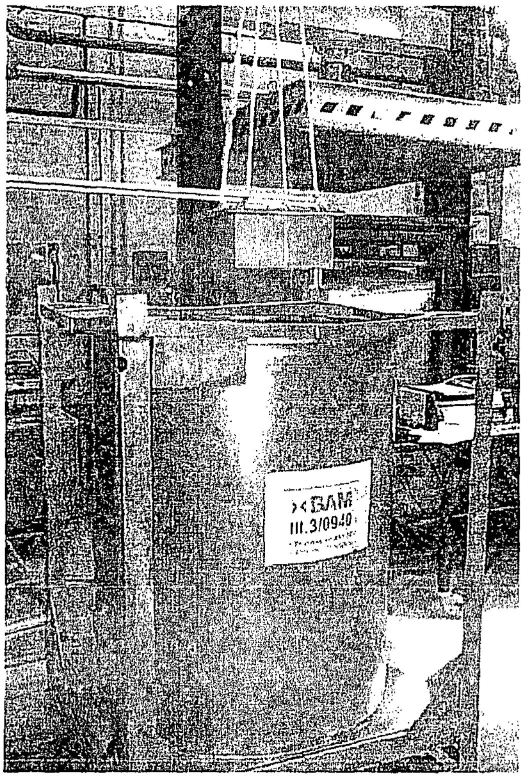
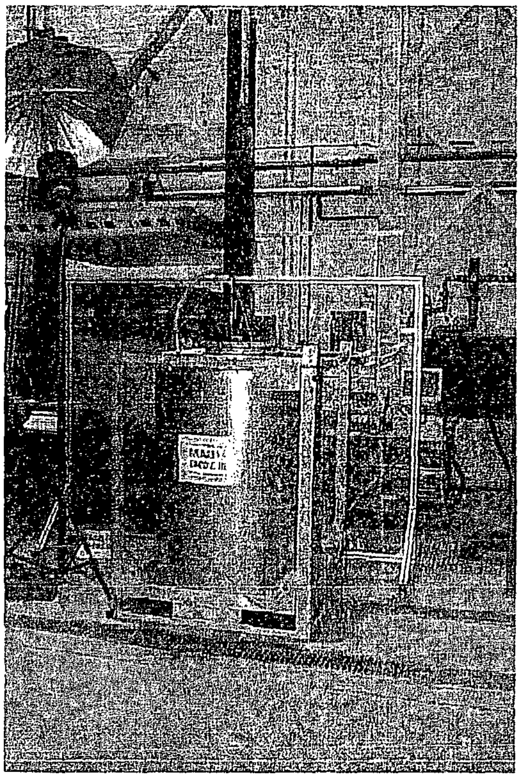


Fig2
Test specimen for water immersion test (III.3/0940)





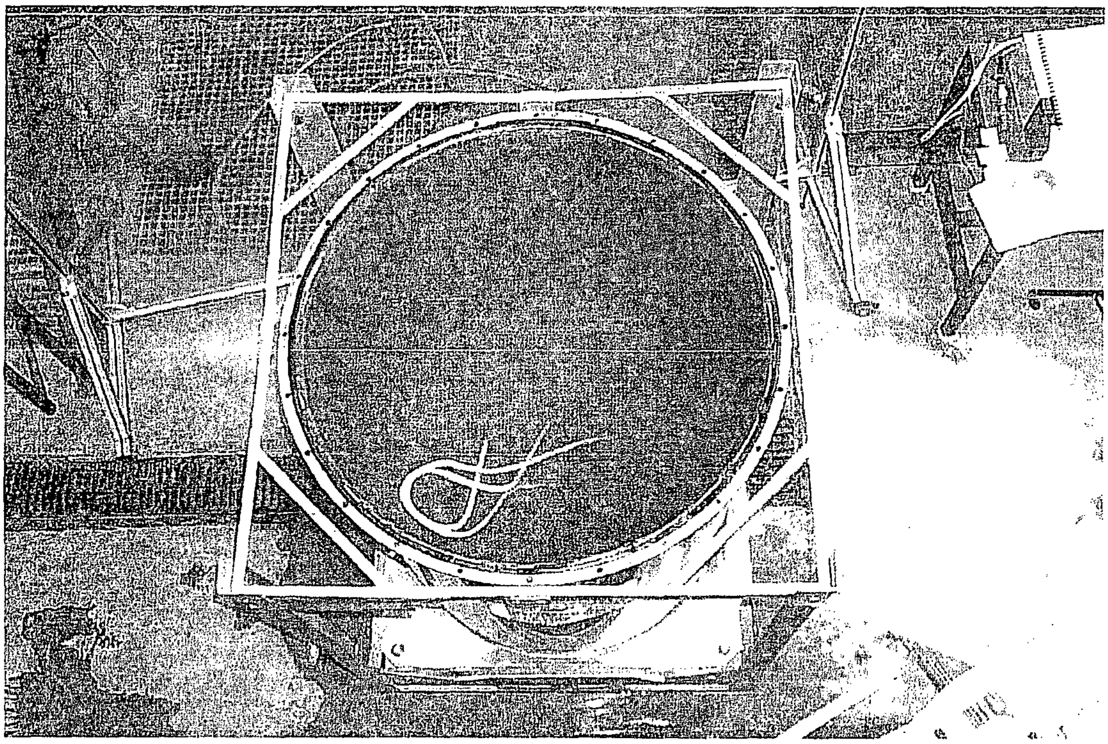


Fig. 3,4 and 5
Test stand for water immersion test

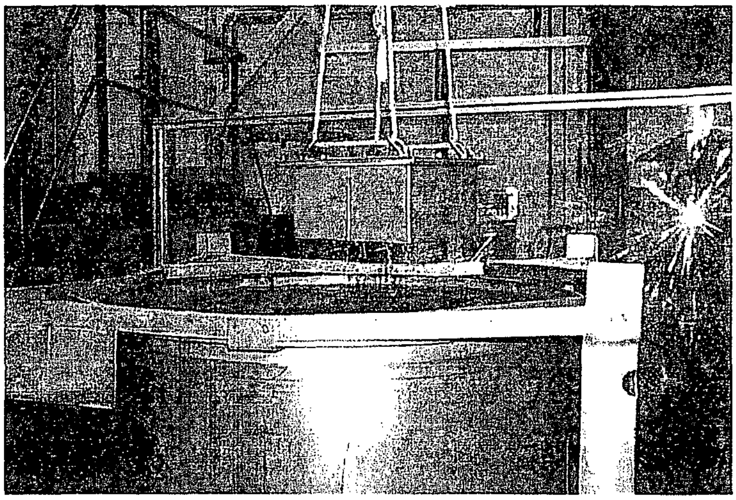


Fig. 6
Test specimen immediately after water immersion test (III.3/0940)

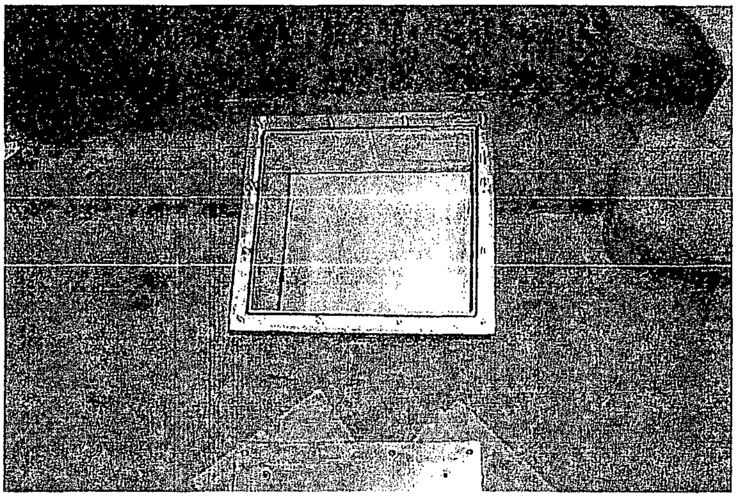


Fig. 7
Opened pellet box

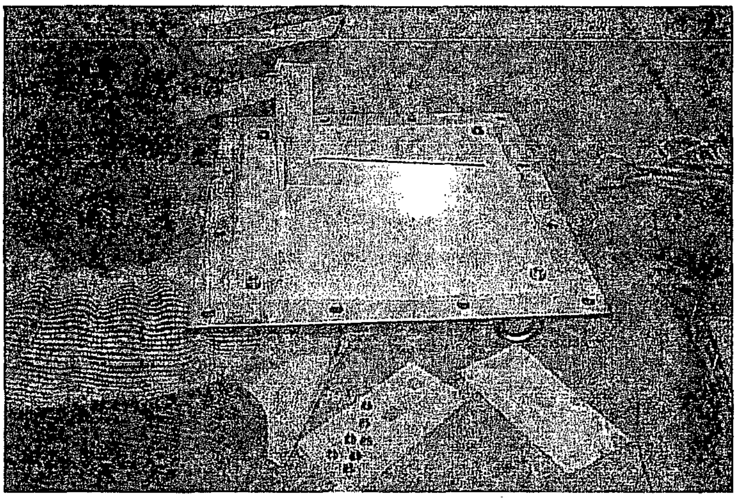


Fig. 8
Inside of pellet box lid

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FRAMATOME ANP

Summary of Data

Report number	
A1C-1314450-1	
Place	Date
Erlangen	March 18, 2004

Title/Subject
Pressure test at an ANF-50 container

Author	Department	Phone	Signature
D. Ziegler	FGTW	95977	Signed Ziegler

Project
ANF-50

Released by responsible department (for contents, handling, distribution)	Released for external distribution (not required for preliminary test report)
Signed Petra Hoffman 29.03.04	Signed Koban
AL: N	ECCN: N

Handling Instructions
restrictive

Export code*)

Project	UAS or DCC	Contents code	Doc. Ident. No.
ZEN000	BK	1285	

Summary*) Pages of text: 3 Appendices: 1 Total pages: 8

According to Appendix 1 (FANP/FGTW/04/1/Zi minutes and PUL/FGTW/ 04/16 test plan of January 13, 2004) a leakage test was carried out on a pellet container (inner container of ANF-50).

1. Result

1.1 1. Test with delivered O-ring

The pressure of 1.5 bars dropped immediately and water escaped from the container. The cause was found to be an imperfectly glued area at the O-ring.

1.2 2. Test with a new O-ring

A new O-ring was made by FGTW.
No leakage was found after ca. 30 min of constant 1.5-bar overpressure. The container remained overpressurized at 1.5 bars for five hours. During this time the overpressure remained constant and no water escaped.

Result verified according to test requirement and released for application: Signed W. Jahreiß 25.03.04
W. Jahreiß / FGTM Date

This report is an English translation of a report that was originally issued in German.
Translation checked: Jahreiß 13.04.06 **approved and released:** Jahreiß 13.04.06

Keywords: Pressure container, pressure drop

*) For reports with technical content, enter not more than 12 keywords at the end of the summary and the export code.

Distribution list (if summary is for information only, add: "for information"):

FGTW Dr. A. Seibold - for information
FGTW E. Ortlieb - for information
FGTM W. Jahreiß
FGS W. Höfers
ANF H. Lampe
ANF T. Steffenewers
ANF D. Steinigeweg

Index	Version	Revision Date	Encl(s):	Prepared by initials	Released by initials
1		23.03.2006	1	Sgd. Zi	Sgd. Ja, Ko

Revision Sheet

Page / Appendix	Change
Page 1	External release, version A1C-1314450-1

2. Rubber cord dimensions

The diameter of the rubber cord for manufacturing the O-ring is between 2.70 mm and 2.80 mm.

3. Rework at the cover of the container

After the tests the tapped bore was welded shut with a stud made of material 1.4541.

4. Evaluation of the results

- With a diameter of the rubber cord (O-ring) of 3 +/-0.3 mm, the leak tightness at the lower tolerance limit is not entirely satisfactory. Therefore, O-rings used should have a diameter of 3 +0.3 mm.

- If there is a defect at the glued area of O-rings which are self-made from a rubber cord, this O-ring is no longer fit to ensure leak tightness (see first test). When self-assembling O-rings, we therefore recommend to exercise utmost diligence and check the result carefully, or to purchase ready-made O-rings.

5. Appendices

Appendix 1: Pages 5
Minutes FANP/FGTW/04/001/Zi and test plan PUL/FGTW/ 04/016 dated January 13, 2004

FRAMATOME ANP

Minutes of test planning meeting

To

Distribution list (participants)

W. Jahreiß	FGTM
B. Block	FGTW
E. Ortlieb	FGTW

Name	Dieter Ziegler
Department	FANP FGTW
Site	Erl S F
Phone	(09131)18-95977
Fax	(09131)18-94705
Email	Dieter.Ziegler@framatome-anp.com
Our reference	FANP/FGTW/04/001/Zi
Date	13th January 2004

On 13th January 2004, W. Jahreiß / FGTM and D. Ziegler / FGTW had a meeting in order to specify the conditions for testing the leak tightness of a pellet container (inner container of the ANF-50).

1. Tested part

ANF-50 inner container, no. S221

2. Test conditions

2.1 Tightening torque of cover screw 25 Nm
2.2 1.5-bar overpressure over a period of 30 minutes
2.3 Install an appropriate pressure connection in the center of the cover. This test bore must be closed again after the test.
2.4 Fill up container entirely with water and check for leakage by applying constant overpressure, see 2.2.
2.5 After the test close the bore again, screw in the threaded bolt, weld it shut and grind off the excess welding seam.

3. Schedule

The test has to be conducted by week 7, 2004.

4. Account assignment

The work expenditure is assigned to the following account number:
F-8065-18-A-5000, Project ANF-50.

5. Appendices

Test plan PUL/FGTW/04/016

FRAMATOME ANP

Minutes of test planning meeting

Date 13th January 2004
Our reference: FANP/FGTW/04/001/Zi

The documents are released and the tests are commissioned by the following signatures:

	Implementation	Commissioning and approval of costs
Name:	D. Ziegler	W. Jahreiß
Department:	FGTW	FGTM
Date:	13th January 2004	22nd January 2004
Signature:	signed D. Ziegler	signed W. Jahreiß

FRAMATOME ANP FGTW	Test Plan	PUL/FGTW/04/016 Page of Test plan Page 1 of 3 pages Appendix1: to minutes (document FANP/FGTW/04/001/Zi dated 13th January 2004)

Test: Pressure test at a pellet container (ANF-50 inner container).

FGTW responsible for the test: Mr. Ziegler

Requirement: **Minutes of meeting:** FANP/FGTW/04/001/Zi **QM-AA: 10 rev. "1"**	**Commissioned by:** W. Jahreiß **Test schedule:** By week 7, 2004

Ser. no.	Test specifications
1	**Test description (use extra sheet of paper if necessary)** The exact description of the work steps to be carried out is given in the minutes of meeting FANP/FGTW/04/001/Zi.
2	**Description of the test setup (drawing on an extra sheet of paper if necessary)**

FRAMATOME ANP **FGTW**	# Test Plan	**PUL/FGTW/04/016** **Page of** **Test plan** **Page 2 of 3 pages** Appendix1: to minutes (document FANP/FGTW/04/001/Zi dated 13th January 2004)

Ser. no.:	Test specifications	Comments
3	**Procurement / provision of test objects / samples**	Mr. Jahreiß / FGTM will procure the pellet container. Installing a test bore in the container cover and re-sealing after the test by FGTW
4	**Preliminary characterization / preparation of the test objects / samples**	- Checking the container - After filling up the container with water, the screws have to be tightened to the specified tightening torque (25 Nm).
5	**Testing facility/measuring tools (to be procured and tested where necessary)**	Pressure facility for pressure gauge measurement at the calibration measuring point
6	**KMS test of the measuring tools (to be calibrated if necessary)**	Only tested (KMS) measuring tools are used. The measuring tools are documented in the SoD to be created.
7	**Measuring accuracy**	The measuring accuracies are documented in the SoD to be created.
8	**Method of measured value acquisition**	Measurements: - Pressure adjusted manually - Visual inspection for leaks
9	**Type of documentation report format**	SoD (Summary of Data)
10	**Involvement of internal / external members**	Mr. Jahreiß / FGTM
11	**Additional agreements (use extra sheet of paper if necessary)** Deviations from the minutes of meeting or additional investigations will be coordinated with FGTM and documented in the SoD to be created. Remark: KMS = calibration laboratory for measuring instruments	

FRAMATOME ANP FGTW	Test Plan	PUL/FGTW/04/016 Page of Test plan Page 3 of 3 pages Appendix1: to minutes (document FANP/FGTW/04/001/Zi dated 13th January 2004)

Test plan created by: Name: Ziegler Signature: signed D. Ziegler Date: 13th January 2004	**Additional remarks:**

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JURY UMWELTZEICHEN

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Issue out of

B-TA-3928-Rev1

Numerical Simulation of IAEA Thermal Test for ANF-50 Pellet Shipping Container

Purchaser:	Advanced Nuclear Fuels GmbH	Contents:	
IABG Order No.:	340 8111 01	Total number of pages	33
Order No.:	77708 dated July 2, 2002	Number of tables	3
		Number of figures	36

Ottobrunn, October 11, 2002

signed Katzenschwanz	signed Becker
(Dr. Katzenschwanz) Department Manager	(Dr. Becker) Project Manager Responsible Coordinator

This report is an English translation of a report that was originally issued in German.
Translation checked: Becker 31.05.03 **approved and released:** Jahreiß 02.06.2003

Report Sheet

IABG

1. Purchaser's report no.	2. Type of report	3. Contractor's report no.
	Final report	B-TA-3928-Rev1

4. Title of report
Numerical Simulation of IAEA Thermal Test for ANF-50 Pellet Shipping Container

5. Author(s) (surname, first name) Dr. Becker, Ingo	11. Date of completion 2002/October/11 12. Date of publication 2002/October/11
6. Contractor, department, address Industrieanlagen-Betriebsgesellschaft mbH Dept. TA 43 CAE Services, Automotive Industry Postfach 12 85503 Ottobrunn	13. Number of pages 33 14. References 5
7. Purchaser, department, address Advanced Nuclear Fuels GmbH Framatome ANP Postfach 1465 49784 Lingen	15. Tables 3 16. Figures 36

8. Summary

For the design of the ANF-50 pellet shipping container the IAEA thermal test was numerically simulated for containers loaded to minimum and maximum degrees. After the heating phase at 800°C for 30 minutes, a subsequent temperature equilibration phase was computed, during which time the outside of the container cooled down but the temperature inside the container continued to rise over a period of more than 2 hours due to the process of temperature equilibration.

The pellets reach their maximum temperature of 162°C in a container loaded to the minimum degree (i.e. with one layer of pellets) after around 2 hours and 20 minutes. This temperature drops only slowly thereafter due to the insulation, with the result that a temperature of around 150°C to 160°C continues to prevail inside the pellets for a period of several hours.

In a container loaded to the maximum degree (i.e. with 14 layers of pellets) the maximum temperature of 147°C is somewhat lower than that in the minimum loading case. Here, too, the temperature in the pellets remains at around 120°C to 140°C for several hours.

The deformations caused by the drop tests have only a slight effect on the maximum temperatures. The numerical simulation yields a temperature increase of less than 1°C in the pellets.

9. Key words

10. Remarks

Table of Contents

1. Task Definition

The ANF-50 pellet shipping container is to be approved for transport of uranium oxide pellets in accordance with the IAEA requirements [1]. This requires performance of a thermal test at 800°C for 30 min in addition to the mechanical tests.

Of key interest in the thermal test are the temperatures reached inside the pellets. Above a certain temperature level and given a sufficient supply of oxygen, sintered pellets (UO_2) are converted to powder (U_3O_8). This powder can be washed out by any water entering the container and the washed-out powder from several containers can then collect in, for example, a corner of the surrounding overpack (criticality criterion).

The thermal test is performed as a numerical simulation to determine the temperature distribution in the interior of the container as well as the maximum temperatures in the pellets.

2. Design of the ANF-50 Pellet Shipping Container

The design of the ANF-50 pellet shipping container is described in [2].

Figure 1 shows an exploded view of the shipping container and Figure 2 a sectional view through the container. Figure 3 illustrates the configuration for the minimum degree of loading with one pellet layer and for the maximum degree of loading with 14 pellet layers. Figure 4 shows the carrying rack with the clamping device for the pellet trays. The outer frame of steel tubes and strips surrounding the pellet box case as well as the protective lid are not relevant for the thermal test and are therefore not accounted for in the numerical simulations.

The pellet shipping container consists of the case for the pellet box and the case lid. The pellet box case surrounds the pellet box which, in turn, contains the carrying rack for the pellet trays with the pellets and a clamping device for holding the pellets and pellet trays firmly in position inside the pellet box. The pellet box is closed off by a plate with flange and integral gasket. The top and bottom ends of the pellet box case comprise square channels. The walls of the pellet box case as well as the case lid consist of two austenitic steel plates with insulating material in-between. The lid of the case completely encloses the upper square channel in order to limit heat flux through the channel into the interior of the case. The steel angle in each corner of the pellet box case is additionally lined with a layer of insulating material.

The plates and channels are made of austenitic steel (material no. 1.4541). *Kerform* KVS 126 made by RATH [3] is used as the insulating material.

3. Modeling

Figure 4 shows both the mechanical design and the finite element (FE) model of the carrying rack with the clamping device for the pellet layers for the maximum loading case. Figures 5 to 8 show the FE model for the pellet shipping container based on minimum loading, as well as partial views of the various components. Figure 9 is a horizontal section through the FE model. Figure 10 shows the FE model of the pellet shipping container for the maximum loading case.

Only a quarter of the structure is considered due to the symmetry of the design. Thin austenitic steel sheets (≤ 3 mm thick) are represented by shell elements, while thick sheets and plates as well as the insulating material are modeled using volume elements. Small air gaps (≤ 1 mm) between the insulating plates are not accounted for.

The pellets are idealized as a homogeneous layer of volume elements. The empty pellet trays of the minimum loading case are likewise modeled using volume elements. The uppermost pellet tray of the maximum loading case is represented by shell elements.

All cavities are described by surface elements which are used to calculate radiative transport. In addition, the entire outer surface is defined using additional surface elements in order to calculate the heat losses from radiation and convection. In accordance with the IAEA requirements [1], an emissivity coefficient of 0.9 and an absorptivity coefficient of 0.8 are assumed. The heat transfer coefficient was taken to be 6 W m^{-2} K^{-1}.

Large air gaps (≥ 2 mm) between individual structural components are represented by volume elements. This enables heat conduction through the air to be accounted for in addition to radiative transport. Only radiative transport is considered in the calculations for large cavities inside the square channels and for the space above the pellet layers.

The temperature dependence of the individual materials is duly accounted for in the calculations. The material properties employed are summarized in Tables 1 to 3.

4. Simulations Performed

The thermal test for the pellet shipping container can be fully covered by investigating the two limiting cases of minimum loading with one pellet layer and maximum loading with 14 pellet layers (see Fig. 3). The effect of the deformation resulting from the drop tests can be estimated by means of an additional simulation. The following calculations were therefore performed for simulating the thermal test:

- Simulation calculation for minimum loading with one pellet layer
  - Heating of outside of container to 800°C for 30 minutes.
    The initial temperature of the container is 38°C. A temperature of 800°C on all exterior surfaces of the container is assumed as a boundary condition.
  - Temperature equilibration phase with cooldown of container exterior for 240 minutes.
    Heat losses by radiation and convection are assumed. The ambient temperature is 38°C.
- Simulation calculation for maximum loading with 14 pellet layers

- Heating of outside of container to 800°C for 30 minutes.
  The initial temperature of the container is 38°C. A temperature of 800°C on all exterior surfaces of the container is assumed as a boundary condition.

- Temperature equilibration phase with cooldown of container exterior for 180 minutes.
  Heat losses by radiation and convection are assumed. The ambient temperature is 38°C.

➢ Simulation calculation for minimum loading with deformation from drop tests

- Heating of outside of container to 800°C for 30 minutes.
  The initial temperature of the container is 38°C. A temperature of 800°C on all exterior surfaces of the container is assumed as a boundary condition.

- Temperature equilibration phase with cooldown of container exterior for 150 minutes.
  Heat losses by radiation and convection are assumed. The ambient temperature is 38°C.

The numerical simulations were performed as nonlinear transient thermal analyses using the FE program MSC Nastran 2001 [4].

5. Results

The thermal test for the pellet shipping container can be fully covered by investigating the two limiting cases of minimum loading with one pellet layer and maximum loading with 14 pellet layers (see Fig. 3). The effect of the deformation resulting from the drop tests is also considered.

5.1. Shipping Container with One Pellet Layer (Minimum Loading)

Figures 11 to 17 show the temperature distribution in the pellet shipping container with minimum loading after 30 minutes (at the end of the heating phase) and after 120 minutes (corresponds to 90 minutes of cooldown).

Whereas, after 30 minutes, the temperature in the pellet container and in the pellets has increased only slightly, a higher temperature of around 160°C prevails inside the container and the pellets after 120 minutes due to temperature equilibration. Most of the exterior of the container has already cooled down; the temperature only remains high at the locations of the steel bolts of the pellet box case which act as a heat reservoir due to their high heat capacity.

From the temperature distribution inside the pellet box case it can be seen that heat primarily flows from the top into the interior of the container. However, this heat flux through the upper square channel is limited by the insulation of the lid enclosing the top of the case.

Also noticeable is the higher temperature of the steel angle in the corner which is directly connected to the austenitic steel bottom plate. This steel angle heats up to roughly 700°C on the bottom (Fig. 15). However, heat transfer from the steel angle to the interior of the pellet box case is reduced by the additional insulation.

Figure 17 shows the temperature distribution in the pellet layer after 120 minutes. The temperature within the layer has nearly equalized, with a maximum value of 160°C at the corner.

Figures 19 to 22 contain the temperature time histories for the locations of the container structure identified in Figure 18. It can be seen in Figure 19 that the maximum temperature of 162°C in the pellet layer is not reached until after roughly 2 hours and 20 minutes following the end of the heating phase. This is due to temperature equilibration and the prevention of heat losses by the "good" insulation. Moreover, this temperature decreases only slowly due to the insulation, with the result that the temperature remains at this level for a period of several hours.

The temperature time histories of the pellet box and pellet box case illustrate once again that the majority of the heat reaches the interior of the container from above. The upper outside corner of the flange on the pellet box reaches a maximum temperature of nearly 320°C, while the upper corner of the case for the pellet box reaches a maximum temperature of around 600°C.

5.2. Shipping Container with 14 Pellet Layers (Maximum Loading)

Figures 23 to 27 show the temperature distribution in the pellet shipping container with maximum loading after 30 minutes (at the end of the heating phase) and after 120 minutes (corresponds to 90 minutes of cooldown).

The temperature distributions are similar to those in the shipping container with minimum loading. In contrast to the minimum loading case, the greater mass of the pellets absorbs and dissipates more heat. This results in less heat diffusing into the lower part of the container.

Figures 28 and 29 show the temperature time histories at the selected locations in the pellets and the pellet box. The maximum temperature of approximately 147°C in the pellets is reached at the upper corner (Fig. 28). Due to their greater mass, the pellets absorb more heat and dissipate it into the interior. As a result, the maximum temperature in the pellets is lower than in the minimum loading case.

This can also be seen in the temperature time histories for the pellet box (Fig. 29). While the curves at the very top are similar to those for minimum loading, significantly lower maximum temperatures are reached in the middle and at the bottom.

5.3. Effect of Deformations from Drop Tests

Four specimens were subjected to drop tests in various positions. Severe defomation occurred in the outer frame and the protective lid, but this has no effect on the thermal test.

Only in two specimens there were deformations of the pellet box case which could be of relevance for the thermal test [5].

Figures 32 and 33 illustrate the deformations that occurred on the exterior of the pellet box case from the drop tests. Figure 32 shows a dent having a depth of approximately 21 mm extending over a length of approximately 150 mm along the container edge of Test Specimen No. 3. Figure 33 shows a roughly 80-mm-wide, 16-mm-deep dent in a corner of Test Specimen No. 1 resulting from an additional drop test onto a vertical bar. Figure 34 shows a schematic representation of this area on the corner of the pellet box case.

In order to investigate the effect of these deformations from the drop tests on the maximum temperature inside the pellets in the thermal test, both deformations were simultaneously modeled in the FE model (Fig. 35) and a numerical simulation was then performed for this model based on minimum loading.

Figure 36 shows the temperature time history at the corner of the pellet layer for both the deformed and undeformed container. Since the deformations occur at locations which are of little significance in terms of heat flux, the temperature increase due to the deformations is less than 1°C.

6. Conclusion

For the design of the ANF-50 pellet shipping container the IAEA thermal test was numerically simulated for containers loaded to the minimum and maximum degrees ("minimum loading" and "maximum loading"). After the heating phase at 800°C for 30 minutes, a subsequent temperature equilibration phase was computed, during which time the outside of the container cooled down but the temperature inside the container continued to rise over a period of 1 to 2 hours due to the process of temperature equilibration.

The pellets reach their maximum temperature of 162°C in the container with the minimum loading (i.e. with one layer of pellets) after around 2 hours and 20 minutes. This temperature drops only slowly thereafter due to the insulation, with the result that a temperature of around 150°C to 160°C continues to prevail inside the pellets for a period of several hours.

In the container with the maximum loading (i.e. with 14 layers of pellets) the maximum temperature of 147°C is somewhat lower than that in the minimum loading case. Here, too, the temperature in the pellets remains at around 120°C to 140°C for several hours.

The deformations resulting from the drop tests have only a slight effect on the maximum temperatures. The numerical simulation yields a temperature increase of less than 1°C in the pellets.

7. List of Tables and Figures

Tables:

Figures:

8. References

[1] IAEA Safety Standards Series No. TS-R-1 (ST-1, Revised), Regulations for the Safe Transport of Radioactive Material, 1996 Edition, International Atomic Energy Agency, Vienna 2000.

[2] ANF-50 Shipping Container, Drawing No. 1-1 27-3750-01, ANF GmbH.

[3] Quality Data Sheet for Kerform KVS126, RATH GmbH.

[4] MSC.Nastran 2001, Installation and Operations Guide, MSC.Software Corporation, 2001.

[5] Measurements of ANF-50 Shipping Container (Test Specimen 1 to 4) before / after IAEA tests, Summaries of Data ANFG-11.119(003), ANF GmbH.

Tables and Figures

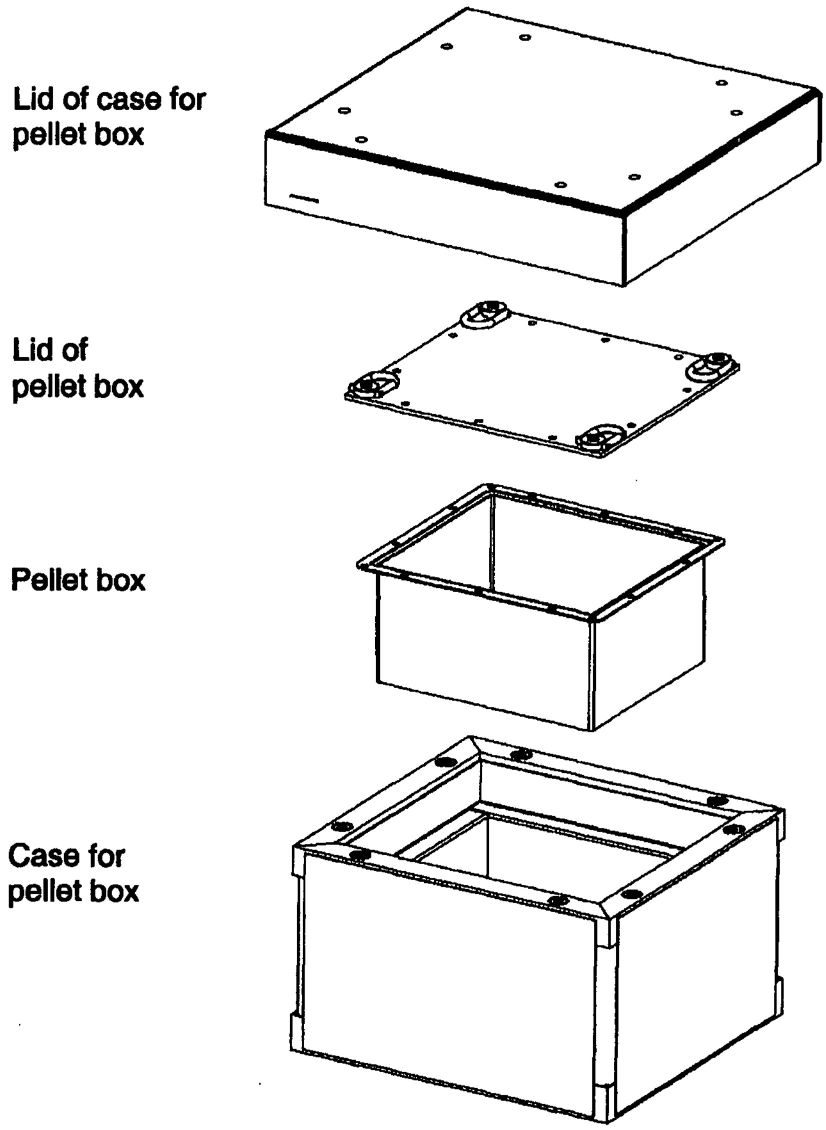

Figure 1: Exploded view of ANF-50 pellet shipping container (without outer frame, protective lid and carrying rack)

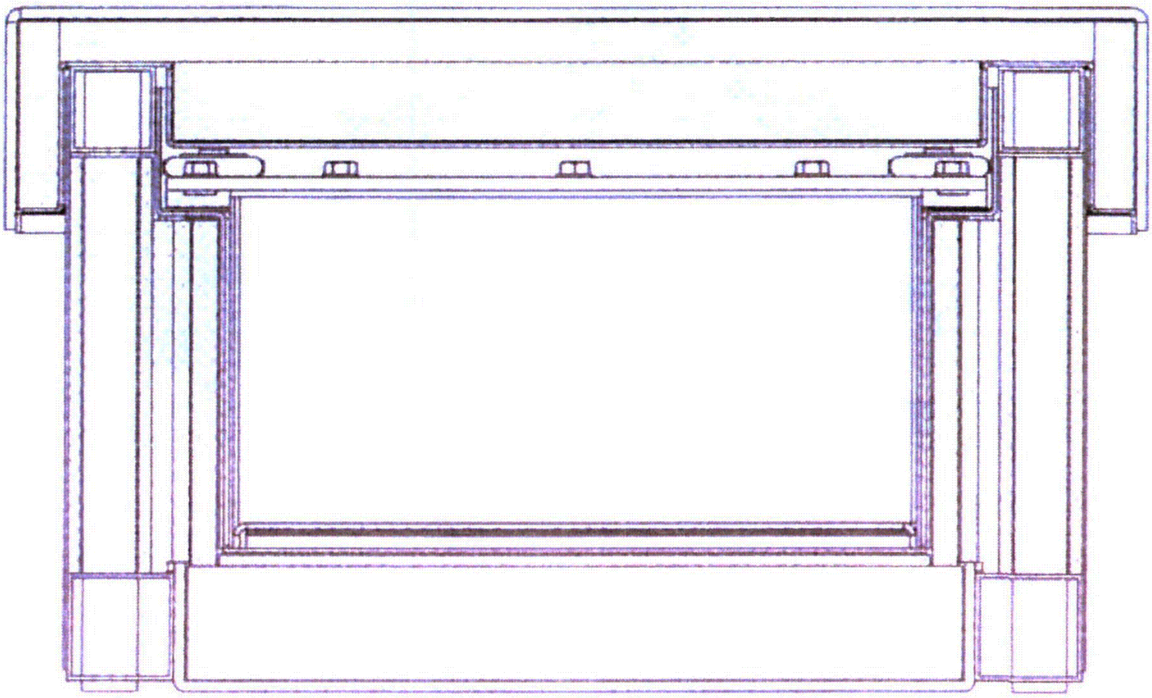

Figure 2: Cross section through ANF-50 pellet shipping container

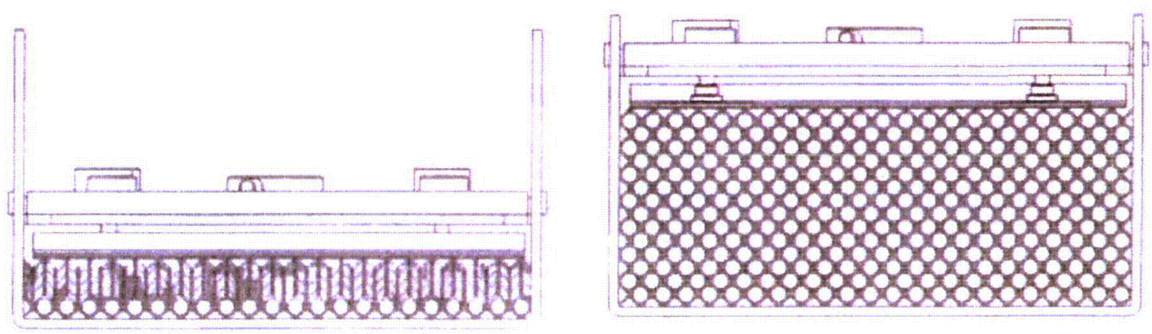

Figure 3: Minimum and maximum loading of ANF-50 shipping container

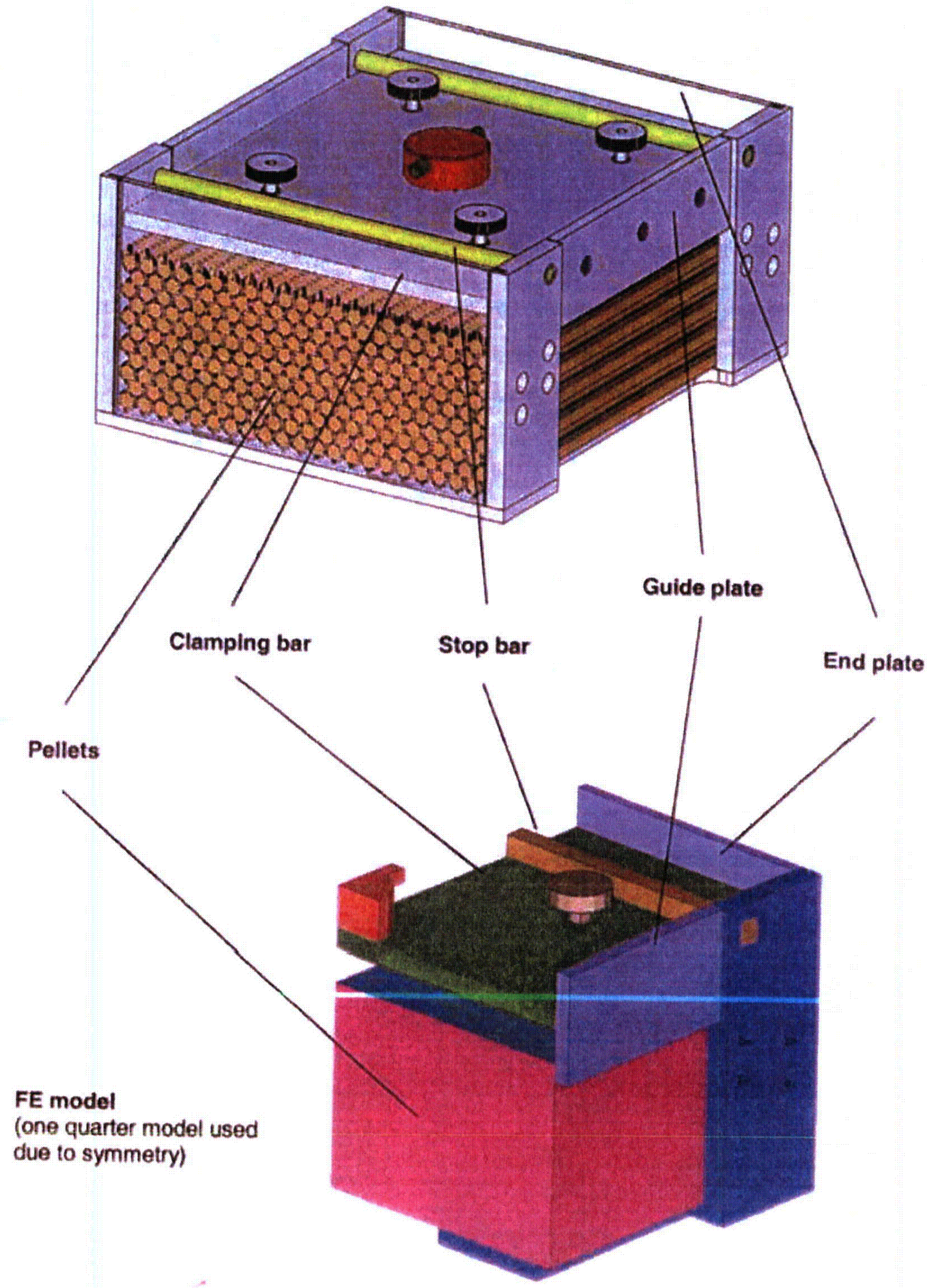

Figure 4: Pellet carrying rack with clamping device and maximum loading

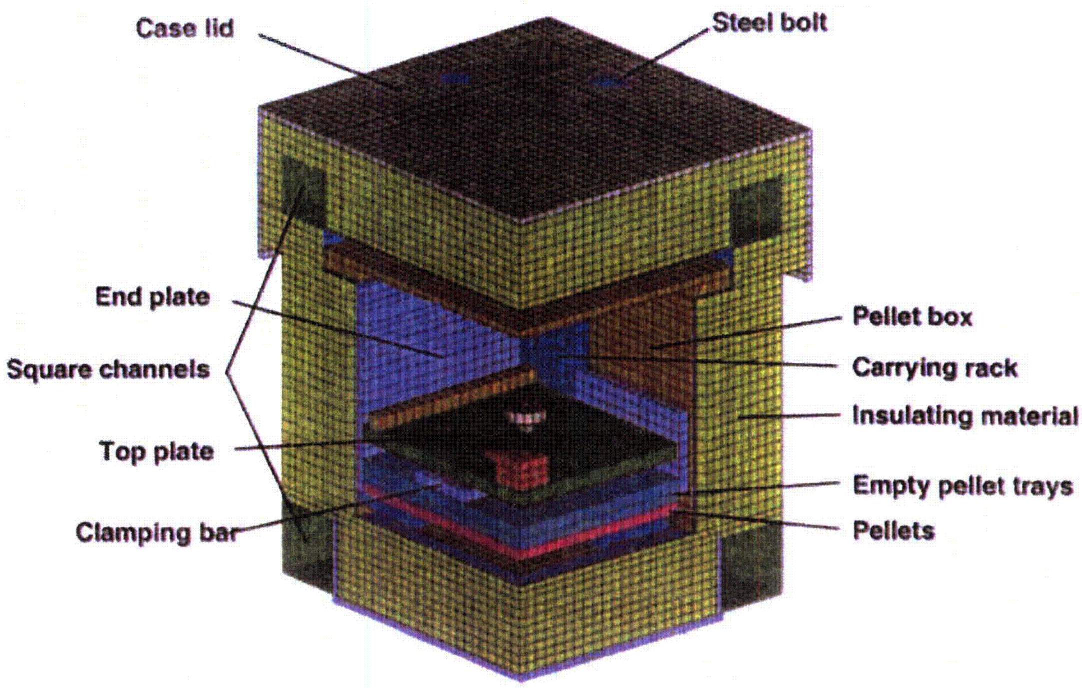

Figure 5: FE model of pellet shipping container (quarter model) with minimum loading

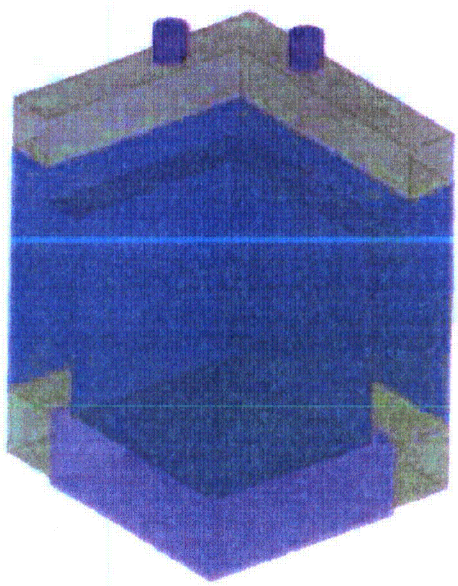

Figure 6: FE model: pellet box case without insulating material

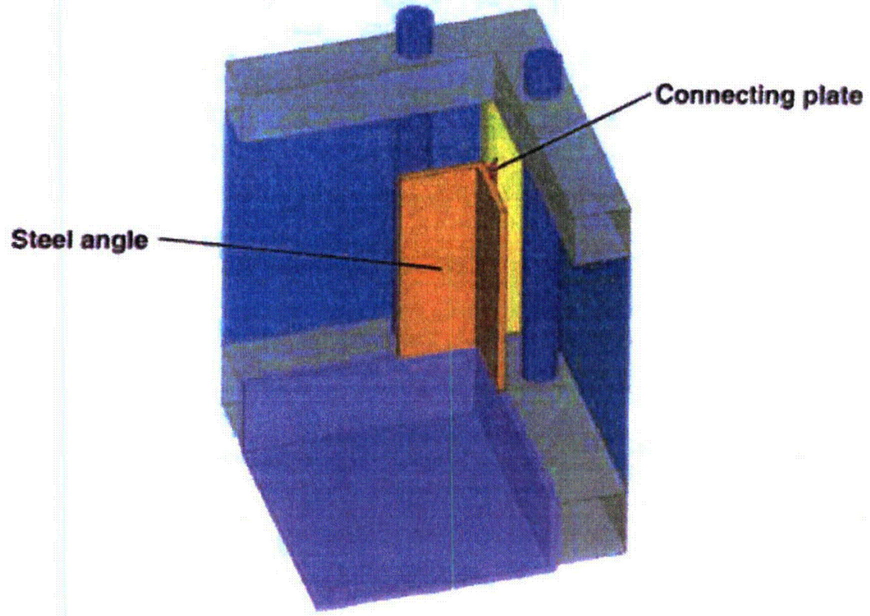

Figure 7: FE model: pellet box case without inner plate and insulation

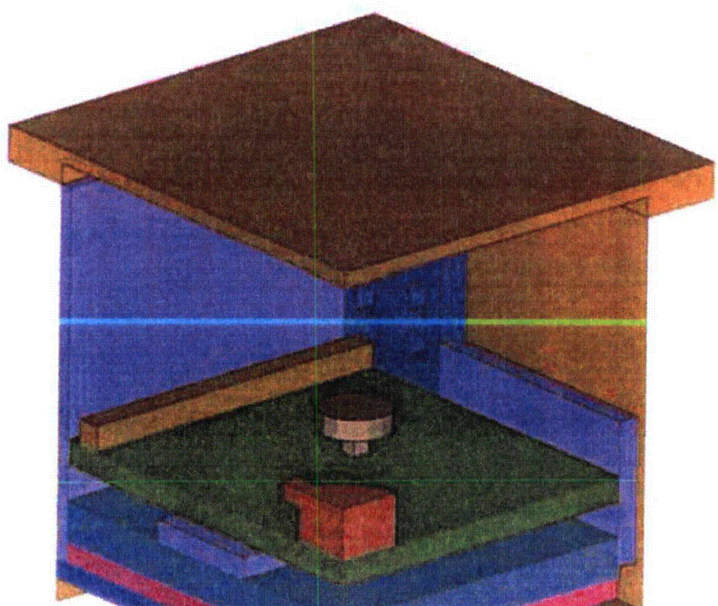

Figure 8: FE model: pellet box

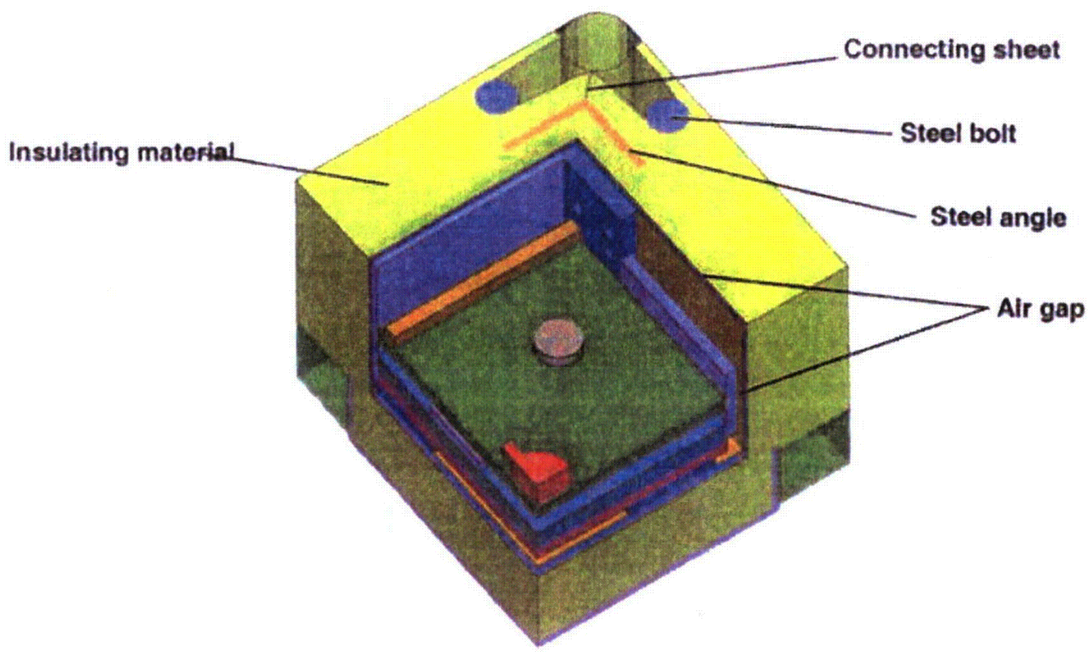

Figure 9: FE model: horizontal section through pellet shipping container

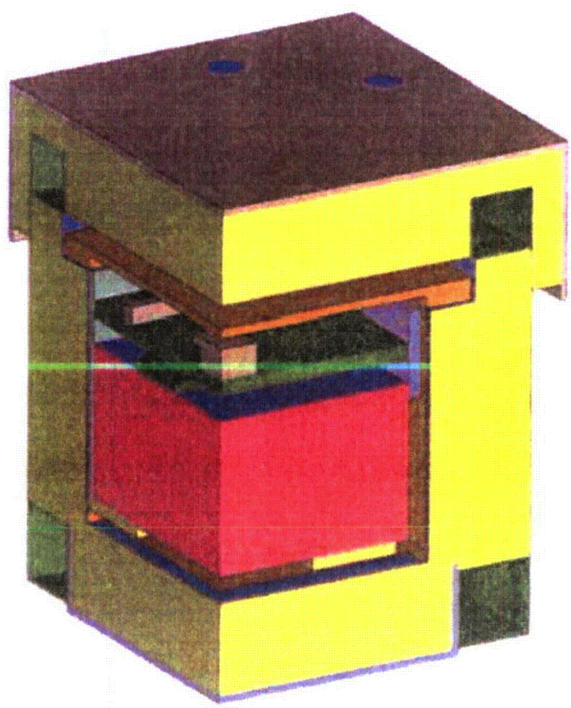

Figure 10: FE model of pellet shipping container (quarter model) with maximum loading

Density: 500 kg/m³

Mean specific heat capacity:

20°C to 400°C: 0.96 kJ/kgK
20°C to 1200°C: 1.06 kJ/kgK

Temperature [°C]	Thermal Conductivity [W/mK]
200	0.11
400	0.14
600	0.18
800	0.23
1000	0.30
1200	0.38

Table 1: Material properties of Kerform KVS 126 insulating material

Density: 10960 kg/m³

Temperature [°C]	True Heat Capacity [J/kgK]	Thermal Conductivity [W/mK]
0	224.24	9.72
100	259.86	8.03
200	278.65	6.85
300	290.15	5.96
400	298.10	5.28
500	304.12	4.74
600	309.01	4.30
700	313.20	3.94
800	316.95	3.63

Table 2: Material properties of pellets (UO_2)

Density: 7930 kg/m³

Temperature [°C]	True Heat Capacity [J/kgK]	Thermal Conductivity [W/mK]
20	472	14.3
100	501	15.8
200	525	17.5
300	532	19.0
400	555	20.5
500	582	21.9
600	604	23.3
700	610	24.6
800	609	26.0
900	615	27.4
1000	641	28.8

Table 3: Material properties of austenitic steel plates and channels (material no. 1.4541)

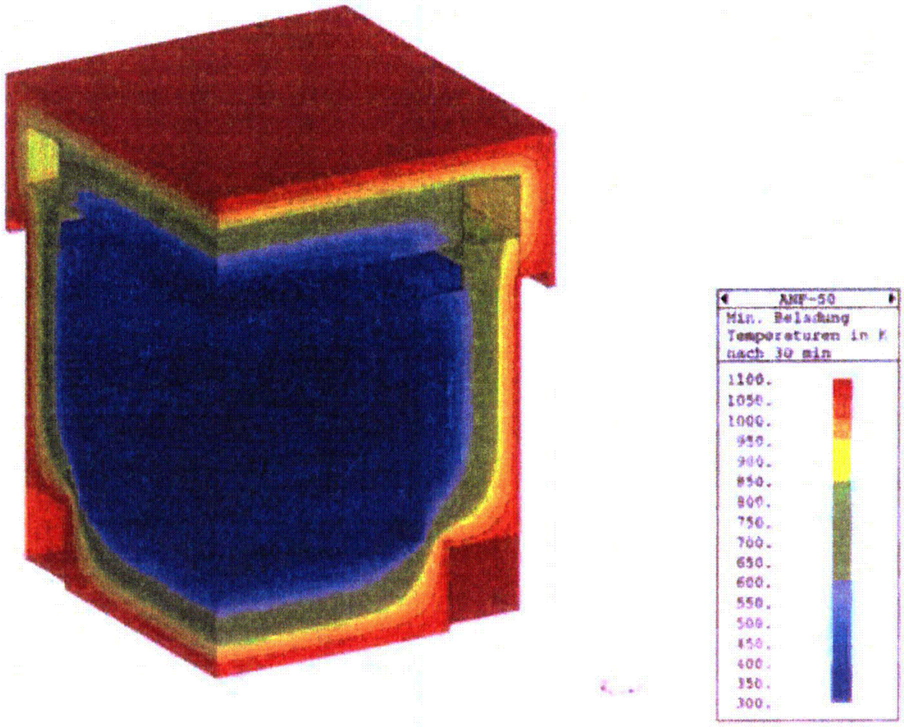

Figure 11: Temperature distribution [K] after 30 min (min. loading)

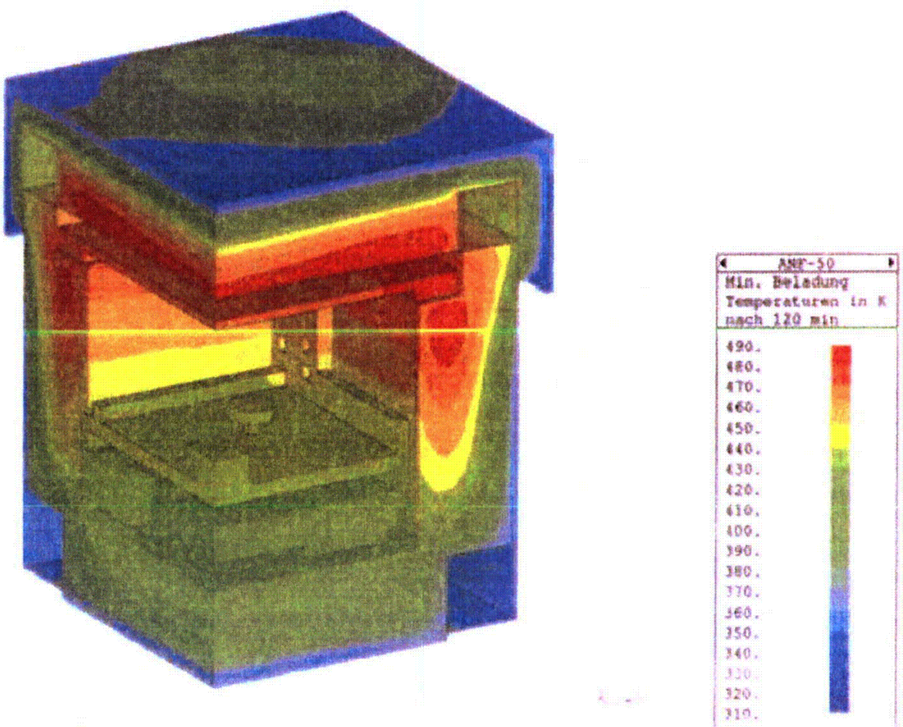

Figure 12: Temperature distribution [K] after 120 min (min. loading)

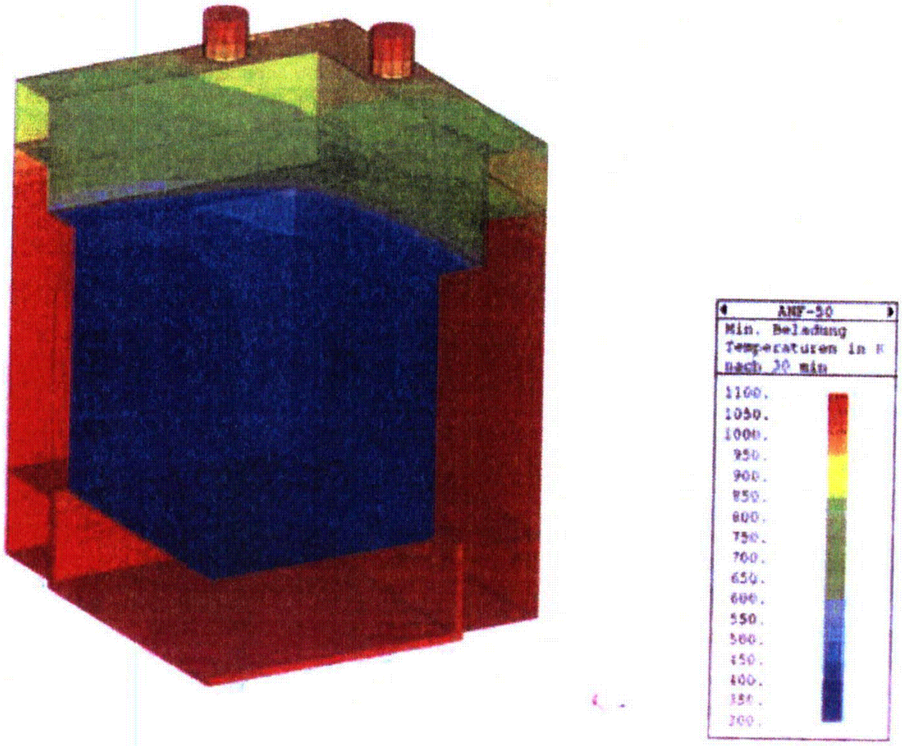

Figure 13: Temperature distribution [K] in pellet box case after 30 min (min. loading)

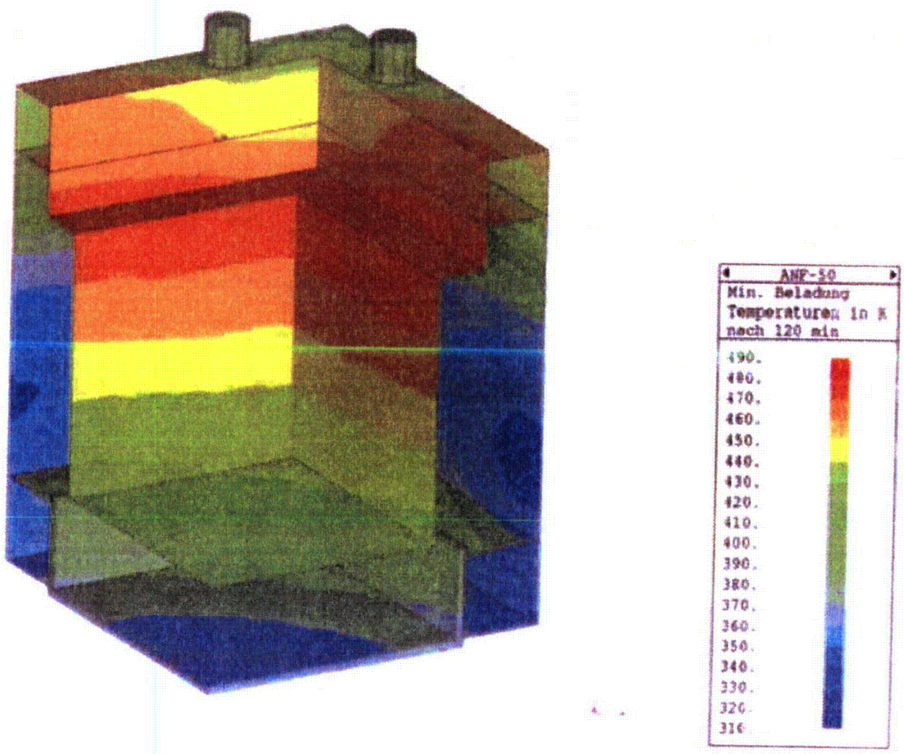

Figure 14: Temperature distribution [K] in pellet box case after 120 min (min. loading)

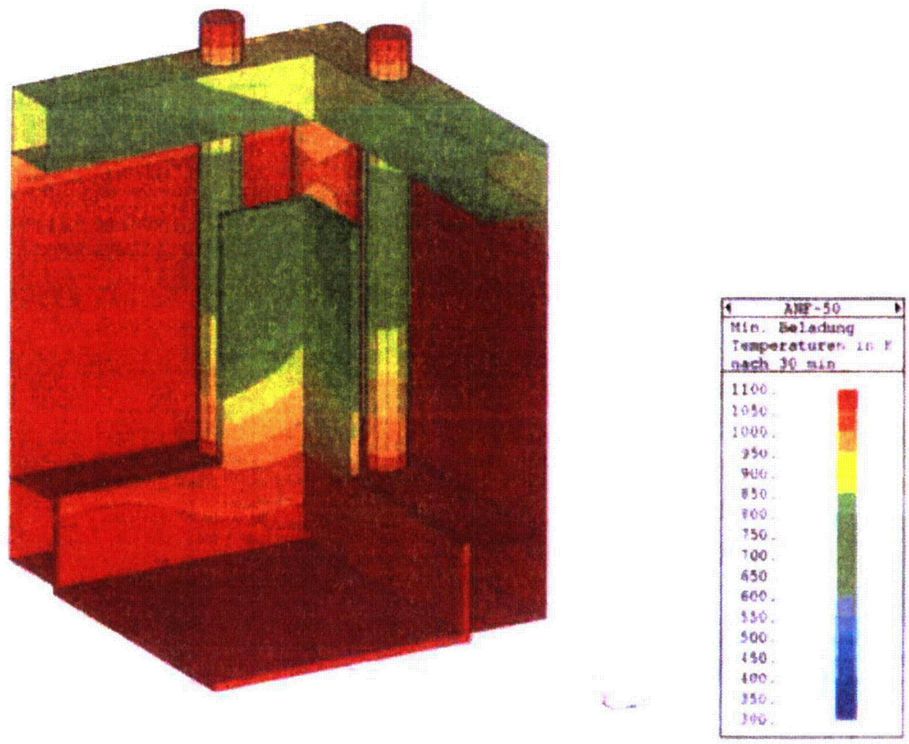

Figure 15: Temperature distribution [K] in steel angle after 30 min (min. loading)

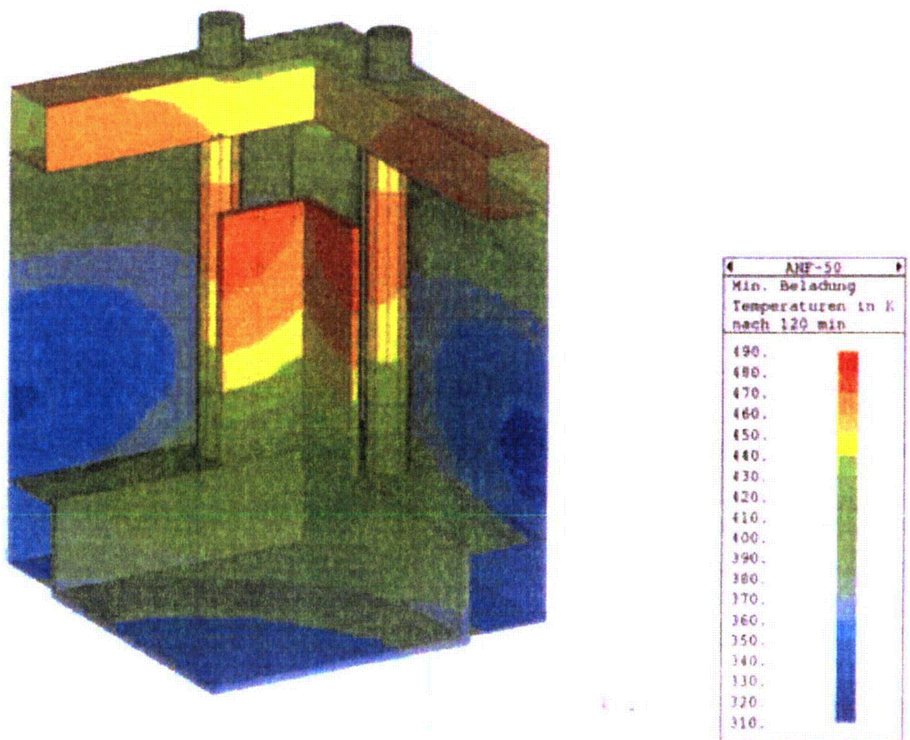

Figure 16: Temperature distribution [K] in steel angle after 120 min (min. loading)

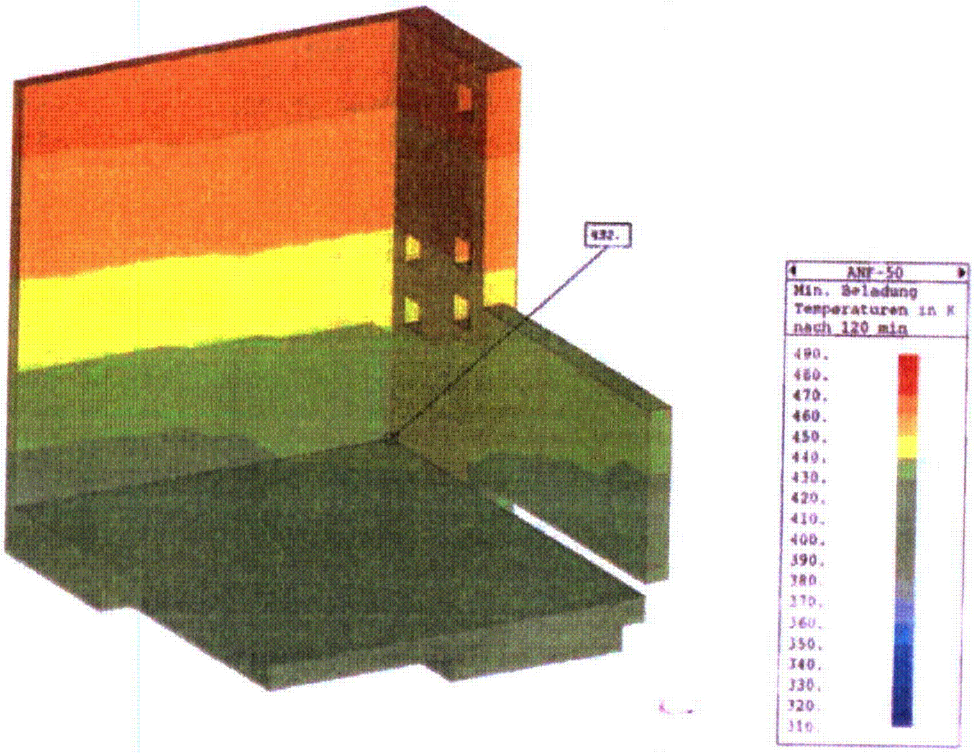

Figure 17: Temperature distribution [K] in pellet layer after 120 min

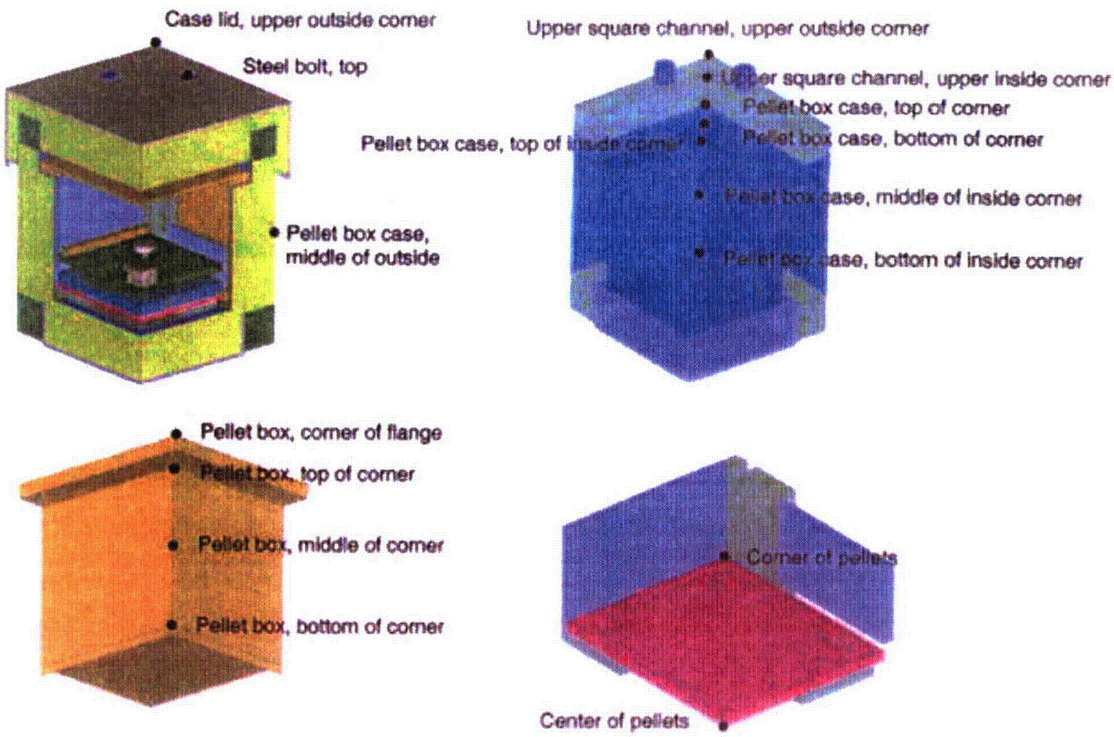

Figure 18: Definition of locations for temperature time histories

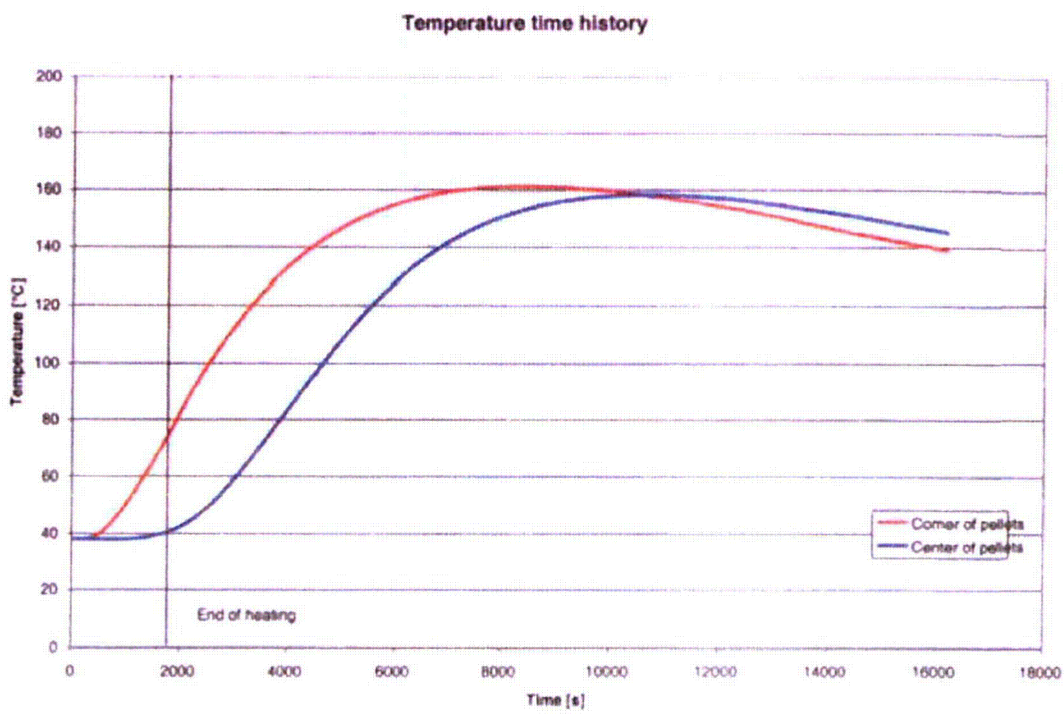

Figure 19: Temperature time history of pellet layer (min. loading)

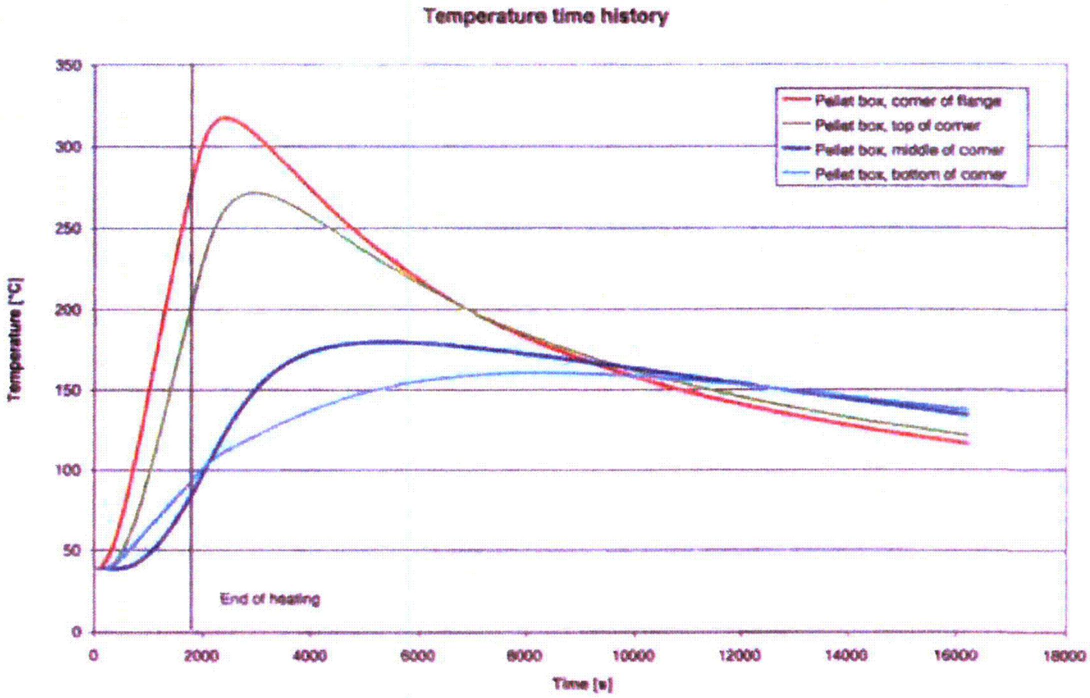

Figure 20: Temperature time history of pellet box (min. loading)

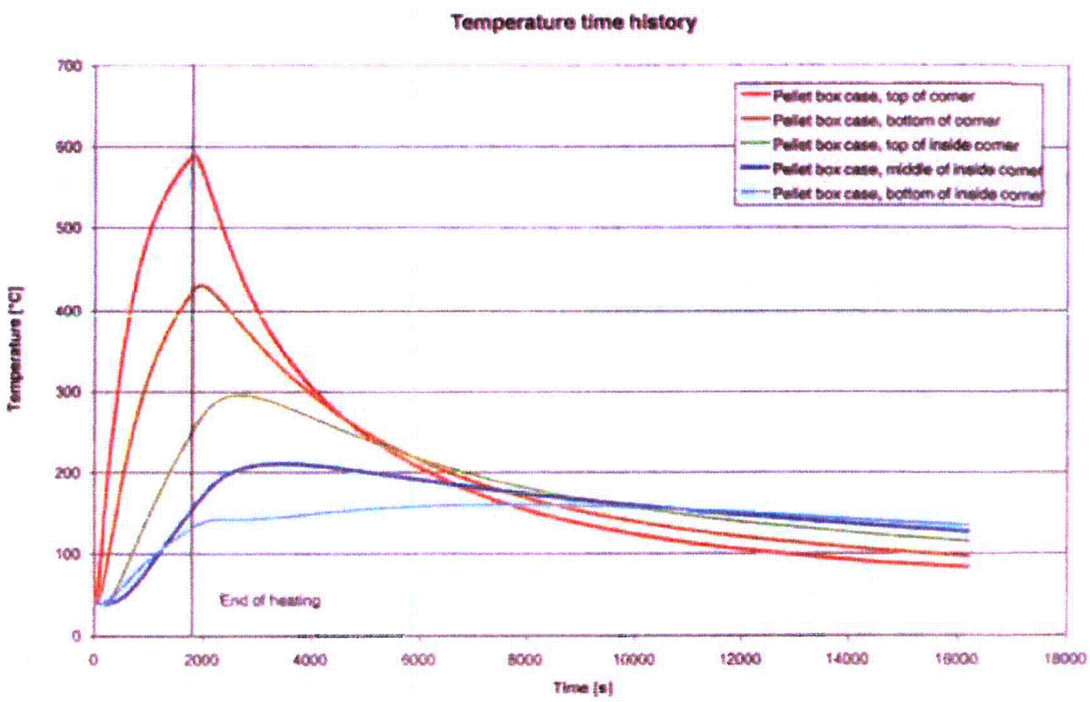

Figure 21: Temperature time history of pellet box case (min. loading)

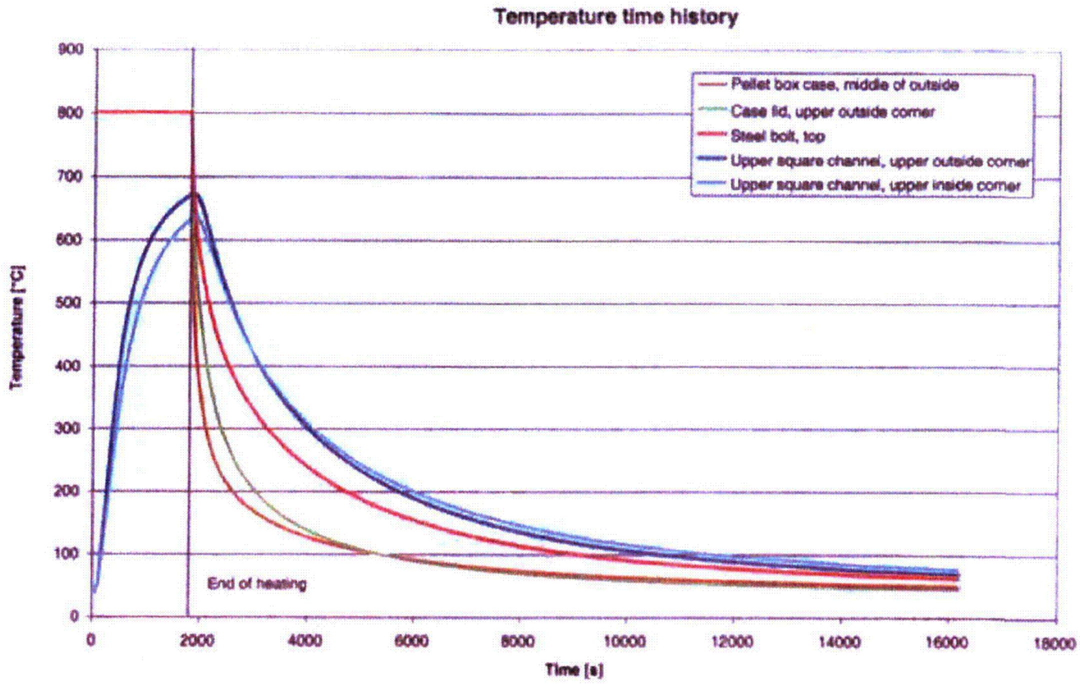

Figure 22: Temperature time history of shipping container (min. loading)

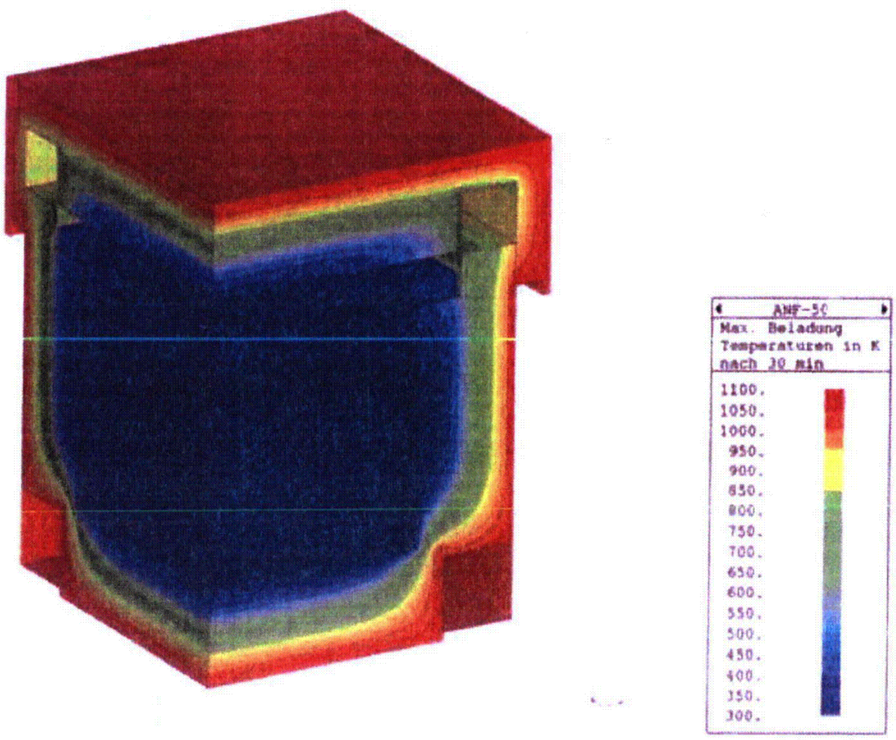

Figure 23: Temperature distribution [K] after 30 min (max. loading)

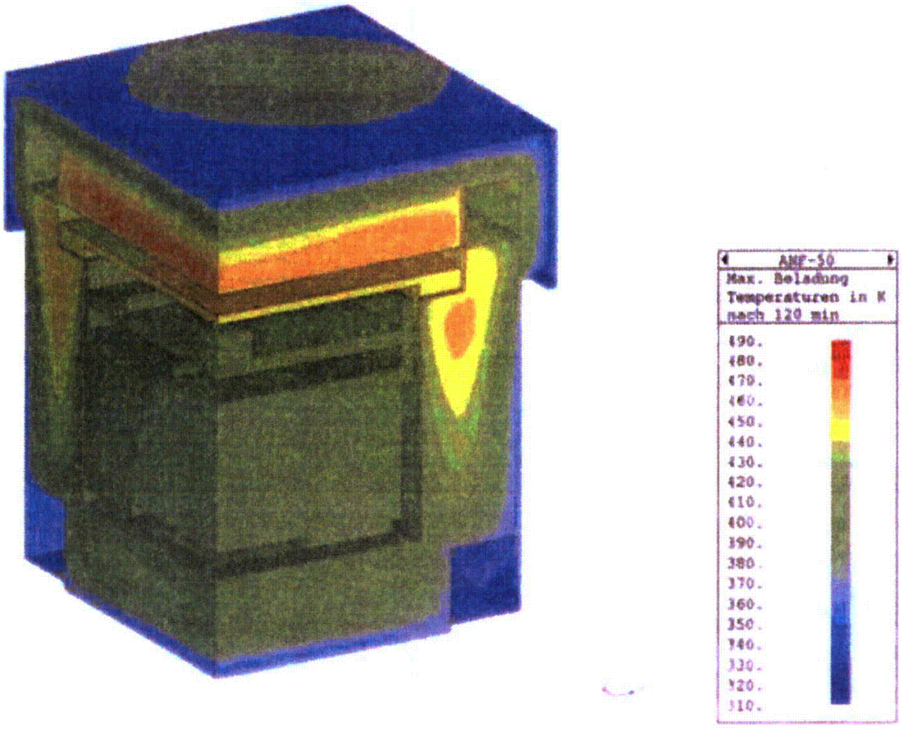

Figure 24: Temperature distribution [K] after 120 min (max. loading)

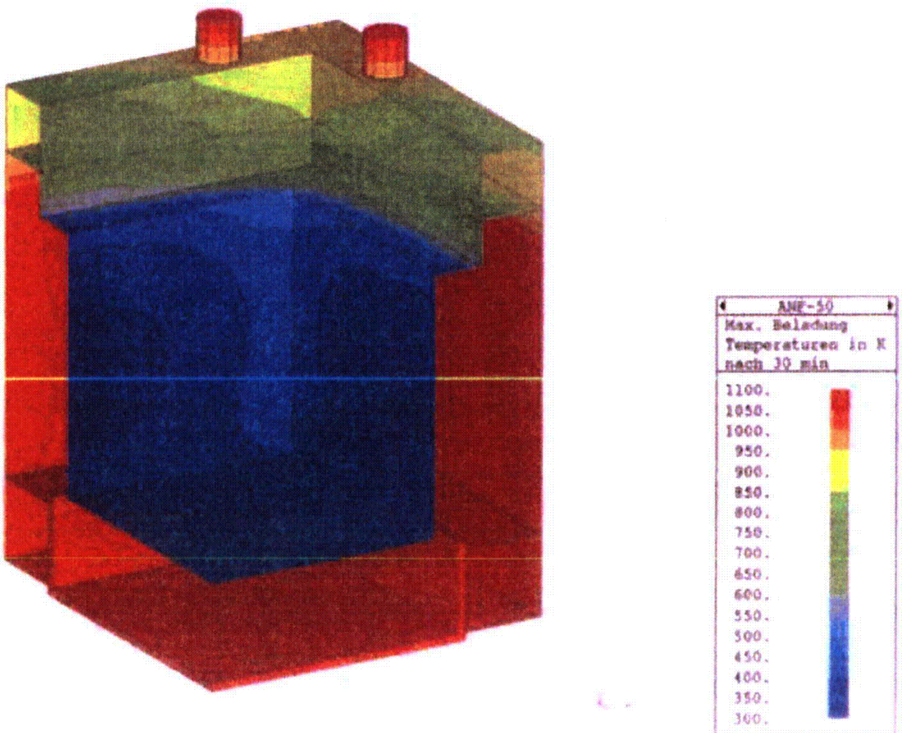

Figure 25: Temperature distribution [K] in pellet box case after 30 min (max. loading)

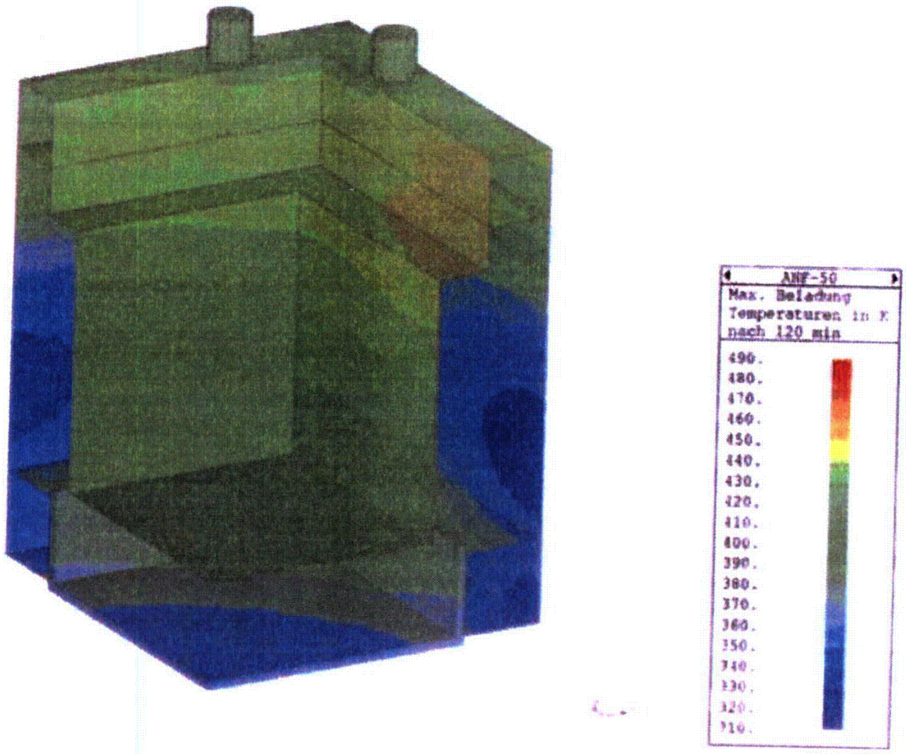

Figure 26: Temperature distribution [K] in pellet box case after 120 min (max. loading)

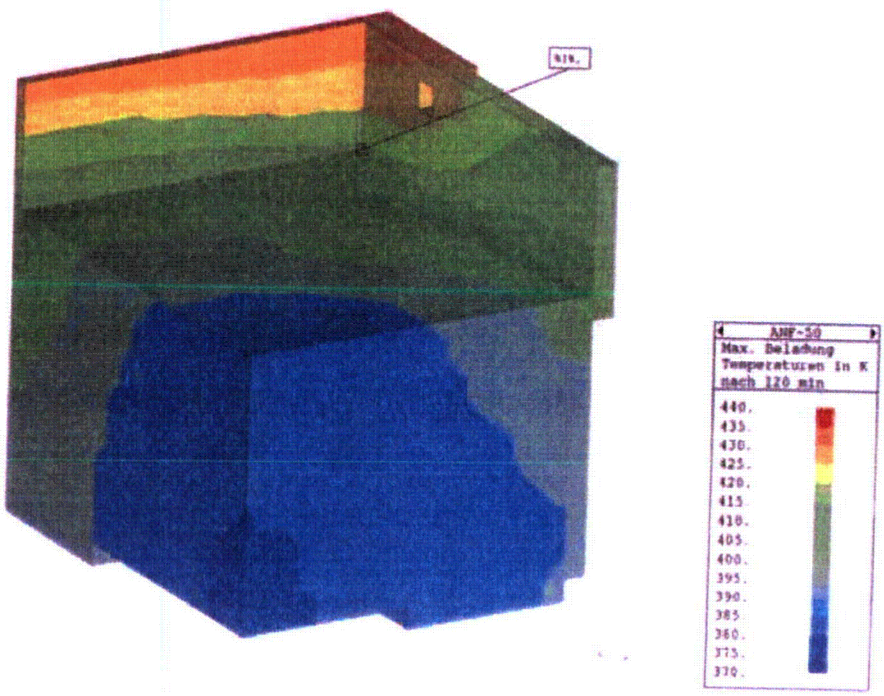

Figure 27: Temperature distribution [K] in pellets after 120 min

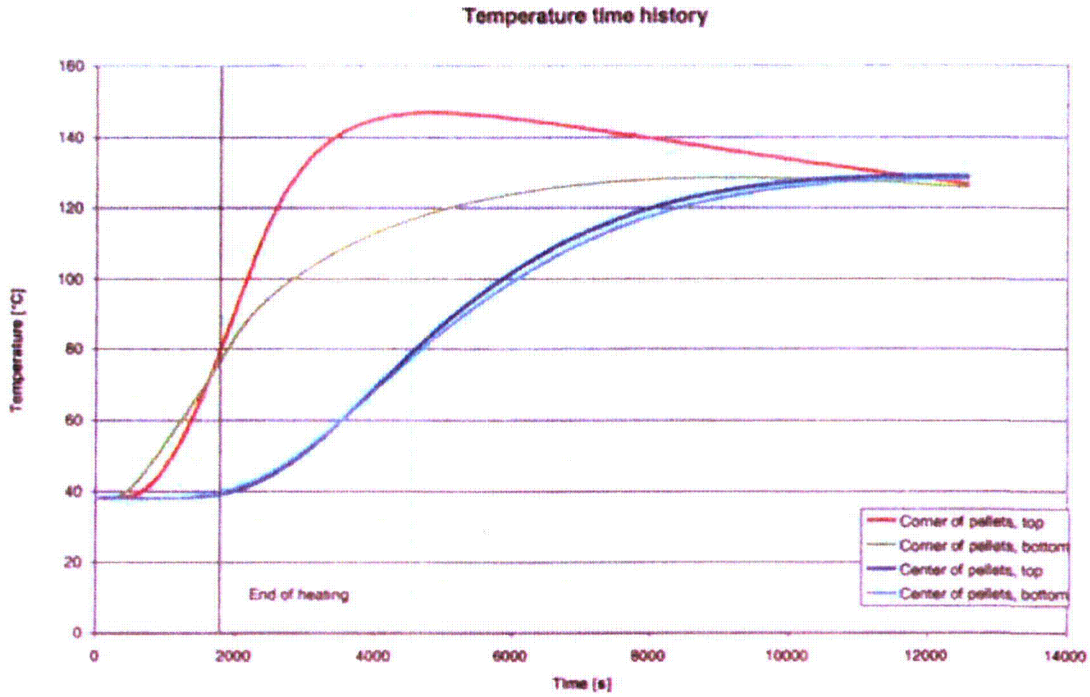

Figure 28: Temperature time history of pellets (max. loading)

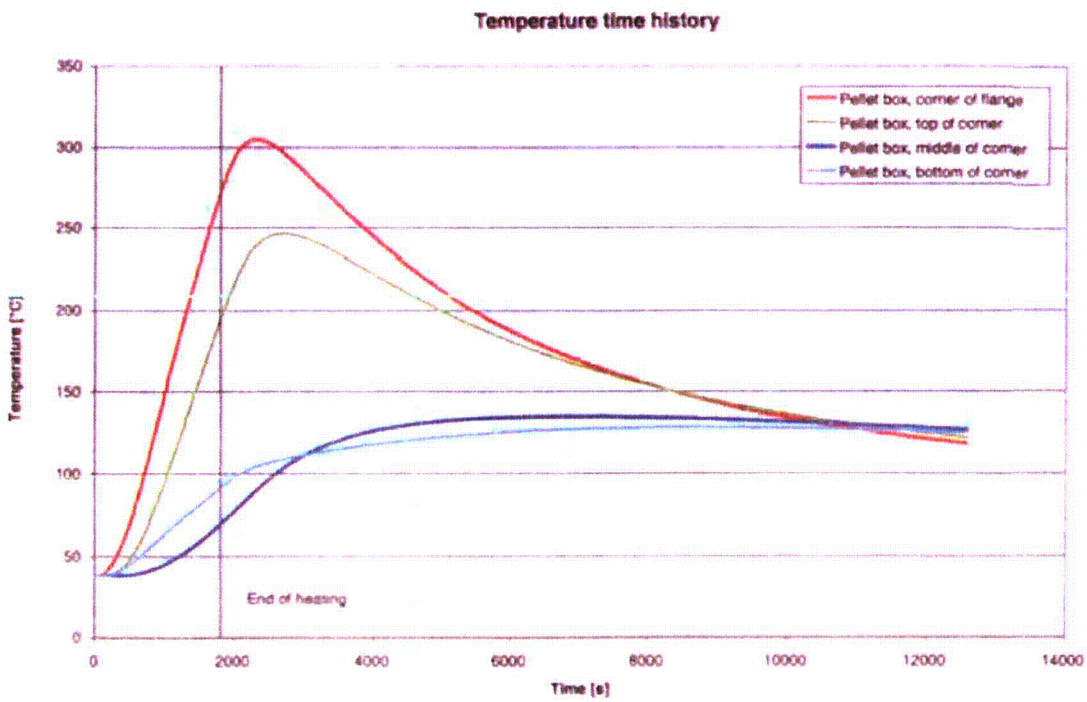

Figure 29: Temperature time history of pellet box (max. loading)

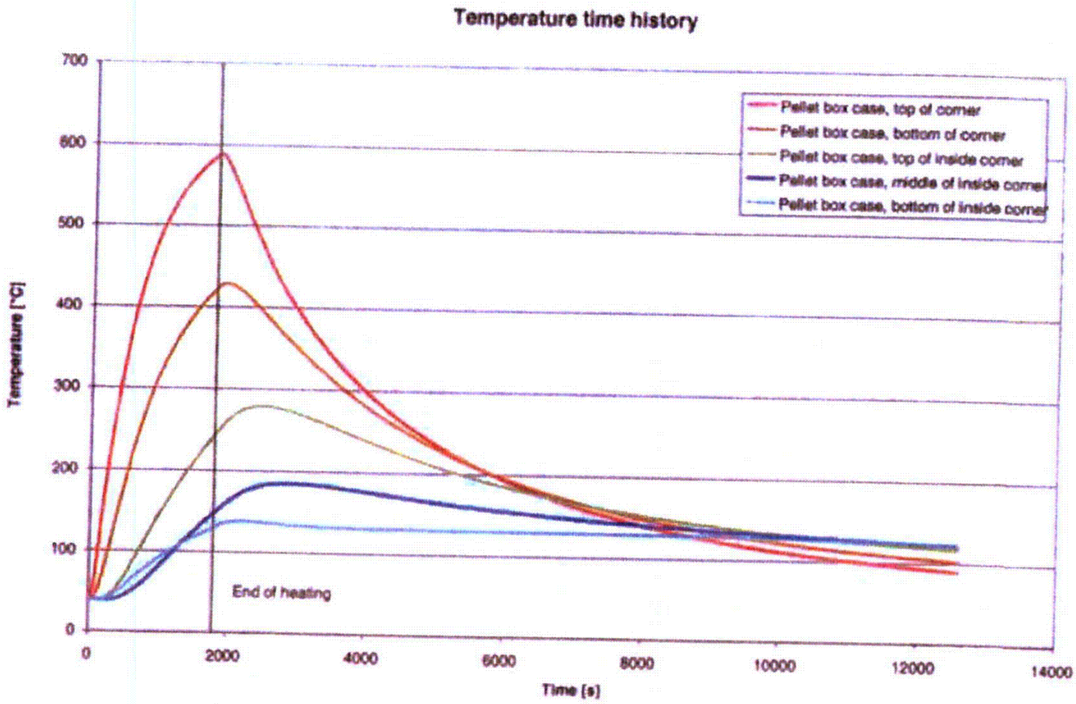

Figure 30: Temperature time history of pellet box case (max. loading)

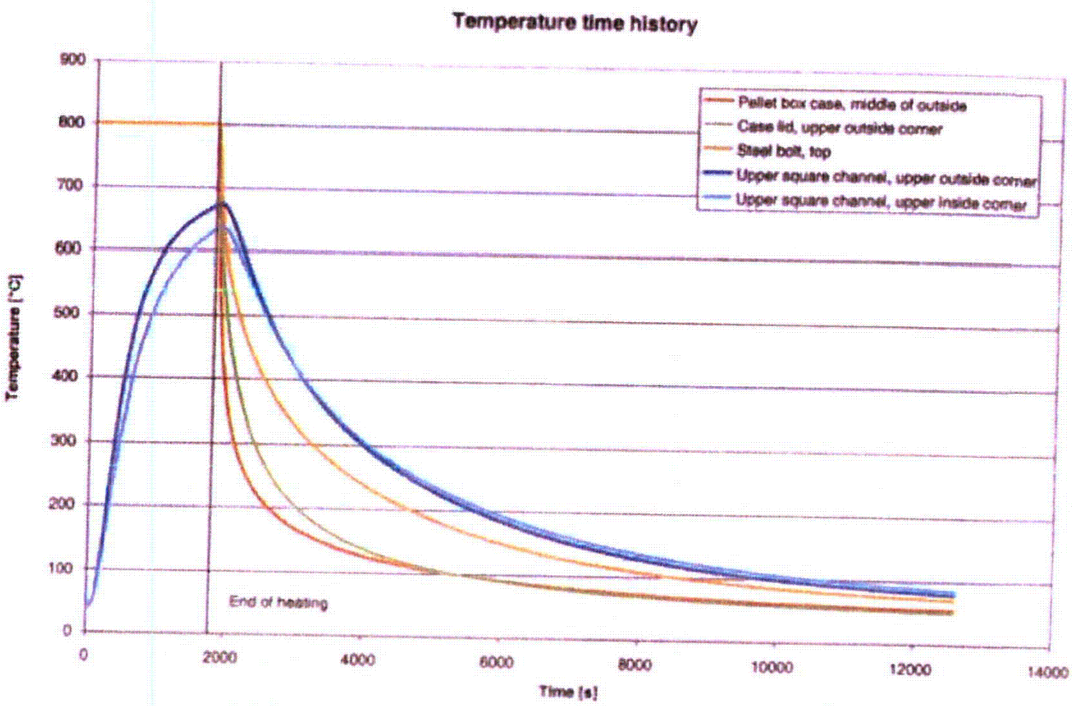

Figure 31: Temperature time history of shipping container (max. loading)

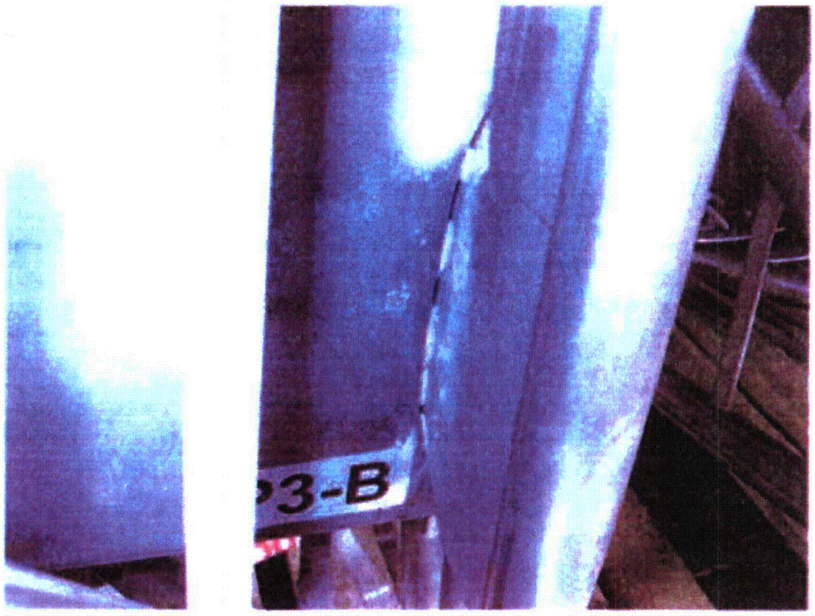

Figure 32: Deformation along container edge (Test Specimen No. 3) from drop tests

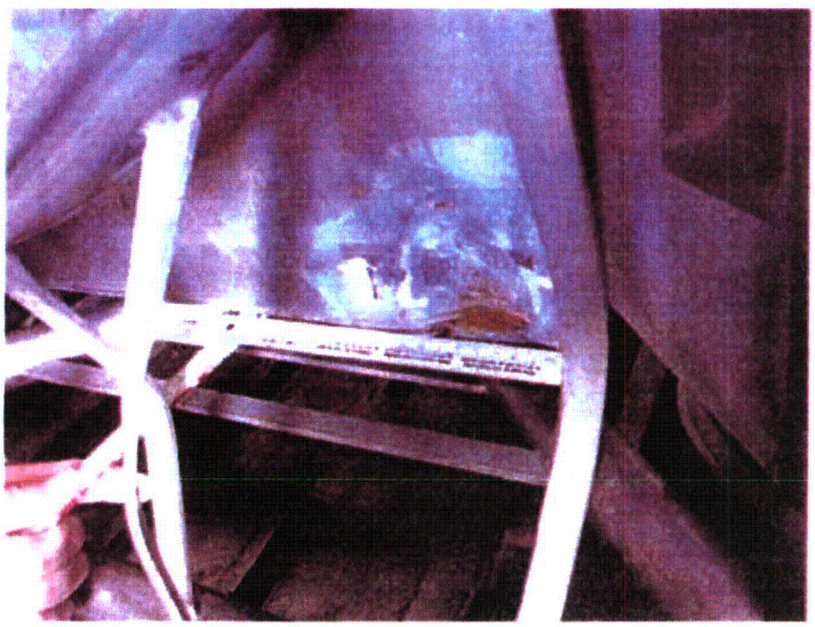

Figure 33: Dent in container corner (Test Specimen No. 1) due to additional drop test onto vertical bar

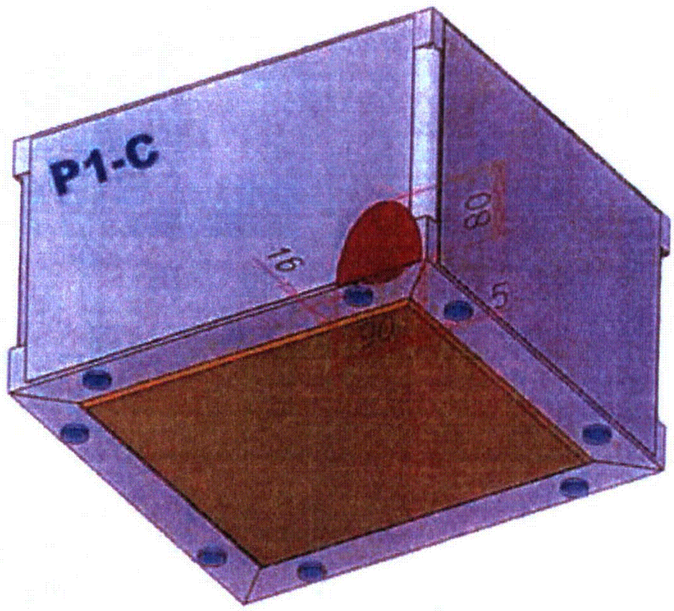

Figure 34: Schematic representation of deformation due to additional drop test onto vertical bar

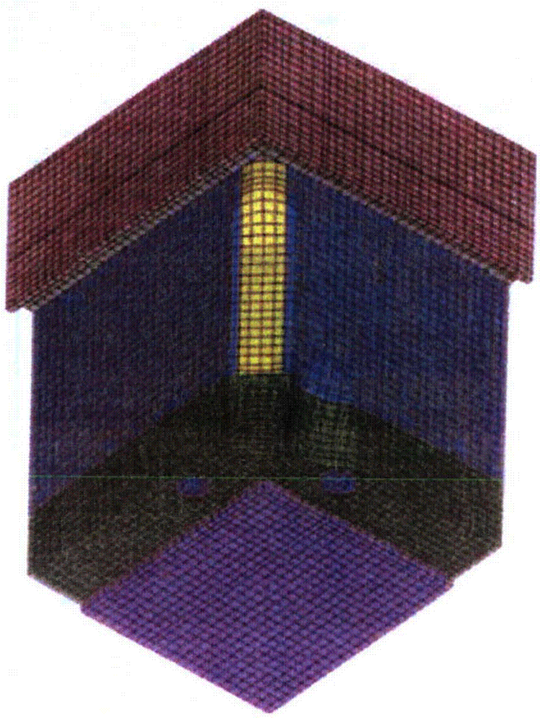

Figure 35: Modeling of deformations from drop tests in FE model

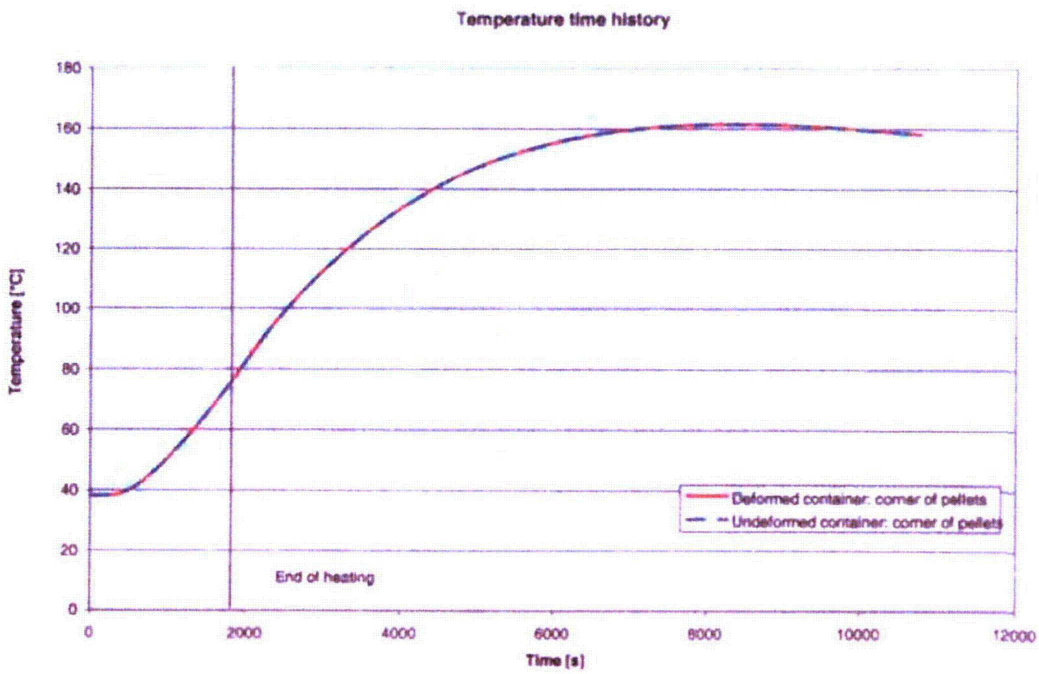

Figure 36: Comparison of temperature time histories of pellets in deformed and undeformed structures (min. loading)

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FRAMATOME ANP

Work Report

Reference			
A1C-1311344-0			
Place	Date		
Erlangen	11.10.2002		

Subject/Title

Laboratory Tests for Oxidation Characteristics of UO_2 and Gd_2O_3/UO_2 Pellets under the Conditions of the IAEA Thermal Test for the ANF-50 Shipping Container

Author(s)	Department	Tel.	Signature
Dr. Lansmann	FGTW	97285	signed Lansmann

Project

All PWR and BWR projects

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Handling Instructions

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ZXX000	BN	1226	

Pages of Text: 15 Appendices: - Complete page number: 15

Summary*)

Tests of the oxidation characteristics of representative UO_2 and Gd_2O_3/UO_2 pellets were performed in the UO_2 laboratory of FGTW Erlangen. The aim of the tests was to show that when subjected to the conditions of the IAEA thermal test, UO_2 and Gd_2O_3/UO_2 pellets inside the ANF-50 shipping container are not oxidised such that they disintegrate into powder or small chips.

The conditions set in the tests were considerably more conservative (particularly in respect of temperature and holding time) than would be expected in the light of previous calculations under the conditions of the IAEA thermal test. The oxidation characteristics of the pellets were assessed based on their appearance after the test and the difference in weight before and after the oxidation test.

After the oxidation tests the pellets showed no signs of flaking off of powder or small chips. The insignificantly small changes in weight also provide evidence that there was no significant oxidation. The tests therefore clearly showed that, under the conditions calculated in the IAEA thermal test, no disintegration of the pellets as a result of oxidation is to be expected inside the shipping container.

This report is an English translation of a report that was originally issued in German.

Translation checked: Pen/Kör 13.06.03 **approved and released:** Jahreiß 14.06.03

Key words: pellet, shipping, shipping container

*) In Technical Reports add key words (max. 12) at the end of the Summary and enter Export Classification

Distribution (add "f.i.o.", if only Summary is distributed for information):

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Framatome ANP GmbH

Revision Sheet

Page / Appendix	Change
	no changes, first edition

1 Introduction

The test program for the ANF-50 shipping container includes investigation of the oxidation characteristics of UO_2 and Gd_2O_3/UO_2 pellets under the conditions of the IAEA thermal test [1]. The major question that needs to be answered here is whether under these conditions oxidation is to be expected with a resultant disintegration of the pellets into small chips or powder. Therefore, original pellets were placed in a laboratory furnace at FGTW Erlangen and subjected to temperature characteristics calculated conservatively under the thermal test conditions.

The oxidation characteristics of UO_2 pellets are mainly determined by their density, grain size and the surface to volume ratio. A further potential variable that may influence the oxidation characteristics of Gd_2O_3/UO_2 pellets is the gadolinium oxide content. In order to determine the possible influence of these parameters on the oxidation characteristics, they were varied within broad thresholds in the original pellets that were tested.

At the start of the tests the characteristics of the pellets were recorded in terms of density, grain size and surface to volume ratio. Following the oxidation test and an initial assessment of the integrity of the pellets (visual appearance of the pellet surface, powder flaking off), the change in weight was measured in order to provide evidence of the level of oxidation.

In order to achieve conservative test boundary conditions, the oxidation tests were performed at 240°C. This meant that the temperature was more than 75°C higher than calculated for the hottest pellet in the analytical thermal test [2]. The pellets were also exposed to the maximum thermal load for significantly longer (10 hours) than would be expected according to the calculations (i.e. in the analytical test the maximum temperature of almost 163°C was reached after approx. 2 hours (accident conditions assumed), which then slowly decreased). Furthermore, a continuous flow of synthetic air (80% N_2 / 20% O_2) was supplied to the pellets in order to create the most conservative conditions possible in terms of oxygen supply.

In order to ensure the reproducibility of the test results, three oxidation tests were performed with all pellet types.

2 Oxidation test procedure

2.1 Characterisation of the different pellet types before testing

As shown in Table 1, the mean theoretical density (measured as buoyancy density) of the original pellets selected for the test was between 94.35% and 95.78% depending on the particular batch. The measured grain size (thermal etching of the sections for 2 hours at 1250°C under CO_2; linear intercept method using Leica Quantimet) varied from 9.0 μm to 12.9 μm for UO_2 pellets and from 7.6 μm to 11.6 μm for Gd_2O_3/UO_2 pellets. The measured surface to volume ratio was between 0.630 and 0.749 mm^2/mm^3. In order to further increase the effective area for oxidation, pellets from batch 612-03 L were sawn up and their oxidation characteristics were analysed at a conservatively high surface to volume ratio of approx. 0.74 and approx. 1.0. As with the test conditions, conservative conditions for possible oxidation were also set for the test pellets in terms of pellet density (lower specified limit 94% for theoretical density), grain size (lower specified limits 9 μm for UO_2 and 5 μm currently or 7 μm in future for Gd_2O_3/UO_2 pellets) and surface to volume ratio (upper limit 0.754 mm^2/mm^3).

2.2 Test design and test procedure

In order to enable well controlled positioning of the sample, the oxidation tests were conducted in a hinged furnace. To remove any residual moisture, the samples were heated in an evacuated drying furnace for 2 hours at 100°C and stored until use in the evacuated desiccator. After being weighed, the samples were positioned inside a quartz glass tube on a glass sample holder in the middle of the furnace. The quartz glass tube was open at one end, while from the opposite end there was a continuous flow of compressed air (0.42 l/min). The temperature around the samples was measured with three calibrated NiCr-Ni thermocouples. These were placed inside the quartz glass tube at the front, at the back and level with the middle of the sample beneath the sample holder. This arrangement of thermocouples enabled a statement about the temperature gradient of the samples. In addition it ensured that all samples were exposed to at least the desired temperature.

In the test the furnace was first of all heated up until all the thermocouples showed a constant temperature of at least 240°C (with temperature data a correction is always included corresponding to the difference obtained by calibration between the setpoint temperature and the displayed temperature). The samples were then inserted and the sample holder was positioned precisely above the thermocouples. After resetting the thermal equilibrium above 240°C, timing of the test started. Throughout the whole test the temperatures of the thermocouples were recorded for control purposes. After more than 10 hours holding time at min. 240°C the power supply to the furnace was discontinued. After cooling, the samples were first of all inspected visually before their changes in weight were determined.

3 Results of the oxidation tests

Appendices 1-3 contain the test protocols and the relevant photographic documentation for the individual tests. All pellets were externally unchanged after the oxidation tests. There was no evidence of the formation of powder or the flaking off of small particles, and so no indication that oxidation was causing disintegration of the pellets.

Similarly, the extremely slight changes in weight of the tested pellets before and after the tests (Tables 2-4) show that no significant oxidation of the pellets took place during the oxidation tests.

4 Discussion and assessment of the results of the oxidation tests

The tests of the oxidation characteristics of UO_2 and Gd_2O_3/UO_2 pellets were performed under conservative test boundary conditions in comparison to the thermal load calculated in the analytical thermal test. Even under these conditions no evidence at all was found after the tests of disintegration of the pellets. The change in weight of the pellets, which would be a possible indicator of their oxidation, was also consistently negligible. If one assumes a stoichiometric value of $UO_{2.0}$ at the beginning of the tests, the change in stoichiometry that was calculated based on the change in weight was low enough to ensure that the specified range of $UO_{2.0\pm0.01}$ would be adhered to. This means that even after the test the pellets were still in accordance with the specifications and – in terms of their stoichiometry – were suitable to be used for loading the fuel rods.

The oxidation characteristics shown in the laboratory tests correspond well with the characteristics described in the literature. For example, Tempest et al. [3] found an oxidation layer of only $\leq 3 \mu m$ even after holding UO_2 pellets for 500 hours at 230°C in air. This slight oxidation also did not lead to any flaking off of small chips or powder from the pellet.

To sum up, based on the laboratory tests that were conducted and the experiences described in the literature, no oxidation with resultant disintegration of UO_2 or Gd_2O_3/UO_2 is to be expected inside the container under the conditions of the IAEA thermal test.

5 Literature

[1] Jahreiß, „Test Program for ANF-50 Shipping Container for Unirradiated Uranium Dioxide Pellets ", Framatome ANP Work Report A1C-1310729-0

[2] Becker, „Numerical Simulation of IAEA Thermal Test for ANF-50 Pellet Shipping Container ", IABG Report B-TA-3928-Rev. 1

[3] P.A. Tempest, P.M. Tucker and J.W. Tyler, „OXIDATION OF UO2 FUEL PELLETS IN AIR AT 503 AND 543 k STUDIED USING X-RAY PHOTOELECTRON SPECTROSCOPY AND X-RAY DIFFRACTION", Journal of Nuclear Materials 151 (1988) 251-268

Batch	U-235 [%]	Gd_2O_3 [%]	Measured density (buoyancy method) [g/cm³]	Theoretical density [%]	Particle size [µm]	Measured surface/volume ratio [mm²/mm³]
928-10 L	3.05	-	10.34	94.35	10.82	0.630
674-02 L	3.65	-	10.47	95.55	12.46	0.745
612-03 L	0.711	-	10.43	95.2	9.01	0.653
617-01 L	3.42	-	10.45	95.3	11.15	0.749
926-03 L	4.60	-	10.42	95.11	12.88	0.706
942-06 L	4.40	-	10.5	95.78	12.89	0.708
553-01 P	4.20	3.00	10.28	94.81	7.6	0.708
267-04 P	2.05	7.00	10.11	94.66	11.58	0.629

Table 1: Characteristics of the tested UO_2 pellet types

Batch	Test	Theor. density (buoyancy method) [g/cm3]	Particle size [μm]	Surface / Volume ratio [mm^2/mm^3]	Weight before [g]	Weight after [g]	Δ Weight [g]	Detectable surface oxidation	Δ x in UO_{2+x}
928-10L	1	94.46	10.8	0.629	7.0026	7.0032	0.0006	none	0.00145
	2	94.32		0.631	6.9003	6.9006	0.0003	none	0.00073
	3	94.28		0.629	6.9527	6.9529	0.0002	none	0.00049
674-02L	1	95.62	12.5	0.743	4.2478	4.2479	0.0001	none	0.0004
	2	95.51		0.746	4.2224	4.2241	0.0017	none	0.00679
	3	95.51		0.744	4.9836	4.9836	0	none	0
617-01L	1	95.24	11.2	0.749	4.1606	4.1607	0.0001	none	0.00041
	2	95.39		0.750	4.1424	4.1416	-0.0008	none	-0.00326
	3	95.43		0.750	4.1438	4.1432	-0.0006	none	-0.00244
612-03L	1	94.95	9.0	0.653	6.4846	6.4845	-0.000	none	-0.00026
	2	95.39		0.652	6.5277	6.5270	-0.0007	none	-0.00181
	3	95.3		0.653	6.5141	6.5136	-0.0005	none	-0.0013
926-03L	1	95.06	12.9	0.707	4.9454	4.9456	0.0002	none	0.00068
	2	95.21		0.707	4.9568	4.9566	-0.0002	none	-0.00068
	3	95.06		0.705	4.9830	4.9832	0.0002	none	0.00068
942-06L	1	95.85	12.9	0.707	4.9836	4.9836	0	none	0
	2	95.67		0.711	4.8996	4.8992	-0.0004	none	-0.00138
	3	95.84		0.707	4.9871	4.9875	0.0004	none	0.00135

Table 2: Results of the oxidation tests for the individual UO_2 pellets

Batch	Test	Theoretical density (buoyancy method) [g/cm3]	Particle size [μm]	Surface / Volume ratio [mm^2/mm^3]	Weight before [g]	Weight after [g]	Δ Weight [g]	Detectable surface oxidation	Δ x in UO_{2+x}
267-04 P	1	94.64	11.6	0.626	6.9126	6.9123	-0.0003	none	-0.00073
	2	94.70		0.631	6.7193	6.7187	-0.0006	none	-0.00151
	3	94.66		0.630	6.7811	6.7805	-0.0006	none	-0.00149
553-01 P	1	94.82	7.6	0.707	4.9002	4.9000	-0.0002	none	-0.00069
	2	94.69		0.710	4.8339	4.8334	-0.0005	none	-0.00175
	3	94.82		0.707	4.9072	4.9072	0	none	0

Table 3: Results of the oxidation tests for the individual Gd_2O_3/UO_2 pellets

Test	Theoretical density (buoyancy method) [g/cm3]	Particle size [μm]	Surface / Volume ratio [mm^2/mm^3]	Weight before [g]	Weight after [g]	Δ Weight [g]	Detectable surface oxidation	Δ x in UO_{2+x}
1	95.2	9.0	1.034	1.9812	1.9808	-0.0004	none	-0.00341
			0.739	4.2591	4.2589	-0.0002	none	-0.00079
	95.15		0.653	6.4846	6.4845	-0.0001	none	-0.00026
2	95.09		1.002	2.0798	2.0790	-0.0008	none	-0.00649
			0.754	4.1354	4.1347	-0.0007	none	-0.00286
	95.39		0.652	6.5277	6.5270	-0.0007	none	-0.00181
3	95.09		0.924	2.4801	2.4789	-0.0012	none	-0.00816
			0.781	3.7380	3.7377	-0.003	none	-0.00135
	95.3		0.653	6.5141	6.5136	-0.0005	none	-0.0013

Table 4: Results of the oxidation tests for UO_2 pellets taken from batch 612-03L with different surface to volume ratios

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Test of oxidation characteristics of UO_2 and Gd_2O_3/UO_2

Test No. 1 Date 17.06.02

Temperature with samples, therm. bal., t'couples 1-3: 243°C, 243°C, 243°C

Time at T ≥ 240°C after start of oxidation time: 10 hrs 38 min Temperature constant during test: Yes

Gas flow at start/end of test: 40 mm = 0.42 l/min

Arrangement of sample holder

	1	2	3	4	5		
Open end	1	7	13	19	27	⇐	Gas supply
	31	31	33	2 Gd	12 Gd		
	6	7	8	9	10		

Position	Pellet no.	Pellet/project Enrichment/Gd	Length [mm]	Diameter [mm]	Surface / Volume ratio [mm^2/mm^3]	Weight before [g]	Assessment of pellet afterwards	Weight after [g]	Weight change [g]	Stoichiomet. change X in UO_{2+x}
1	1	928-10 L	10.691	9.061	0.629	7.0026	OK	7.0032	0.0006	0.00145
2	7	674-02 L	7.620	8.328	0.743	4.2478	OK	4.2479	0.0001	0.00040
3	13	617-01 L	7.425	8.332	0.749	4.1606	OK	4.1607	0.0001	0.00041
4	19	942-06 L	9.502	8.051	0.707	4.9836	OK	4.9836	0	0.00000
5	27	926-03 L	9.523	8.054	0.707	4.9454	OK	4.9456	0.0002	0.00068
6	31	612-03 L	3.610	8.329	1.034	1.9812	OK	1.9808	-0.0004	-0.00341
7	31	612-03 L	7.740	8.329	0.739	4.2591	OK	4.2589	-0.0002	-0.00079
8	33	612-03 L	11.583	8.336	0.653	6.4846	OK	6.4845	-0.0001	-0.00026
9	2 Gd	553-01 P/3%Gd	9.512	8.051	0.707	4.9002	OK	4.9000	-0.0002	-0.00069
10	12 Gd	267-04 P/7%Gd	10.872	9.054	0.626	6.9126	OK	6.9123	-0.0003	-0.00073

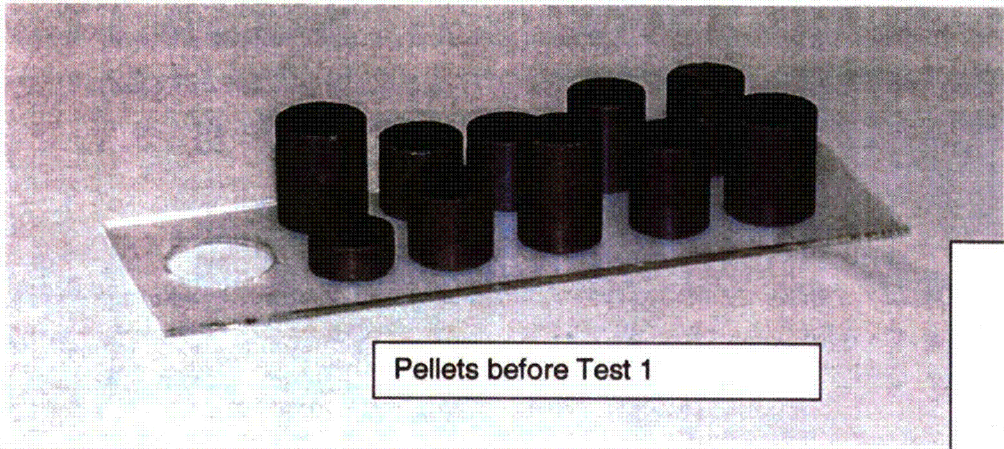
signed 19.06.02 Peter Kellner

Date / Signature / Author

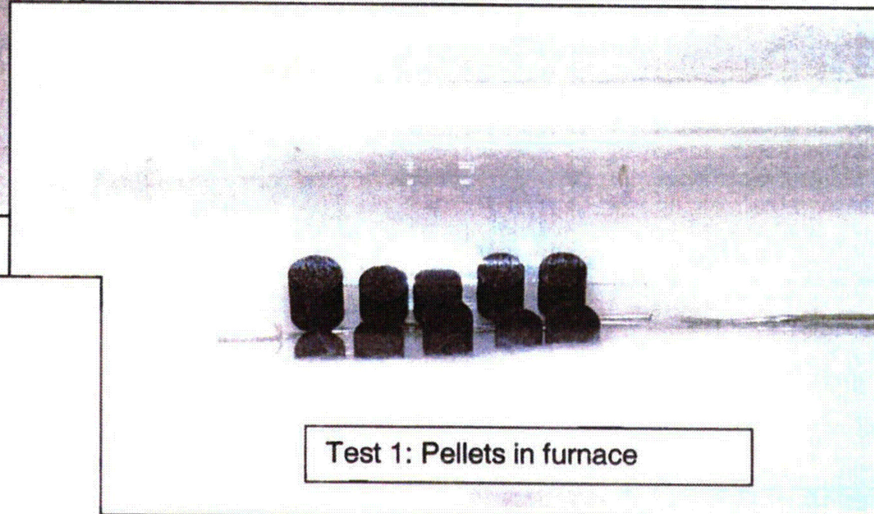
signed 19.6.02 [Lansmann]

Date / Signature / Checker

Annex 1: Page 2/2



Pellets before Test 1



Test 1: Pellets in furnace

Pellets after Test 1

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Test of oxidation characteristics of UO_2 and Gd_2O_3/UO_2

Annex 2: Page 1/2

Test No. 2 Date 18.06.02

Temperature with samples, therm. bal., t'couples 1-3: 243°C, 243°C, 243°C

Time at T ≥ 240°C after start of oxidation time: 10 hrs 40 min Temperature constant during test: Yes

Gas flow at start/end of test: 40 mm = 0.42 l/min

Arrangement of sample holder

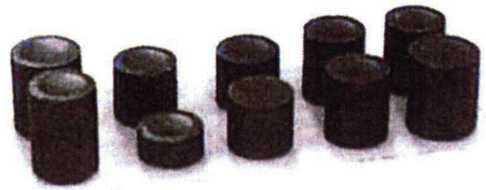
	1	2	3	4	5		
Open end	3	8	16	20	29	⇐	Gas supply
	34	35	35	4 Gd	14 Gd		
	6	7	8	9	10		

Position	Pellet no.	Pellet/project Enrichment/Gd	Length [mm]	Diameter [mm]	Surface / Volume ratio [mm²/mm³]	Weight before [g]	Assessment of pellet afterwards	Weight after [g]	Weight change [g]	Stoichiomet. change X in UO_{2+x}
1	3	928-10 L	10.565	9.058	0.631	6.9003	OK	6.9006	0.0003	0.00073
2	8	674-02 L	7.526	8.332	0.746	4.2224	OK	4.2241	0.0017	0.00679
3	16	617-01 L	7.414	8.328	0.750	4.1424	OK	4.1416	-0.0008	-0.00326
4	20	942-06 L	9.328	8.051	0.711	4.8996	OK	4.8992	-0.0004	-0.00138
5	29	926-03 L	9.520	8.053	0.707	4.9568	OK	4.9566	-0.0002	-0.00068
6	34	612-03 L	11.60	8.333	0.652	6.5277	OK	6.5270	-0.0007	-0.00181
7	35	612-03 L	3.830	8.332	1.002	2.0798	OK	2.0790	-0.0008	-0.00649
8	35	612-03 L	7.300	8.332	0.754	4.1354	OK	4.1347	-0.0007	-0.00286
9	4 Gd	553-01 P/3%Gd	9.384	8.051	0.710	4.8339	OK	4.8334	-0.0005	-0.00175
10	14 Gd	267-04 P/7%Gd	10.565	9.053	0.631	6.7193	OK	6.7187	-0.0006	-0.00151

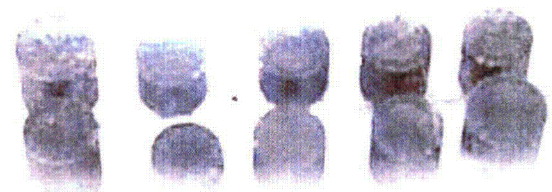
signed 24.06.02 Peter Kellner signed 2.7.02 Lansmann

Date / Signature / Author Date / Signature / Checker

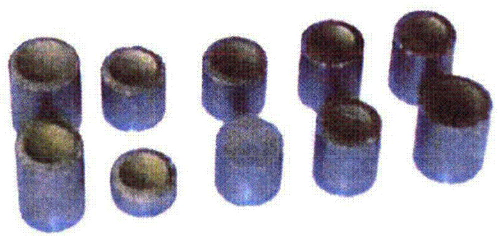
Annex 2: Page 2/2



Pellets before Test 2



Test 2: Pellets in furnace



Pellets after Test 2

Annex 3: Page 1/2

Framatome ANP

Test of oxidation characteristics of UO_2 and Gd_2O_3/UO_2

Test No. 3 Date 24.06.02

Temperature with samples, therm. bal., t'couples 1-3: 243°C, 243°C, 243°C

Time at T ≥ 240°C after start of oxidation time: 11 hrs 20 min Temperature constant during test: Yes

Gas flow at start/end of test: 40 mm = 0.42 l/min

Arrangement of sample holder

	1	2	3	4	5		
Open end	5	10	17	23	30	⇐	Gas supply
	37	37	38	8 Gd	16 Gd		
	6	7	8	9	10		

Position	Pellet no.	Pellet/project Enrichment/Gd	Length [mm]	Diameter [mm]	Surface / Volume ratio [mm²/mm³]	Weight before [g]	Assessment of pellet afterwards	Weight after [g]	Weight change [g]	Stoichiomet. change X in UO_{2+x}
1	5	928-10 L	10.653	9.059	0.629	6.9527	OK	6.9529	0.0002	0.00049
2	10	674-02 L	7.566	8.332	0.744	4.9836	OK	4.9836	0.0000	0.00000
3	17	617-01 L	7.414	8.335	0.750	4.1438	OK	4.1432	-0.0006	-0.00244
4	23	942-06 L	9.500	8.049	0.707	4.9871	OK	4.9875	0.0004	0.00135
5	30	926-03 L	9.572	8.058	0.705	4.9830	OK	4.9832	0.0002	0.00068
6	37	612-03 L	4.500	8.341	0.924	2.4801	OK	2.4789	-0.0012	-0.00816
7	37	612-03 L	6.630	8.341	0.781	3.7380	OK	3.7377	-0.0003	-0.00135
8	38	612-03 L	11.585	8.332	0.653	6.5141	OK	6.5136	-0.0005	-0.00130
9	8 Gd	553-01 P/3%Gd	9.537	8.051	0.707	4.9072	OK	4.9072	0	0.00000
10	16 Gd	267-04 P/7%Gd	10.610	9.056	0.630	6.7811	OK	6.7805	-0.0006	-0.00149

signed 25.06.02 Peter Kellner signed 2.7.02 [Lansmann]

Date / Signature / Author Date / Signature / Checker

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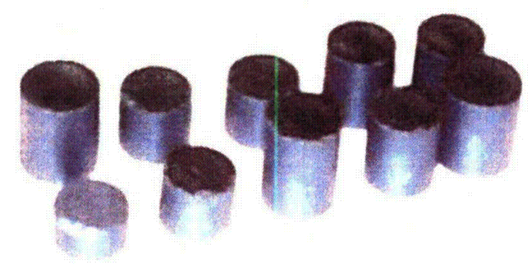
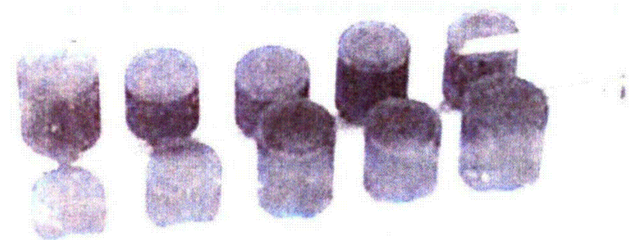
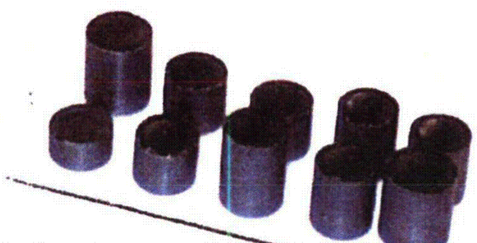


Pellets before Test 3



Test 3: Pellets in furnace



Pellets after Test 3

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DER BLAUE ENGEL
weil aus 100% Altpapier
JURY UMWELTZEICHEN

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FRAMATOME ANP

Work Report

Report No. A1C-1311432-1

Subject/Title
Description and Assessment of Changes to Series-Production ANF-50 Shipping Container with Respect to Tested Container Prototype

Place	Date
Erlangen	15.11.2002

Author(s)	Department	Tel.	Signature
Jahreiß	FGTM	93109	signed Jahreiß

Project
All PWR and BWR projects

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Proj.-Code	UA or DDC	Contents Code	Doc. Ident. No.
ZXX000	BN	1261	

Pages of Text: 15 Appendices - Pages total: 15

Summary

Experience gained during the fabrication and handling as well as drop testing of the ANF-50 pellet shipping container prototype has been used as a basis for improving the design of the series-production container.

This report describes the modifications made to the design of the series-production shipping container with respect to the tested prototype and assesses the effects of these changes on the results of the drop tests.

It is demonstrated that the modifications are marginal and that the strength and deformation behavior of the series-production container is enveloped by the test specimens.

This report is an English translation of a report that was originally issued in German.

Translation checked: Peu/Aur 31.05.03 **approved and released:** Jahreiß 02.06.2003

*) In Technical Reports add key words (max. 12) at the end of the Summary and enter Export Classification

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FG	Mr. Giese
FGT	Mr. Lettau
FGTM	Dr. Heins
FGS	Mr. Höfers
ANF	Dr. Siebert
ANF	Dr. Bendick
ANF	Mr. Paulinyi
ANF	Mr. Kramer / Mr. Steffenewers
BfS ET 3.2	
BAM Ref.III.3	

Index	Vers.	Date	Page(s)	Initials of Author(s)	Initials for Release
1		24.01.03	2	signed Ja.	signed Peu. Ja. Op.

Framatome ANP GmbH

Revision Sheet

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1	24.01.03	New Section 2.1.3	3
		New Section 2.1.4	4
		Section 2.5.1: mass increased to 248 kg	6
		Revision of drawing	7
		Figure 1 added	8

1 Introduction

Experience gained during the fabrication and handling as well as drop testing of the ANF-50 pellet shipping container prototype [1] has been used as a basis for improving the design of the series-production container.

These improvements are to be incorporated into the series-production ANF-50 pellet shipping container [2] without any new drop tests being necessary. The changes made to the design of the series-production container with respect to the tested prototype will therefore be such that the deformations determined on the prototype (Test Specimens Nos. 1 to 4) envelop those anticipated for the series-production container for purposes of criticality safety analysis.

2 Description of Modifications and Assessment

The series-production container [2] will incorporate the following modifications with respect to the ANF-50 prototype [1].

2.1 Outer Frame with Protective Lid

2.1.1 Continuous seal weld on underside of protective lid joining square channels to lid plate (Fig. 1).

The continuous seal weld is intended to prevent dirt and impurities from entering the gap. When necessary, the underside of the protective lid can thus be more easily decontaminated.

The additional seal weld will not have any adverse effect on the strength and integrity of the joint between the plate and surrounding channels of the protective lid.

2.1.2 The slotted (oblong) holes for fastening the protective lid will be replaced by circular holes. One of the four holes will be slightly offset in order to ensure that the lid can only be mounted in one specific position (Fig. 1).

The holes ensure that the protective lid can only be mounted in one specific position.

The holes will not have any adverse effect on the strength and integrity of the bolted connections joining the protective lid to the outer frame.

2.1.3 The four gusset plates welded to the inner corners of the outer frame for fastening the protective lid will be moved farther back into the corners. The center-to-center spacing of the holes thus increases to 532.7 mm (Fig. 1).

The change in the position of the gusset plates will provide more space inside the outer frame for removing and re-installing the lid of the pellet box case.

The new position of the gusset plates will not have any adverse effect on the strength and integrity of the bolted connections joining the protective lid to the outer frame.

2.1.4 The four bent straps used for fastening the protective lid will be bent at oblique angles (of 135°) and will be extended in length to accommodate the gusset plates' new positions (Fig. 1).

This modification is a direct consequence of the change described in Section 2.1.3.

This change will not have any adverse effect on the strength and integrity of the bolted connections joining the protective lid to the outer frame.

2.2 Pellet Box Case with Case Lid

2.2.1 Bolt sleeves in case lid to be provided with collars (Fig. 2).

The collars will make it easier to weld the plate of the case lid to the sleeves. Also, the collars will prevent any water still present underneath the heads of the bolts from entering the sleeves or the threaded blind holes in the pellet box case.

The bolt sleeve collar will not have any adverse effect on the strength and integrity of the bolted connection.

2.2.2 KVS 126 to be used as insulating material in pellet box case and case lid

KV 122 is listed as the insulating material in the manufacturing documents for the test specimens. Due to a mix-up by the manufacturer Rath, the insulating panels for the pellet box case and case lid were made from KVS 126. As KVS 126 has good mechanical properties and its higher thermal conductivity compared to KV 122 nevertheless yielded acceptable results for the thermal test, the series-production containers are now to be equipped with insulating panels made of KVS 126.

Thus no difference will exist between the insulating material used in the test specimens and that of the series-production containers.

2.3 Pellet Box with Pellet Box Lid

2.3.1 Continuous seal weld between pellet box walls and bottom plate (Fig. 3).

The continuous seal weld is intended to prevent dirt and impurities from entering the gap. When necessary, the interior of the pellet box can thus be more easily decontaminated.

The additional seal weld will not have any adverse effect on the strength and integrity of the joint between the pellet box walls and bottom plate.

2.3.2 The insert for the lifting lug in the pellet box lid will be replaced by a machined component with an internal thread. The lug will be fastened to the pellet box lid by screwing in a bolt from underneath (Fig. 4).

The overall height of the installed insert for the lifting lug is thus reduced by the height of the bolt head. This will rule out any restraint of movement by the inserts in the inner plate of the case lid.

The change in the design of the inserts will not have any adverse effect on the strength and integrity of the connections joining the lifting lugs to the pellet box lid.

2.4 Carrying Rack with Clamping Device and Pellet Trays

2.4.1 The length of the carrying rack will be increased from 310 mm to 316 mm and the width from 276.5 mm to 280 mm. The thickness of the steel plates of the carrying rack is to be increased from 5 mm to 8 mm and the width from 50 mm to 60 mm. The vertical positioning plates of the carrying rack (plate thickness increased from 5 mm to 12 mm, width from 50 mm to 60 mm) are to be bolted to the base-plate. The number of openings in the vertical plates for positioning the clamping device is to be reduced from 10 to 5; circular holes are to be provided instead of rectangular openings (Fig. 5).

The increased length and width of the carrying rack reduces the gap between the rack and the pellet box, thus making it more difficult for pellet fragments to reach the space above the clamping device.

The thicker and wider plates of the carrying rack give it greater stability and result in a tighter bundle of loaded pellet trays.

The vertical positioning plates are to be bolted to the baseplate of the carrying rack since, if the plates were to be bent inwards at the bottom, the bend radius would interfere with the bottommost pellet tray.

The number of vertical locking positions for the clamping device in the vertical plates is to be reduced since only a certain number of loading configurations are to be made possible. The rectangular openings are to be changed to circular holes for fabrication reasons.

All modifications, with the exception of the bolted connections at the bottom of the vertical positioning plates, increase the strength of the carrying rack.

The bolted connections are only subjected to mechanical loads when the loaded carrying rack is being handled. Forces arising under the postulated accident conditions of transport will be transmitted directly (without stressing of the bolts) into the surrounding structure (pellet box, pellet box case and outer frame).

2.4.2 The thickness of the end plates of the carrying rack will be increased from 2 mm to 5 mm. The end plates will be guided in grooves in the vertical positioning plates extending over the entire height of the plates. The end plates will also be guided at the bottom in two keyways provided in the baseplate of the carrying rack. Along their guided edges the end plates will have a reduced thickness of 2 mm. When inserted, the end plates will form a flat surface that is flush with the ends of the baseplate and the ends of the vertical plates (Fig. 6).

These modifications have been introduced to improve the connection between the end plates and the carrying rack.

The strength and integrity of the end plates will be significantly improved by the modifications. As a result of the end plates being flush with the ends of the baseplate and the ends of the vertical plates, forces arising under the postulated accident conditions of transport will be transmitted directly into the surrounding structure (pellet box etc.) without imposing any mechanical loads on the locations in which the end plates are guided.

2.4.3 The thickness of the top plate of the clamping device will be increased from 8 mm to 10 mm. The top plate will be locked in its vertical position in the carrying rack by means of two 12-mm-diameter rods instead of the previous four sliding bars. Two plates are to be bolted onto the long sides of the top plate between the vertical positioning plates of the carrying rack (Fig. 7).

The modifications will result in better positioning of the clamping device in the carrying rack. The plates bolted onto the long sides of the top plate are intended to prevent pellet fragments from reaching the space above the clamping device.

The strength and integrity of the clamping device will be significantly improved by these modifications. The cross-sectional area of the locking elements (rods) is thus increased from 52 mm² to 113 mm². The rods' length of 280 mm ensures that the clamping device will not come loose even under accident conditions of transport.

2.4.4 Single-bevel-groove welds will be used to join the side pins to the lifting attachment at the center of the clamping device (Fig. 7).

The fillet weld originally used to join the side pins to the lifting attachment of the clamping device is to be replaced by a single-bevel-groove weld in order to eliminate interference with the grab.

This modification will not have any adverse effect on the strength and integrity of the weld joining the pins to the lifting attachment.

2.4.5 The dimensions of the pellet trays will be changed from 293 mm x 266 mm to 302 mm x 254.5 mm (Fig. 8).

The pellet trays will be narrower since only 21 pellet rows are to be accommodated instead of 22 rows. The increase in pellet tray length will reduce the gap between the trays and the end plates of the carrying rack.

This modification will not have any adverse effect on the strength of the pellet trays since the number of pellets will not be increased.

2.5 Pellet Shipping Container

2.5.1 The mass of the loaded pellet shipping container will be increased from 229 kg to 248 kg.

The greater mass of the loaded pellet shipping container (8.30%) results from the design modifications.

The IAEA drop tests were performed using test specimens having a mass of 229 kg. The larger mass of the loaded shipping container is enveloped by the higher drop height used in the free drop tests (1.3 m instead of 1.2 m; i.e. increase of 8.33%) and the higher drop height used in the drop test onto a vertical bar (1.1 m instead of 1.0 m; i.e. increase of 10.0%).

3 References

[1] ANF-50 Shipping Container
Drawing No. W4435, Werkstätten

[2] ANF-50 Shipping Container
Drawing No. 1-1 27-3750-01 Rev. 2, ANF

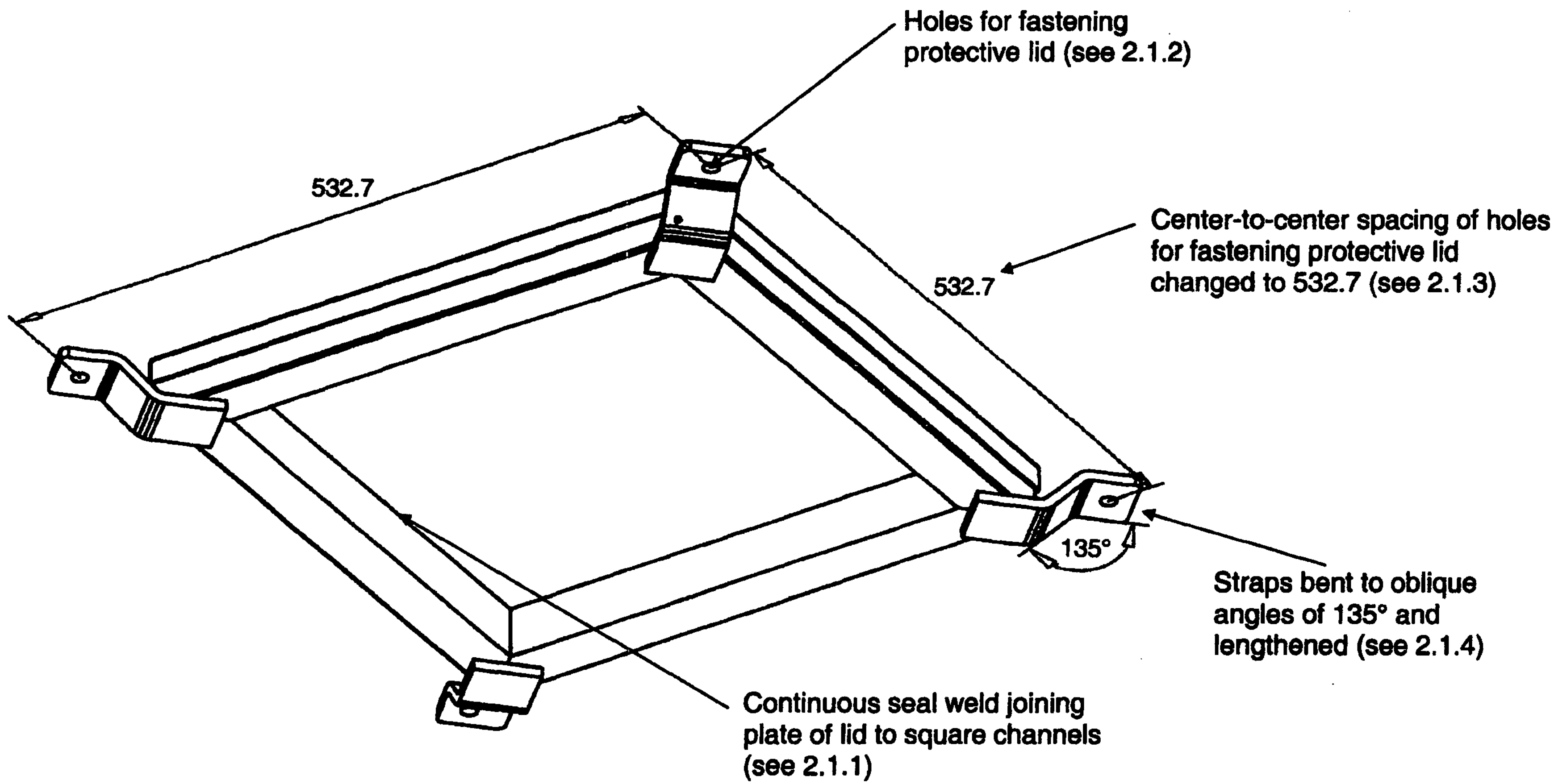

Figure 1: Protective lid

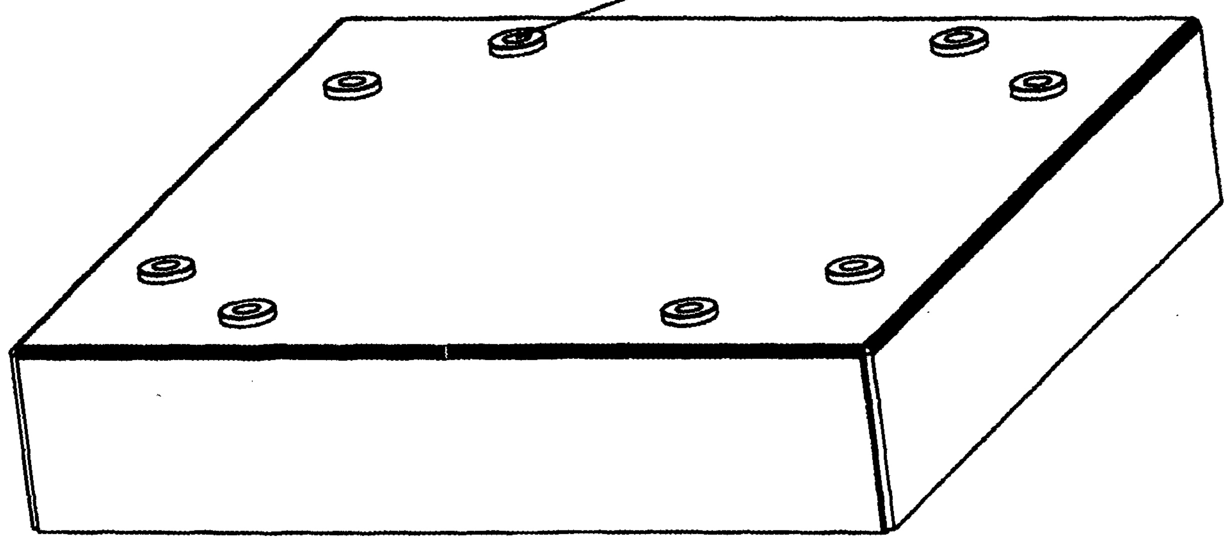

Figure 2: Case lid

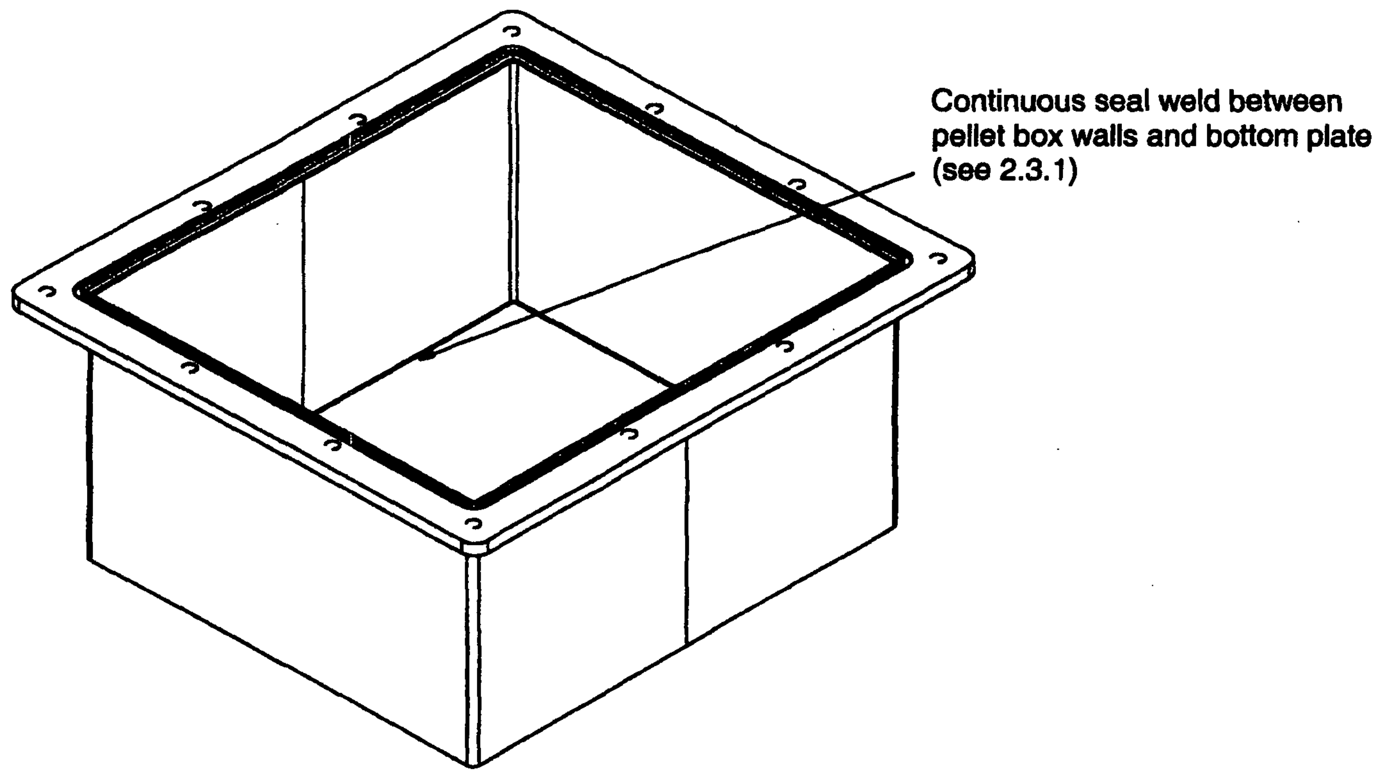

Figure 3: Pellet box

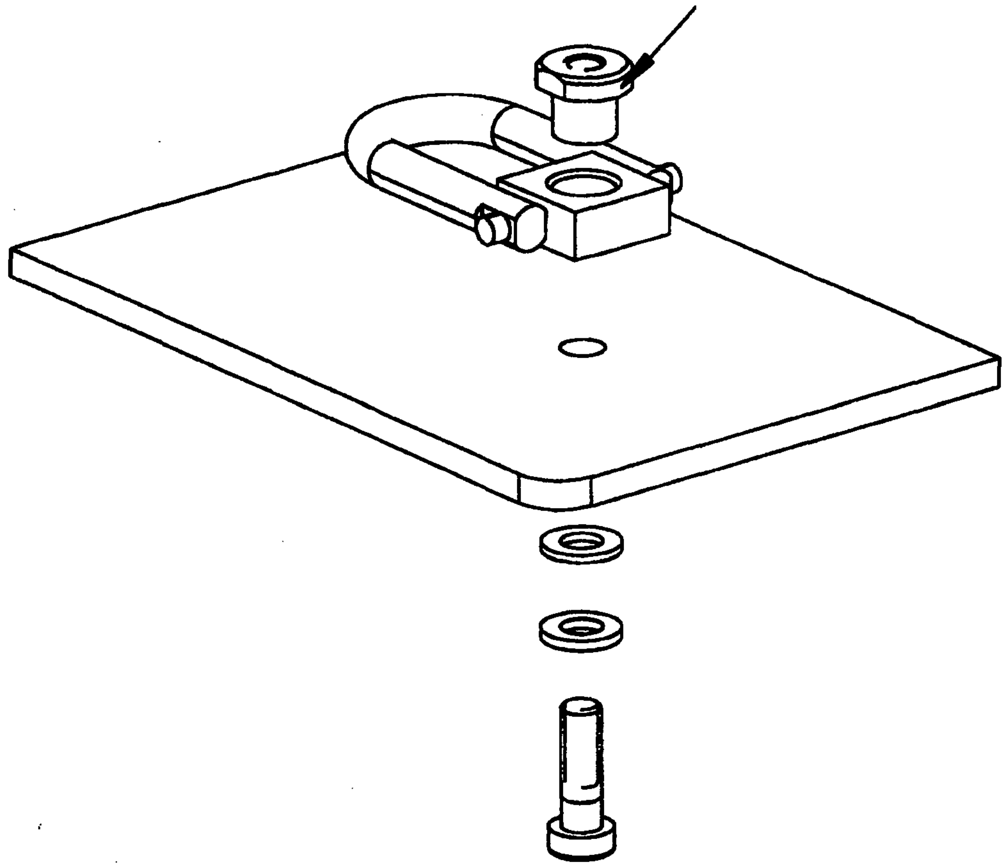

Figure 4: Attachment of lifting lugs to pellet box lid

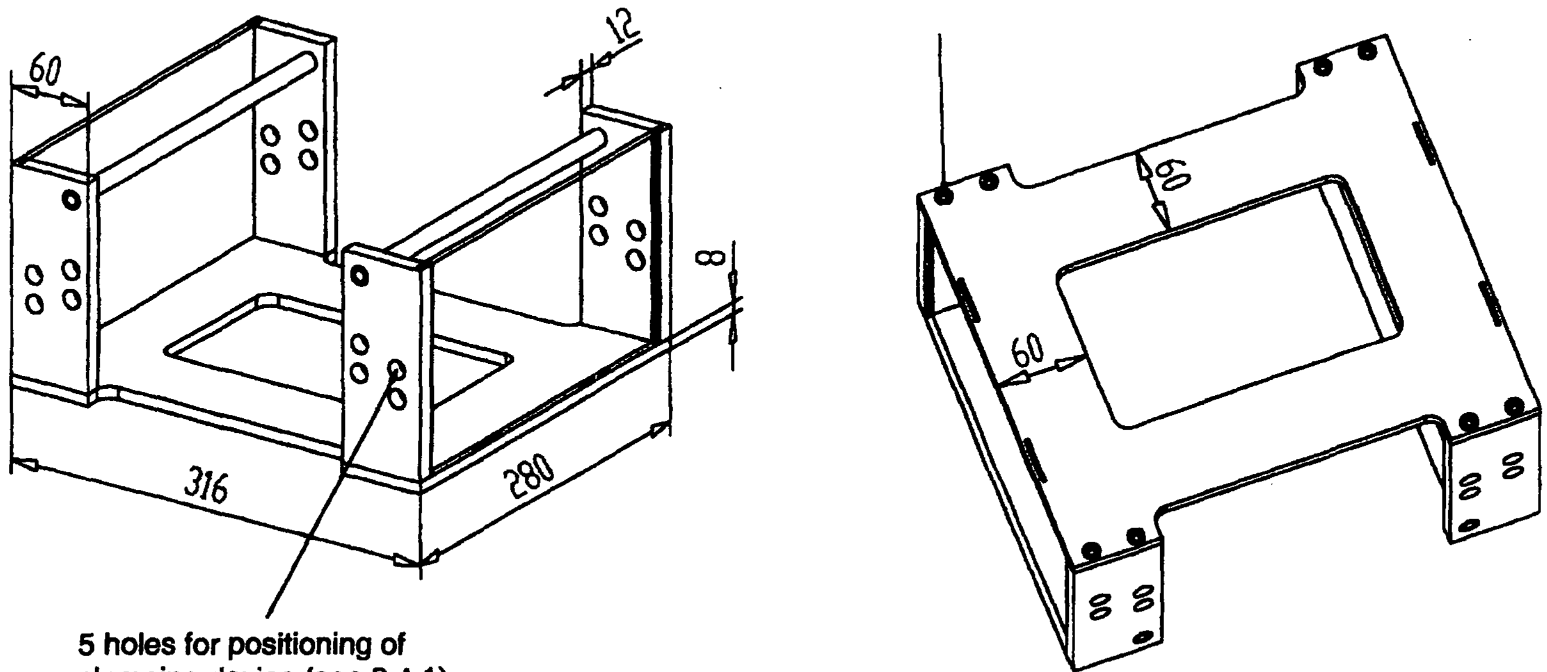

Figure 5: Carrying rack

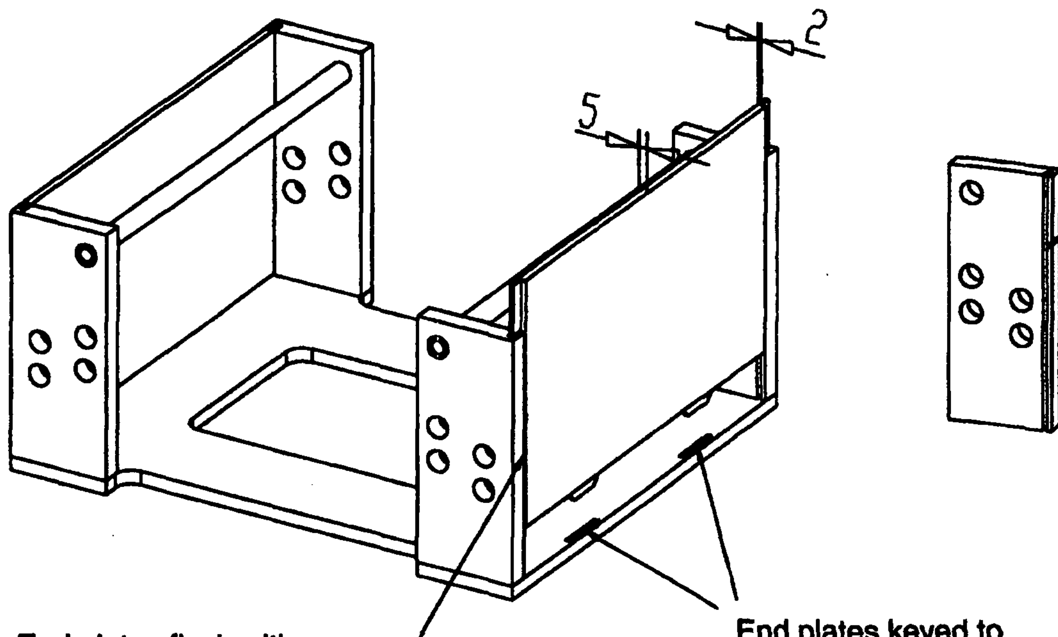

Figure 6: End plates in carrying rack

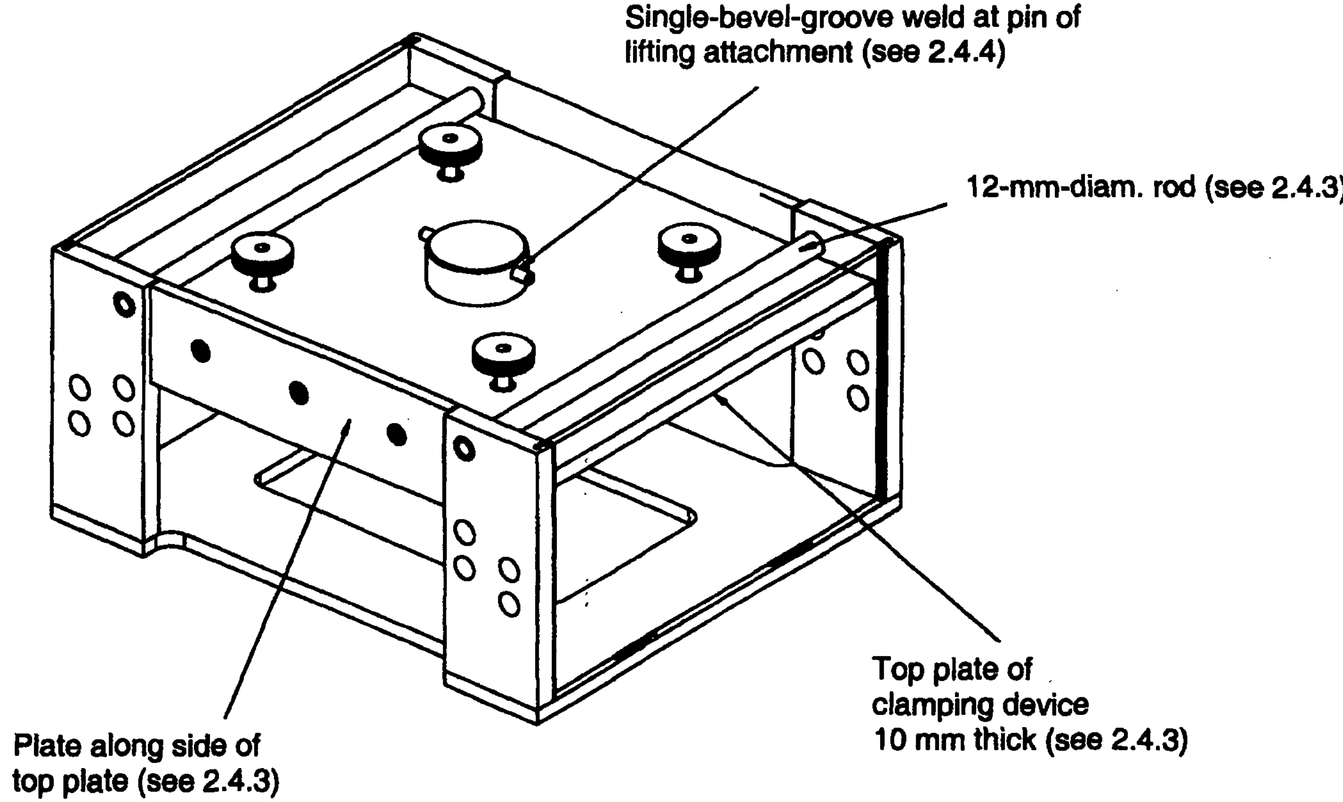

Figure 7: Clamping device with lifting attachment

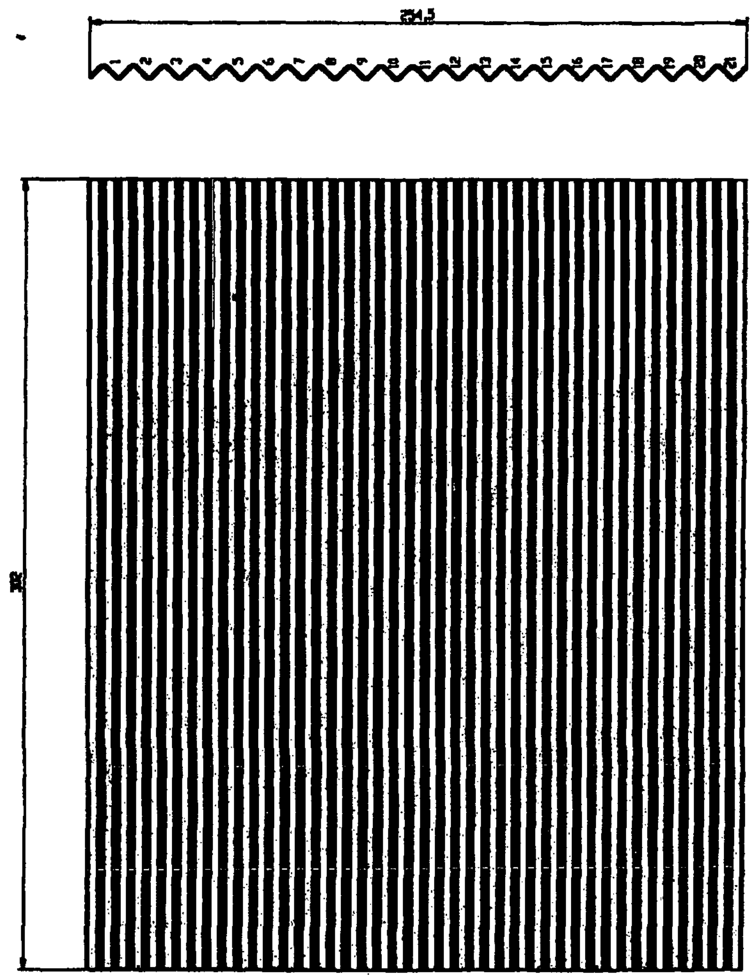

Figure 8: Pellet tray

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ADVANCED NUCLEAR FUELS GmbH

Final Report

Titel/Title:	
Drop Tests with ANF-50 Pellet Shipping Container	
	Nummer/Number **WTD 91**

Translation verified:	D. Steinigeweg	03rd November 2006 **Date**
Translation approved:	i. V. **R. Witten** (i.v. W. Rakel)	03rd November '06 **Date**

WTD 91

German Federal Armed Forces

Wehrtechnische **D**ienststelle für Waffen und Munition
[**WTD** - Defense Technology Bureau for Arms and Ammunition]

WTA-No.: C/ E915/ 41569/ 00000

Final Report

Drop Tests with ANF-50 Pellet Shipping Container

Prepared by: **TROAR** [Civil servant grade] **Walter Bloch**

WTD-No.: 91-**500 – 26 / 05**

Final Report

Meppen, 23rd March 2005
Tel.: 05931/ 43 0
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WTD-No.:	91-500 – 26 / 05		
Code:	91-530/12-05		
Project designation:			
Project number:			
Initiated by:	Framatome ANP/FGTM Erlangen		
Ordered by:	Framatome	Steffenewers	
	Org. Ind.	In Charge	Telephone

Defense Technology Application (WTA)

Order designation: Drop Tests with ANF-50 Pellet Shipping Container

Order number:	C/	E915/	41569/	00000
		Org. Ind.	Cont. WTA-No.	Cont. Project No.

Order responsible:	530	Bloch	1921
	Org. Ind.	Person in charge	Telephone

Business area: Environmental Simulation

Short summary

Several drop tests were performed with two ANF-50 pellet shipping containers as ordered by the company ANF, Lingen.

The evaluation of the test results was performed by employees of the company ANF, Lingen.

A photo CD is included with protocol copies no. 1 – 5.

signed Bloch

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TROAR Walter Bloch

Key words: Drop tests with ANF-50 pellet shipping container

Distribution list: Pages: 7

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WTD91-FISt	6.

Contents

1 Order description

According to the specifications by FRAMATOME ANP, drop tests involving different drop heights and drop positions as well as impact configurations had to be performed with two pellet shipping containers.

The evaluation of the test results was performed by the ordering party.

2 Short description of test specimen

ANF50 Pellet shipping container (birdcage, rebuilt)

Container no. 1, 2

Loaded with dummy masses (lead poles), total mass 250 kg

3 Timeframe

The drop tests were performed on February 15th, 2005.

4 Order execution details

Test facility: Stationary drop facility with digital drop height indicator and electromagnetic trigger mechanism
2t – DEMAG crane
Impact medium: Steal, thickness 80 mm, HB210
cast in reinforced concrete B25, thickness 1m

Load: The following table shows the test sequence:

Container	Drop position	Drop height [m]
1	Cover down, parallel to impact surface	1.35
1	as above	9.9
1	500 kg plate, parallel to impact surface drops onto container, cover up	9.0
2	Diagonal edge down	1.35
2	as above	9.9
2	500 kg plate, parallel to impact surface drops onto container diagonal edge	9.0
2	Bar dropping, details see photo documentation	1.0

5 Determination of results and evaluation

The representatives of the ordering party, who attended the drop tests, independently evaluated the test results. A photo documentation according to the specifications of the ordering party was prepared. The following annex represents a selection of these photos.

The protocol copies intended for the ordering party include a photo CD containing all photographs shot in the course of the test sequence according to the table below.

Photo no.	Container no.	Load
01.jpg	1	1.35 m drop on cover side
02.jpg	1	9.9 m drop on cover side
03.jpg	1	do.
04.jpg	1	do.
05.jpg	1	do.
06.jpg	1	do.
07.jpg	1	Impact 500 kg plate from 9.0 m on cover
08.jpg	1	do.
09.jpg	1	do.
10.jpg	1	do.
11.jpg	1	do.
12.jpg	2	1.35 m drop on diagonal edge
13.jpg	2	9.9 m drop on diagonal edge
14.jpg	2	do.
15.jpg	2	do.
16.jpg	2	do.
17.jpg	2	do.
18.jpg	2	Impact 500 kg plate from 9.0 m on diagonal edge
19.jpg	2	do.
20.jpg	2	do.
21.jpg	2	do.
22.jpg	2	do.
23.jpg	2	do.
24.jpg	2	Bar dropping, test setup
25.jpg	2	do.
26.jpg	2	do.
27.jpg	2	1.0 m bar dropping, test result

6 Annex: Photographs

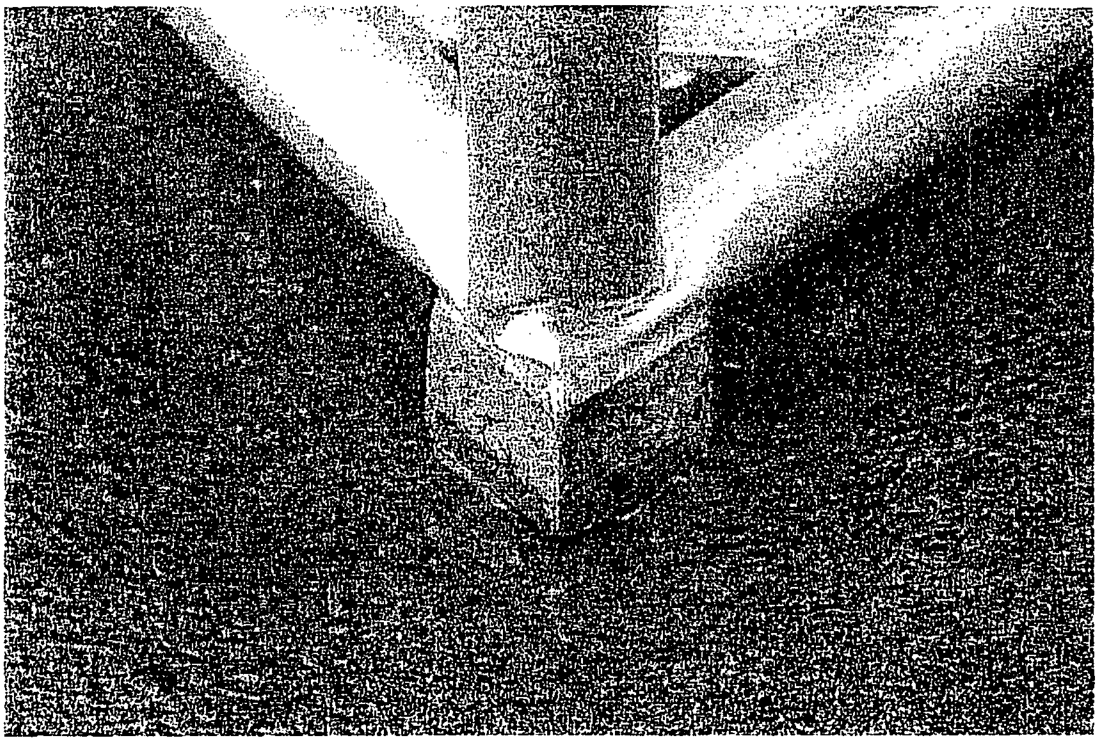

Photo 01: After 1.35 m drop on the cover side

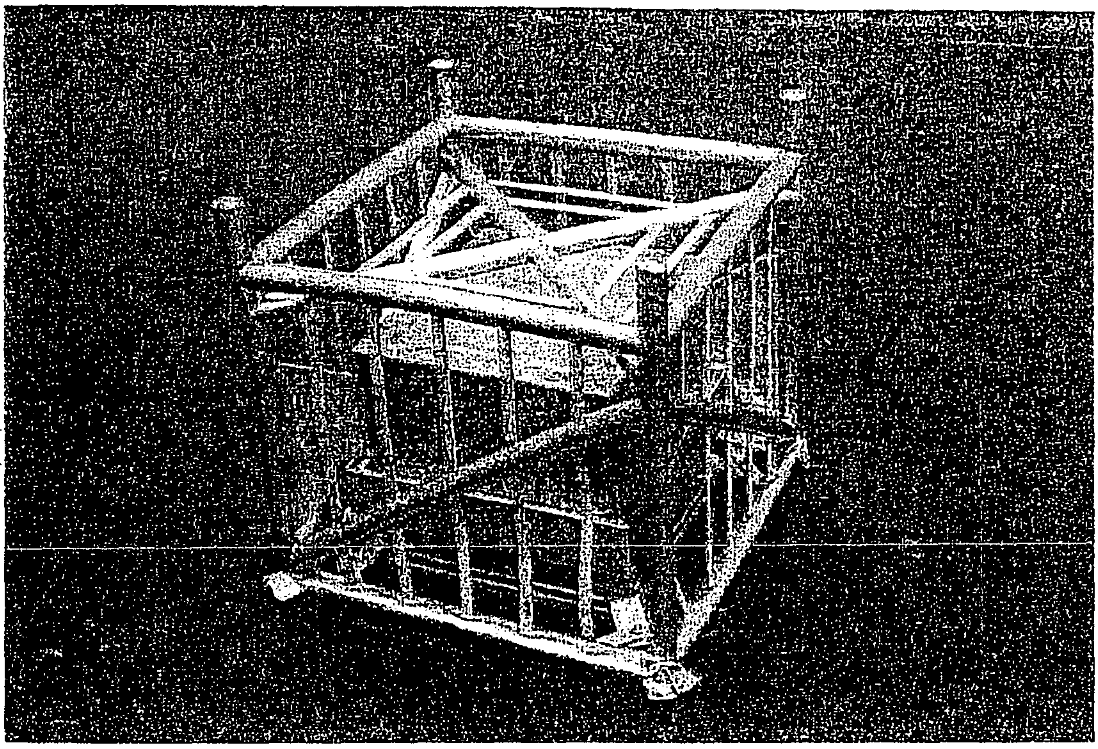

Photo 03: After 9.9 m drop on the cover side

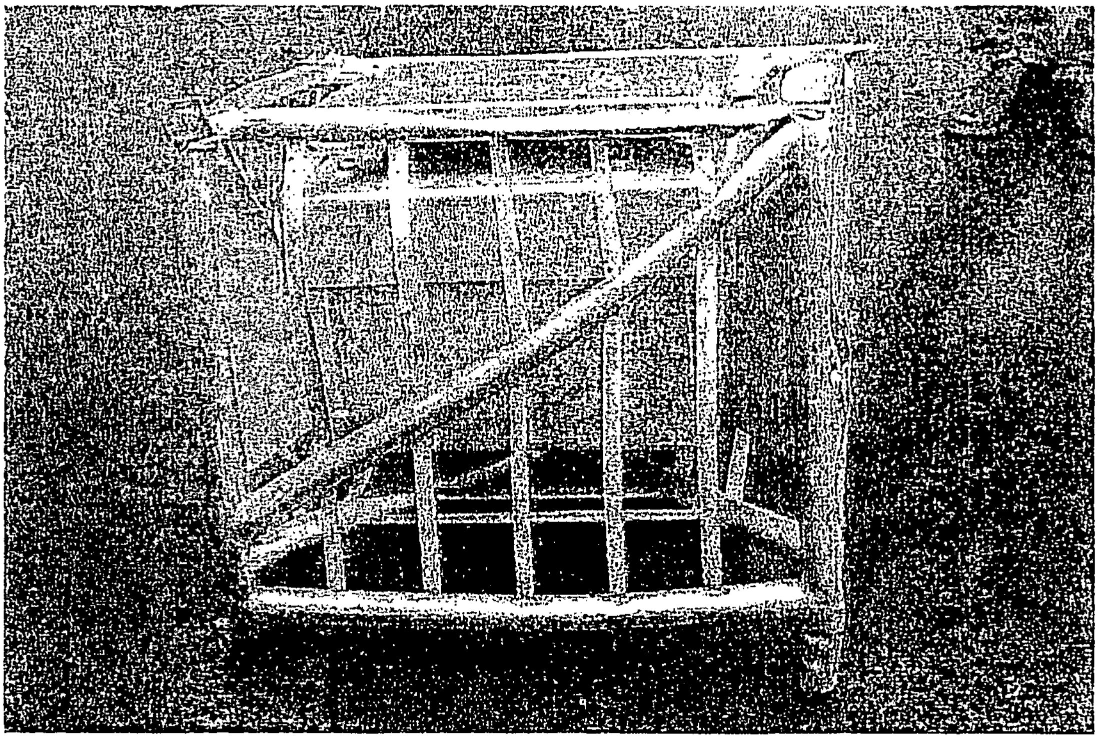

Photo 09: After impact of a 500 kg plate on the cover side

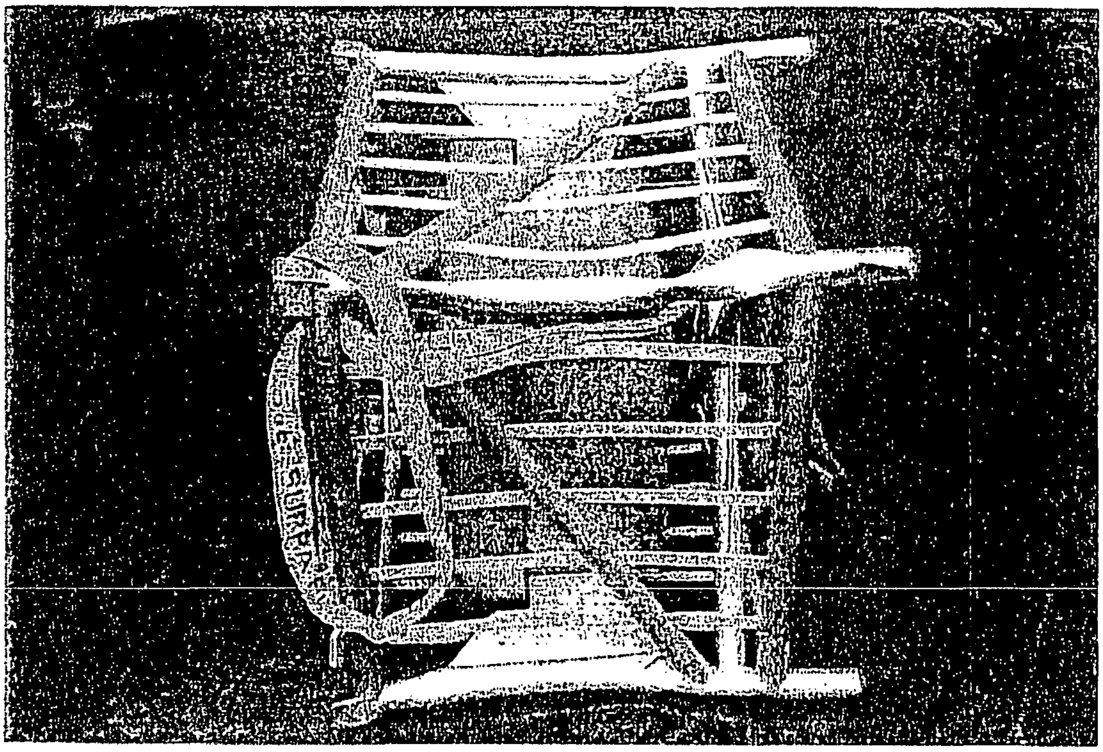

Photo 13: After 9.9 m drop on the diagonal edge

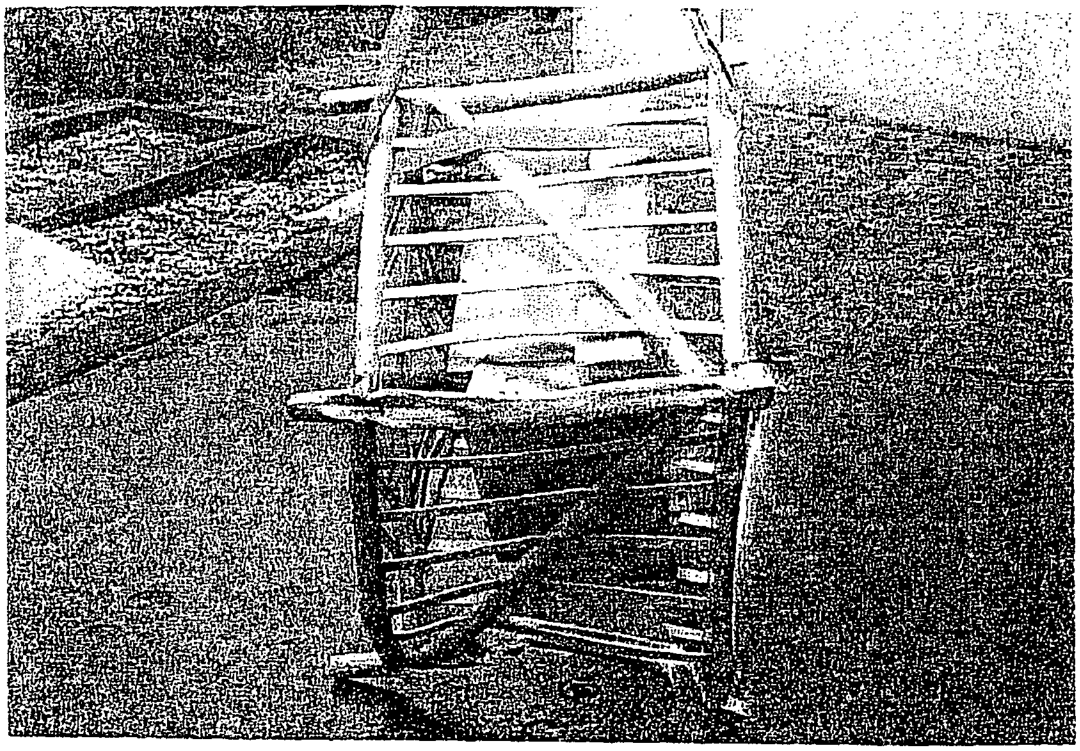

Photo 18: After impact of a 500 kg plate on the diagonal edge

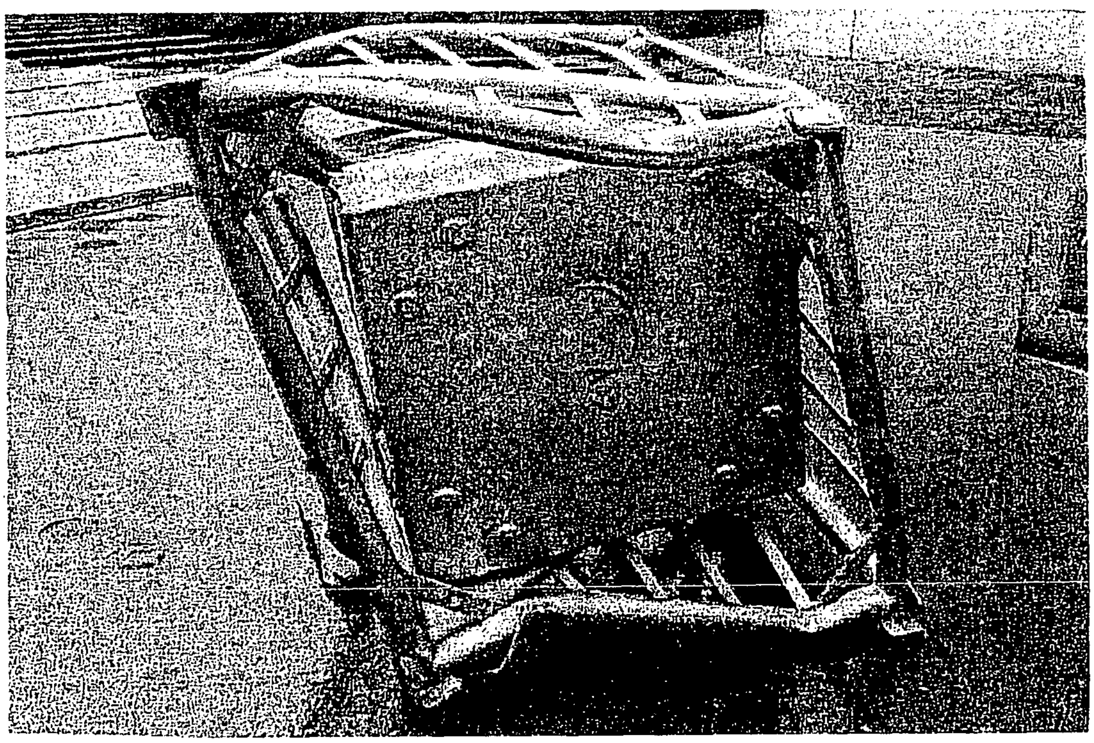

Photo 27: After the 1.0 m bar dropping