Continuous Contaminated Site Monitoring (CCS M) Integrated remote real-time supervision for an old coking-p lant

Frédéric Portet

Konrad Szafnicki

Jacques Bourgois

Véronique Milon

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Frédéric PORTET[ab], Konrad SZAFNICKI[b], Jacques BOURGOIS[b], Véronique MILON[a]

[a] *Centre National de Recherche sur les Sites et Sols Pollués (CNRSSP), F-59505 Douai Cedex, France, (cnrssp@cnrssp.org)*

[b] *Centre SITE, Ecole Nationale Supérieure des Mines de Saint-Etienne (ENSM-SE), F-42023 Saint-Etienne Cedex, France, (portet@emse.fr)*

Abstract: The purpose of the Continuous Contaminated Site Monitoring (CCSM) is to develop a **real time management methodology** for PAHs (Polycyclic Aromatic Hydrocarbons) contaminated aquifer resulting from coal activity. For full-scale experimentation, since June 2000 an old coking plant site has been instrumented (sensors, analysers, datalogger, programmable logic controller, etc….). Its follow-up currently continues with remote supervision, via telecom connection.

The Contaminated Sites Monitoring is a necessity to control the evolution of pollution and therefore the risk to human health or environment. With aromatic hydrocarbons contamination, one is generally satisfied with selective investigation, in fact incomplete and non-representative of the reality. Rarely a real time supervision of the natural evolution of PAHs pollution in the groundwater or in the ground combined with surrounding parameters (weather, rains,etc…) is carried out.

This experimental CCSM is able to highlight some correlation between pollution evolution and weather conditions. For the natural attenuation activity deduced from measurements of biogaz in unsaturated area, a strong activity has been observed in hot temperatures (consumption of oxygen and emission of carbon dioxide) and a low one in cold periods. For the **daily rate PAH analysis** of aquifer water, a field UV-fluorometer is used. Calibrated with naphthalene (the most soluble PAH), the water fluorescence is equivalent to a concentration of naphthalene but a post-treatment of data is necessary in order to correct the drift of the analyser between calibrations. Subsequently the measured & treated data are restituted/exploited using an integrated tool consisting of a GIS (Geographic Information System), interconnected to a Database and a mass transport model. The whole results are presented with a convivial and ergonomic integrated tool adapted for decision making support. The polluted site managers can thus visualise any aspect of the pollution and identify the relevant indicators, which can then be compared with other parameters or transport simulations.

Keywords: Contaminated industrial sites, real-time monitoring, knowledge-based systems, modelling, knowledge acquisition

1 INTRODUCTION

Regarding the management of contaminated sites, present French policy is based upon a classification of couples "site - use", according to the potential risk and danger for humans. Selection is being done so as to achieve a simplified evaluation, consisting of the three following classes [BRGM, 1997]:

- ✓ **"class 1" sites**, i.e. requiring complementary investigation as well as detailed evaluation of risk in order to make the best choice of decontamination methodology;
- ✓ **"class 2" sites**, i.e. requiring monitoring;
- ✓ **"class 3" sites**, i.e. which can be rendered common-place and dedicated to some other use.

The application of this policy requires from the "class 2" sites owners a rigorous following of their sites evolution, which implies additional cost owing to regular, recurrent investigation. The CCSM present a solution for the following of these sites. Also for "class 1" site owners, a real time monitoring of decontamination efficiency is worth while to optimise the treatment.

A CCSM is therefore an integrated evaluation system enabling real-time management of the "quality" of a site being monitored and/or decontaminated. Moreover, if associated with a hydrodispersive modelling tool as well as with an objective database, it will enable a decision making assistance, e.g. by generating possible evolution scenarii at different time ranges compared with the site owner's requirements.

Such a system offers a solution to the major problem of risk and danger management in time and space relative to industrial pollution, old or recent, enabling a continuous follow-up (data acquisition, treatment, presentation and analysis).

It will consist of a sequence of stages, as illustrated in **Figure 1**, enabling:

- ✓ real-time in-situ data acquisition, corresponding to the key parameters;
- ✓ data treatment, modelling of the site's evolution in terms of the decontamination methodology efficiency and/or deterioration of the site's quality, comparison of the results with the site owner's requirements;
- ✓ clear presentation of the integrated information to the persons in charge, e.g. via a dedicated application coupled with a GIS, as a decision-making assistance.

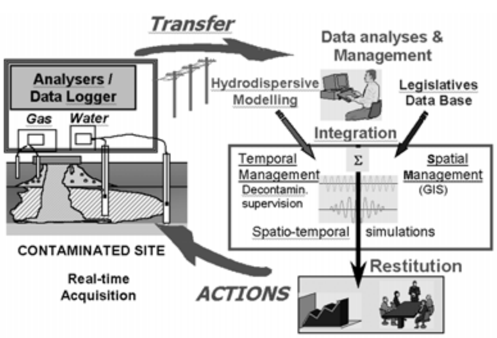

Figure 1: Scheme of a CCSM methodology

2 EXPERIMENTAL CONTAMINATED SITE

The validation of the CCSM methodology has commenced on a real experimental contaminated site, located in the north of France, which housed a coking-plant between, operating 1906 and 1955, demolished in 1976. The site, shown on GIS Arcview© visualisation in **Figure 4**, is mainly contaminated with PAHs, BTEX and ammonium. It is a relatively limited area and has not been used for any other polluting activity since then. One is therefore in the presence of a rather simple historical pollution scheme, whose extent can be determined by on-site sampling and investigation.

The site is located in an alluvial plain, on the right bank of a large canal. The land consists of a 3m thick embankment bed (schist, sand and silt) followed by 7m of recent alluviums (sand, loess and grave). Then come 4m of clay and, finally, a chalky formation down to a depth of 14m.

Two different types of groundwater can thus be determined: subsurface groundwater (or superficial groundwater) and deep groundwater (confined groundwater) under the clay bed. The superficial groundwater (semi-confined) is directly fed by surface water infiltration (rainfalls, overflows, etc.), and therefore vulnerable to pollution. There is no communication between the aquifers.

Since the end of production in 1955, important tar stocks have remained on the site, either on the surface, or in old un-emptied leaky tar reservoirs. During dismantling in 1970, volumes of tar were not entirely removed and some have remained hidden under a layer of fill

In-situ investigations and subsequent analyses have confirmed the presence of PAHs, BTEX and ammonium (a few mg/L for each) specifying more in detail their extension within the unsaturated soil (surface pollution due to discharges) as well as in the superficial groundwater (diffuse pollution, subsequent to the hydrodispersive transport).

Hydrologic investigations show a cohabitation of an important altimetric fluctuation of the superficial groundwater with the channel artificially maintained at a constant water level Theses conditions generate a cyclic inversion of the flow direction between high and low ground water periods (seasonal inversions).

3 SITE MODELLING

Elaborated with quantitative modelling methods, the software FEFLOW ©, developed by WASI (Germany), is used for the Continuous Contaminated Site Monitoring project, as decision-making support shell including simulation utilities of diffuse pollution plume at various scales of time.

3.1 Model description

The current version of the finite-element package FEFLOW© [Diersch, 1998] is able to model 2D and 3D flow, contaminant mass and heat transport processes in unsaturated and saturated porous media. It is capable of handling complex 3D, 2D geometries *via* unstructured meshes, moving meshes for free surface problems, temporal dependencies in material data, particular boundary conditions and accompanying constraints relationships. These features together with the solving of large 3D systems and the open GIS-oriented data interface have proven to be powerful for complex applications in the field of water pollutions.

The governing equations are derived from the macroscopic phase-related conservation principles for mass, linear momentum and energy. The resolution method used the finite element method in three and two dimensions. The spatial discretization is based on triangular elements in 2D and pentahedral elements in 3D.

3.2 Groundwater flow modelling

Before approaching the contaminant mass transport modelling, it is necessary to fix the flow data conditions. That has been carried out using piezometric and pluviometric data recorded since 1997 thus allowing hydrogeologic parameters adjustment of the various layers.

Modelling concerns a limited field, corresponding to the investigated zone skirting the channel, of 1km² approximately. The flow conditions retained for modelling are based on the data from 1999 (water levels and rain) considered more or less identical to a normal year. Any other simulation will thus be a cyclic reproduction of these hydrogeological conditions.

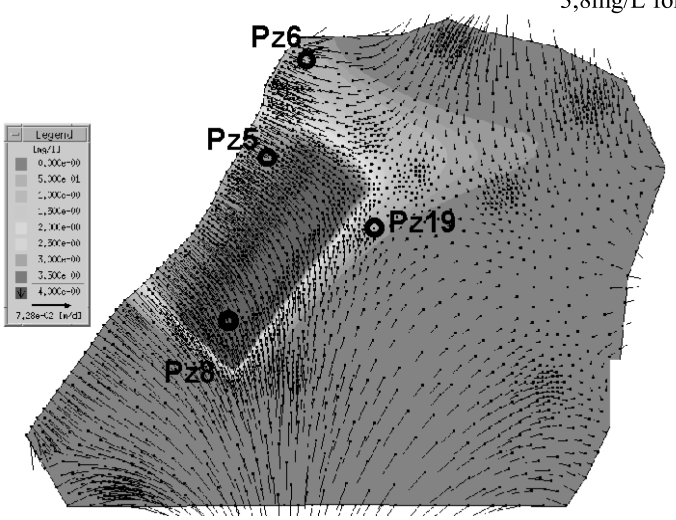

Figure 2: PAHs pollution plume in grave after 97 years

For the hydraulic charge boundary conditions, the water height in the channel has been considered stable at 16,3m. For the rest of the contour of the investigated zone, the cyclic season fluctuation of the surface aquifer have been taken into account and therefore the underground flow inversion. So, the hydraulic charge conditions were extrapolated from the site periodic piezometric measurements. Precipitations have an influence on the hydrodynamic behaviour of thick aquifer like this one. Also, in order to correctly translate the cyclic evolution of the aquifer, the pluviometry of reference was discredized in 12 monthly averages then imported under Feflow as a cyclic function of time over a 365 days period.

3.3 Naphthalene mass transport conditions

The single source of pollution retained is the old coking plant (the most polluting zone) where investigations confirmed the presence of pollution. This source, appeared in 1906 with the set up of the coking plant, continues today and is therefore considered as “constant pollution source”. In terms of space extension and transported mass, the most unfavourable conditions have been considered:

- ✓ The results presented will be those of naphthalene (the most soluble PAH) in the grave layer (the most productive layer);
- ✓ The phenomena of adsorption and/or biodegradation have not been taken account.

Under these conditions, the results suggested will present an increase in pollution diffusion, without however being able to specify the uncertainty degrees. The boundary conditions of naphthalene mass transport are a constant concentration of 3,8mg/L for the all saturated zone under the polluting source (zone of the coking plant). This balanced concentration has been calculated by using SIMUSCOP Software, regarding the spectrum of PAHs distribution in the original tar, and data from a similar site near the zone.

The validation of the simulation requires analyses of samples taken in the pollution plume, e.g. between the channel and the old factory area. Unfortunately, a new company now occupies this zone. As a consequence sampling is impossible there because of legal responsibilities. The only possible samples have been taken on the East edge of the contaminated zone where the concentrations represent less than 4% of the maximum concentration (around 2mg/L of naphthalene). The model validation has been done essentially on hydrological criteria completed with concentrations verifications for the mass transport: the naphthalene concentration, measured when possible, are in the same order as calculated values (Pz19 : 100µg/L calculated for 6,5µg/L analysed in January 2002).

3.4 Naphthalene mass transport results

The results of modelling over 97 years thus correspond to the current state of the site (state used for the validation of the model). For the transport evolution of naphthalene over 97 years in the grave layer, the diffuse pollution plume stabilizes in ten years (**Figure 2** & **Figure 3**).

The naphthalene concentrations represented in **Figure 3** describes a sinusoidal stabilization of mass transport on the same wavelength as the cyclic hydraulic conditions in the superficial aquifer.

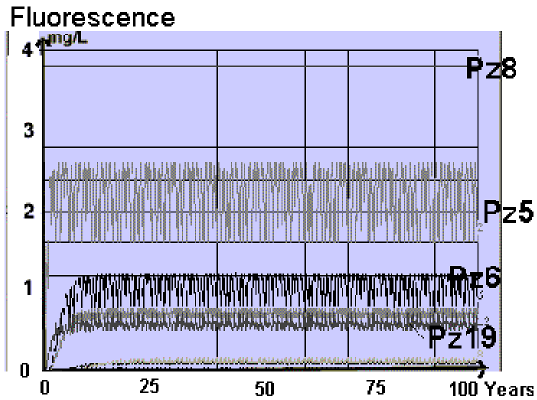

Figure 3: Naphthalene Mass evolution during 97 years.

4 SITE MONITORING

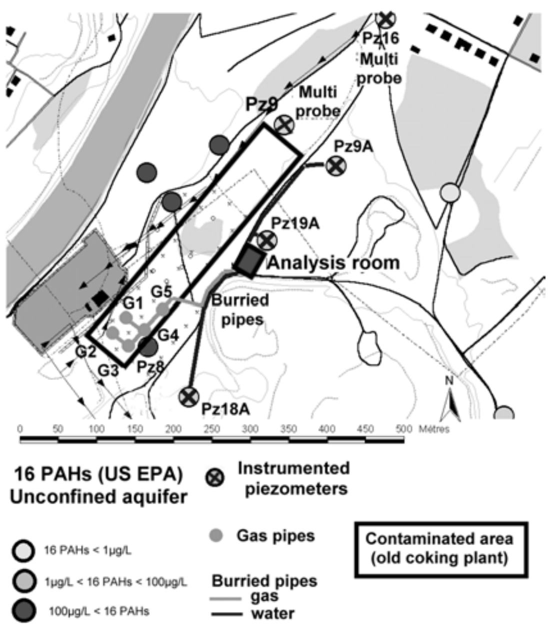

Figure 4: Situation of the measurement points (gas & water) and the analysis room

For the superficial groundwater continuous follow-up, 3 piezometers (Pz9A, Pz18A & Pz19A) were instrumented because of their common characteristics: situation at the edge of the most contaminated zone (old coking area represented by the black rectangle on **Figure 4**) and partially located in the plume of diffuse pollution with similar concentration ranging, between 1 and 20µg/L for the sum of the 16 Polycyclic Aromatic Hydrocarbons (PAHs) - 16 priority congeners according to US EPA list (USEPA 1988). Submerged pumps in every piezometer pump the water samples through buried water pipes to the analysis room. The analyser is a UV fluorometer which measures a factor of fluorescence equivalent naphthalene

For gases the follow-up in the unsaturated zone, 5 gas pipes were positioned in the ground (**Figure 4**), at 1,5 m depth, in a strongly polluted zone near Pz8 (G1, G2, G3, G4 & G5). An aspiration pump in the analysis room collects the samples through buried pipes. The biogas analyser measures CO_2 and O_2 concentrations in order to appreciate the respiratory activity of the soil.

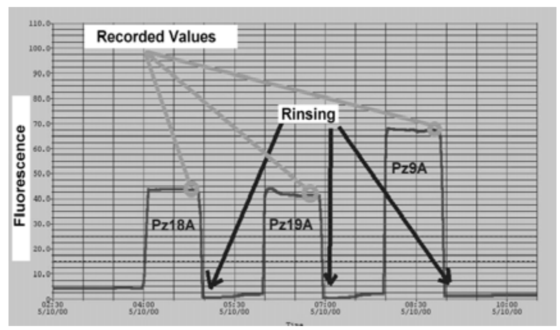

Figure 5: fluorescence acquisition of Oct. 25th, 2000.

Finally various probes are used for the follow-up of general parameters (temperature, moisture, rain, etc…) including 2 multi-parameter probes immersed in Pz9 and Pz16 (temperature, Eh, pH, NH_4).

For real-time monitoring, each analyser is connected to data logger for continuous acquisition, then to a modem for remote control. Ground water fluorescence and biogas analysis are done every day for each measurement points, **Figure 5**. For weather parameters, the rate time acquisition is 10 minutes but only the values at 4pm and 0am are stored in the database.

The automate ensures the piloting of the system, the selection of the measurement points and the rinsing of the fluorometer's cell according to the preset grafcet. All the data can be aquired in real time or later by remote control. This data is stored in Access database and, if necessary, corrected because of the drift of the analyser (fluorometer).

5 RESULTS OF THE CONTAMINATED SITE MONITORING

5.1 Biogas concentration in unsatured area

The **Figure 6** presents the evolution of carbon dioxide and oxygen concentrations in unsaturated zone at the points G1, G2, G3, G4 and G5.

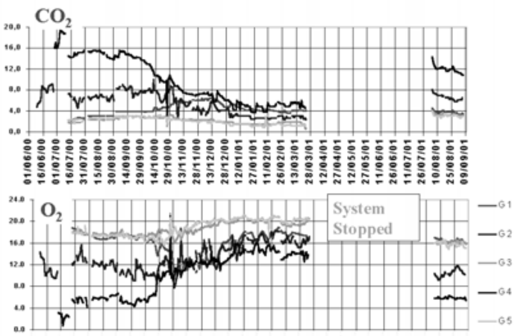

Figure 6: Biogas concentrations

The evolution of concentrations in every point are similar: carbon dioxide concentration decreases when the oxygen concentration augments. These daily observations show a correlation between the temperature and biogas evolution: the reduction of biodegradation activity ($\nearrow O_2$ & $\searrow CO_2$) for cold period, **Figure 6**. The analyse values of August 2001 confirm those of the previous year at the same time (end of the summer, autumn 2000): oxygen uptake and presence of $C0_2$ in hot period. The observations of winter 2001 will have to confirm or not falls of the CO_2 concentration and the oxygen uptake during the cold season.

Moreover, a longer acquisition period and complementary laboratory analyses must be carried out in order to check if these contents are really owing to the natural biodegradation activity of the soil.

5.2 Naphthalene concentration

It is relatively difficult to measure in-situ an uninterrupted factor of fluorescence equivalent naphthalene of groundwater water. The clogging of the cell, the drift of the analyser, the variations of flows are as many factors which strongly influence the measurement and which need to be quantified to extract a consolidated data representative of the real evolution.

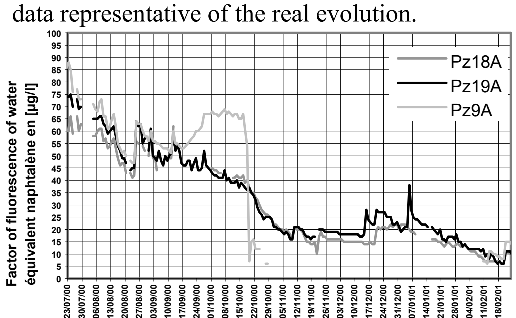

Figure 7: evolution of fluorescence without maintenance

Left in free evolution during several months, except cleaning of the cell, the fluorometer signal decreases gradually thus masking the real evolutions of fluorescence at the points of measurement (**Figure 7**).

Each dysfunction was studied to define the functioning of the fluorometer UV under continuous site exploitation. This fall of signal comes from the combination of several causes such as the deterioration of the intensity of the source of light, the clogging of the cell and the general disordered state of the fluorometer. To cure the problem a procedure of maintenance was set up in order to reset the analyser together with a new recalibration (every 15 days with a standard of naphthalene solution).

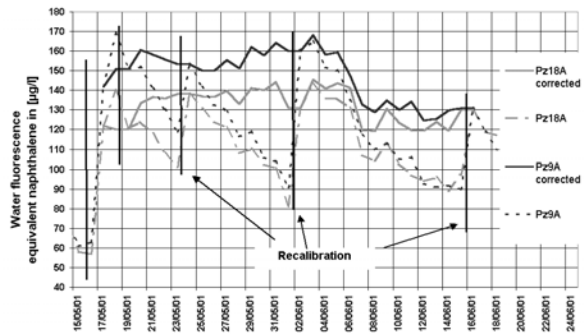

Figure 8: example of correction during post treatment of data acquired from Pz9-18

At each recalibration, the drift of the analyzer over the operating period is determined, and data consolitated by post treatment. The curves thus corrected presented on the **Figure 8** are more representative of the real evolution. The are. However, it appears that the repeated pumping at the three points of measurement with approximately 1m^3 per day per piezometer disturbs the "natural balance" by drying the ground around the piezometers.

5.3 General parameters

Finally some general parameters like the rainfall, the temperatures and humidity are recorded in the same way to highlight a possible correlation with the evolution of pollution. The **Figure 9** show the influence of temperature on CO_2 outbursts (therefore O_2 consumption) characteristic of natural attenuation.

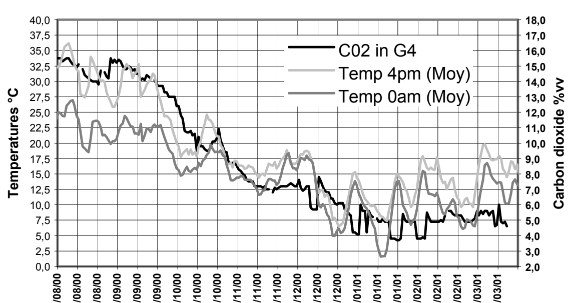

Figure 9: highlight between CO_2 and temperature

6 DATA MANAGMENT

For the data management, a MS Visual Basic© interface has been created to guide the site's owners in the data acquisition, their post treatment and their visualization in time and/or space via an interconnection with GIS Arcview©. This GIS combined with DGPS (Differential Global Positioning System) are initially used to establish a personalized numerical cartography of precision. In the second time, it offers the possibility of to superpose all kinds of georeferenced theme like the piezometer's characteristics, the result of mass transport modelling or data interpolations (water level, pollutant concentrations, ...).

The visualisation of the data curves evolution vs time is possible by clicking on the desired measurement point on the map, **Figure 10**. The tool enables a visualization of the space interpolation of the corrected fluorescence of water on a fixed date. This possibility is offered via an interconnection (protocol ODBC) between the SIG (Arcview©), the database (Access©) and the application of visualization creates with MS Visual Basic© (application). Obviously with only 3 points of measurement for our case, the interpolation is not pertinent, but the system is ready to function with more points of analysis.

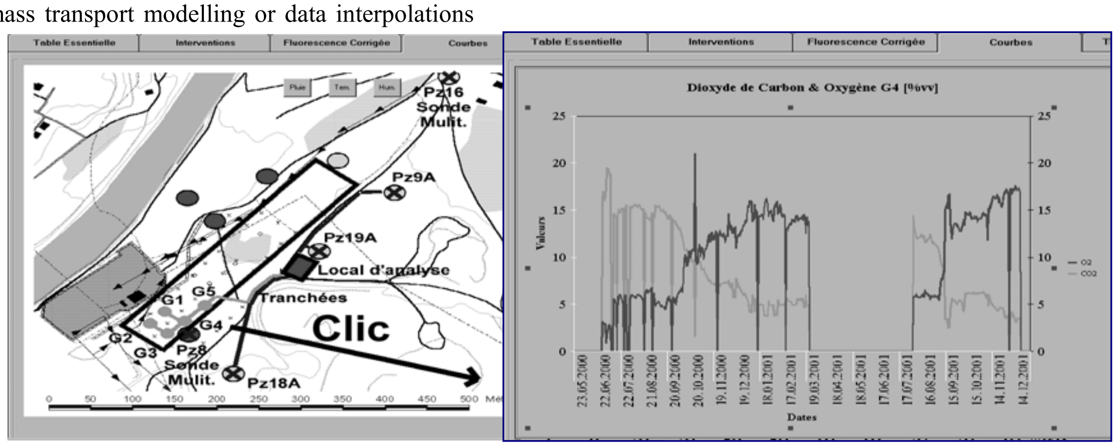

Figure 10: MS Visual Basic application

7 CONCLUSION AND PERSPECTIVES

The development of an integrated CCSM methodology involves a significant amount of measurement and other information, which is not always available and/or reliable. For example, in the case of this project, there are only *five* piezometers equipped in an area of ~50 ha, although the recommended number is of 20-25 sampling points/ha [Cairney & Hobson, 1998]. The lacking information must then be completed using, on the one hand, a *quantitative* site modelling (which is being done with FeFlow) and, on the other, the acquisition and implementation of *qualitative, integrated* knowledge about the site evolution. The latter will be taken into account using a visual real-time device for restitution and decision making support. This experimental CCSM (methodology, instrumentation, acquisition and restitution) has now been achieved and the methodology valided. However, there is almost no former experience available concerning this type of system; therefore this first experiment will allow the setting of several recommendations for a good CCSM concerning the choice of sensors (limitations of the UV fluorometer in a hydro carbonated environment) and the remote control (utilisation of the internet technology combined with GSM). However, for the site's follow up and eventually decontamination, new sampling points may become necessary. As a consequence, the fitting of new piezometers and/or new drillings should not be excluded in the (near) future.

Last but not least: *vandalism* remains an important limitative constraint for the project. As a consequence, the equipment had been designed so as to take this factor into account, which implied additional costs.

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