HOW TO GET A CAMEL TO GO THROUGH THE EYE OF A NEEDLE: SUCCESSFUL SITE REMEDIATION OF A FORMER EXPLOSIVES PRODUCTION SITE: SAFE HOUSING, WORKING AND DRINKING WATER PRODUCTION ON A LONG-TERM BASIS

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1. The challenge

Anyone visiting Stadtallendorf in the State of Hesse will find a more or less typical German small town with some 22,000 inhabitants, its commercial, industrial and residential areas. It is home to a few large business enterprises, many small businesses and, in between all this, houses where people live. For visitors it might seem strange that many of the houses have enormously thick concrete flat roofs, many of which are covered with trees and greenery (Fig. 1).

Fig. 1 Old building (historic Photo)

Instead of this booming industrial estate there could actually be flourishing forest. After the end of World War II it was uncertain for a long time what was going to happen to this area. The problem was / is that during the war this was the largest munitions production site in Europe. Here, under strict secrecy, the two armaments manufacturers, WASAG and DAG produced explosives to arm bombs and grenades on site. The two ammunition factories covered an area of some 1,000 ha and, as camouflage against air reconnaissance, were located in the midst of the forest. More than 15,000 forced laborers had to work here in the arms factories.

During the Second World War the site was untouched by Allied air raids. It wasn't until after the war that the Americans dismantled and blew up parts of the armament plants. And this resulted in one of the worst cases of environmental damage in Germany: soil, streams and groundwater in a wide surrounding area were all contaminated with highly toxic substances from the explosives. At that point there was no talk of investigations, not to mention remediation. In the post-war period buildings which were half-way intact were put to use – despite the contamination – and new buildings constructed on site. It wasn't until the 1980's and a change in our environmental awareness made it clear just how great the extent of contamination was and its risk to human health and environment. However, since neither the technology nor the finances for a remediation were in place, the retrogression to a forestal area closed to the public was in real terms the option for a long time.

But things turned out differently: among the local people and the town itself there was a total lack of understanding and little support for the option "Forest". They had been living and working here too long and simply could not imagine such a hard cut. The realization of this option would have meant the relocation of all the people living there and all the business enterprises plus the abandonment of the waterworks. Since this option was neither enforceable nor politically desired, a remediation process was started, although at this point no one really had an idea of how this remediation could work. What about the contaminants from the explosives in the soil and groundwater? Would it be possible to remove the contaminated soils without evacuating parts of the area – or indeed the entire area? Would the excavation not mean an enormous increase in the groundwater pollution – more than ever before? And who was going to assume responsibility for such work whose consequences cannot be foreseen because no one has any experience in this field. These were just a few of the very many questions and issues that concerned and moved the people at that time. For most people remediating the site seemed as impossible as getting the proverbial camel through the eye of a needle.

2. Soil and groundwater pollution, risk assessment

It was clear from the beginning that, if a remediation were to be taken into consideration, an accurate picture of the actual pollution had to be made. This meant answering the following questions: Where is there soil pollution, what kind of pollution and how deep does this go? How far had the substances already been transported by the groundwater, and again, how deep? It was also necessary to answer the question as to the risks for health and environment connected to the pollution. There was only very little scientific background available on such work. At that time there was a fierce debate on the extent of the danger involved.

The first orienting investigations and an historical examination were carried out from 1988 to 1991. In the subsequent years until 1997 a complete risk assessment with thousands of drilling and probing activities were carried out.

The examinations showed the following on-site contaminant spectrum:

By the production of explosives as well as by decommissioning, dismantling and construction work in the post-war era there was an input of contaminants by fluids, dusts as well as particles into the soil and groundwater. The dominating contaminants were aromatic nitro compounds, in particular:

- 2,4,6-trinitrotoluene (TNT)
- 4-amino-2,6-and 2-amino-4,6-dinitrotoluene (A-DNT)
- 2,4-and 2,6-dinitrotoluene (DNT)
- 1,3,5-trinitrobenzene (TNB)
- 2-,3,and 4-mononitrotoluene (MNT)
- 2-amino-4-nitrotoluoene (A-NT), 2-amino-6-nitrotoluoene (A-NT)

In addition contamination with RDX and hexyl as well as with contaminants, which are not explosive-specific, in particular PAH had been detected.

The contaminants were found in the soil, soil vapour, room air, building structure, organic materials (e.g. leaves, fruit, fungi, fish), sewage system and groundwater.

The distribution of contaminants was heterogeneous, contamination was both scattered and concentrated in hot spots. Sporadically crystalline pure TNT was found (Fig. 2). The contamination in some areas was so severe that a risk to human health could not be excluded. People could come into contact with hazardous substances in particular via the soil (consumption of home grown food). The data from groundwater monitoring showed that the aquifer was contaminated.

A site-specific and target-specific risk assessment had been elaborated. Soil action values could be deduced considering toxicity data, tolerable body doses, relevant exposure scenarios and the relevance and importance of the individual exposure pathways. Evaluation of single substances would have led to an underestimation of the total risk. The evaluation was done by a weighted summation of individual substances, meaning that the resulting tolerable soil values are given in mg TNT-equivalents (TNT-TE). Toxicity coefficients were developed for relevant contaminants and for short, medium and long term exposure to evaluate the toxicity.

On this basis intervention values for the sum of 10 aromatic nitro-compounds as well as for four individual substances were determined, differentiating use and exposure time.

Fig. 2: Fragment of cristalline TNT

3. Overall concept of remediation

At the beginning of the remediation process the many stakeholders (e.g. The State of Hesse, municipality, water suppliers, property owners, residents) all had very different interests and objectives. However, in a long discussion process a consensus of shared objectives could be reached:

- The overall objective was the successful, i.e. the economically and ecologically effective and socially compatible realisation of a use-specific remediation.
- The remediation should eliminate or significantly reduce the impairments caused by soil and groundwater pollution to the land use and to the general public.
- The location should be kept as a residential and business location and interventions in green areas should be minimised.
- Drinking water production from the Stadtallendorf waterworks should be kept on a long-term basis. The soil decontamination should not pose a risk to drinking water production.

At the outset of the work it was critical that among the many parties involved the objectives and the appropriate measures could be defined. The discussion was carried out using an overall concept of remediation which, bit-by-bit in the many discussions, developed into an overall concept.

The various people involved were asked the same question: From your point of view, what has to happen to ensure that the site has a secure future? Here the similarities and differences among the various ideas were weighed up and systematically dealt with. The overall concept of remediation evolving from this summarized all elements of the remediation strategy in a poster. This clear visualization turned out to be extremely helpful in the discussions with inter-disciplinary experts (e.g. engineers, chemists, geologists, urban planners, politicians) as well as in discussions with the general public. The contexts and interrelationships of the individual remediation elements were comprehensible and the people involved could see a common goal. This clearly understandable overall concept of remediation, which was shown at every meeting over the years, was at the end of the day one of the reasons for the high level of acceptance of the planned measures.

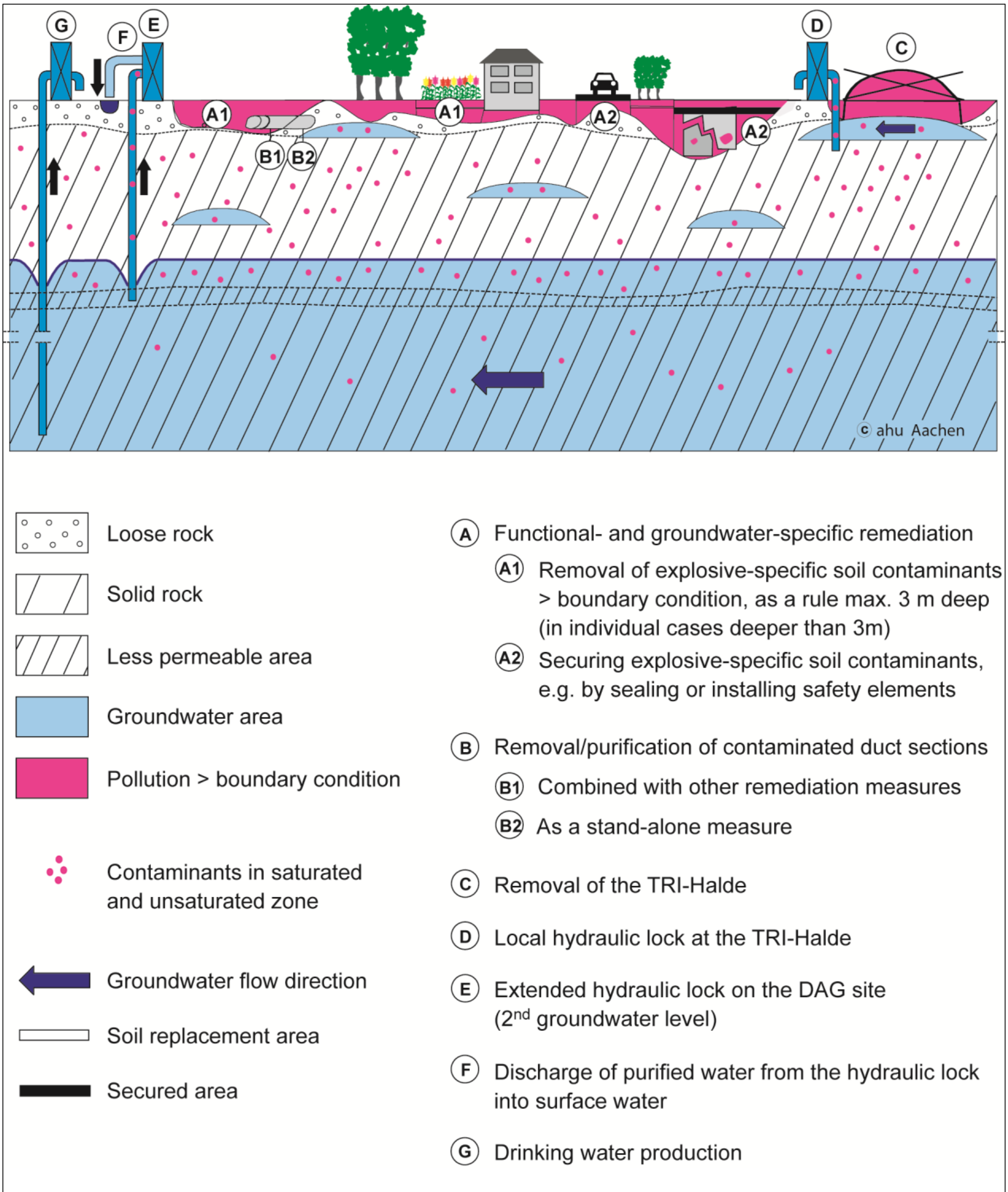

Fig. 3: Overall concept of remediation in Stadtallendorf

4. Remediation measures

Going by the overall objectives, the following issues were included in the overall concept of remediation and detailed measures carried out.

Soil remediation

In open spaces and gardens soil excavation was carried out up to a depth of 3 metres – sometimes even deeper. The crucial factor here was that the use-specific intervention levels were exceeded (soil excavation up to 1 m) and a soil remediation on a groundwater basis (up to 3 m and deeper) (Fig. 4). The entire excavation volume amounted to some 220,000 tonnes and the removal of explosive-typical substances approx. 125,000 kg. The proceedings were carried out under the highest precaution measures (under the aspect of work safety and protection of the local residents). For instance, the excavation work was mostly carried out under the protection of tent constructions. The excavated soil was transferred to an interim storage and thermally treated in an incineration plant. After the soil remediation there is still a diffuse residual contamination in the soil and aquifers. The remediation of these would be almost impossible or only possible with unreasonable expenditure and effort. The residual pollutant potential is estimated at approx. 30 - 40 t of explosive specific compounds.

Fig. 4 Soil remediation

Remediation of a waste dump

One of the biggest challenges on site was the removal of a dump (*TRI-Halde*) comprising sludge from the production explosives. The sheer size (240 m long, 50 m wide and 7 m high) and the substances meant considerable pollution for the groundwater. During this remediation measure approx. 96,000 t of material with some 270 t of explosive-specific compounds removed. This was the largest single measure on site: a largely air-tight hall (steel construction) with dimensions of 65 m x 248 m and 14 m high was built to encase the whole dump in order to prevent emissions (Fig. 5). The encapsulation was of priority to prevent pollutant emissions from the open dump via the air. Due to its high water content the removed material had to be conditioned on site, so that it could be transported and stored. The material then underwent thermal treatment and rendered harmless.

Fig. 5: Remediation of TRI-Halde

Sewer renovation
From 1996 to 2004 a **sewer system** covering some 70 km was investigated. Contaminated sewer lines were cleaned with high pressure, closed down, backfilled or in some places removed. All in all, a total of 3 t TNT was removed from the pipes or from the contaminated flushing water.

Groundwater protection
The waterworks of the explosives production continued to be used after the end of the war and has provided the public within a wide radius with drinking water (up to 13 million m³/a).
In the development of the overall concept of remediation maintaining the water extraction and supply was always a basic requirement. In the beginning there was great concern that the soil remediation would increase the pollution of groundwater and pose an additional hazard for the drinking water supply.

To protect the drinking water supply a hydraulic safeguard was planned and went into operation in 1995. In the immediate proximity of the contaminated areas this comprises nine wells, which prevent the inflow of contaminated groundwater into the extraction wells for the drinking water supply and minimises the contaminated groundwater downstream from the former explosives production site. It was only with this protection that the soil remediation could be carried out. The water collected by the hydraulic safeguard is purified using wet activated carbon in a special water treatment facility. This hydraulic safeguard has been in operation for 20 years now without any failures or the permissible values being exceeded. The volume of groundwater extracted from 1995 to 2013 amounted to 8.5 million m³; the load of explosive-specific compounds removed in the same period was approx. 1,700 kg.

The hydraulic measures have to date always been accompanied by extensive groundwater monitoring programmes. The some 160 remediation wells, drinking-water wells and groundwater monitoring wells are analysed on a regular basis. This includes examining whether there are any changes in the quality of the groundwater or deviations from the prognosis, whether there is a spread of pollutants beyond the protected area and whether the threshold values for drinking-water wells are observed.

After ten years' remediation work the remediation was successfully completed in 2010. Fig. 6 shows the remediation result of the individual measures. In a cost/benefit balance these items are on the cost side. The expenditure can be offset by the benefit: as far as ground and water are concerned, basic needs for life have been secured for the people living and working there and, to a large extent, a protected environment and a tenable industrial location important for the region and securing more than 8,500 jobs.

Soil excavation volume	**200,000 t**
Soil load	**125,000 kg**
Water output	**8.500,000 m³**
Water load	**5,800 kg**
Sewer load	**3,000 kg**
Explosives	**24,000 kg**
Area	**420 ha**
Cash flow	**168 million €**

Fig. 6 Remediation Balance, Stadtallendorf

5. Factors of success

In retrospect, the following factors were decisive in the successful completion of the remediation and in “getting the camel through the eye of the needle”:

(1) The common will for the remediation and the will of the State of Hesse to bear the remediation costs

These were the basic prerequisites for starting the project and being able to pursue it from more than 25 years. One thing that was particularly noteworthy was the political support received, which despite changing political majorities and directions, was always in place. Once the remediation had started it was never seriously questioned or disputed in all that time, even if major individual measures such as the remediation of TRI-Halde with more than 50 million € remediation and disposal costs truly were milestones. Remediation agreements made between property owners and the State of Hesse exempted the property owners from any costs for the remediation of explosive-specific compounds without a time limit. This was the basis for a remediation without any legal disputes.

(2) Communication among all involved and affected

The fact that the many stakeholders were from different disciplines, had various responsibilities and interests, as well as different experience called for good **communication skills** so that they were able to communicate with one another and with the people affected.

Successfully structuring and organizing the communication was one of the key success factors. Here it was just as important to ensure **transparent decision-making processes** and **clear competencies** as it was to provide **data and information** and seek a **dialogue and consensus** among the specialists.

Active and comprehensive **PR work**, taking all interests into consideration and the emphasis on di**alogue and consensus** as the decisive principles were a key prerequisite for the success of the project. Participation and open information did not impede the remediation, they played their part in finding better solutions.

A citizens’ bureau was a central contact point and was there to support the people affected during the remediation process. These public participation tools tried out for the first time here have since become established forms of involving the parties concerned in planning and decision-making processes.

(3) Support by two major research projects
In the Federal Ministry for Education and Research [BMBF] project **MOSAL** the fundamental principles for the various fields of work were laid down. The funds made available were for the Stadtallendorf remediation ultimately a start-up financing.
The **MONASTA** project, also funded by BMBF and carried out in the KORA R+D joint project, focussed on natural attenuation processes of explosive-specific compounds in the soil and groundwater and provided a basis for a reliable estimation of the operating time for the hydraulic safeguard and strategic concepts for dealing with residual pollution.
The R+D projects provided diverse access to information sources and to become part of nationwide and international debate.

(4) Thorough and comprehensible project management
The high specialist and technical safety requirements, the scope and the duration of the work, plus the amount of people involved meant that an effective p**roject management** was of key importance for the success of the project. The essential instruments here were the overall concept of remediation, the project manual and coordination and communication committees.
A project manual that was available to all formed the basis of the project management. It documented the goals, organisation (responsibilities) and structure of the project, as well as the essential procedures and issues. A major positive effect was the joint elaboration of the basics with the key stakeholders in facilitated workshops. The results achieved in this often multi-level coordination and quality assurance process have proved to be lasting.

(5) Investigation planning and execution of remediation work
Whereas new approaches had to be found in the project management and procedures, the actual remediation work could resort to conventional engineering methods. Here, however, the careful planning, execution and monitoring of the remediation work played an important part. This meant that the confidence in the work and in the success of the remediation was never undermined.

(6) Courage, patience and understanding on the part of the many people involved at all levels, i.e. politicians, local administration, residents and employees
Without this, such a project would have been inconceivable. When money is tight, publicly putting up a case for such a costly remediation measure and tolerating soil excavation work with heavy equipment in "your own backyard" shows just how convinced the people involved were of the benefits of the project.

6. Perspectives and follow-up work

With the soil remediation completed in 2005 the idea was that the project had been wound up. On both the administrative and operative side funds personnel could indeed be reduced, and the public interest the project had enjoyed over the years diminished.

At non-accessible levels or where contaminants have not been removed for functional and strategic reasons, it is still necessary to continue with the hydraulic safeguard and controlled handling and treatment of soil during construction projects. The **handling** of these "residues" also calls for a carefully planned approach.

For this reason the State of Hesse will have to allocate personnel and financial resources for the follow-up for several decades. And this will remain a topic on the agenda for the municipality and the property owners.

The objective of the follow-up work is that the residual contaminants after the remediation pose no danger to human safety and health or risk to the environment in connection with the existing and planned use of the land. Fig. 7 shows the fields of the follow-up activities.

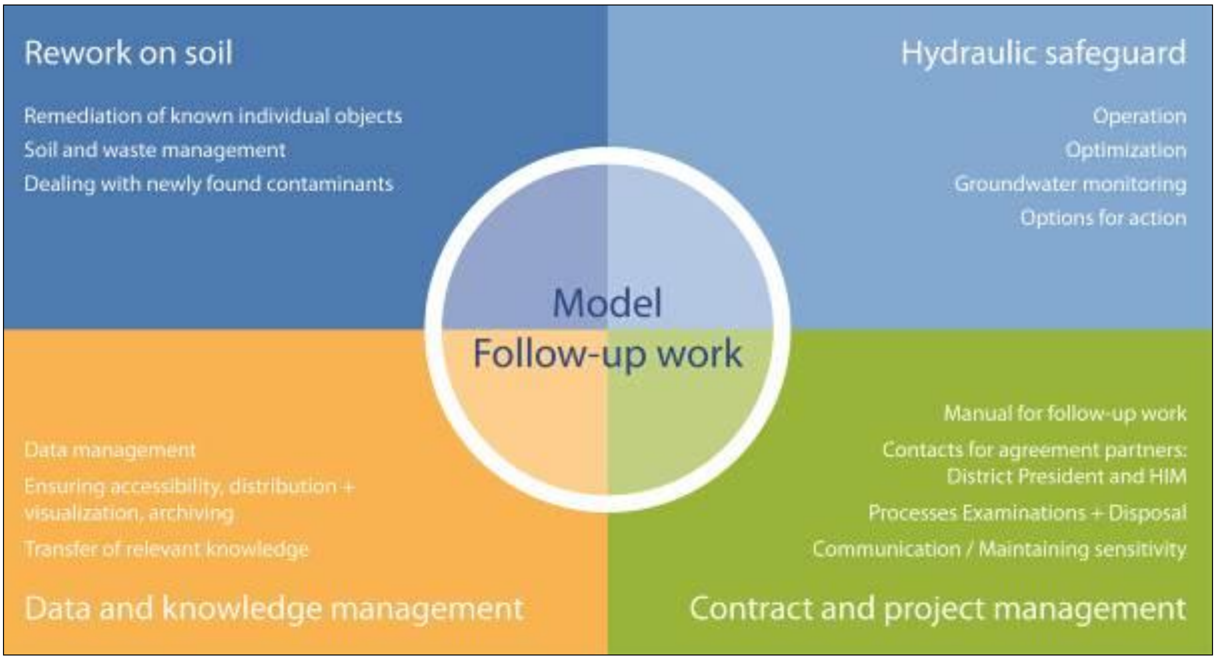

Fig. 7: Follow-up model for Stadtallendorf

7. Concluding remark

For some time now there have been no considerations of abandoning the location and any fears that a remediation of this location would be impossible have been clearly refuted. To the contrary, the work carried out in Stadtallendorf have played a substantial part in showing that nowadays there are no insurmountable technical challenges in the remediation of inhabited former armaments sites – neither in the exploration nor in the evaluation or remediation. All instruments have been tried and tested and are available. Remediation is possible! The camel got through the eye of the needle.

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