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Remediation of the low-level radioactive
waste tailing pond at Kowary, Poland

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Remediation of the Low-level Radioactive Waste Tailing Pond at Kowary, Poland

Final Report

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Summary

The last remaining uranium mining tailing pond in Poland, situated at Kowary, was the subject of the “Kowary Tailing Pond Remediation Programme” financed by Polish public bodies (70%) and by the European Commission (30%) within the framework of its programme of co-operation on radioactive waste issues with candidate countries.

The EC-part of the project comprised investigations of the site, project management duties and large-scale civil works following the initial remediation planning performed by the Wroclaw University of Technology (WUT) in 1998-2000. The EC-part was contracted to G.E.O.S. Freiberg Ingenieurgesellschaft mbH following an Open Call for Tender launched by the European Commission in 1999.

The following general tasks were performed in close co-operation with WUT, with the construction works subcontracted to local companies, as proposed in the Terms of Reference (TOR) of the EC-part (see Annex 1):

- review of General Remediation Plan (GRP),
- technical design of the pond cover,
- construction work: internal drainage system, pond cover and site reclamation.

From the information in the TOR, the following aims of remediation were defined:

- minimise the detrimental impact of the tailing pond on the environment,
- provide long-term stability of the slopes surrounding the pond,
- ensure the remediated site is in harmony with the surrounding natural scenery.

Based on the experience gathered in similar projects, which had been running under PHARE-MCE or which belonged to the WISWUT-remediation programme in Germany, cost efficient remediation solutions were designed in close co-operation with all involved parties. They were delineated in the detailed planning documents approved in the overall remediation programme managed by WUT.

The planned remediation works were prepared and performed successfully according to Polish law and in agreement with the competent local authorities. The aims of remediation were met. However, some additional tasks have been recommended in zones adjacent to the tailing pond remediation area.

The efforts of all involved partners have allowed the EC-part of the Kowary Remediation Project to be completed on time and within the planned financial budget.
Fig. 1  Situation on site prior to remediation

Fig. 2  Completion of pond cover
1. Introduction

Past mining and processing of uranium ore led to the construction of the tailing pond in Kowary, located in the Jelenia Gora District at the northern slope of Karkonosze mountains. Mining ceased in 1963 but ore processing continued until 1972. In the early seventies, Wroclaw University of Technology (WUT) took over ownership of the area and facilities. In addition, the ore processing plant and the tailing pond were used for experimental processing of rare metals containing sands. The tailing pond was recommended for technical remediation measures because of contamination with radionuclides and limited geotechnical stability (see the TOR, Annex 1, for more detailed background information on the site).

A number of bodies have contributed to the overall remediation project. In general, WUT financed the preliminary studies and technical work. The National and Regional Environmental Protection Funds (NFOS/WFOS) supported the investigation programme on-site and the preliminary design. The European Commission financed part of the detailed design and the final remediation (construction) works (EC-part) - for details see annex 1.

The EC-part of the overall Kowary remediation project started in April 2000. It included the review of the General Remediation Plan (GRP, Task 1), the technical design of the pond cover (Task 2) and the remediation civil works (Task 3) performed via subcontract with a local construction firm. The preparation of the call for tender for Task 3 and the evaluation of the resulting bids were also tasks under the responsibility of the EC contractor.

The 1st Progress report, dated 2000-10-4, reviewed the basic aspects of the General GRP for the Kowary site, produced by the WUT. The 2nd Progress report, dated 2001-04-30, reviewed the detail technical planning documents and the preparation of the technical remediation works.

Planning of technical remediation based on GRP was carried out by WUT in co-operation with G.E.O.S. / GEOBAD and was finished in December 2000. The technical remediation works started in early July and were finished in September 2001. Some guarantee works of the sub-contractor TRASKO, responsible for the construction works, continued until October 2001.

Close co-operation between WUT and G.E.O.S. was crucial for the effective running of the project and was responsible for the high quality of the finished result. In line with the Co-
operation Agreement between both sides signed in September 2000, close working contacts were developed to ensure the required progress during the project and the overall performance.

Key decisions concerning the EC-part of the project were discussed with the European Commission’s Technical Project Manager and the Polish Atomic Agency/Steering Committee (Dr. Z. Waclawek).

2. Review of General Remediation Plan (GRP)

2.1 Evaluation of PHARE Pilot Projects

Within the PHARE Programme of the European Commission there were a number of uranium mining pilot projects having some relevance to the situation at Kowary, namely:

- Preparing remediation at uranium milling and mining sites in the PHARE countries; provisions of means to assess radiological risk (1998)
- Remediation concepts for the uranium mining operations in CEEC (1998)
- Technical planning of the long-term stabilisation of tailing ponds (1999)
- Concepts and design of reshaping and covering the Sillamae radioactive tailing pond.

The EC Contractor's team was familiar with results of some of these projects and in addition took the opportunity to consult with leading experts such as Prof. Gatzweiler, Dr. Jakubick, Dr. Hähne (all from Chemnitz) and to discuss with them in detail how to transfer results and experiences obtained from these projects to the Kowary project, with the aim of improving the tailing pond remediation planning. In addition, the Polish team members, Dr. Koszela and Mr. Krzyskow, visited the Steering Committee expert, Ms. Dr. Waclawek, in Warsaw in order to study the reports and to discuss specific problems.

Furthermore, expert meetings were used intensively during the performance of Task 1:

- Excursion to Sillamae (Estonia) by Dr. Koszela and other experts of WUT,
- Participation in the WISMUT Conference on "Mine closure and remediation", held in Schlema/Germany during the EXPO 2000 (July 2000)
- Ms. Dr. Waclawek from the Polish Atomic Agency took an active part in all the project workshops.

In this way, the relevant results and experiences from other uranium mining remediation projects were of direct benefit to the Kowary project.

Analysis of former or current remediation works at similar small tailing ponds in Germany/Saxony, like Bielatal (Altenberg), Saugrund (Freital) and Borbachtal (Schlema) was also of high value. At these sites, G.E.O.S. had carried out investigations for various clients. Furthermore, information was gathered in the context of professional visits. Another source of experience and know-how used by the Contractor in the Kowary project was from contracts concluded by WISMUT with G.E.O.S. for the planning and supervision of dump remediation at various other mines (Gittersee, Schlema). This allowed specific experience to be gathered in the evaluation of remediation characteristics even down to the fine detail, and this was of special importance with regard to the selection of suitable remediation technologies. This experience was used directly in the detailed planning at Kowary and for the deduction of specific proposals to optimise the project and to find cost efficient solutions within the foreseen budget.

2.2 Assessment of Data Completeness

WUT performed a large scientific investigation programme at the tailing pond site in 1998/1999. The results are described in more than 30 reports in Polish. The parts most important for remediation planning were translated into English. The Contractor’s study of these documents concentrated on problems and information essential for the site remediation.

Additionally, two site visits to Kowary were used at this stage to

- discuss the results and the method of radiological measurements with the responsible Polish experts,
- carry out comparison measurements of the direct gamma-radiation,
- check the conditions of measurements and sampling,
- take additional samples for comparing analyses of the specific activity concentration of radio-nuclides in tailing pond material.
Through these reports and the consultations, much information was provided from the comprehensive investigation programme already carried out by WUT. The results can be summarised as follows:

(1) **Groundwater:** The natural aquifers at the site are of minor importance, because they are limited to the weathered upper zone of the hard rock and the fractured zones within the hard rock. Both show mostly low permeability and low water flow. Effluents from the abandoned mines sampled in the adits occur with different flow rates depending on seasonal changes of the precipitation. Some of these samples showed increased concentrations of pollutants. Because it was known that the flooded mine was located away from the tailing pond, this contamination could not be connected with effects from the tailings. For this reason, this contamination path was not considered further. For technical reasons, it was necessary to impose a relatively high minimum detectable radionuclide concentration during the laboratory analyses of water samples, and in addition the number of data points for evaluation was limited. Despite this, it could be concluded that the results were sufficient for the purposes of the ensuing planning and remediation works.

(2) **Surface water:** The investigations included water from the tailing pond, the Jedlica river and effluents from the tailings penetrating the dam. Although the pond water and the effluents showed strong contamination with salts, heavy metals and radionuclides, no significant contamination in the Jedlica water could be found. This is probably linked to the poor transport qualities of the aquifers, as described above. Again, for technical reasons, it was necessary to impose a relatively high minimum detectable radionuclide concentration during the laboratory analyses of water samples, and in addition the number of data points for evaluation was limited. This required very conservative calculations of exposure rates (see [BPS00-1]). Nevertheless, it could be concluded that the results obtained were sufficient for the purposes of the ensuing planning and remediation works. In future, an additional sampling point should be planned downstream of the tailing pond in the Jedlica river as part of the monitoring programme, and the detection limits for radio-nuclides in water should be lowered to at least

- 0.5 Bq/l for U-238
- 0.2 Bq/l for Ra-226
- 0.1 Bq/l for Pb-210
- 0.1 Bq/l for Po-210
This is according to experience gathered in uranium mine remediation in Germany. Water sampling and analyses are part of the planned site monitoring to control the environmental quality after completion of the pond remediation.

(3) **Soils:** The comprehensive investigation programme provided detailed information about chemical and radioactive characteristics of the tailing pond. The materials disposed of in the pond are in a mostly alkaline environment. Only at one site on the southern dam did sulfidic waste rocks of high heavy metal concentration and high radioactivity occur. Here, owing to alteration and oxidation, the pH-value decreased to such a low level that this area remained free of vegetation. All these different conditions have been investigated and described in sufficient detail. As the ambient gamma dose rate was especially important in the evaluation of the radiological situation at the surface, comparison measurements were performed as part of the quality assurance measures. These took place at different characteristic locations of the tailing pond using the measurement devices provided by the Polish partners, which had been used during the former measuring campaigns, and a device belonging to G.E.O.S. (calibrated at the Federal Radiation Protection Agency). The outcome was that in those locations where anomalies had been noticed, both devices produced similar quality of results. However, a check of the analysed radionuclide concentrations in solid matter obtained using gamma spectroscopy at the WUT laboratory showed some apparent discrepancies between the values for different nuclides in the decay chain. These could not be cleared up in later discussions (see detailed report in [BPS00-1]). Finally, four new samples were taken, divided each into two identical parts and then analysed in parallel in the laboratory at WUT and that of IAF-Radioökologie GmbH in Germany. Unfortunately, only the data of the German laboratory were available at the time of reporting, so at the moment conclusions can only be drawn on the level of the radionuclide concentrations and not on the distribution. Nonetheless, it is confirmed that there were high levels of radioactive contamination at the four sampling points. The discrepancies between the two laboratories are to be discussed and cleared up later.

(4) **Air:** WUT carried out measurements of the radioactive noble gas Radon-222 in the near surface atmosphere and in the ground air. Comparing the radon concentration in the soil with the average Ra-226 activity (calculated from the ambient gamma dose rates at the point of measurement), the radon concentrations appear to be quite low. This can be a result of the specific soil conditions (small grain size, high water content etc.). The measurements of the Rn-222 activity concentration in the atmosphere above the tailing pond provided results of limited use. This was because they were carried out only over a
period of one hour. This method, which is very sensitive to changing meteorological conditions, provides less reliable results under the given conditions. A second problem was that the measurements took place immediately above the ground so they could not be used to provide reliable conclusions with regards to the breathable air at level of about 1.5 m above ground. Other measurements, e.g. of dust, were not carried out at the tailing pond site. It was therefore concluded that the radon data were not usable in the estimation of dose. Also, calculations of the inhalation of contaminated dust could not be carried out because gamma spectrometric analyses of dust samples were not available. However, as radon and dust were not the main decision criteria for site remediation, this lack of precise information was acceptable at this stage.

(5) The investigation and description of the situation of the Kowary site contain extensive analyses of the microbial composition of the water and in the disposed solids. For a better understanding of the microbiological problems and the action of micro-organisms under different conditions in the site compartments, a detailed description of all scenarios and probabilities had been advantageous. This meant the description of:

- the activity of the micro-organisms in the hazardous material and of the escape of harmful substances under aerobic conditions characterised by high or low contents of oxygen and at different pH-values,
- the activity of micro-organisms in the hazardous material and of the escape of harmful substances under anaerobic conditions at different pH-values and different degrees of anaerobic state,
- the influence of natural organic materials in the disposed wastes on the microbial reactions and the possibly formed metabolites,
- the effects of complex-forming substances and the transport of harmful substances by nano-particles or by molecular dispersal.

Based on such a description, a complex estimation of the microbiological behaviour in the disposed materials on the site and the future development of reactions was possible. This was a prerequisite for the application and installation of a suitable monitoring system (frequency, type, recommendations in event of irregularities).

(6) Geotechnical data:
First it was checked whether the geotechnical data from the performed investigations corresponded to the requirements of the remediation programme. Geological-
hydrogeological data necessary for the planning of the construction works and the design of the drainage system were already known, whereas soil-physical parameters and classification of soils were provided as a result of the site exploration. The existing pre-design of the internal dewatering system and of the layer-drainage (using geotextiles, stabilising “GEOGRID” and broken dolomite rock) consisted of cutting into the southern disposed tailing to increase the dewatering efficiency using a combination of a drainage layer and drainage ditches. The technical equipment used in such construction works required operation on a safe and stable tailing ground surface. Investigations on this topic, e.g. soil bearing capacity and shear strength of the tailing material, were therefore carried out. Contouring of the surface shape of the remediation site and construction of the final pond cover should be based on the use of displaced soil materials from the tailing pond and from other sources. The suitability of material from the site (northern dam) was investigated. This allowed consideration of such parameters as suitability for re-deposition or compactibility of the soils during execution of the planning works. Additional soil material to be procured from outside the tailing pond had to comply with certain quality control parameters defined for each single vertical section of the multi-layer cover system. A prognosis concerning the tailing deformation under load was done as a prerequisite for the assessment of settlement as well as for the planning of the site shaping. Deformations were evaluated in the stability analysis report. The question of dam stability had been investigated by the method of finite elements. In connection with the planning of the remediation works, new stability calculations were necessary with regard to the different technical solutions. This included the stability state of the tailing during the construction activities as well the stability under the final conditions. A soil-physical model was provided for the existing soil materials. The required basic soil-physical parameters for soils to be used for the cover system were defined during the planning. The hydrogeological model was supplied. The final geometrical model for the remediated site was designed during the planning works and took into consideration the results of the stability calculations.

The dam slopes near to the Jedlica riverbank had already been protected against erosion, though the measures taken were not of a long-term character. However, such water-engineering and technical works were not the responsibility of WUT, as stated above, and any further measures were therefore not part of the original Kowary project (NB In 2001, WUT applied for additional funds to cover works on the riverbed).
2.3  Technical Assistance concerning the General Remediation Plan

2.3.1 Consulting Activities

Consultations were used to support the elaboration of the General Remediation Plan (GRP).

The EU project experts and the WUT contacted the Polish State Atomic Agency in order to agree how to consider the radiation protection requirements in the Kowary remediation project. The answer from the responsible authority (letter, dated 13 June 2000, see enclosure 5) indicated:

- The remediation project will not fall under the Polish Atomic Law.
- The remediation project should be based on the European standards for the remediation of mining sites characterised by increased levels of naturally occurring radioactivity.

Following this recommendation, WUT first of all decided to base their planning on German experience and regulations - i.e. the remediation measures employed by the uranium company WISMUT at the BORBACH DAM at Schlema and other tailing dam sites in Saxony and Thuringia.

The Polish experts (WUT, GEOBAD and proGEO) and the EU experts (G.E.O.S. and B.P.S.) met several times during Phase 1 of the Kowary project to discuss the different options for the remediation works and to transform German experience to Polish conditions.

The limits of the remediation were set by the overall project manager of the Kowary remediation programme. First defined in the General Remediation Plan, they were later specified as a result of detailed planning (see [WUT00-2]). The following specific features had to be considered:

- The eastern section of the remediation site was bordered by the surface drainage system constructed by WUT.
- The southern section of the remediation site was bordered by the southern dam slope.
- In the west, the dam foot located on the banks of the Jedlica river remained outside of the remediation site because it extended beyond the WUT property area; WUT stated that requirements for final rehabilitation of this section, i.e. to prevent damage by flood waters, were under the responsibility of the local water
authority. Here, therefore, the remediation site border ran along the top of the dam.

- In the northern section, the limit of the area of remediation coincided with the dam foot.

One crucial aspect was the cover system. As a result of two common meetings and site visits, the works were focussed on optimising the technical efforts. The aim was to reduce the radiation level at the site and to reduce to an acceptable level the infiltration of precipitation waters into the covered mine wastes. Special attention was given to the stability of the tailing pond dam during the construction works.

Further emphasis was on the design of the drainage system. The first ideas foresaw the construction of an inner drainage system directly on top of the disposed tailing, but this would have been too costly in both time and money. However, as a result of the co-operative work between the partners in the project, a more efficient solution was found.

### 2.3.2 Evaluation of the General Remediation Plan (GRP)

The GRP (see Annex 2) submitted by WUT to the competent Polish authorities for approval briefly described the aims and the content of the planned remediation works at the Kowary tailing pond. This plan did not contain any explicit listing of emission levels or remediation target values (i.e. the gamma-dose rate above reclaimed ground, the concentration of radionuclides in solids and waters, or heavy metals in the effluents from the site). It was foreseen that such target values and aims would be agreed with the Polish authorities on the basis of the detailed planning documents to be provided in Task 2 [WUT 00-1].

The general aims of the GRP were:

- to minimise the environmental impact to an acceptable level (radiation, water pollution); concerning heavy metals there wasn’t any certain demand, the planned remediation would have as a side effect, that the release of heavy metals decreased with any additional measure
- to guarantee long-term stability of the dam,
- the contouring of the remediated site in harmony with the local landscape,
- to ensure that the remediated site is not crossed by infrastructure facilities and that any contaminated soils in neighbouring areas be disposed of in the pond.
Water management:

The planned measures allowed dewatering of the tailing mass.

Cover system:

The intended multi-layer system would be limited to the pond area only. The dams were to be covered with a single layer of mineral soil material. The final design for the cover system had to be elaborated in Phase 2. Contouring of the tailing pond site was a prerequisite for covering. The cover system guarantees a long-term and stable collection and discharge of precipitation water.

Revegetation:

The originally foreseen reforestation corresponded to the woodland character of the surrounding landscape. In general, the reclaimed site should be left in a state of sustainable land-use requiring only low maintenance costs. Sowing grass and herbs as a first step would allow a quick revegetation and protection from erosion. A detailed revegetation plan was to be provided in Phase 2. However, in the end the competent authorities decided to develop open grassland with some shrubs and small trees on the remediated site.

3. Review of Technical Design

3.1 Organisation of Works

During the initial phase of the contract, numerous contacts and meetings had enabled the establishment of a well co-ordinated basis for the detailed planning works to be undertaken during Phase 2 of the project - “Technical Design”. One crucial aspect was the development of a common professional opinion of all parties involved in the project. Another consisted of completing the negotiations with the various Polish authorities concerning responsibilities, legal base for the remediation works and the aims of these works.

At the different stages of the planning activities, preliminary results were discussed and conclusions reached concerning the ensuing implementation phase. Practical experience in
the evaluation of radiation exposure, elaboration of guidelines for radiation protection and organisation of radiological monitoring could be directly transferred from the German situation.

A planning workshop with a small expert group took place in Kowary at the beginning of February 2001. It was connected with a site visit, which took place after the completion by WUT of essential technical works as part of site preparation prior to construction. This workshop ensured best possible conditions for the specification of crucial parts of the planning documents and for the successful completion of the project.

However, delays in obtaining some documentation and statements from local authorities caused a prolongation in the time required for the preparing of the tender documents.

3.2 Internal Stabilisation and Drainage System

Planning of the final shape of the tailing pond by WUT led to a concept of flattened slopes of the northern dam. The geotechnical stability calculations showed that this concept would be reliable in terms of long-term stability. Another important contribution to internal chemical stability would be achieved by covering the bottom of the dewatered pond with a thin lime layer to compensate the acidic potential in the upper part of the disposed tailings.

The drainage system consisted of two parts:

a) An inner system was planned at the interface between the pond bottom and the covering layers. The fishbone-like arrangement of ditches filled with coarse broken dolomite rock would collect all water liberated from the underlying tailings under the load of the constructed cover and conduct it by free gravitative flow to a common discharge point out of the dam. This technical solution was considered to be efficient and quick to construct.

b) In the final stage of remediation, a surface drainage system was planned in order to complete the measures for water management. The flat concave surface morphology of the covered pond should be drained by diagonal and circular ditches filled with broken hard rock. The collected water was then discharged directly into the open outer drainage ditch running along the southern foot of the dam. This ditch had already been constructed by WUT as a part of the preparatory tasks before the main remediation works started.
In order to guarantee the long-term functionality of the constructed drainage system, these planning measures took into account the settlement of the site over time.

### 3.3 Pond Cover

The planning of the pond cover is described in \[WUT00-2\].

The starting point for the planning of the cover system corresponded to the situation following completion of the works to ensure mechanical stabilisation of the tailing dam.

The principle profile of the multi-layer cover system is given in fig. 3.

**Fig. 3 Scheme of the planned cover system**

The pond cover construction consisted of several steps to be carried out in sequence:

- Filling of the depression over the basin by using local material, approximately 2 950 m³ over an area of approximately of 5 500 m² with a thickness up to 1.25 m and a surface dipping from north to south;
- Local shaping of the outer dam slopes in the northern part, decrease of the dipping angle from 30-35° to 20-25°, the remaining surplus masses had to be used for filling the depression;
- Radiological control;
- Covering of the disposed material with a bentonite mat (5kg/m² bentonite, 5,500 m², 4.5 m with of roll, over-lapping 15 cm, linear drainage of 100 mm diameter along the rim);
- Construction of a radiation-attenuating dolomite layer, which worked additionally as a drainage on an area of 5,800 m² of tailing and 7,000 m² of the dams (10 cm unsorted dolomite),
- Construction of an upper layer consisting of humus soil for re-vegetation, in the level up to 576 m above sea level with 15 cm thickness, above that level with 35 cm;
- Dewatering of the site by using the general inclination from north to south – construction of a drainage ditch according to the planning documents;
- Reshaping of the southern dam slope after extraction of 350 m³ highly contaminated masses (in year 2000) and covering with 10 cm dolomite as well as 30 cm humus soil.

**Evaluation of the planning document:**

- The planned cover system was to guarantee the aims of remediation:
  - reduce the radiation level
  - environmental protection with regard to impacts from tailing erosion
  - mechanical stability of the covered surface
  - controlled collection and discharge of surface water
  - establishment of prerequisites for re-vegetation
  - guarantee erosion protection due to vegetation cover
  - reduce precipitation infiltration

- The construction requirements corresponded to the basic principles for normal civil works. High-level technical requirements were imposed in connection with:
  - mechanical stabilisation of tailing
  - flattening the steep dam slopes during initial work on the upper parts
  - displacement and covering of the bentonite mats according to the construction guidelines of the manufacturer.

- The planned workings and the temporary loads during the pond cover construction were within the limits imposed by the submitted stability evidence. The conditions listed in the planning documents had to be fulfilled during construction. These works were deemed feasible.
The project was carried out as economically as possible:
- dolomite and humus soil were to be procured from local sources;
- the bentonite mat should be used instead of expensive clay, which would have to be transported over long distances;
- the pond cover was planned with minimum possible thickness and was limited to the smallest possible areas and functional elements.

Technical solution:
The succession of cover layers was defined. With regard to favourable materials, further optimising was necessary.

- Planning documents:
  They were adequate in connection with the scope of works delineated for the construction of the pond cover. The planner was contracted over the construction period to be able to verify planning details immediately, if necessary.

3.4 Reclamation and Civil Works

The primary concept in the GSP, consisting of a site revegetation with a forest character, did not obtain the approval by the competent authorities. As a result of negotiations, a more park-like land use character was specified, with lawns, bushes and small trees.

WUT completed the infrastructure and preparatory works, which provided good conditions for a quick start to the remediation works. It was decided that:

- water and electricity supply would be guaranteed by HYDROMET,
- a large place at the southern dam would be prepared outside of the radioactive contaminated area to be used for storage of material and equipment,
- two access roads to the remediation site would be prepared,
- trees and shrubs were to be cut down over the area of the construction works.

The area of remediation was demarcated in such a manner that the borders did not cross supply infrastructures such as buried water pipelines, electricity or telecommunication lines.
3.5 Review of Completed Detail Design Documentation

At the end of the preparatory phase, both the project documentation and the preparatory works on the site had been completed.

The documentation included:

- Dendrologic project for the cutting down of (self-sown) trees and shrubs and the plantings in the area of reclamation.
- Explanation for the reclamation method in the light of the current regulations taking into account the local conditions.
- Technical design of the reclamation - volume 2 - Surface drainage (Technical University of Wrocław, Wrocław, September 2000);
- Technical design of the mechanical and chemical stabilisation - volume 2 - Technical design of the chemical stabilisation (Technical University of Wrocław, Wrocław, September 2000).
- Technical design of the mechanical and chemical stabilisation of sediment - volume 1 - Technical design of the mechanical stabilisation (Technical University of Wrocław, Wrocław, September 2000).
- Design of the filling technology for the pond to be reclaimed (“GEOBAD”, Wrocław, December 2000).

3.6 Approval of Plans by Polish Authorities

The site was originally part of the mining area around the “Wolność” mine. When the mine was decommissioned in 1963 and crossed off the register of mining areas, the settling pond was no longer subject to Geological and Mining Law. Furthermore, owing to its character, the pond did not fall into the category of a hydrological structure. Additionally, a project for the reclamation of the settling pond was, according to the letter by District Starosty in Jelenia Góra (dated 31.08.2000), not subject to Building Law but to the Act of Protection of Agricultural Land and Woodlands (dated 3 February 2000).

The President of the State Nuclear Agency confirmed in his letter of 13th June 2000 that the material in the settling pond should not be treated as radioactive waste but as a material with
increased contents of natural radioactive isotopes. Based on the evaluation results there was no need to introduce time limits for the employees performing the reclamation works.

The scope and methods of the reclamation works were included in the planning documents prepared by the design from WUT and the local company GEOBAD. The selected solutions were first discussed with the experts from G.E.O.S. They were then subject to agreements with the City and Municipality Boards of Kowary, District Starosty in Jelenia Góra, the Department of Environment Protection of Voivodship Board, State Nuclear Agency (see encl. 4 Regional Mining Office, and Regional Board of State Woodlands. According to these agreements, the Starost of Jelenia Góra District is responsible for taking the final decision regarding the method of reclamation.

Some of statements required from local authorities were delayed, which in turn caused a delay in the date of publication of the call for tender.

4. Construction Works (Task 3)

4.1 Initial Surface Situation on Site

The basis for the remediation planning is the GRP part III detailing the technical work that was produced by WUT in 2000 as part of the Polish contribution to the project. The contractor discussed the status of this work with WUT (Dr. Grabas, Dr. Koszela) on 19th September 2000. This was combined one day later with a technical visit to the remediation site by the Contractor’s European project manager.

Evaluation of the preparation works up to the end of September 2000:

1. Interruption of the water inflow into the pond: The wastewater inflow from the WUT facilities was stopped, though the inflow of surface drainage water continues. Rainfall caused elevated level of free water in the pond.
2. Pumping the water out of the pond: The pumping and water treatment systems were installed. They were operated by WUT. The purpose of the water treatment system was to clear additionally the wastewater discharged by the Hydromet facilities. The applied technology consisted of:
   a/ neutralisation and adjustment of pH-value in the wastewater,
b/ removal of sediment fright (coagulation with Zetag Magnofloc)

c/ sedimentation of solids in a settler

d/ removal of remained heavy metals in a filtration-sorption process (two – stage process) in columns with “Hydrosorb”

e/ dewatering of sediments in a filtration press and disposal according to Polish legislation at licensed disposal sites.

The treated (purified) wastewater met the Polish standards and could be discharged to the Jedlica river. The water was controlled by the National Sanitary Office.

3. Cutting down the trees: This work took place in the area of the foreseen civil works, along the lines of planned transport roads and on the technical service area. The works were finished before winter.

4. Immobilisation of chemically active substances in the uppermost deposit layers: This was not performed, as the pond bottom was not yet dry (no access). This measure was performed at a later date immediately prior starting with the inner drainage system.

5. Removal of most radioactive material from the southern dam to inner parts of the remediation site: performed only partially because of concerns that the stability of this dam might be adversely effected. For this reason the construction of the final pond cover had been carried out at this section with special care to reach despite of this the required reduction of the radiation level here.

In parallel with the planning works, practical measures took place took place up to April 2001:

- partial dewatering of the pond (comment: owing to the technology used, there was a limited capability to draw off the water following winter rainfall; WUT was working to solve this problem before the main remediation works started);
- construction of a drainage ditch at the eastern border of the pond to avoid inflow of surface water from this side;
- construction of a collection well for seepage.
- Comment: as a result of these works it could be observed that all seepage on the western dam had dried out, which was reflected by higher dam stability in this section.
These works led to an increased geotechnical and chemical stability of the pond area and were the basis for starting the main remediation works, to be performed by the subcontracted construction company.
The topographic characteristics of the site, after all main preparatory works by WUT, are documented on maps in Annex 5.

4.2 Tendering of Remediation Works

As laid out in the ToR for the EC-part of the remediation project, the civil works were to be performed under a subcontract between the EC contractor and a local construction firm, selected via call for tender and paid for out of the EC-part. The tender documents, which, following Polish practice, are the so-called “Specification of Essential Contract Conditions”, were prepared in March – April 2001. Since the call for tender was to be arranged in accordance with Polish procedures, the queries in writing were sent to:

1. The Office for Public Contracts, Legal Department in Warsaw: Requesting an opinion on tender procedure to be applied in the case of the Kowary Project and
2. The Office of the European Integration Committee, Department of Foreign Aid, Funds and Programmes in Warsaw: Requesting the rules for VAT rate decisions concerning subcontractors in Poland.

The tender documents consisted of basic terms and 10 enclosures (see 2nd Interim report) and were approved by the General Manager of G.E.O.S.
The tender evaluation committee was approved by the General Manager of G.E.O.S. and led by the Project Manager, Dr. Görner. There were representatives from WUT, Kowary District Authority and proGEO.

In line with the information received from the Office for Public Contracts in Warsaw, a restricted call for tender was prepared. Although this tender, for formal reasons, was not subjected to Polish Public Law, it followed in general the rules of public tendering.

The Tender Committee received 6 offers and the evaluation was performed on 29th May 2001. The results were documented in the “Protocol of Tendering Procedure”. The decision reached by the committee was approved by the General Manager of G.E.O.S. and endorsed by the EC Technical Project Manager. The respective contract was signed by the representatives of G.E.O.S. and TRASKO-Invest Sp. z o. o. in the middle of June 2001.
4.3 Radiation Protection Measures

The situation prior to the site remediation was characterised by significantly increased radiation levels. According to measurements carried out in a 10 m grid by the Polish Atomic Agency on 17th and 18 June 1999, the tailing pond showed maximum dose rate values up to 7100 nSv/h, whereas the natural background was between 120 and 180 nSv/h. The average for the pond site as a whole was 640 nSv/h. This radiation was caused by increased concentrations of natural radionuclides in the tailing and waste rock of the settlement pond. The specific activity concentration of Ra-226 was up to 5 Bq/g, as analysed in soil samples from the site (see [BPS00-1]).

Based on these data, a Radiological Assessment (calculation of radiological exposure) was carried out, which showed that for the public there was a certain risk of exposure to a dose of > 1 mSv/a if no remediation was undertaken at the site (see [BPS00-1]). The principle pathways for the radiation exposure to the critical group are the direct gamma-radiation and water. Concerning the water this assessment must be specified due to the fact, that the analyses data provided by WUT gave the base for very conservative effective dose assessments, only, because the detection level for the single radionuclides had been too high in the most of the cases. So not really analysed concentration values but the named detection levels had to be used for calculation, which lead to exposure rates, that are too high after the Contractor’s opinion. Nevertheless, looking at the other exposure pathways the total exposure exceeded 1 mSv/a. Consequently, recommendations were made concerning the required radiation protection measures and monitoring, both during the performance of the remediation works and in the longer term (see [GEOS00-1] and [GEOS00-2])..

WUT was recommended that the following monitoring measures had to be carried out in connection with remediation works:

(a) Measurement of dose rate:

- after removal of the radioactive soil material from the northern dam to the inner parts of the pond, measurement in a 10 x 10 m grid on the excavation site and on the disposal site;
- after construction of the cover consisting of clay/bentonite layer, dolomite layer and cultivation layer final, measurements in a 10 x 10 m grid to check remediation effectiveness – criteria: the dose rate has to be lower than 300
nSv/h at each point. This was in accordance with the recommendations of the Polish Atomic Agency (see enclosure 5) and based upon practical experience gathered by the Contractor in similar remediation projects carried out in uranium mining areas in Germany.

(b) Radon measurements in order to obtain reliable data about the average concentration on and beyond the construction site. Number of detectors: at least 5; duration of exposure: 3 months; location: on the building site and between the dwelling houses to the north of the tailing dam. The Contractor was recommended to use alpha-sensitive plastic film detectors. The measurements should be carried out at an elevation of 1.5 m above ground.

(c) Measurement of dust concentration in air during movement of ground material with increased natural radioactivity (from the northern dam).

(d) Monitoring of the water path before and during remediation – 2 sampling cycles
   - Jedlica river up and downstream of the tailing pond,
   - Seepage water outlets in the tailing dam,
   - Groundwater in existing wells at the borders and downstream of the tailing dam.

The EU experts provided WUT with guidelines regarding the organisation of radiation protection measures during the construction works on the pond. These recommendations were based on practical experience in similar projects in Germany. As agreed, WUT used these guidelines for instructing the staff of the contractor’s construction firm about the requirements regarding radiation protection before the main remediation works got underway at the pond site. This instruction was documented in the “Daily Construction Record”. The results of final radiation situation is presented in enclosure 8, which shows the data measured by WUT. The results correspond to control measurements carried out by the Contractor and the Polish Atomic Agency.

4.4 Organisation of Supervision and Quality Management

The performance of the remediation works on the Kowary site was not formally subject to Polish Construction Law. Nevertheless, with respect to the very special character of the executed services, supervision of the remediation works was organised and performed in
accordance with Polish law. Supervision concerned the quality of construction works and the quality of the construction materials used.

Following the interpretation of Polish law, G.E.O.S. acted as "Investor". For this reason, the Contractor, i.e. G.E.O.S., was responsible for so-called "Investor's Supervision". The authors of the detailed design documentation (WUT and G.E.O.S./GEOBAD) were responsible for "Author's Supervision". In this way, the latter had to be involved by the Investor in any situation requiring specification stemming from the detailed design documents.

Supervision from Investor's side was provided by Msc Andrzej Olas, the "Inspector of Supervision" according to Polish law.

The carrying out of "Author's Supervision" involved on several occasions the planning engineers from WUT, GEOBAD and the G.E.O.S./proGEO Consortium.

On the side of the subcontracted building company, TRASKO-Invest, supervision was executed by managers with the appropriate permissions: Msc Jolanta Ryszkiewicz and Msc Wojciech Borkusz. They approved the certificates of construction materials provided by the Institut of Construction Technics and the producers or traders of special material. Copies of the certificates were handed over to G.E.O.S. and archived for later use, if necessary.

Additionally, the owner of the site and Overall Remediation Programme Manager, WUT, nominated an "Inspector for Quality", Dr. Inz. Olgierd Pula.

The radiological control at all stages of works was performed by WUT at their own cost. This was in accordance with the TOR (see 4.6) and in line with consultation between WUT and the Contractor.

Before starting the remediation works, a “Quality Management Plan” was elaborated and agreed with all parties. Following this guideline, supervision was carried out on site, either continuously or according to the single phases of the remediation works. Results and decisions were documented in the “Daily Construction Manual” along with certain protocols. These documents are archived by the Contractor.

The supervision activities allowed problems arising during the remediation works to be dealt with successfully. Arranged measures include (selected list):
- procurement of dolomite for covering system according to planned quality parameters;
- intensify geodetic monitoring during remediation works;
- additional gamma dose rate measurements in event of unexpected observations from the radiological monitoring (as part of cover quality control and checking of radiation level stipulated in remediation aims) and instructions to perform corrective/guarantee services to improve local cover quality;
- instructing the building company to reduce the organic content in the soil for the re-cultivation layer.

As a result of intensive supervision measures, good co-operation of all project partners and correct performance of works by the construction firm TRASKO-Invest, the remediation of the tailing pond could be completed as required in TOR and the planning documents. Some guarantee services that did become necessary were performed immediately by TRASKO in compliance with the subcontract.
4.5 Review of Remediation Works

The remediation works began on site on 26th June 2001. On this date, the “Daily Construction Record” (in accordance with Polish regulations) was opened and used for detailed documentation by the Building Site Manager of work performance and of supervision activities on site.

**Task 1 – Drying out and Chemical Stabilisation of the Pond Surface**

It was completed on 14th of July; as specified in the planning documents, the lime was spread not as a suspension but as a dry fine-grained matter, which was later sprinkled with water.

**Task 2 – Mechanical Stabilisation of the Pond**

Reconstruction of the seepage water outlet through the dam: the work was completed successfully; no damage occurred to the tailing pond surface during the very heavy rainfalls during the month of July, and within a few hours all the precipitation water that had collected on the pond area could flow off and was discharged to Jedlica River.
Dewatering of the pond reduced the penetration of the west dam by water, as observations had shown during August and September. This was considered important for improving the dam stability.

**Tasks 3 – Mechanical Stabilisation of the Pond**
Construction of basic cover: Geotextiles and geogrid have been laid out just in time. Covering them with the multifunctional layer (25%) consisting of broken rock (“Dolomite”) was interrupted for 2 weeks due to the massive rainfall during previous weeks. Geotextiles and geogrid fulfilled the requirements according to their production certificates. The pond surface was covered using a pattern of overlapping strips. The surface of the pond was then stable enough for the construction of the drainage layer, which started from the dams. This layer with a thickness of 0.5 m was stable even under the load of dumpers and bulldozers.

**Task 4 – Construction of inner drainage channels**
This was carried out in connection with the works of Task 2 prior to the construction of the drainage layer. It very quickly conducts away the water occurring in the inner part of the pond.

**Task 5 – Construction of basic cover (75%) and geotextiles**
Quality control of the grain size of the supplied dolomite showed too high an amount of fine-grained material; the quarry company was requested to provide the required grain size spectrum, but they could not meet this requirement in sufficient measure. For this reason the drainage layer showed changing permeability and this problem was discussed with the planning engineers of WUT (“Author’s supervision”). According to the decision taken by the supervisors, additional drainage channels with drainage pipes were constructed, lined with geotextiles and filled with broken dolomite. Simultaneously, the main sampling drainage was deepened and linked to the tube leading to the water collection well. This task was finished by laying out of geotextiles on 30th of August. All during the execution of Task 5 the meteorological conditions were unfavourable due to periodic rainfall.

**Task 6 – Reshaping of northern dam and using the surface masses for covering the pond**
The works have been performed in several phases. Separated humus-containing material could not be used for the final humus layer on top of the multi-layer cover system as this material consisted of sandy tailings with significant increased natural radioactivity. It was pointed out to the construction company that the humus layer has to be free of radioactive contamination and that all of the surplus material from the northern dam does not fulfil this criterion. That’s why all material removed from the northern dam was filled into the pond and was then covered as described in the planning documents.

**Task 7- Laying out the bentonite mats**
The bentonate (5kg/m²) was used to construct a low-permeable barrier on 5 500 m² to cover the local material removed from the northern dam to reshape the central part of the pond. The application of the bentonite mats was equivalent to that of a corresponding clay layer with a thickness of
approximately 40 cm, which would have been more expensive due to high transportation costs.

**Task 8- Construction of peripheral drainage**
The constructed drainage system consists of 100 PVC drainage pipes, 330 m length altogether, placed along the bentomate border at its contact to the foot of the internal slopes. This system collects surface water inflows from the slopes as well as infiltrating surface water that reaches the bentomate after passing the dolomite layer above.

**Task 9- Covering with dolomite**
A dolomite layer of 10 cm thickness - called “Dolomite II” – covers the bentomate as measure of mechanical protection and water draining towards peripheral drains, on adjacent areas and slopes the primary function is radiation attenuation. Unsorted crushed rock has been used for the Dolomite II layer.

**Task 10- Covering with soil**
The soil layer has been constructed as prerequisite for revegetation. The average thickness of this layer is 30 cm covering 8 440 m². Carefully selected material was used free of pollutants.

**Task 11- Construction of central ditch**
A central ditch was constructed on top of the covered tailing pond to collect and drain rain-fall water (approximately 60 m length) leading from the central part of the concave surface to a culvert in the southern embankment. The ditch was filled with well-washed broken stone material that additionally supports the stability of the ditch slopes.

**Task 12- Sowing grass and settling bushes**
As a final measure to avoid surface erosion grass was sown. Landscape was arranged by planting bushes (with shallow roots) at certain places.

On 28th September 2001, a final site control took place with participation of all project partners. At the following final meeting in Jelenia Gora, it could be stated that the project work had been completed successfully. Following this meeting and considering some correction works (guarantee services of the construction company) the completion of the remediation project was documented in protocols (see enclosure 11). Some additional tasks were recommended (see chapter 6).

### 4.6 Radiological Control and Final Assessment

The radiological monitoring was part of the Polish contribution to the project and was the responsibility WUT. The measurement of the dose rate were used for checking the
remediation progress and the quality of the final pond cover. The final gamma-dose rate map is presented in enclosure 8.

Following the presentation of the radiological monitoring results by WUT at the project meeting in Jelenia Gora on 28th September 2001, and because of uncertainties in these data, the Contractor agreed with WUT and the Polish Atomic Agency to carry out an additional final common measurement campaign. The measurements were performed on 17th October 2001. The measurement devices of the Contractor and of the Polish Atomic Agency showed the same readings. However, the one of WUT did not work reliably in the low dose rate range below 1000 nSv/h. For this reason, the assessment given here in the Final Report is based on the data obtained by the Contractor on that day:

The measurements carried out on 17th October 2001 showed a completely improved radiological situation. The average dose rate amounted to 325 nSv/h for the whole investigated area. In detail, the measurements showed good remediation quality on over 90% of the remediation site with a dose rate < 300 nSv/h, which corresponded to the area of remediation as defined by WUT. This was obtained as a result of covering the radioactive tailings with crushed rock and soil from outside the pons site with sufficient thickness (according to the planning documents). However, some problems were noticed in marginal areas where cover thickness was insufficient (a strip to the east of the site), and in a local area on the north-western dam where sandy tailings intercalated in the soil caused slightly increased dose rates up to 380 nSv/h. But the slopes here showed a dense vegetation cover consisting mainly of grass and some shrubs and small trees.

As a result, it was decided:

- to accept the north-west anomaly because of its borderline nature and the favourable surface conditions.
- that the anomaly in the east with values up to 600 nSv/h had to be eliminated by an additional soil layer to be constructed by the contracted construction company as a guarantee service.

Other readings taken outside the defined remediation zone showed locally unexpected increased dose rate values. They were found in places where uranium ore containing waste rock was located. Over approximately 700 m² on the southern dam foot, levels of more than 300 nSv/h were detected. In places, the dose rate went as high as 4000 nSv/h.
A final dose rate measurement carried out by WUT on 26th and 27th October 2001, after completion of the guarantee works by the building company, provided the proof that the remediation target of < 300 nSv/h had been achieved even in the problem area (see Annex 8; [WUT01-1]).

From these final measurements, the average dose rate over the whole area of the tailing pond and adjacent areas is now at the greatly reduced level of 300 nSv/h, and as low as 195 nSv/h within the borders of remediated area itself.

5. Assessment of Fulfilment of the Remediation Objectives

The general aims of the GRP were in accordance with TOR:

- minimise the environmental impact to an acceptable level (radiation, water pollution),
- guarantee long-term stability of the dam,
- reshaping of the remediation site in a manner appropriate for the surrounding landscape,
- remediation site not to be crossed by infrastructure facilities;
- contaminated soils in adjacent areas outside the pond should be removed and disposed of in the pond area.

The results of remediation can be assessed as follows:

a) Covering of the tailing pond allowed significant reduction of the radiation level on the remediation site to an average of 195 nSv/h. Connected with this measure, inflow of surface water was prevented and infiltration of precipitation was reduced. This effect will become even more marked when the vegetation cover becomes denser. As a resulting, the volume of effluents discharged to groundwater and the Jedlica river is minimised and the total concentration of transported pollutants will be reduced.

This leads to the conclusion that the radiological aim of remediation has been achieved and the radiation exposure on this site will be < 1 mSv/a even under conservative assumptions (with regard to [BPS00-1]).

b) Dewatering of the pond and construction of cover and drainage systems reduced the water volume stored in the dam construction. This and the flattening of the
northern dam have been the most important contributions to the improvement in the stability of the disposed tailings. The seepage evident on the steep and least stable dam to the west have dried out following dewatering of the pond and construction of the cover. This was an important sign of successful remediation. **Nevertheless, a stability deficit must be stated for the western dam foot, because it is located in the immediate range of the influence of storm floods, which can cause significant erosion damage.**

c) Flattening of the northern dam slope and the soft shaping of the pond top have led to contours that merges in very well with the surrounding landscape.

d) Surplus masses of radioactive tailings and waste rock from the dams have been removed and disposed of in the central part of the pond before constructing the cover. The risk that subsequent erosion would lead to dispersion of the radioactive matter has therefore been reduced.

e) Construction of the surface drainage systems prevents infiltration of significant volumes of precipitation water into the covered tailings and allows controlled discharge into the Jedlica river.

On 28th September 2001, the results of the remediation were presented to WUT. Following a visit to the site and presentation of the finished work, the protocols were signed by WUT, the subcontractor TRASKO and by proGEO (as representative of the Project Contractor) thus marking a successful completion to the project and allowing WUT to repossess the newly covered pond site (see Annexes 10 and 11). As documented in the protocol, the project was finished in accordance with the planning documents. WUT took over all executed work in the demarcated area of remediation without reservations. With regard to the final situation at the site and the newly obtained information, certain follow-up activities were nonetheless documented. These concern construction works in the Jedlica river bed to rectify damage caused by the last storm flood as well as to prevent further such damage to the dam. In addition, a recommendation was made regarding the covering of the radioactive waste rock discovered outside the remediation area (i.e. outside the demarcated site owned by WUT).
6. Recommendations Concerning Follow-up Activities

6.1 Site Monitoring after the Remediation Works

(a) Geodetic control of pond cover settlement is necessary in order to evaluate dam and pond cover stability. The number of measurement campaigns depends on observed settlement rates.

(b) Radon measurements in two cycles to obtain reliable data about the concentration average on the construction site and in the neighbouring areas. Number of detectors: at least 5, duration of exposure: 3 months, location: on the remediation site and amongst the dwellings to the north of the tailing dam. The measurements shall be carried out at an elevation of 1.5 m above ground. Time: (1) June to August (2) December to February.

(c) Monitoring of the water path

- Jedlica river both up and downstream from the tailing pond
- Groundwater in existing wells at the site borders and downstream of the tailing dam
- Number of sampling cycles: 3 at least
- during the first year after remediation: 2 campaigns with interval of half year
- a third campaign one year later

Should the water quality meet the governmental standards and does not show further impacts from the tailings then the monitoring can discontinued. Otherwise, a specified programme for further observation shall be planned.

(d) Monitoring of Soil Erosion

- Growth of a dense vegetation cover
- Prevention of erosion processes on the slopes
6.2  Covering of Southern Dam Foot

The radioactive anomaly over 700 m² detected at the southern dam foot should be covered with soil of at least 30 cm thickness. Care must be taken to avoid negatively affecting the dam stability during the construction works. The transition from dam foreground to dam body should be shaped in such a way so as to allow a continuous and low-inclined slope.

Success of this measure shall be controlled by gamma dose rate measurements in a grid of x 5 m. The remediation aim is to obtain values of < 300 nSv/h at each point.

Considering the relief of this area, a volume of approximately 1200 m³ of soil is needed for the cover construction.

6.3  Stability Improvement of Western Dam Foot

Since the water-technical works at the western dam foot, which is located on the Jedlica river banks, were not in the responsibility of WUT, these works did not form part of the Kowary project. This is under the responsibility of the local water authority:

- With the aim of ensuring long-term dam stability, it is recommended that as far as possible the Jedlica river bed should be replaced at the same time as the necessary renovation work is carried out on the weir (damaged partially during the last flood in summer 2001).
- The dam foot should be protected by a massive wall made of concrete or broken stone.

6.4  Jedlica River Improvement

The last storm flood of summer 2001 deposited a thick layer of river rubble and gravel. The existing wooden bridge at the south-western entry gate to the tailing pond estate acted as an obstacle to the running water and there was a risk that the river might seek a new path through soil erosion, possibly at the dam foot. For this reason, the following works should be performed without delay:
- demolition of the bridge,
- as a substitute, construction of a reinforced ford,
- dredging of the disposed river sediments and deepening of the river bed.

6.5 Costs of Follow-up Activities

These recommended additional works are estimated to cost approximately 50,000 €.
7. References


[GEOB00-1] Koszela J., Brzakala W., Strozyk J: Design of the filling technology for the pond to be reclaimed. GEOBAD, Wroclaw, December 2000


[WUT00-3] Pawlik L., Koszela J., Brzakala W., Technical design of the reclamation - volume 2 - Surface drainage. WUT, Wroclaw, September 2000


Enclosure 6  Map of Surface Situation on the Dam Site,
State: December 2000, scale appr. 1 : 1,750
Enclosure 8  Final Gamma Dose Rate Map
Enclosure 9  Registered final topographic map

- **Border of remediation area**
- **Area of increased gamma-dose rate on southern slope**