REALIZATION OF THE GERMAN CONCEPT FOR INTERIM STORAGE OF SPENT NUCLEAR FUEL – CURRENT SITUATION AND PROSPECTS

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ABSTRACT

The German government has determined a phase out of nuclear power. With respect to the management of spent fuel it was decided to terminate transports to reprocessing plants by 2005 and to set up interim storage facilities on power plant sites. This paper gives an overview of the German concept for spent fuel management focused on the new on-site interim storage concept and the applied interim storage facilities. Since the end of the year 1998, the utilities have applied for permission of on-site interim storage in 13 storage facilities and 5 storage areas; one application for the interim storage facility Stade was withdrawn due to the planned final shut down of Stade nuclear power plant in autumn 2003. In 2001 and 2002, 3 on-site storage areas and 2 on-site storage facilities for spent fuel were licensed by the Federal Office for Radiation Protection (BfS).

A main task in 2002 and 2003 has been the examination of the safety and security of the planned interim storage facilities and the verification of the licensing prerequisites. In the aftermath of September 11, 2001, BfS has also examined the attack with a big passenger airplane. Up to now, these aircraft crash analyses have been performed for three on-site interim storage facilities; the fundamental results will be presented. It is the objective of BfS to conclude the licensing procedures for the applied on-site interim storage facilities in 2003. With an assumed construction period for the storage buildings of about two years, the on-site interim storage facilities could then be available in the year 2005.

INTRODUCTION

In 1998 the new German government decided - in accordance with the utilities - to phase out of commercial nuclear energy utilization. In context with this change in energy policy, a new waste management program was developed including a new concept of dry on-site interim storage instead of centralized interim storage. Negotiations of the German government and the utilities resulted in the "Agreement between the Federal Government and the Utility Companies" of June 2000.

In April 2002, a new Atomic Energy Act (1) came into force that legally secures this agreement on a phase-out of nuclear power. According to the amendment to the Atomic Energy Act, waste management shall be restricted to final disposal. As from July 2005, transports of spent fuel rods to the reprocessing plants at La Hague in France and Sellafield in Great Britain will be prohibited. In addition, operators of nuclear power plants have to erect and to use interim storage facilities for spent nuclear fuel on the site or in the vicinity of nuclear power plants. The aim is to reduce transports of spent fuel and to bridge the time until a geological repository for radioactive waste will be available.

In Germany, the Gorleben salt dome had been explored since 1979 with regard to its suitability as a repository for radioactive waste. However, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) doubts the suitability of Gorleben. Its exploration was interrupted in October 2000 for at least 3 years, at most however 10 years. BMU established a Committee of experts to develop a procedure and criteria for the selection of repository sites for radioactive waste. The Committee delivered its recommendations in December 2002. These shall be discussed with experts on a national and international level and with the interested public in order to achieve transparency and acceptance for further decisions. After a phase of political and legal implementation, site selection is expected to start in several years. The goal of the German government is to establish a geological repository for all kinds of radioactive waste starting operation by 2030.

Up to this, interim storage of spent fuel has to be performed. Spent fuel elements are intermediately stored in Germany in cooling basins under water inside the power plants as well as in external central or decentralized interim storage facilities. The internal storage facilities in cooling basins are licensed pursuant to § 7 Atomic Energy Act. The Federal Office for Radiation Protection (BfS) is responsible for the licensing of external interim storage facilities pursuant to § 6 Atomic Energy Act (2).

PRESENT SITUATION

From the 19 German nuclear power plants approximately 450 Mg of spent fuel elements are annually discharged. Altogether spent fuel amounting to approximately 12,000 Mg of heavy metal is produced – besides the spent fuel elements transported to reprocessing plants – during the phase of nuclear energy use, which is clearly limited now.

Two central interim storage facilities are in operation located in Gorleben and Ahaus. The licensed capacities are 3,800 Mg heavy metal (HM) respectively 3,960 Mg HM. The interim storage facility at Gorleben is the only one in the Federal Republic of Germany that has a license for the storage of vitrified high level radioactive waste (HLW) from reprocessing of German fuel rods abroad. Presently 5 casks with spent fuel from light water-cooled reactors (LWR) and 27 casks with vitrified HLW are stored. It is planned to store 12 additional casks with vitrified HLW per year. The main role of the Gorleben facility will be the storage of vitrified HLW. The Ahaus facility actually houses 6 casks with spent fuel from LWR and 305 casks with fuel from the Thorium high temperature reactor (THTR) that was finally shut down in 1989. The storage of additional casks with fuel from experimental reactors is planned. The goal of the new interim storage concept is to avoid further transports of casks with spent fuel from nuclear power plants to Gorleben and Ahaus and to the reprocessing facilities La Hague (France) and Sellafield (Great Britain).

In addition, two interim storage facilities for spent fuel elements are in operation at the sites of reactors already decommissioned: The AVR interim storage facility of the Research Center Jülich for spent fuel elements from the decommissioned experimental high temperature reactor AVR (3) and the Interim Storage Facility North (ZLN) at Rubenow near Greifswald for spent fuel originating from the decommissioned nuclear power plants at Greifswald and Rheinsberg. The AVR facility has a license for a total of 158 casks; presently 129 casks are stored. The ZLN (capacity: 585 Mg HM, 80 casks) actually houses 26 casks.

DECENTRALIZED INTERIM STORAGE

In order to realize the new decentralized interim storage concept, the utilities have applied for 13 on-site interim storage facilities and 5 on-site interim storage areas at 13 nuclear power plant sites (see Figure 1). The 18 applications were filed between December 1988 and February 2002. In between, applications have been modified and one application for the interim storage facility at Stade was withdrawn in August 2001 due to the planned final shut down of the Stade nuclear power plant in autumn 2003. The capacity of the storage facilities applied for has been reduced from a total of 18,650 Mg to 14,300 Mg. The mass of heavy metal applied for varies between 300 Mg and 2,250 Mg for on-site storage facilities and between 120 Mg and 300 Mg for interim storage areas. The number of casks varies between 80 and 192 for interim storage facilities and between 12 and 28 for on-site storage areas (4).

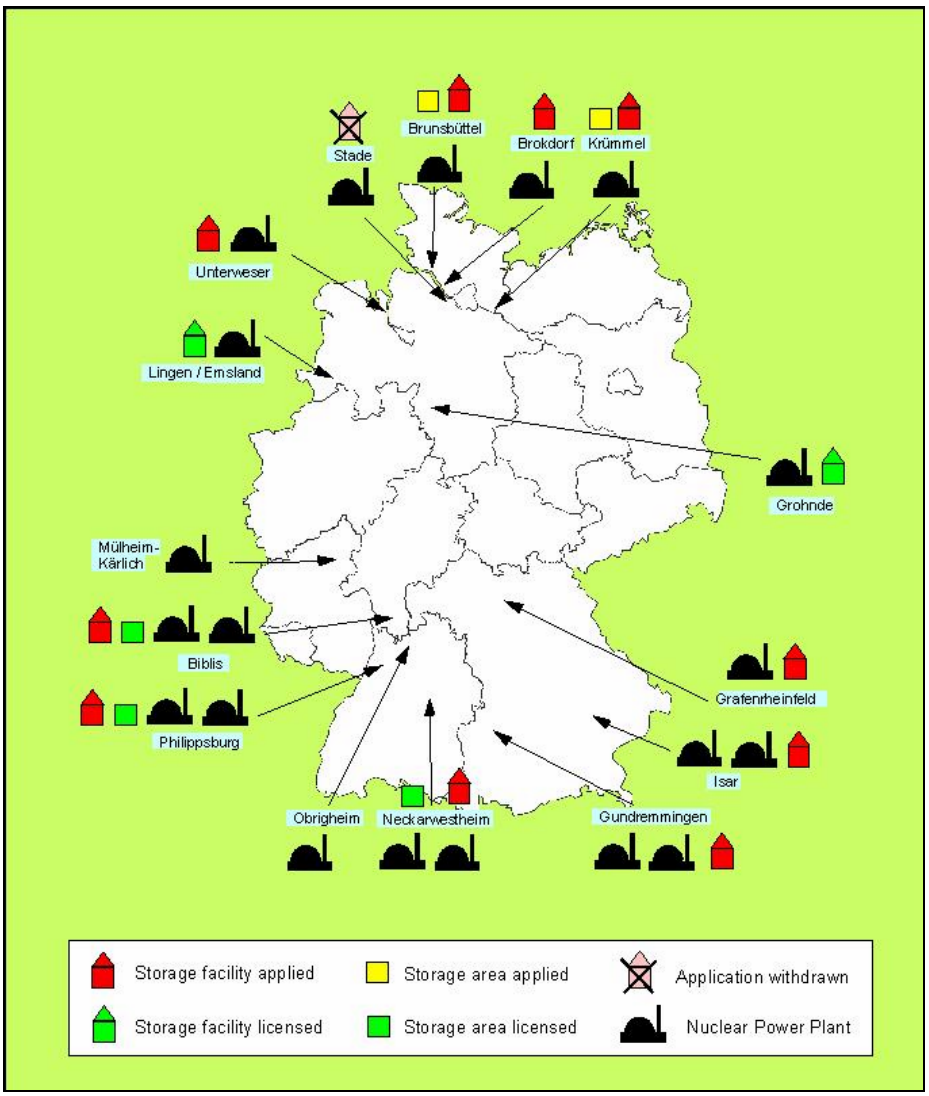

Fig. 1. On-site Dry Interim Storage in Germany

The storage facilities shall operate for about 40 years, the storage areas for about 5 years. These short-term interim storage areas are necessary for power plants with limited fuel pool capacity in order to bridge the time gap until the on-site storage facilities are in operation.

The technical concept of theses facilities is based on dry storage of massive casks. The applications represent three basic concepts: The storage building, the storage tunnel and the interim storage area.

The storage building concept exists in two technical variants (see Figure 2), the WTI-concept (5,6) and the STEAG-concept (5,7).

- STEAG-concept (a storage hall designed by the company STEAG encotec GmbH, Essen), characteristic: monolithic building, thick concrete structures (in situ concrete), wall thickness approximately 1.2 m, roof thickness approximately 1.3 m, one-nave building. The STEAG concept has been applied for the 6 North German sites of Brokdorf, Krümmel, Brunsbüttel, Grohnde, Lingen and Unterweser.

- WTI-concept (a storage hall designed by the company of consulting engineers **W**issenschaftlich-**T**echnische **I**ngenieurberatung GmbH, Jülich), hall similar to the storage facilities at Gorleben, Ahaus and Lubmin/Greifswald, characteristic: pillar-/binder-system, separate bed plate, in situ concrete / pre-cast concrete-system, wall thickness approximately 0.7 m or 0.85 m, roof thickness approximately 0.55 m, two-nave building consisting of two halls separated by a wall. The WTI-concept has been applied for the 5 sites of Biblis, Philippsburg, Grafenrheinfeld, Isar and Gundremmingen located in the southern part of Germany.

For the site of Neckarwestheim, on-site interim storage in two tunnel tubes lined with concrete has been applied for (8). This special solution below ground was developed due to site-specific conditions, i.e. a narrow location in a quarry. It has the advantage of shielding through the rock. Heat removal is achieved via exhaust air chimney.

In interim storage areas the storage casks are stored on a defined area on the power plant terrain. In contrast to storage in upright positions in interim storage buildings, horizontal storage of the casks on concrete slabs has been applied for. To shield gamma and neutron radiation and as protection against the weather, each cask is covered by prefabricated concrete elements.

Since the only purpose of the interim storage area is to bridge the period until the 40-year on-site storage facility is ready for operation, a low number of casks is characteristic. It has the advantage of a short construction period of about 1 to 2 months in comparison to about 1,5 to 2 years for storage buildings or storage tunnel.

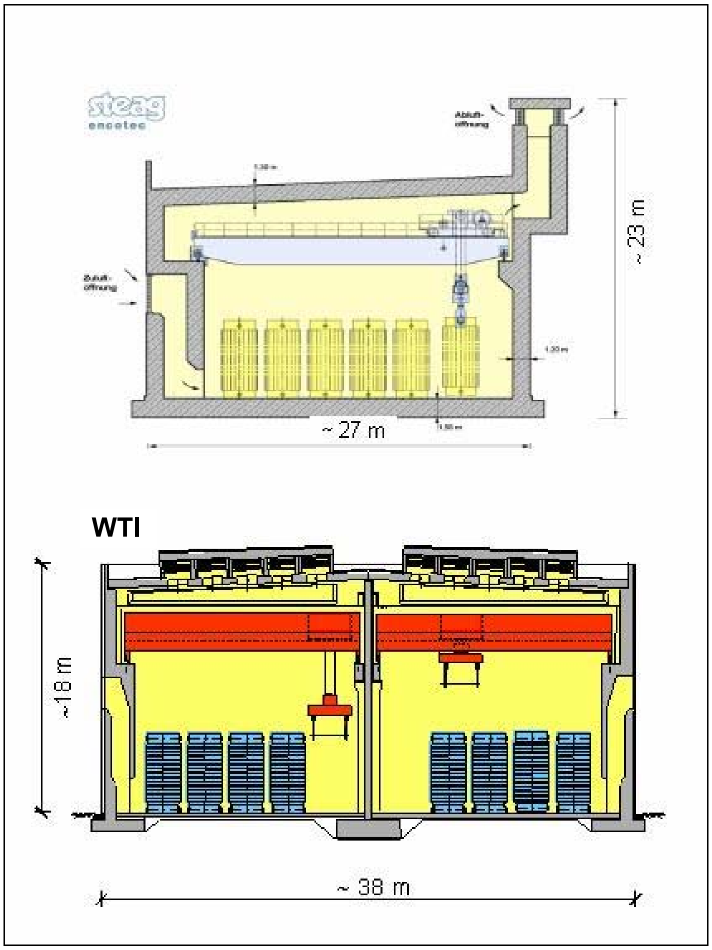

Fig. 2. Concepts for Interim Storage Buildings

ACTUAL STATUS OF LICENSING PROCEDURES

Involvement of the Public

BfS concluded the participation of the public as an essential part of the licensing procedures in the year 2001. Disclosure to public inspection and hearings have been performed for all of the 17 licensing procedures (9). A total of 250,000 objections was raised against the storage facilities. There are significant regional differences in public interest and opposition. The number of objections varies between less than 2,000 against the on-site storage facility at Brunsbüttel (Northern Germany) and more than 75,000 against the on-site interim storage facility at Gundremmingen (Southern Germany). 3 public hearings were held in 1999 and 2001. 14 hearings were carried out in 2001. A total of approximately 1,700 objectors participated in the 17 public hearings with altogether 63 days of discussion.

Transboundary Environmental Impact Assessment

In addition, participation of the public and of authorities of the Republic of Austria was carried out for the six interim storage facilities located in the south of Germany with regard to a transboundary environmental impact assessment (10). Other neighboring countries did not ask for such a participation in the licensing procedures. A total of 60,000 objections was raised from Austria. A public hearing for Austrian citizens took place on April 9, 2002, in Munich, Germany. Main topics of this hearing were questions concerning an attack by a large passenger airplane, a possible release of radioactive material and the risk of significant adverse transboundary environmental impact on the territory of the Republic of Austria.

Three Interim Storage Areas and Two Interim Storage Facilities Have Been Licensed

In 2001, BfS granted three licenses for interim storage areas at the sites Neckarwestheim (10^{th} April 2001), Philippsburg (31^{st} July 2001) and Biblis (21^{st} December 2001). In 2002, two licenses for on-site interim storage facilities of the STEAG-type at the sites Lingen (6^{th} November 2002) and Grohnde (20^{th} December 2002) were granted as well as the first supplementary license for the interim storage area Neckarwestheim (also 20^{th} December 2002).

According to applications the licenses comprise only one first licensing step. The applicants ask for a stepwise licensing of parts of an application to expedite issuing of a license. The excluded parts of the application remain to be pursued later on. For the three interim storage areas a second licensing step for parts that had not been decided yet (i.e. higher thermal output of the container inventory, wet loading process) was applied for. These supplementary licenses are elaborated in parallel to the first step licenses for the other on-site storage facilities.

The Neckarwestheim and Philippsburg interim storage areas took up operation immediately after the license had been granted. Presently 6 casks are stored at Neckarwestheim and 5 casks at Philippsburg. Both have a total capacity of 24 casks. The Biblis interim storage area was taken into operation in March 2002. It has a license for 28 casks, 12 casks are actually stored.

In difference to the licenses for the interim storage areas at Neckarwestheim and Philippsburg, no lawsuits were entered against the interim storage permission for the storage area Biblis; thus, this license is non-appealable.

With the license for the on-site interim storage facility Lingen is was permitted for the first time in Germany to store spent fuel for a longer period on the site of an operating nuclear power plant. A second license was granted for the smaller but almost identical storage facility at the site of Grohnde.

The license for Lingen allows the storage of 1,250 Mg heavy metal (HM) in up to 125 casks of the CASTOR V/19 type. For Grohnde, the storage of 1,000 Mg HM in up to 100 casks of the same type is permitted. Due to the early application of the Lingen facility in December 1998 and legislation at that time, no environmental impact assessment was required and it was possible to build the storage hall in advance, far before a license for the storage of fuel pursuant to Atomic Energy Act was granted. For the other interim storage facilities that have been applied for in 1999 or 2000, this is not possible due to changed legislation.

The interim storage facility Lingen took up operation on December 10, 2002 with the emplacement of one first cask containing 18 spent fuel elements. It is planned to add 5 more casks in 2003. The commencement of construction for the interim storage facility Grohnde is scheduled for spring 2003; operation will presumably start in 2004. The licenses for on-site interim storage facilities are published under www.bfs.de.

Status of Further Licensing Procedures

The status of verification of licensing prerequisites and the progress of the other licensing procedures for on-site storage facilities depends on the status of document submission by the applicants. BfS has involved experts and has ordered expert opinions for all projects with regard to safety of the facility, safety of the storage casks and environmental impact assessment. According to the German Atomic Energy Act, the necessary protection against disruptive action or other interference by third parties - including terrorist and sabotage acts - has also to be ensured. In 2001 the German Reactor Safety Commission (RSK) issued safety guidelines for dry interim storage of irradiated fuel assemblies in storage casks (11), which are applied for in the actual licensing procedures.

According to the actual time schedule, BfS plans to grant the first license for a WTI-type interim storage facility in February 2003.

CONSEQUENCES OF A FORCED AIRCRAFT CRASH

Detailed results of the different analyses concerning a forced aircraft crash cannot be released to the public because of security considerations. Nevertheless the procedure of the analysis and the fundamental results will be presented. The September 11, 2001, terrorist attacks on the WTC and Pentagon have drawn public attention to the consequences of a crash of large modern aircraft into nuclear interim storage facilities.

According to the German Atomic Energy Act, the licensing authority has to examine if the required protection is guaranteed. Acts of terror and sabotage have to be included in this examination. After September 11, 2001, it cannot be excluded any more, that also an interim storage facility will be the target of such an attack. That is why the German licensing authority, the Federal Office for Radiation Protection (BfS), has decided to include the analysis of an terrorist attack with an aircraft in the examination; the results are taken into account for the decision on the license of an interim storage facility. Before September 11, 2001, only accidental crashes of smaller military jets with much less amounts of jet fuel had been taken into consideration.

To fulfil the protection goals regarding impacts of a forced aircraft crash, this event must not lead to a considerable release of radioactive substances into the environment. This means, that the radiological effects have to remain below 100 mSv per person.

The analysis of a forced aircraft crash onto on-site interim storage facilities was started in May 2002 by an expert consortium commissioned by BfS. Subjects of the analyses are

- Aircraft crash scenarios, fire scenarios, load cases,
- Analysis of the mechanical and thermal impact on the different interim storage containment buildings (STEAG, WTI, tunnel),
- Analysis of the mechanical and thermal impact on the nuclear fuel storage casks including the impact on the nuclear inventory,

- Analysis of the consequences with respect to release of radionuclides,
- Radiological effects.

Up to now, aircraft crash analyses have been performed for the STEAG-designed storage facilities Lingen and Grohnde and for the WTI-building Grafenrheinfeld. 4 additional STAEG-facilities and 4 additional WTI-buildings will be analyzed. Moreover, the forced airplane crash has to be examined for the storage tunnel concept at Neckarwestheim. The existing interim storage facilities at Ahaus and Gorleben will also be analyzed with regard to the consequences of an aircraft attack.

Aircraft Crash Scenarios

For these analyses different sizes and types of aircraft categorized as light, middle heavy and heavy aircraft haven been considered up to the Boeing 747-400 and the Airbus 340-600. The maximum take off weights have been taken into account which include 216 m^3 (57,000 gallons) of fuel for the B747-400 and 195 m^3 (51,500 gallons) of fuel for the A 340-600. These reference aircraft are chosen, since they cover the wide range of possible mechanical and thermal impacts. The assumed flying speed of the aircraft is based on an analysis of the September 11 events, the maneuverability of an aircraft, the precision flying close to the ground to hit small targets and the reduced speed limit near surface due to aerodynamic difficulties. To complete this, flight simulator experiments were carried out. Also experienced pilots were consulted.

It is very unlikely that a terrorist pilot could strike an interim storage facility at the conservative impact points assumed in the analyses. Storage buildings have the following sizes: Length 80 m to 110 m, width: 27 m to 38 m, height: 18 - 24 m. Figure 3 provides a perspective of the size of a storage building (STEAG-concept) relative to the size of a Boeing 747.

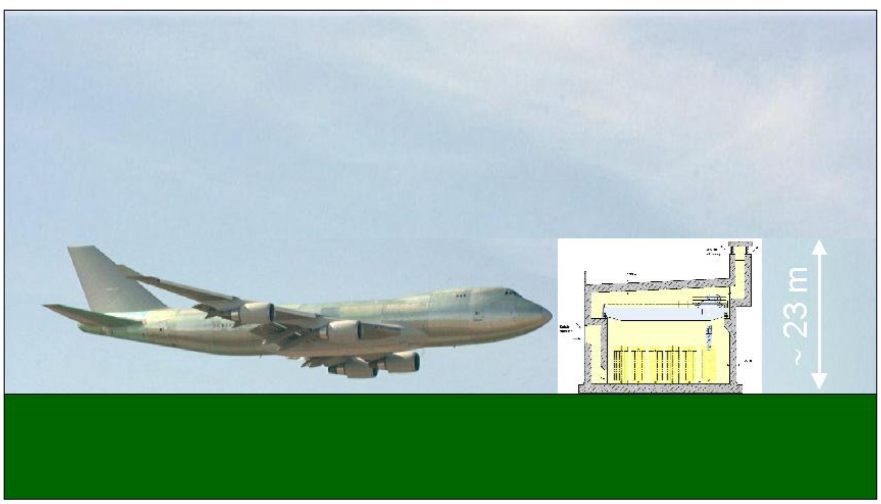

Fig. 3. STEAG-Building, Boeing 747, True Ratio of Size

Mechanical Impact onto Building

For the different types of aircraft the time dependent mechanical impact to a heavily steel-reinforced concrete wall has been calculated. The mechanical momentum of fuselage, wings and engines on a solid target has been analyzed in order to calculate whether an interim storage building can withstand direct aircraft crashes. If not, the remaining momentum of penetrating aircraft debris and the momentum of accelerated concrete wall and roof pieces have been considered.

Thermal Impact onto Building

For a forced aircraft crash onto an interim storage facility it has to be considered which amount of aviation fuel would enter the containment building and contribute to a thermal impact onto a spent fuel cask. Besides the aviation fuel the flammable parts of the airplane have to be taken into account. Depending on the robustness of the concrete wall of the interim storage facility all or at least parts of the fuel remain outside the building creating a fireball. Only a certain amount of the fuel can enter the building and contribute to a fire inside the partly destroyed interim storage facility.

The results of these analyses show that for the interim storage facilities with thick walls (1.2 m, STEAG-building) only 34 m^3 of fuel could get into the building leading to a fire duration of about 10 minutes. For interim storage facilities with less wall thickness (0.7 m / 0.85 m, WTI-building) a drainage system restricts the duration of a fuel fire also to about 10 minutes. The contribution of the flammable parts of the airplane has also been considered.

The consequences of this thermal impact with respect to the tightness of the casks and the release of radioactivity will be discussed below.

Consequences of an Aircraft Crash on the Building Structure

A first step in the modeling of an aircraft crash was the identification of hits relevant with respect to the dynamic response of interim storage building structures. Using sophisticated computer models the capacity of building structures to withstand an aircraft impact were analyzed. The design parameter included reinforcement of the concrete and thickness of the concrete structure. The analysis codes employed are recognized as state-of-the-art codes.

For the identified relevant hits the sequence of failure of the building structure, localized crushing and cracking of the concrete wall, the resulting debris configuration the building and the ventilation condition for the subsequent fire were analyzed. Hits onto the side walls and the roof were identified to be relevant. The analysis of the representative interim storage facility incorporates best estimate calculation methods in order to provide results that are as realistic as possible. As physical parameters of steel, concrete, reinforced concrete, fracture development and realistic material behavior is assumed. Figure 4 shows the results of the computer simulation for interim storage facilities of STEAG- and WTI-type.

The most important results of a nonlinear finite element calculation are that for an interim storage facility of the STEAG-type only local penetration of aircraft parts take place. The engines and other hard components of the front part of a disintegrating aircraft remain outside the building since - at that time – the integrity of the building is still given. Only the rear end of the fuselage can enter the building. The individual fragments are limited to a few hundred kilograms with a reduced speed in comparison with the arriving aircraft. This does not lead to any relevant mechanical impact onto the casks.

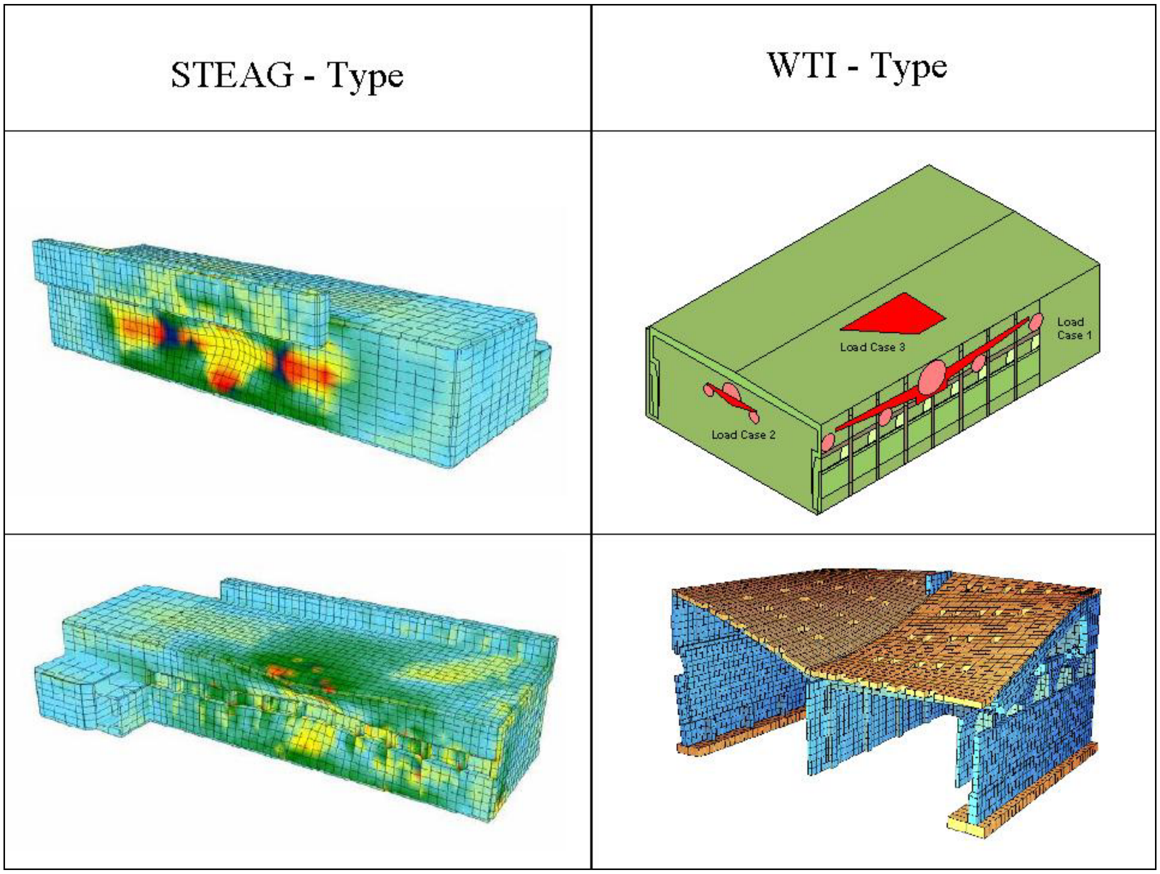

Fig. 4. Results of computer simulation of an aircraft crash onto an interim storage facility of the STEAG- and WTI-type.

The dynamic nonlinear finite element calculations for a WTI-type interim storage facility show that large aircraft with high speed would penetrate and travel completely through the building. Only aircraft with a reduced speed would remain inside the building. In this case the roof may be completely destroyed.

Thermal and Mechanical Impact onto Casks

The thermal impact onto casks depends on the amount of fuel getting into the building. For the STEAG-concept, the conditions of a restricted oxygen supply, a resulting burning rate of 2 mm/min and a mean temperature of 1,100°C would lead to a fuel fire duration of about 10 minutes in the worst case. For the other burnable materials a maximum temperature of 940°C and a fire duration of less than one hour was calculated. For the WTI-concept– due to the drainage system – the fuel fire would achieve a maximum temperature of less than 1,100°C and a duration of also about 10 minutes, whereas the other burnable materials would lead to a maximum fire temperature of about 700°C after 23 minutes.

One of the main results of the analyses is that the thermal impact onto casks does not cause any relevant decrease of the leak tightness.

The mechanical impacts onto the fuel storage casks were also analyzed. A hitting engine or falling roof elements might slightly reduce the integrity of the casks and increase the leakage.

The German Reactor Safety Commission (RSK) has also stated that the licensed casks for spent fuel will ensure the fundamental safety function of safe enclosure of radioactive substances also in the event of a deliberate crash of a large aircraft due to the construction of the casks (12).

Radiological Effects

The radiological effects of an aircraft crash have been calculated. Such an incident does not lead to any risk of health or life due to radioactivity release out of the nuclear fuel storage casks caused by mechanical and/or thermal impact, assuming that the consumption of contaminated food can be excluded. The maximum effective dose is limited to less than 10 mSv outside the site taking into account a seven day exposure to the calculated radioactivity release. This means that a forced aircraft crash leads to a maximum dose which is by factor 10 lower than the required dose limit.

PROSPECTS

It is the objective of BfS to decide on the applications for 10 further on-site interim storage facilities and 2 further storage areas successively in the year 2003. Essential for this is, however, that the applicants submit verifiable licensing and verification documents in time and that the licensing prerequisites can be met. Organizational measures and project management methods enable the licensing team to elaborate one license per month. With an assumed construction period for the storage buildings of about two years, the on-site interim storage facilities could then be available around 2005.

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