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SOILS RADIOLOGICAL CHARACTERIZATION UNDER A NUCLEAR FACILITY

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ABSTRACT

Nowadays, nuclear industry is facing a crucial need in establishing radiological characterization for the appraisal and the monitoring of any remediation work.

Regarding its experience in this domain, the French Alternative Energies and Atomic Energy Commission (CEA) of Fontenay-aux-Roses, established an important feedback and developed over the last 10 years a sound methodology for radiological characterization. This approach is based on several steps:

- historical investigations
- assumption and confirmation of the contamination
- surface characterization
- in-depth characterization
- rehabilitation objectives
- remediation process

The amount of measures, samples and analysis is optimized for data processing using geostatistics.

This approach is now used to characterize soils under facilities. The paper presents the radiological characterization of soils under a facility basement. This facility has been built after the first generation of nuclear facilities, replacing a plutonium facility which has been dismantled in 1960.

The presentation details the different steps of radiological characterization from historical investigations to optimization of excavation depths, impact studies and contaminated volumes.

MATERIAL

The very first CEA centre was set up in 1946 in the Fort of Châtillon, located in Fontenay-aux-Roses, 7 km south from Paris. After two generations of nuclear facilities, a remediation plan of the whole site was elaborated in 1995. Facilities are going through a remediation program that will allow setting up buildings for new research activities. In parallel to the facilities dismantling, exterior contaminated parcels are also considered for remediation. CEA formalized for the Nuclear Safety Authority, in 2000, its decontamination methodology that was already applied for years on CEA centres [1].

In Fontenay-aux-Roses CEA Centre, there is an action plan 2009-2010 aiming at assessing the activity level under accessible facilities. The paper concerns the characterization of soils under a facility basement located in the CEA centre. This facility was built after the first generation of nuclear facility in place of a plutonium facility (fig.1) which has been dismantled at the end of the fifties.

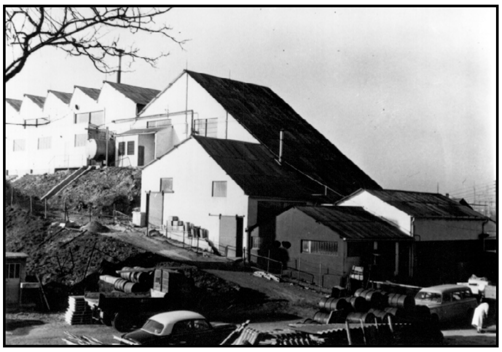

Figure 1: plutonium facility during the fifties

A remediation was carried out and contaminated soils were removed. However, at that time and according to the regulation, it was considered that conventional waste could have an activity up to 74Bq/g. This value was widely applied for soils and facilities remediation. Therefore, at present, activities around this value could be still found under the facility.

The basement (fig.2) which is the subject of this paper includes several mechanical rooms, two archives rooms and a public place for exhibition or school visit. The surface is about 700m².

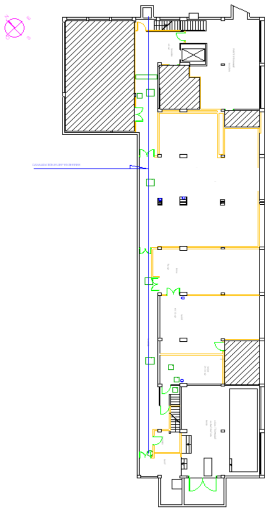

Figure 2: basement plan

METHODOLOGY

The general methodology applied for soils remediation in the CEA is partly based on the IRSN guide: “Managing places potentially contaminated by radioactive substances” [2]. In France, there is no waste release threshold; consequently the remediation process aims at removing the maximum of the artificial activity considering technical and economical constraints. This is the ALARA approach (as low as reasonably achievable).

This approach is based on several steps (fig.3):

- The historical investigations [1].
Understanding the radiological past of the target area is fundamental to calibrate/orientate the subsequent characterization. This includes gathering information from archives, operational characteristics, materials handled, measurement results, accidents, interviews (workers, residents), maps and aerial views, records about former characterization or remediation.

- The assumption of a contaminated area.
A radiological control with a simple radiation detector shows high level of radioactivity in some areas. The contamination must be confirmed with more measurements.

- The surface characterization.
A detailed map of the radiological activity has to be established thanks to surface measurements (in situ gamma spectrometry, soil surface samples). The risks to the environment can be identified this way.

- The in-depth characterization.
A campaign of drill holes indicates the contamination depth in the ground. The drilling samples should also go through chemical analysis to complete the detailed evaluation. Any potential transfer towards the groundwater has to be considered.

- The rehabilitation objectives.
Realistic scenarios of rehabilitation are defined. The radiological sanitary impact after remediation is calculated and according to the costs/benefits analyses, the excavation depth is determined.

- The remediation process.
Together with the removal of the contaminations, a survey of the operations is performed to guarantee the safety of the workers.

- The final characterization.
Some measures are collected to validate the achievement of the remediation (end-point dose assessment) and to keep informed about the radiological status of the area for any future use.

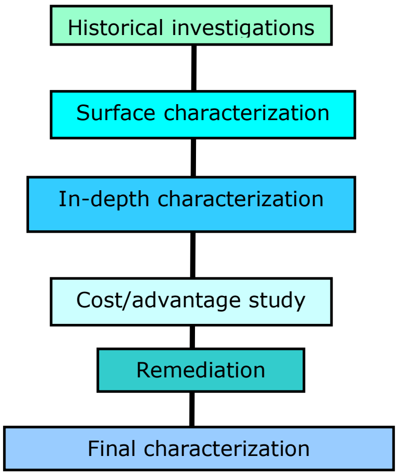

Figure 3: soils remediation methodology steps

This approach is now used to characterize contaminated soils under facilities.

RADIOLOGICAL CHARACTERIZATION

Surface characterization

In 2010, the surface radiological characterization was carried out. More than 200 in situ measurements with a NaI detector (sodium iodide detector) and 59 measurements by in situ gamma spectrometry GeHp were performed (fig.4).
The NaI detector is placed on a table 70cm above the ground. One acquisition is performed during 100s in order to get a global counting. The amount of points is optimised to allow a geostatistical data processing.

Gamma spectrometry measurements are positioned mainly in the areas of interest, according to the results of the NaI cartography. The device is a hyper pure Germanium collimated by 10cm lead. The related modelling takes into account the 14 or 20 cm depth concrete slab which is not contaminated associated to a homogenous contamination in 30cm of sand.

Cartographies are made through kriging which is a data interpolation method using geostatistics [4]. This method captures the spatial structure of the pollution and, according to measurements points, predicts a likely value on each map point while also quantifying the associated uncertainty. All geostatistical calculations cartographies are performed using ISATIS software. The surface characterization brings to light several areas which showed a significant rise of the global count rate or of the activity (fig.4).

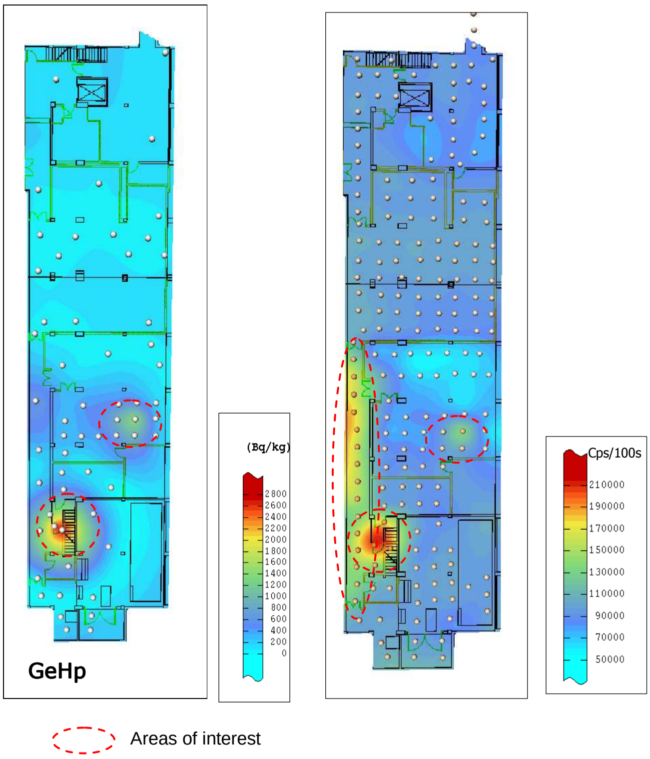

Figure 4: surface activity maps

Surface characterization gives first indications concerning the activity levels, the pollution extent and the radionuclides. Surface measurements are generally easy to implement, and relatively inexpensive comparatively to drillings. As a result, this step should be as complete as possible in order to save money during the in-depth characterization.

In-depth characterization

These surface cartographies are used to define the drillings position. 27 drillings have been placed: few of them in the most contaminated area to get the highest activity, few of them in the low activity area in order to confirm the non-contamination and most of them are placed in intermediate areas where a doubt subsists as regards contamination (fig.5).
Drillings arranged at a short distance are useful to capture the spatial structure in order to perform the 3D data processing by geostatistics.

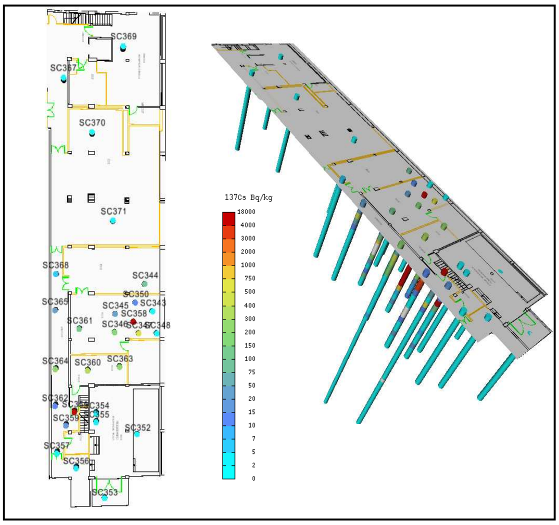

Figure 5: drillings layout

The depth of the drillings is 4m except for two of them (10m and 15m). The drilling machine is used without fluid with a 60mm-diameter core drill (fig.6). The work is consistently followed by a geologist who observes the soil lithology and carries out VOCs (volatile organic compounds) measurements. Then, each core is divided in 25cm samples which are ground and packaged before analysis (fig.7).

Figure 6: core drill

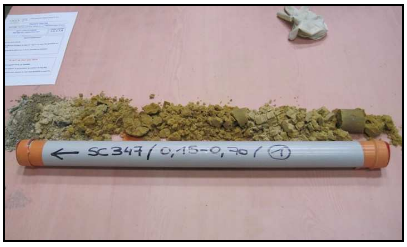

Figure 7: core before sampling

Radiological analyses and data processing

470 samples from the 27 drillings are analysed by gamma spectrometry in laboratory. Acquisition time is 240min in order to get a detection limit below 1Bq/kg in ^{137}Cs. 55 samples from 7 different drillings are analysed by alpha spectrometry and liquid scintillation to get the alpha activity and the pure beta activity (^{238}Pu, $^{239+240}$Pu, ^{241}Pu and ^{90}Sr). Drillings profiles are drawn (fig.8). In the example below, the pollution is mainly located in the first 80 centimetres depth with ^{137}Cs activity of 18Bq/g. A second episode of pollution with a lower activity is present around 180 centimetres depth. Alpha and pure beta activity are detected were there is also activity in caesium.

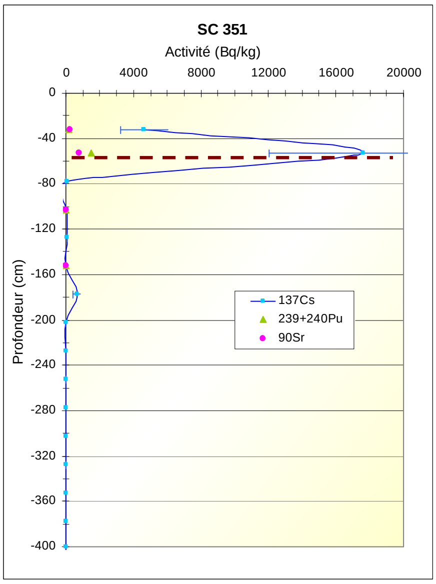

Figure 8: example of profile drawing

Profiles allow understanding better the migration of the pollution. Then, data processing is made through geostatistics. Although the process is a 3D kriging, the two variograms horizontal and vertical, are similar and have the same spatial structure (fig.9).

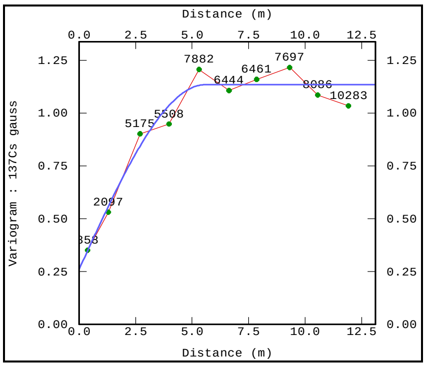

Figure 9: variogram

3D kriging cartography and probability map allow estimating the contaminated area surface (fig. 10 and 11). The cartography shows a well delimited area mostly in agreement with the surface cartography (fig.4).

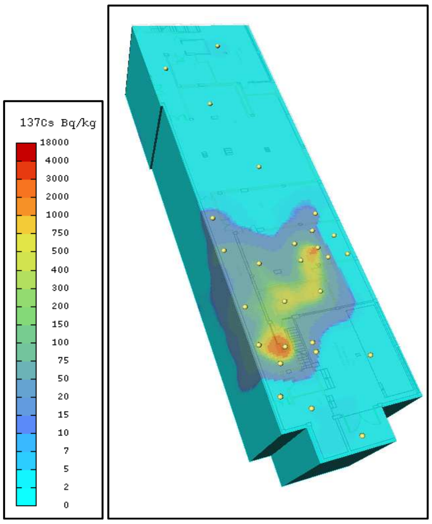

Figure 10: ^{137}**Cs activity estimation by kriging**

The probability map (fig.11) quantifies a risk of exceeding a defined threshold. For example, in the areas represented on the map in red, orange and yellow colours, the risk of exceeding an activity of 100Bq/kg in ^{137}Cs is greater than 70%.

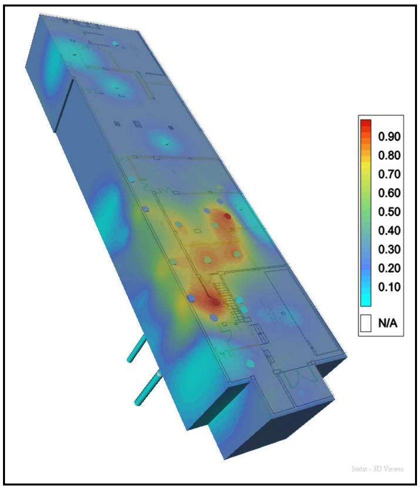

Figure 11: probability map to exceed 100Bq/kg in ^{137}Cs

Kriging cartographies per layer (fig.12) show the evolution of the contaminated surface depending on depth.

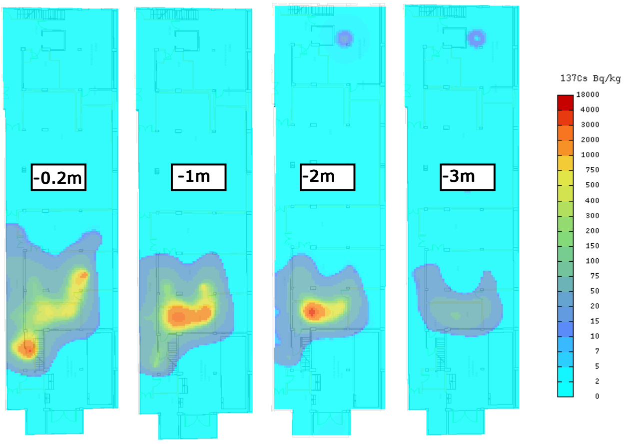

Figure 12: kriging per layer: -0.2m; -1m; -2m; -3m

3D cartography results confirm the surface characterization and highlight a new contaminated zone deep down. However the extent of the pollution is larger on the first 20 centimetres. The theoretical remediation surface is about 180m².

The predominant radionuclide is ^{137}Cs with a maximum activity of 18Bq/g. 8 drillings present, on at least one sample, an activity over 1Bq/g. $^{239+240}$Pu and ^{90}Sr are the other radionuclides measured with an activity below 1,5Bq/g. These radionuclides confirm the former plutonium facility as the origin of the pollution.

Most of the pollution is located between 15cm and 2m depth. As a result of profiles plotting, 3 zones are defined (A, B, C) with corresponding surface of 20, 30 and 130m² (fig.13).

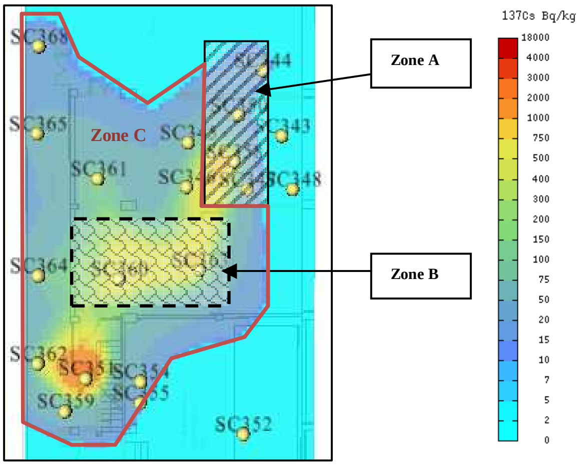

Figure 13: zone A, B and C

In the “zone A” contamination is located only on the 50 first centimetres and all profiles of the drillings are similar. In that area, drillings are placed at short distance from each other which allows an accurate characterization. In the “zone B”, profiles are different from the zone A and the contamination is deep down to 3m. The “zone C” contains the rest of the contamination area with a pollution depth down to 2m. In the “zone C”, the drillings profiles are too different to define smaller zones.

Cost/benefits analyses and remediation scenario

A costs/benefits impact study is carried out. This study aims at determining for each zone, the optimum excavation depth in function of a remediation scenario and considering technical and financial constraints.

For each remediation project, different scenarios are generally proposed. The scenario depends on the future use of the site. It is evident that the radiological impact objective will be different if the site becomes a waste storage or a primary school. The scenario takes also into account technical constraints such as buildings stability or accessibility problems. In addition, financial means could influence the final choice when the budget allocated to the project is restrictive. In the end, the radiological evaluation file outlines the most relevant scenarios and the project manager decides which scenario to apply.

The basic remediation scenarios are the ones described in the IRSN guide [2]. In our case, plausible scenarios for a reuse of the site are “building construction”, “parking construction”, “offices” and “parking”. “Building construction” is the more restrictive and the one chosen for calculation.

The impact study for the zone C is presented below (fig.14):

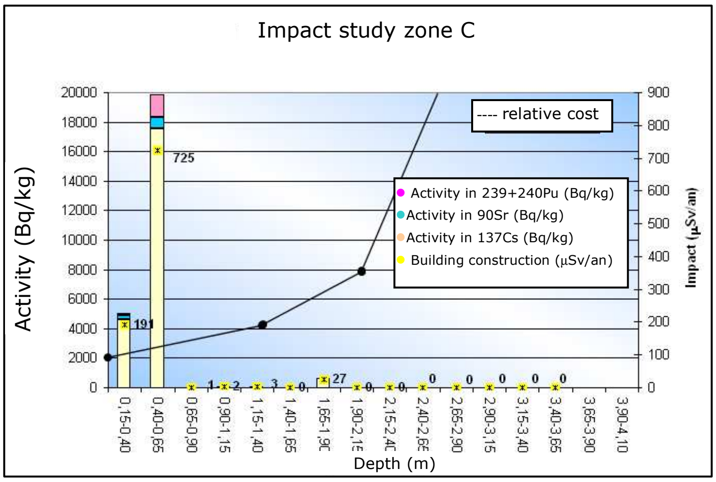

Figure 14: graph impact study for the zone C

This graphic presents the average activity and the dosimetric impact for each soil layer in function of the excavation depth according to the scenario "building construction". This scenario considers workers who are exposed during 800 hours (6 months of work). The scenario takes into account external exposition, dust inhalation and dust ingestion.
For the zone C, the radiological impact becomes insignificant after 2m depth.

The cost line gives an indication about the technical constraints which sharply increase the cost, as shoring or underpinning. In our case shorings are necessary for excavation below 1.40m. Moreover the foundations pillars are located around 2.30m. Therefore, excavations below 2m require underpinnings to avoid damaging the building stability. This is the reason why the cost line increases sharply from 2m depth.

Considering all this information, the optimized excavation depth is chosen. The excavation depth for the zone C is 2m. Indeed, after 2m the radiological impact is insignificant, and the excavation cost is reasonable because underpinnings are not necessary.

In such cost/benefits study, sampling step has a lot of importance [3]. In our case a 25cm step allows an efficient optimization. When the sampling step is too large, larger security margin should be taken and optimization is not precise. There are more risks of leaving pollution in soil or excavating non-contaminated area, and therefore sending non radioactive wastes in the waste storage.

A similar impact study is performed for the zone A and the zone B. In the zone A, the optimized excavation depth is 0.5m. In that zone, the number of drillings allows a precise study. In a logical way, the more drillings, the more information and precision. It is necessary to reach a compromise between the number of drillings and the cost associated while keeping in mind that drillings and analyses cost money but waste production and waste storage as well.

Concerning the zone B, the impact study shows a significant impact down to 3m. In that area underpinnings are necessary because we need to dig below 2m. The data processing and the cartographies are precise enough to define the zone with a minimum of uncertainty. When not enough drillings are done or without the help of the geostatistics, the whole area (zone A, B and C) should be excavate down to 3m, involving an important project price increase.

The table below (table.1) presents for each zone after optimization, the surface, the excavation depth, and the waste volume. The scenario guaranties a very low radiological impact after remediation, less than 10µSv/year considering the IRSN scenario building construction.

Zone	Excavation depth	Surface (m²)	Volume to remove (m^3)
A	0,5	20	10
B	3	30	90
C	2	130	260
Total zone A to C		180 m²	360m^3
Total volume zones A to C			**610m^3**

Table 1: excavation depths and wastes volume

The radioactive waste volume is 360m^3. Considering a coefficient of expansion of 1.7, the final waste volume is 610m^3.

Project cost estimation:
- Radiological evaluation : 394k€
- Remediation work including the wastes cost : 1600k€

Evaluation represents 25% of the project cost. This is significant, however according to our feedback and previous works, a complete characterization avoids losing time and money during the remediation process.

CONCLUSIONS

After 10 years of feedback, the original approach developed at CEA for soil characterization is now a sound methodology with more than 120 characterized sites. Investigations take a critical place and each project should be carefully optimized. The use of geostatistics allows an efficient data processing while quantifying the risk. The graph below (fig.15) represents the main idea of the paper, that is to say the interest in putting financial means at the beginning of the project. Knowing as much information as possible regarding the site and the contamination, allows decreasing significantly the global cost of the project.

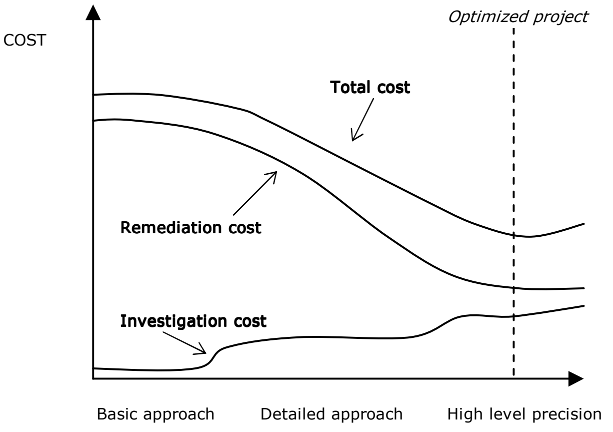

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Figure 15: project optimisation graph

The transfer of the methodology to nuclear facilities is under process, aiming at providing a suitable framework to address a tremendously increasing demand about the characterization of contaminated concrete structures and facilities.

REFERENCES

[1] Dubot D., M. Vacheron (2009) Radiological state of the CEA of Fontenay aux Roses, updated 2009.

[2] IRSN (2008) Managing places potentially contaminated by radioactive substances, Version 1, 2008.

[3] Aubonnet E. (2010) Sampling and characterization of soils contaminated by radioactive substances, CETAMA symposium, April 2010.

[4] Geosipol (2005) Practical contributions from geostatistics for the characterization and management of contaminated sites.

[5] Attiogbe J. (2010) French CEA Site Clean-up Methodology and related applications, In Proceedings of the DDR international symposium, Idaho Falls, United States, September 2010.