DEMONSTRATION TESTS FOR THE SIMULATION OF SHAFT TRANSPORT

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ABSTRACT

Based on the concept of a shaft hoisting equipment for 85 t payload the need in R&D-work to reach license maturity has been derived by comparison with reference plants. Safe charging of the hoisting cage has been demonstrated in the test stand for simulation of shaft transport processes and measures to eliminate all possible radiologically relevant operational disturbances have been performed. Within the scope of simulation tests all safety-technical relevant components have been successively tested regarding their mechanical layout.

After an evaluation of these results considering investigations of rope loads, reliability and probabilistic safety analysis the overall conclusion was derivable that shaft transport of heavy loads is technically feasible and licensable even under consideration of nuclear licensing aspects.

INTRODUCTION

Spent fuel disposal without reprocessing in Germany is being developed to technical maturity within an ambitious R&D program on direct disposal (1). Since it is a principle in German licensing practice to license only demonstrated technology the demonstration of the safe shaft transport is a key item of the program, especially considering payloads of up to 85 t (65 t forthe POLLUX cask plus max. 20 t for the railbound transport car).

Shaft hoisting equipment for the transport of radioactive waste in a repository mine gains beside normal operational tasks safety-technological importance. Its failure may result in danger for persons, release of radioactive substances into the plant and environment. That means, shaft hoisting equipment has to be designed in accordance with the present status of science and technology to correspond to necessary safety requirements.

The aim of this demonstration test is verification of technical feasibility of a shaft hoisting equipment with a payload of 85 t including all essential components as well as demonstration of safe transport operation especially regarding aspects of radiation protection. It has to be demonstrated that the planned plant can be licensed according to conventional regulations as well as under consideration of nuclear aspects within the scope of a plan permission procedure.

Investigations start from the supposition that radioactive waste is transported in cask which correspond to transport requirements for dangerous goods and have a type-B-certificate. The overall plant was designed under special consideration of following accidents:

- drop of waste packagings during the loading process;
- mechanical impact on waste packagings during the transport into the mine;
- drop of waste packagings during transport processes;
- drop of heavy loads onto waste packagings.

When the plant with large hoisting cage and counterweight including surface loading facility (Fig. 1) and underground unloading facility on the disposal level was planned it was necessary to consider especially aspects to avoid above mentioned accidents. For this reason the shaft lock gate additionally received the function of a safety gate which is not only electronically monitored and interlocked (control and safety circuit) but also mechanically interlocked to avoid in all cases the drop of a loaded transport car into the shaft.

The hoisting cage is built with an intermediate cage bottom which is the deck for loading the transport car. During loading and unloading operations the intermediate cage bottom is rested on hydraulically actuated rests and this way definitely fixed and controllable. Only when the cage is lifted by the hoisting machine the payload is transmitted to the 8 hoisting ropes (see Table I).

ANALYSIS ON THE BASE OF EXISTING REFERENCE PLANTS AND DERIVATION OF NECESSARY R&D-WORK

Assessment of all relevant shaft hoisting parts and components regarding transferability of state of art to payloads of 85 t has been carried out under consideration of numerous reference plants. Results of these investigations which are suited to proof application maturity of essential components by reference plants have also been reported on in (2). This

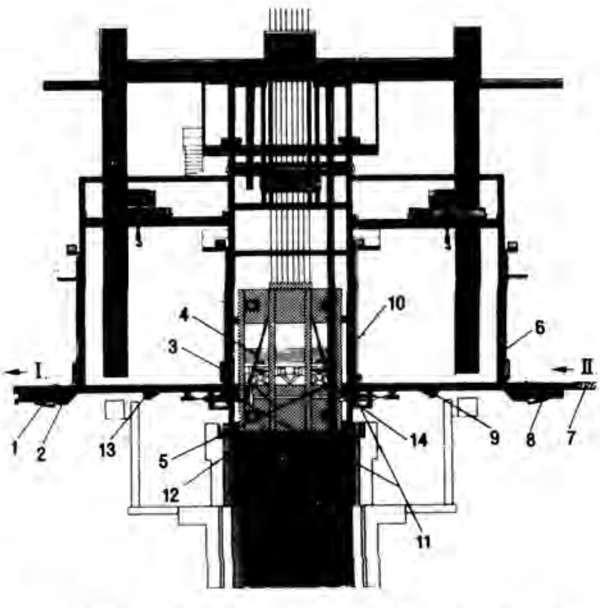

Fig. 1. Surface installations of a shaft hoisting equipment with payload of 85 t.

TABLE I
Description of Shaft Hoisting Equipment (see Fig. 1)

Item	Component Description	Item	Component Description
1	shaft safety gate 1	8	shaft safety gate 2
2	air lock gate 1	9	loading device 1
3	lift gate 1 with interlocking	10	lift gate 2 with interlocking
4	transport car	11	cage rests 1 - 4
5	car catch 1	12	hoisting cage
6	air lock gate 2	13	unloading device 1
7	weigh bridge	14	car catch 2
I.	Unloading direction		
II.	Loading direction		

proof can't be given for following components which have to meet special requirements with respect to repository planning. Their applicability has to be confirmed within the scope of this test:

- hoisting cage with intermediate cage bottom,
- cage arresting system during loading and unloading,
- mechanical overwinding arrestor systems,
- loading and unloading device,
- safety locks.

Furthermore, handling processes and interlocking conditions considering the whole shaft transport under requirements and boundary conditions of a repository mine can't be evaluated by reference plants. Hence, it was necessary to plan all required handling schemes and interlockings and verify their completeness and consistency.

PLANNING OF TEST PROGRAM AND CONSTRUCTION OF TEST STAND

Based on the aim of this project it is planned to demonstrate safe onsetting under real conditions with all necessary components including locking systems in the function of precautional measures to exclude drop of heavy loads into the shaft. For this purpose a test program focussing three investigation fields as well as a test stand considering all requirements of the test program have been planned in detail.

The test stand was mounted in a power plant on the foundations of a shut down turbine. The existing bridge crane in the turbine house with a payload of 110 t was available for the test and was used as hoisting unit to handle the test components (hoisting cage with transport car and POLLUX-cask) for vertical hoisting. In addition to test-specific installations the following components - schematically demonstrated in Fig. 2 - have been realized in accordance with the concept for realizing the test in the test stand.

1. Safety gate and hold-back which are mechanical measures to avoid the drop of a transport car into the shaft. The safety gate can only be opened by a hydraulic cylindre and is automatically closed in case of power loss.
2. Loading device which is designed for horizontal movements of transport car on charging level and intermediate cage bottom and which is mounted in the middle of the charging level track bed.
3. Transport car with inactive cask.
4. Air lock gate which is air gate and additionally has the same function as the safety gate with respect to safety of the overall plant.
5. Cage rests (four) which serve to arrest the intermediate cage bottom including payload in front of the loading device, to fix them in both horizontal directions and take up the mentioned loads. Cage rests are designed to act also as track bridge.
6. Hoisting cage with intermediate cage bottom for taking up a transport car for vertical hoisting. During the hoisting process the intermediate cage bottom rests upon the cage deck and is positioned by two vertical catch pivots which are anchored in the cage deck and simultaniously avoid rolling off of the transport car.
7. Car catches (two) which stabilize the transport car in its horizontal position until catch pivots reach their full effectiveness.
8. SELDA-arrestor system for braking the hoisting cage after overwinding. The hoisting cage bounces on an arrestor beam which hangs on flat steel strips above 8 roller boxes. When arrestor beam and roller boxes move downwards the flat steel strips will be deformed and afterwards straightened again, hence, kinetic energy of the pushing hoisting cage will be converted (not illustrated).
9. Wooden wedge guides - according to the conventional mining regulations - to jam and stop the hoisting cage in case of overwinding (not illustrated).

ITEM	COMPONENT DESCRIPTION
1.	Shaft safety gate
2.	Loading device
3.	Transport car with inactive cask
4.	Air lock gate
5.	Cage rests with track bridge
6.	Hoisting cage
7.	Car catch

Figure 3 gives an impression of the placed hoisting cage.

TEST PERFORMANCE

The test program was classified in following three sections:

- demonstration tests
- test to eliminate operational disturbances
- simulation tests.

The test was carried out from July 1991 till September 1992.

DEMONSTRATION TESTS

All safety-technological interlockings for components realized in the test stand have been developed on the base of processes necessary for charging and transport in a planned repository. These interlockings have to be directly transferrable to a shaft hoisting equipment, but plant-specific

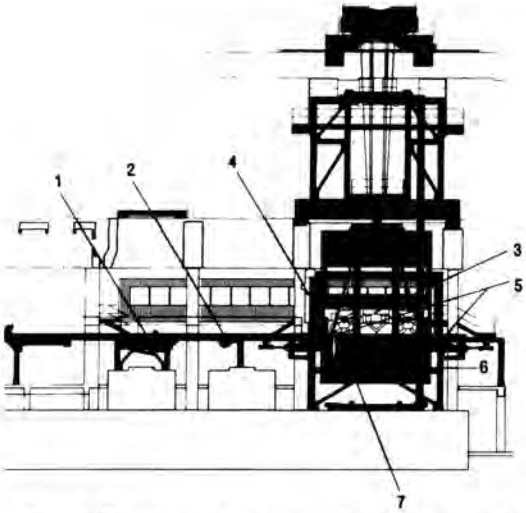

Fig. 2. Positions of components in test stand.

Fig. 3. Loading of the hoisting cage.

interlockings especially regarding hoisting machine and braking systems have to be added.

Hence, this test phase tested the safe interaction of components. By combination with a special test program it is possible to obtain at the same time experimental data for a reliability analysis for the whole shaft hoisting equipment.

During demonstration tests for simulation of shaft transport processes 2,001 cycles have been carried out which correspond to 484 operating hours. 17 failures have been noticed during these cycles but only one belonged to the category "random" failure (defect relay). All other failures mainly resulted from design or handling deficiencies and in accordance with the aim of these demonstration tests their causes were realized and afterwards eliminated.

Test evaluation resulted in an upper limit of failure probability per cycle of 0.002 (confidence level = 90 %). This value is in accordance with reliability requirements.

TESTS TO ELIMINATE OPERATIONAL DISTURBANCES

First of all possible operational disturbances have been analyzed to plan systematically their elimination. All operational disturbances with radiological consequences can be eliminated by one of the following measures or by combination of them:

- recovery of servicable transport car,
- recovery of derailed transport car,
- recovery of unservicable transport car (Fig. 4).

Because the test stand is assembled almost identically to the loading area of a real shaft hoisting equipment it is possible to transfer obtained test results concerning elimination of operational disturbances to a real plant at a scale of 1 : 1. Additionally the tests provide data to evaluate radiation exposure of the operating staff during periods necessary for elimination of operating disturbances in a repository and furtheron a detailled package of measures for the elimination of operational disturbances will be established and become part of a future repository manual.

The test came to the result that 4 members of the operating staff are able to recover servicability of a derailed unservicable transport car within 1 h with the help of a conventional rerailing unit of the Federal Railways and an auxiliary undercarriage. The calculated whole-body dose remains clearly beneth 10 % of the limit value for one calender year of 50 mSv fixed in the Radiation Protection Ordinance.

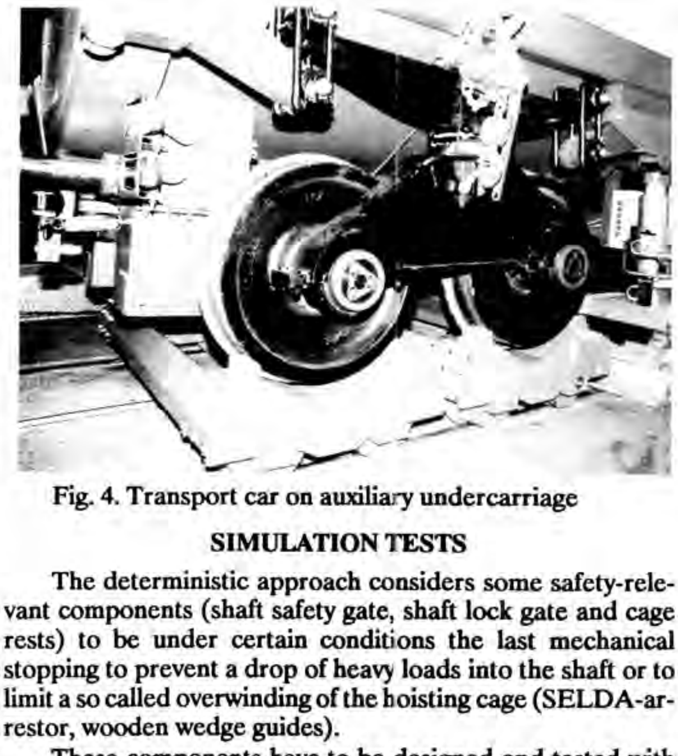

Fig. 4. Transport car on auxiliary undercarriage

SIMULATION TESTS

The deterministic approach considers some safety-relevant components (shaft safety gate, shaft lock gate and cage rests) to be under certain conditions the last mechanical stopping to prevent a drop of heavy loads into the shaft or to limit a so called overwinding of the hoisting cage (SELDA-arrestor, wooden wedge guides).

These components have to be designed and tested with respect to requirements and under consideration of the high transport weight of a loaded transport car which is 85 t. Occurrence of operational disturbances will be simulated.

Test of Safety Gate

In case the loaded transport car is pushed into the area of the shaft lock because of loading device malfunction the safety gate has to stop the transport car (at the maximum rate of loading device). This has been successfully tested.

Test of Shaft Lock Gate

In case the loaded transport car is pushed towards the shaft because of loading device malfunction this shaft lock gate has to act as safety gate. This has also been successfully tested.

Test of Cage Rests

Behaviour of intermediate cage bottom and cage rests has been tested assuming that one of the extended cage rests is blocked by disturbing material. Investigations resulted in no significant safety-relevant conclusions. In all cases it is possible to unload the transport car.

Cage Braking Tests

Overwinding of the hoisting cage has been simulated and functionability of planned overwinding arrestor systems verified. This test included free drop of hoisting cage with transport car loaded with an inactive cask with a maximum velocity of 8.5 m/s and for safe braking by the SELDA-arrestor with a deceleration of appr. 1 g. Kinetic energy is converted by continuous bending of flat steel strips within roller heads (Fig. 5).

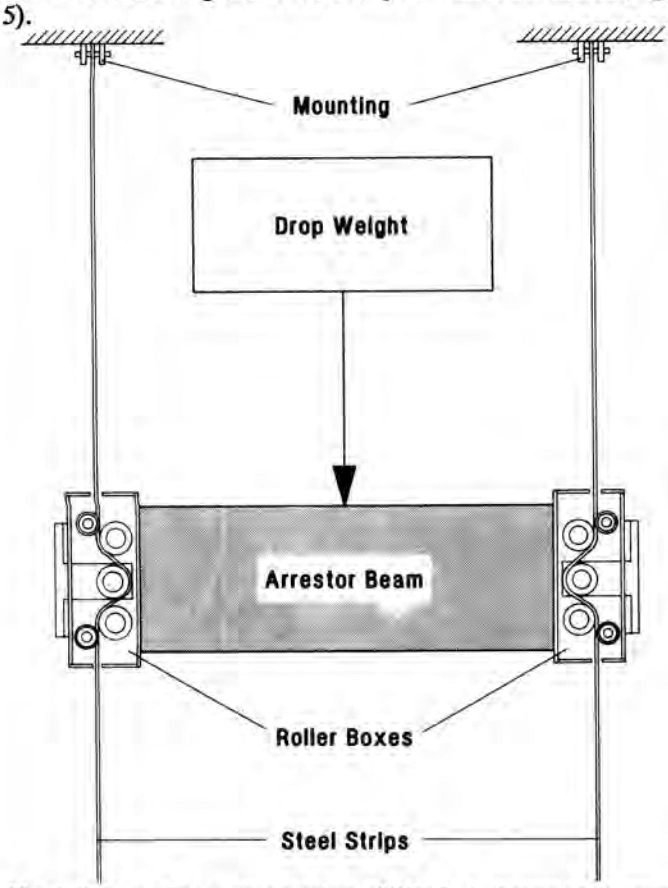

Fig. 5. Schematic representation of SELDA-Arrestor System.

This special test has been carried out 29 times. Figure 6 shows the typical function of braking power in a SELDA-strip and resulting tensile stresses.

Another test investigating system behaviour of conventional mining technology (wooden wedge guides) in case of overwinding showed unsatisfying results. During the brake test the hoisting cage was seriously deformed. After passing the planned braking distance it stroke the bottom plate with appr. 8 m/s. The curve of braking powers as a function of time is shown in Fig. 7 and velocity in one measurement point of the inactive cask is represented in Fig. 8. Even this test wouldn't have damaged the POLLUX-cask.

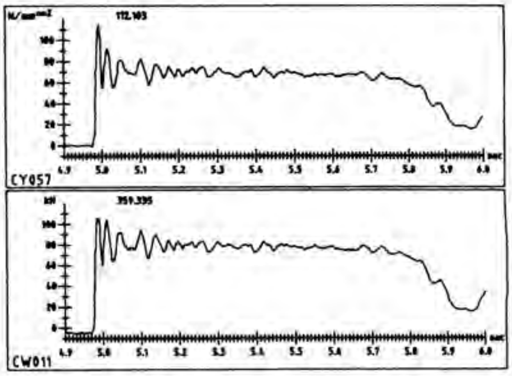

Fig. 6. SELDA-braking test (height of drop: 309 cm).

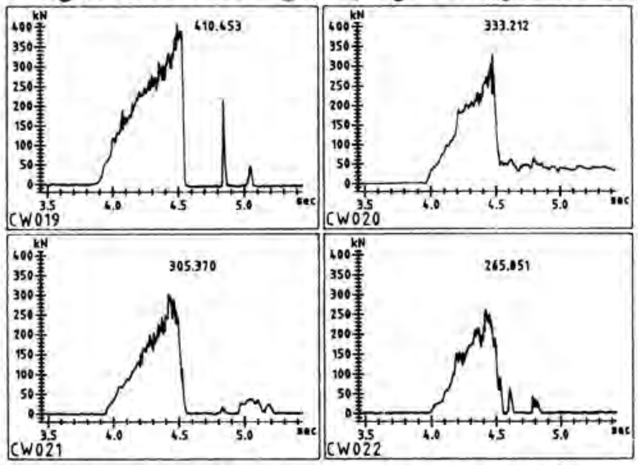

Fig. 7. Braking test with wooden wedge guides (braking power).

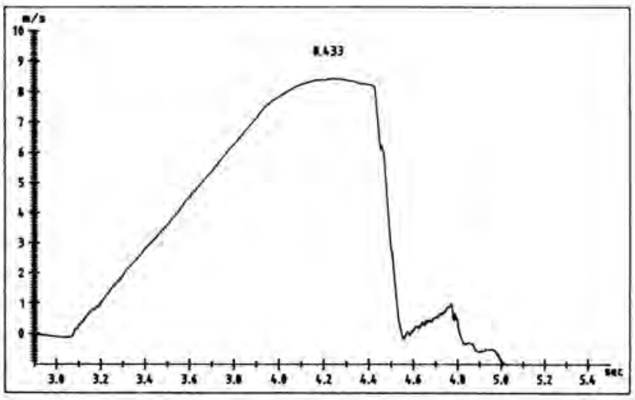

Fig. 8. Braking test with wooden wedge guides (velocity).

INVESTIGATIONS OF ROPE LOADS

An analysis of expected loads and estimated service time until a necessary change of ropes under consideration of special operational conditions has been carried out for selected three-ply flattened strand ropes (50 mm diametre). Hence, rope tensions during the operation are similar to those in conventional plants of the same scale. But when the ropes are charged with heavy loads and the hoisting cage is lifted, in that moment tensions increase by the factor 4 per time unit. Tests with four ropes of the planned design demonstrated that under realistic charging conditions - after 20,000 cycles per rope - no broken wires and no excessive wear was noticed. That means, the analysis and tests which have been carried out confirmed safe operation of hoisting ropes.

RELIABILITY INVESTIGATIONS

Safety and economy of a disposal technology heavily depends upon reliability and availability of applicated technical systems. Reliability defines the probability of a unit to correspond to preset requirements for a defined period of time (3).

Reliability considerations are carried out with the help of the error tree method. Quantitative evaluation of the error tree under application of temporary reliability data for basic events is carried out on the base of failure frequency, unavailability and avarage failure duration of the whole system and its essential components. The share of these components in the total failure frequency provides the "reliability profile" of the system which reveales possible trouble spots and therefore a systematic representation.

Evaluation of the quantitative error tree concluded that the whole shaft hoisting system is expected to show appr. 30 failures per service time of 8760 h (= 1 year). Avarage duration of a failure is appr. 17 h and resulting unavailability appr. 6 %.

The calculated number of 30 failures per year corresponds to a failure frequency of 1.7×10^{-3} per cycle if an avarage duration of 30 min per hoisting cycle is assumed. This value can be accepted because this result also includes minor operational disturbances with their effects.

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