# A COMPLETE AND INTEGRATED APPROACH FOR THE ASSESSMENT OF NON-PIGGABLE PIPELINES

***M. van Burgel***

*M. de Wacht*
*M.T. van* Os

KEMA NETHERLANDS B.V.

## ABSTRACT

In the Netherlands, approximately 12.000 km of high-pressure pipeline exist, most built between 1960 and 1980. Pipeline integrity management is a vital activity to achieve a reliable and safe operation of this gas transmission system. Especially on the older pipelines, mechanical damage or coating degeneration, followed by corrosion, has resulted in areas with reduced wall thickness. Of the various existing corrosion threats, Microbiologically Induced Corrosion (MIC), detected firstly in 1999, has found to be the major threat to the integrity of the Dutch grid.

For maintaining the required level of integrity, a number of methods is available, in-line inspection (ILI), also called pigging, being the most commonly used. Although the major part of the Dutch pipeline grid is conventionally piggable, there is also a significant part that is considered to be non-piggable for various reasons. For these lines, External Corrosion Direct Assessment (ECDA), as described by the ANCI/NACE SP0502-2010, is a valuable method to assess and reduce the impact of external corrosion to the integrity.

KEMA has developed an optimal solution to manage the entire ECDA process. This solution is based on a fully integrated combination of:

- The Direct Assessment (DA) software module. SRA in combination with Bayesian statistics, makes it possible to quantify the results obtained during the different steps of an ECDA process;
- A specially designed Cathodic Protection Survey Set (CPSS) to detect possible corrosion activity. The Cathodic Protections Survey Set (CPSS) was developed, with functionalities of DCVG (Direct Current Voltage Gradient ), CIPS (Closed Interval Potential Survey) and dGPS efficiently combined in one device, making it possible to perform all surveys in one run. It has been proven that the workability for surveyors has improved significantly. In addition, the quality of survey data is better. The survey data can directly be imported into the DA module with less postprocessing efforts, considerably saving time;
- One Pipeline Integrity Management System. To allow efficient, structured and reliable data processing in support of pipeline integrity management, all data are available in one software system: PiMSlider.

Overall, the KEMA ECDA solution gives the benefit of easy access to all relevant data from the pipeline under investigation, as well as from other pipelines. It offers considerable time-saving, increased transparency and better reproducibility throughout the ECDA process. In addition, it enables quantification of each mitigating activity to the overall integrity of the pipeline, thereby minimizing the overall cost of mitigating measures. And finally, the DA module accounts for most of the uncertainties generally encountered within the ECDA process.

This paper describes the complete and integrated approach for the assessment of non-piggable pipelines, as developed by KEMA, by using an illustrative examples.

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# 1 INTRODUCTION

In the Netherlands, approximately 12.000 km of high-pressure pipeline exist, most built between 1960 and 1980. Pipeline integrity management is a vital activity to achieve a reliable and safe operation of this gas transmission system. Especially on the older pipelines, mechanical damage or coating degeneration, followed by corrosion, has resulted in areas with reduced wall thickness. Of the various existing corrosion threats, Microbiologically Induced Corrosion (MIC), detected firstly in 1999, has found to be the major threat to the integrity of the Dutch grid.

For maintaining the required level of integrity, a number of methods is available, in-line inspection (ILI), also called pigging, being the most commonly used. Although the major part of the Dutch pipeline grid is conventionally piggable, there is also a significant part that is considered to be non-piggable for various reasons. For these lines, and with the major threat of corrosion, External Corrosion Direct Assessment (ECDA), as described by the ANCI/NACE SP0502-2010 [1], is a valuable method to assess and reduce the impact of external corrosion to the integrity.

KEMA has developed an optimal solution for the entire pipeline integrity management process for non-piggable pipelines with the major threat of corrosion. This solution is based on a fully integrated combination of:

1. The ECDA methodology;
2. The Direct Assessment (DA) software module to manage all ECDA related data in a probabilistic way;
3. A specially designed Cathodic Protection Survey Set (CPSS) to detect possible corrosion activity.

To allow efficient and reliable data processing in support of pipeline integrity management, all data are available in one software system: PiMSlider. This system consists of a number of modules that cover the whole range of data management (pipeline-, environmental- and incident data), Cathodic Protection (CP) system monitoring, analyses of ILI data, defect assessments and quantitative risk calculations. With all data available in one Pipeline Integrity Management System, this has proven to be an optimal solution for a structured and efficient ECDA process.

This paper describes the complete and integrated approach for the assessment of non-piggable pipelines, as developed by KEMA, by using an illustrative examples.

# 2 THE METHOD: EXTERNAL CORROSION DIRECT ASSESSMENT

The ECDA process, as described by ANCI/NACE SP0502-2010 [1], integrates information on the pipeline's physical characteristics including operating history (pre-assessment) with data from multiple field examinations (indirect inspections) and pipe surface evaluations (direct examinations). The process consists of a continuous improvement four step process, as indicated schematically in Figure 1.

1. In the Pre-Assessment step historical and current data of the pipeline(s) under investigation is collected and analyzed;
2. The objective of the Indirect Inspections step is, by conducting aboveground inspections, to identify coating faults and areas at which corrosion activity might be occurring, thus defining the risk for corrosion. Result of the Indirect Inspections is a priority list with an indication of the seriousness of the indications, which is used as input for the
3. Direct Examination. Excavations are performed in this step, in order to collect data to assess corrosion activity and to repair critical defects;
4. The final Post-Assessment step integrates information on the pipeline's physical characteristics gathered during the previous three steps, in order to assess the pipeline integrity and to determine the reinspection interval, thereby helping to prevent future external corrosion damage.

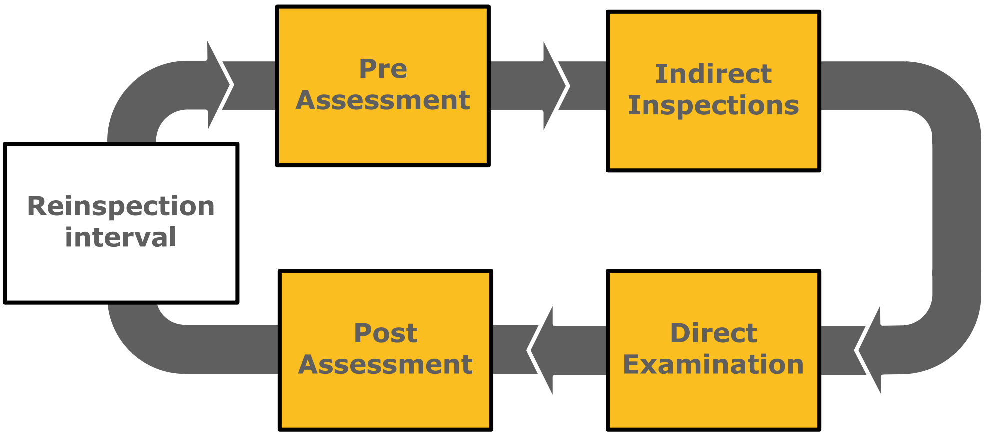


**Figure 1: The basis of the ECDA process**

The four different steps of ECDA will be explained in more detail in the following section.

# 3 THE ANALYZING SYSTEM: THE PIMSLIDER DIRECT ASSESSMENT MODULE

Most of the data collected during the ECDA process is subject to uncertainty. For instance, the number of coating and corrosion defects detected during Indirect Inspections will also be depended on the Probability of Detection (POD) and the Probability of False indication (POF) of the used survey technique. In order to quantify the structural integrity of a pipeline with a certain level of confidence, it is therefore necessary to account for these uncertainties. For this purpose a probabilistic methodology has been adopted. This methodology is based on Bayesian updating techniques and Structural Reliability Analysis (SRA). A combination of those techniques allows one to quantify the qualitative ECDA process, by calculating the effect of inspections and excavations on the integrity level of the pipeline, hereby supporting the integrity manager in determining the optimum inspection program. The increase in reliability that can be achieved by application of SRA and Bayesian statistics, can result in substantial savings on the cost of inspections.

From 2007 on, the ECDA methodology is implemented in a specially developed DA software module, developed in corporation with Andrew Francis & Associates Ltd. (Derbyshire, UK), ATP Ltd. (Hampshire, UK), and Neftegazsystema (Gomel, Belarus). The DA module helps the integrity manager to perform the ECDA process by gathering and analyzing the relevant data, storing data, and presents the required data and results in a clear and comprehensive manner by plotting (combinations of) graphs on the screen, thereby simplifying interpretation of data [2-5]. The DA module is integrated in the pipeline integrity management system PiMSlider [6].

In each step of the ECDA process, the user benefits from pipeline integrity analyses performed with the PIMSlider DA module. We can illustrate this by showing the four different steps of the ECDA process into more detail with the help of some 'real pipeline' examples.

## 3.1 Pre-assessment

The pre-assessment step in the ECDA module has the following three objectives:

1. Data collection and visualization;

2. Identify ECDA regions, these are section(s) of a pipeline with similar physical characteristics and operation history, in which the same indirect inspection tools can be used;
3. Establish the prior condition of the pipeline.

### 3.1.1 Data collection and visualization

Consistent with SP0502-2010 [1], this first part of the pre-assessment requires a sufficient amount of data collection, integration and analysis. All parameters that impact the selection of the indirect inspection tools and the definition of the ECDA regions shall be considered for initial ECDA applications. As an example, in Figure 2 an example of the different pipe ages occurring along the length of a pipeline is shown. It can be seen from this screenshot that, although this particular pipeline was constructed in 1953, several sections have since then been replaced for various reasons.

The first set of data in this figure, indicated by arrow 1, contains all the respective pipe ages for each section of the pipeline. The second set shows all the occurring pipe ages, as well as the total length of pipeline associated with each pipe age. The third set is a result of the selection made by the operator. In this case, only three out of the occurring seven pipe ages are selected for identification of ECDA regions, to avoid that too many ECDA regions are created in the next stage of the pre-assessment. The pipe ages that have not been selected, are "conservatively" added to the next occurring earlier year of construction (e.g. for the section that has been constructed in 1974, it will be assumed by the SRA model that it has been constructed in 1967).

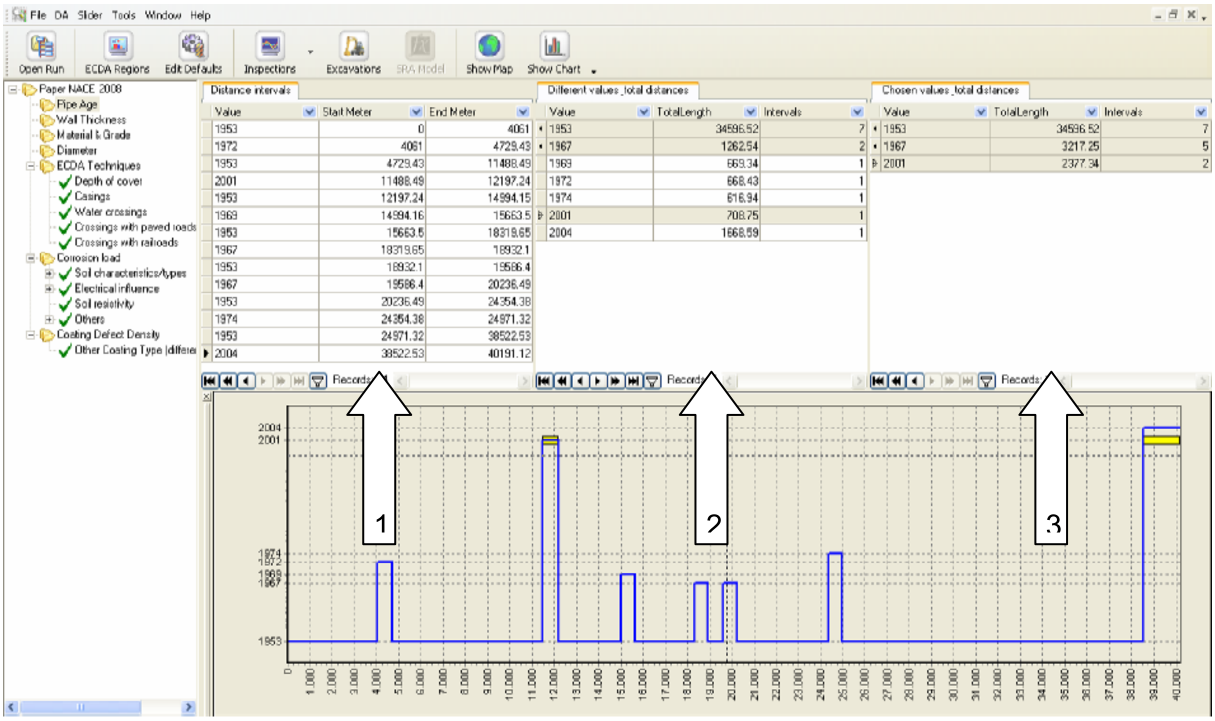


**Figure 2: Pipe age along the pipeline**

The parameter "ECDA Techniques", indicated by arrow 1 in Figure 3, assists the operator in identifying where the application of general indirect inspections may cause problems due to safety issues or a reduced performance of the ECDA techniques. This parameter consists of a number of sub-parameters, namely:

- depth of cover: if greater than a certain threshold value, the indirect inspections techniques are assumed to have a lower probability of detection (POD) and a higher probability of false indication (POF);

- casings: the presence of casings may require additional indirect inspection techniques or integrity assessments;
- water crossings;
- crossings with paved roads: inspection of paved roads may raise safety issues or require the drilling of holes to improve the contact with the electrolyte;
- crossings of railroads: gives rise to safety issues

For illustration purposes, the screenshot in Figure 3 also shows where the pipeline is protected by casings (arrow 2), the exact position of these casings in a GIS environment (arrow 3), and where the application of indirect inspections (or the interpretation of their results) may not be possible or needs extra attention (arrow 4). In other words, the parameter “ECDA Techniques” (arrow 1 and 4) applies where at least one of the subparameters (e.g. depth of cover, casings, water crossings, crossings with paved roads, crossings with railroads) apply.

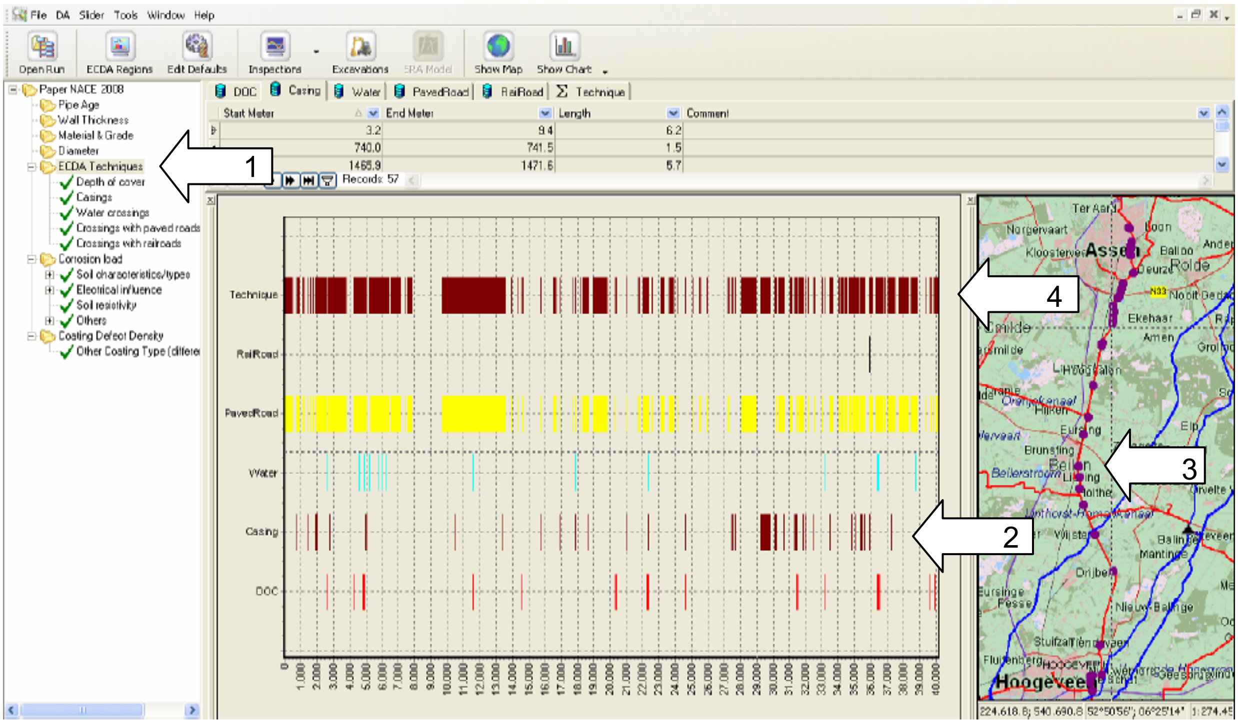


**Figure 3: ECDA Techniques**

The factors that may somehow influence the corrosion or the corrosion growth rate of the pipeline can be found under the parameter “Corrosion load” (see arrow 1 in Figure 4). This parameter is subdivided into four different categories, namely:

- soil characteristics/types;
- electrical influence;
- soil resistivity;
- others, like anaerobic circumstances.

In this particular case, a significant part of the pipeline suffers from DC interference, due to the close vicinity of a DC railway. Therefore the parameter “Close vicinity of DC Railways” (under “Electrical influence”) is selected (arrow 2 in Figure 4). The other Corrosion load parameters are discarded, since none of them are expected to be applicable or relevant to this pipeline under investigation. The length of the section that can be expected to be influenced by DC is approximately 21 km long, part of which is indicated by arrow 3. Finally, arrow 4 in this same figure refers to the parameter “Coating defect density”. This parameter is related to the type of coating of the pipeline. Where most of the Dutch pipelines constructed after 1970 have been coated with PE of relatively good quality, older pipelines, such as the one described here, mostly contain bituminous coatings of much poorer quality. This coating type information from the PiMSlider database can clearly be used to estimate the coating defect density for each ECDA region, a parameter which can be updated later in the process upon receiving new information from the indirect inspections and excavations.

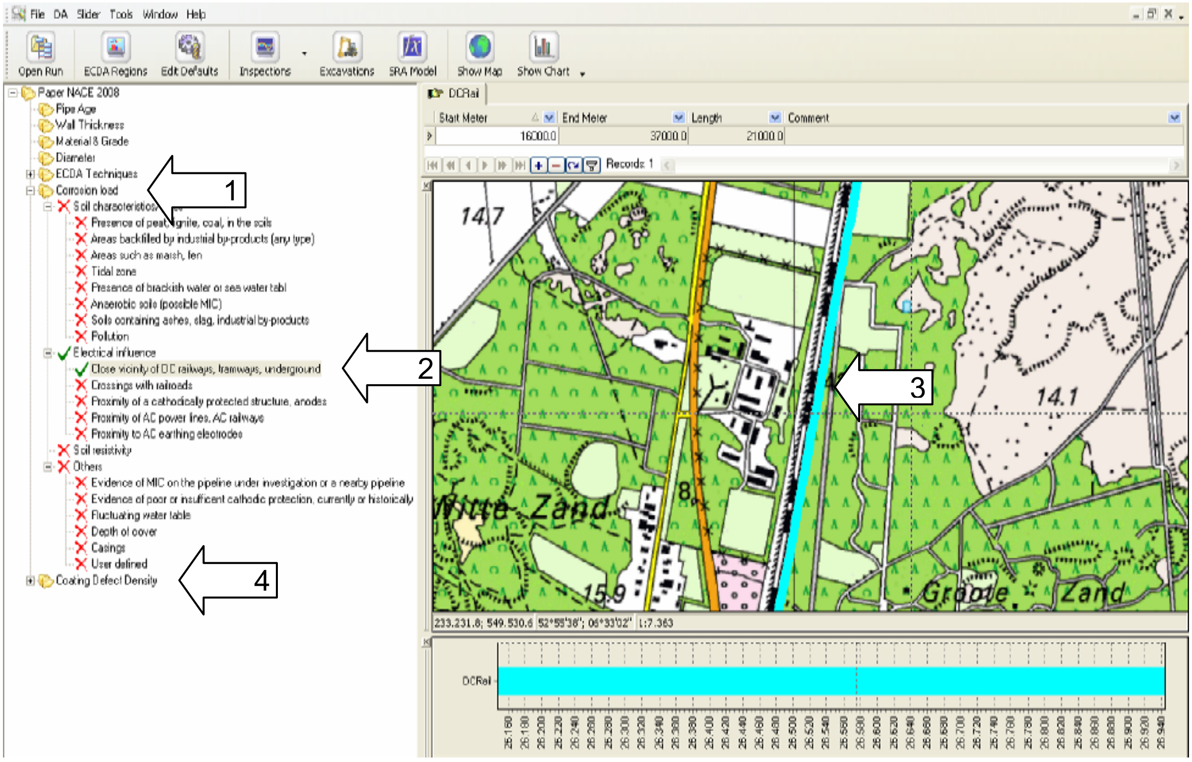


**Figure 4: DC interference**

### 3.1.2 Identification of ECDA regions

In the second part of the Pre-Assessment, the gathered information is used to define a number of ECDA regions. After the user has defined all the parameters to be taken into account for the definition of ECDA regions, the ECDA module calculates the regions automatically, as illustrated in Figure 5. In this case, the assumptions made in the previous step result in 14 different ECDA regions, varying in length from 60 m to 13 km. These ECDA regions can then assist the user throughout the Direct Assessment process to interpret results, to decide which indirect inspection tools can be used and where direct examinations should be performed.

### 3.1.3 The prior condition of the pipeline

Thirdly, the prior condition of the pipeline under investigation is quantified, by assessing the failure frequency for each ECDA region. In order to calculate this failure frequency, estimations must be made for, among other factors, the following key parameters:

- Time of initiation of corrosion defects. Corrosion can start to take place immediately after construction (for instance as a result of mechanical damage and insufficient CP), but also many years later (for instance due to deterioration of the coating);
- Defect density (both for coating and corrosion defects). This parameter firstly consists of a starting value representing the damages originating from the transportation and construction phases of the pipeline. Secondly, this consists of a term representing the rate of introduction of new defects;
- Defect depth. A certain initial distribution for the defect depth is assumed at the time of initiation due to mechanical damage, which then increases annually depending on the corrosion growth rate;

- Corrosion growth rate. The rate at which the defect depth grows. This is in general a major cause of uncertainty and is likely to vary considerably between pipelines.

The estimations of the parameters listed above can generally be based on information collected in the pre-assessment. Data regarding factors such as the age of the pipeline, coating type, level of CP, soil conditions etc. are appropriately combined to determine prior distributions of the numbers and geometry of corrosion defects. If relevant information is not available for a specific pipeline, data of pipelines with similar specifications or environmental conditions can be used for the required analysis. In practice, parameters concerning the geometry of the pipeline (e.g. wall thickness) or material properties (e.g. flow stress) are also subject to uncertainties, especially in the case of older pipelines. Therefore these quantities are also represented by distributions rather than constants.

When appropriate prior distributions have been established for the relevant parameters, the probability of failure for each ECDA region can be calculated by the SRA model.

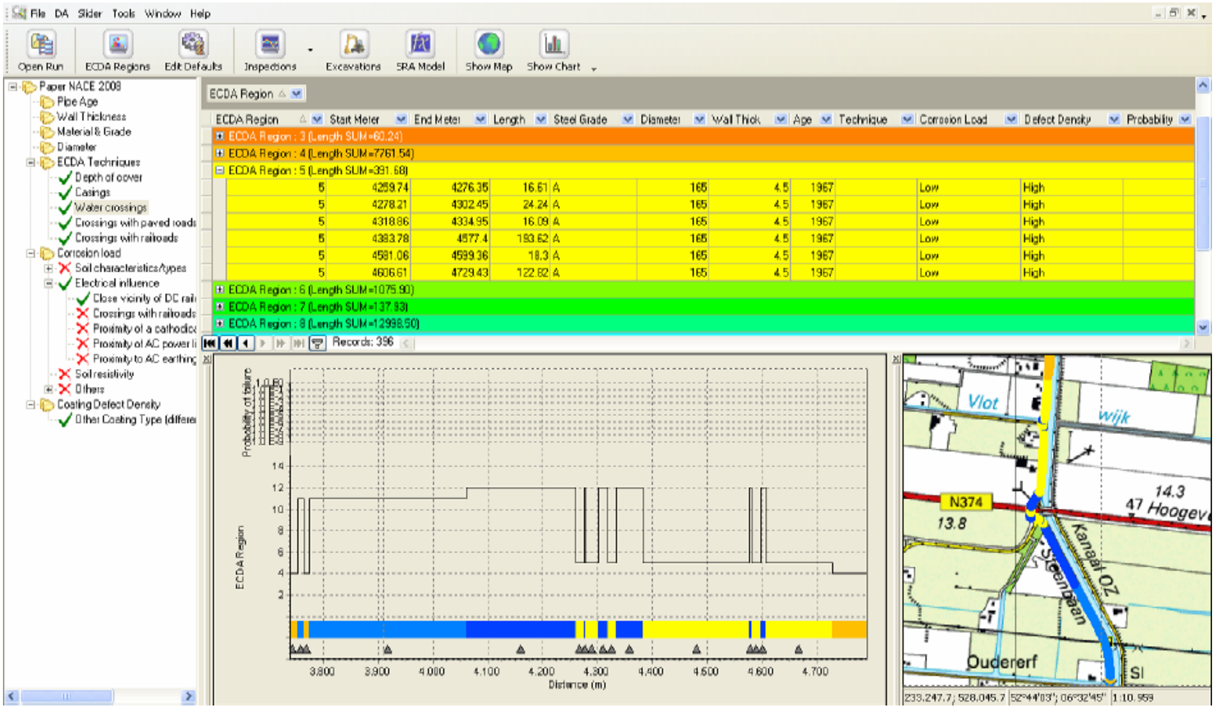


**Figure 5: Identification of ECDA regions**

## 3.2 Indirect Inspections

With respect to the Indirect Inspections step, the ECDA software can assist the corrosion engineer in achieving the following four goals, which are all briefly explained in the following paragraphs:

1. Data storage, processing, interpretation and visualization;
2. Generation of a priority list for direct examinations;
3. Update the condition of the pipeline.

### 3.2.1 Data storage, processing, interpretation and visualization

The data from the aboveground surveys are stored in a database for processing and for future reference. If required, the data from the surveys can be corrected for factors such as the depth of cover, the soil resistivity, or for currents through the pipeline. The ECDA module also calculates the IR-free potential (the potential of the steel at the exact point where the surface of the steel meets the surrounding environment, not distorted by the soil resistance between reference electrode and pipeline) and the corresponding uncertainty of this potential. The software presents the required data in a clear and comprehensive manner by plotting (combinations of) graphs on the screen, thereby simplifying interpretation of data by the operator. An example is given in Figure 6, where the on-potential, the off-potential and the DCVG %IR are plotted below each other, linked to the GIS environment.

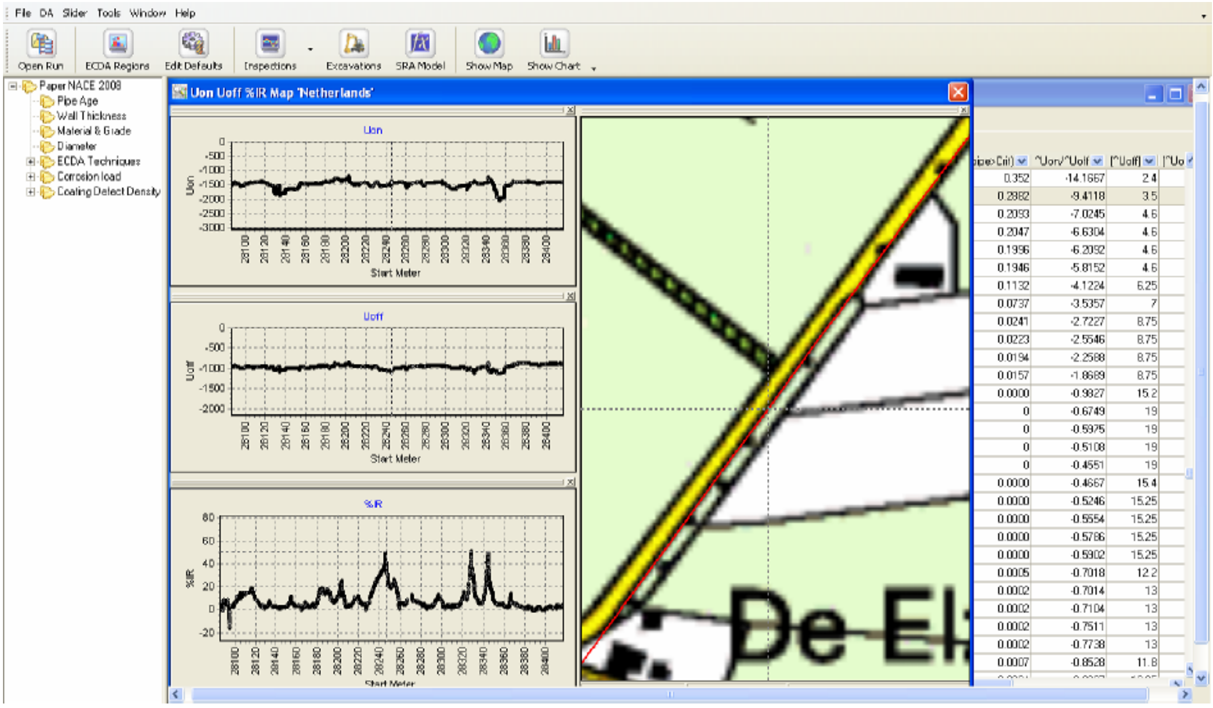


**Figure 6: Indirect Inspections**

### 3.2.2 Generation of a priority list for direct examination

The corrosion engineer can use various sorting and filtering functions to determine which indications need to be excavated for direct examination. Although generation of the priority list by itself is an automatic process, the success of this important process step depends only on the experience of the corrosion engineer interpreting the data, and of course the quality of the gathered data.

### 3.2.3 Update the condition of the pipeline

After new information has become available in the form of indirect inspection results, this information can be used to update the prior view on the integrity of the pipeline (e.g. numbers of coating and corrosion defects and failure frequency) by using Bayesian updating techniques. Before doing so, the uncertainties associated with the inspection tools must also be addressed. Since no inspection technique is 100% reliable, the performances of the used inspection tools are also taken into account by the SRA model. The performance of an aboveground survey technique often depends on factors such as coating type, soil conditions, depth of cover, experience of the operator etc.. It can be characterized by the following two variables:

- Probability of Detection (POD): the probability that a defect present is detected by the survey technique;

- Probability of False Indication (POF): the probability that the survey technique gives an indication where no actual defect is present.

The prior distributions of the POD and the POF of a survey technique can be constructed from previous experience with the technique or from recommendations of the manufacturer.

## 3.3 Direct Examination

In the direct examination step, indications from the previously mentioned priority list are excavated, starting of course with the highest-risk ECDA region found in the pre-assessment where indirect inspections could be performed. The outcome of each excavation determines whether additional excavations need to be carried out for the respective ECDA region, after which the pipeline integrity is evaluated again.

Based on the findings during the excavations, the information used in the pre-assessment and the indirect inspections will be updated, including:

- The survey characteristics POD and POF of each survey technique;
- The number of defects (coating and corrosion);
- The defect depth, corrosion growth rate and time of initiation;
- The critical defect depth.

After these updates, new values can be calculated for the failure frequencies of all ECDA-regions. The direct examination step is illustrated in Figure 7. In this example, a total number of 11 defect indications have been excavated altogether for this specific ECDA region. However, as shown by the arrows 1a-d, the 11 indications are located close to each other, resulting in only four (extended) Bell holes. In other words, the 4 most severe indications were selected for direct examination, but if less severe indications were present in the vicinity of those severe indications, they were subjected to direct examination as well, in order to generate more data for little extra cost.

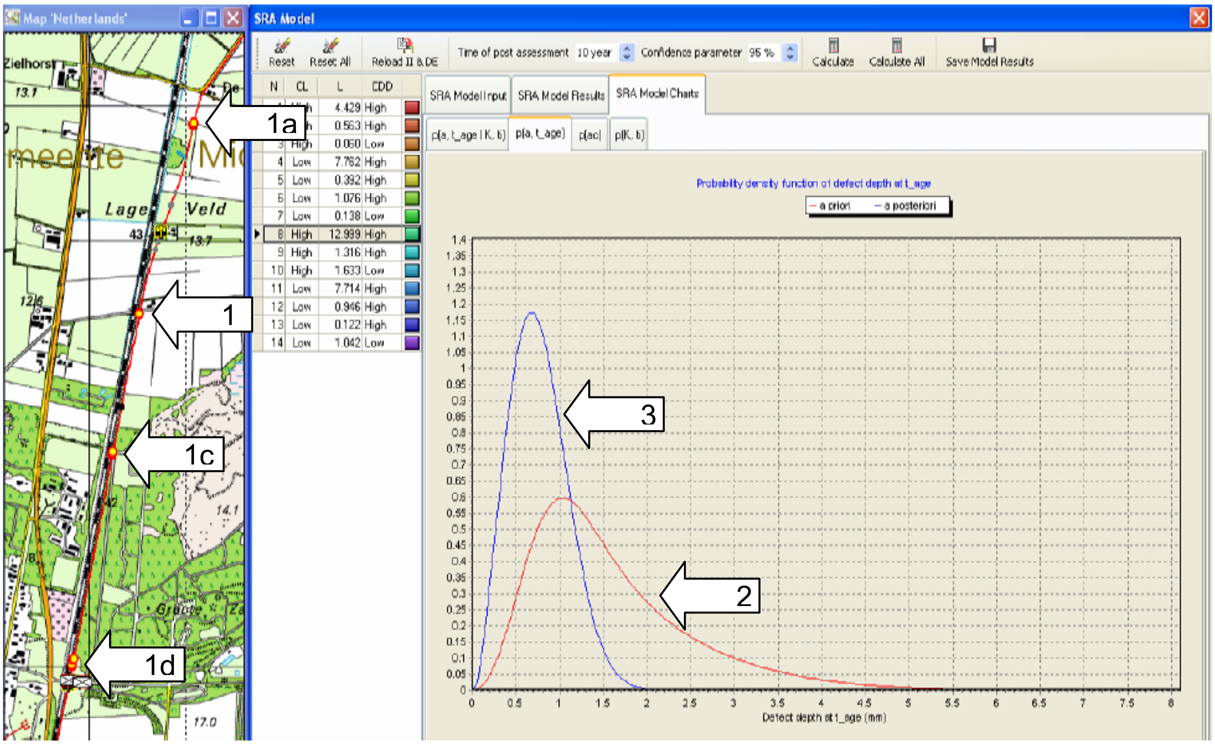

**Figure 7: Direct Examination**

In this example, during the excavations, mild corrosion was found at 5 out of 11 indications, with a maximum defect depth of 1.2 mm. Finding defect depths less than estimated in the pre-assessment (arrow 2 in Figure 7) results in an overall shift to the left of the defect depth distribution (arrow 3).

The probability of failure for a single defect will change with each excavation where corrosion is found as the distributions of the corrosion growth rate and time of initiation also change. In general, when the parameters have been chosen conservatively in the pre-assessment, the failure frequency will decrease. This updating process can be performed after each excavation if required, until the criterion used for failure frequency is met, showing that sufficient excavations for the specific ECDA region have been carried out. This allows the integrity manager to minimize the number of excavations required.

### 3.4 Post-assessment

According to NACE [1], the objectives of the post-assessment are to define reassessment intervals and to assess the overall effectiveness of the ECDA process. The ECDA module assists the integrity manager in the first part of this process step, by accurately calculating the failure frequency of each ECDA region in the years to come in order to calculate an appropriate reassessment interval for the pipeline.

## 4 THE INDIRECT INSPECTION TOOL: THE CATHODIC PROTECTION SURVEY SET

Indirect inspections for ECDA purposes usually consist of the following measurements (next to soil resistivity measurements at regular intervals along the route):

- Direct Current Voltage Gradient (DCVG) survey: to detect and pinpoint coating defects along the pipeline;
- Close Interval Potential Survey (CIPS): to measure the on- and off-potentials over the pipeline, as well as the on- and off-potential gradients to remote earth. These measurements are used to determine whether a possible coating defect is sufficiently protected by the CP system;
- dGPS-measurements: to measure the position of coating defect indications, soil resistivity measurements and characteristic features along the pipeline.

Within the ECDA process, the Indirect Inspections have been found to be one of the most critical factors in the ECDA process. With the objective to further improve the productivity and reliability of the ECDA process, KEMA has developed a new survey set. After significant R&D effort since 2007 and extensive field testing, a computerized solution has come available. At present, the survey set is successfully applied in the process of ECDA.

In the developed Cathodic Protections Survey Set (CPSS), functionalities of DCVG (Direct Current Voltage Gradient ), CIPS (Closed Interval Potential Survey) and dGPS are efficiently combined in one device (as can be seen in Figure 8), making it possible to perform all surveys in one run. The complexity of the measurements requires a CPU, which is provided by a solid notebook PC.

Surveyors appreciate the automated zero adjustment, reduced weight of poles. The CPSS also adds new innovative functionalities [7]. For instance, processed information is directly available to the surveyor. This gives the surveyor the ability to take adequate actions when measurements appear to be unreliable and draws additional attention to undesired situations. It has been proven that the workability for surveyors has improved significantly. In addition, the quality of survey data is better, particularly in situations with external interference by stray currents and for pipelines with rather large depth of cover. The survey data can directly be imported into the DA module with less postprocessing efforts, considerably saving time.

**Figure 8: The Cathodic Protection Survey Set**

## 5 CONCLUSIONS

For non-piggable pipelines, External Corrosion Direct Assessment (ECDA), as described by the ANCI/NACE SP0502-2010, is a valuable method to assess and reduce the impact of external corrosion to the integrity. KEMA has developed an optimal solution to manage the entire ECDA process. This solution is based on a fully integrated combination of:

- The Direct Assessment (DA) software module. SRA in combination with Bayesian statistics, makes it possible to quantify the results obtained during the different steps of an ECDA process;
- A specially designed Cathodic Protection Survey Set (CPSS) to detect possible corrosion activity. The Cathodic Protections Survey Set (CPSS) was developed, with functionalities of DCVG (Direct Current Voltage Gradient ), CIPS (Closed Interval Potential Survey) and dGPS efficiently combined in one device, making it possible to perform all surveys in one run. It has been proven that the workability for surveyors has improved significantly. In addition, the quality of survey data is better. The survey data can directly be imported into the DA module with less postprocessing efforts, considerably saving time;
- One Pipeline Integrity Management System. To allow efficient, structured and reliable data processing in support of pipeline integrity management, all data are available in one software system: PiMSlider.

In this paper it was shown that the benefits of the KEMA solution during the different steps of the ECDA process are numerous:

- In the pre-assessment, the ECDA module assists the operator in gathering and analyzing the relevant data, and to quantify the current condition of the pipeline by calculating a failure frequency for each ECDA region, using the developed SRA model;
- For the second survey step, the specially developed CPSS makes it possible to perform all surveys in one run. It has been proven that the workability for surveyors has improved significantly. In addition, the quality of survey data is better. The survey data can directly be imported into the DA module with less postprocessing efforts, considerably saving time;
- Survey data from the indirect inspections are stored in the PiMSlider database. The ECDA module assists the user in determining the severity of defect indications, and to identify areas where corrosion is likely to occur. Subsequently, the ECDA module applies Bayesian updating techniques to update the number of defects estimated in the pre-assessment, after which the failure frequency can be updated;
- In the next process step, the ECDA module uses the information from direct examinations to update parameters such as:
    - the POD and POF of each survey technique,
    - the number of coating and corrosion defects,
    - the defect depth,
    - the time of initiation and the corrosion growth rate.

  Again, based on these updates, the failure frequency of the pipeline under investigation is calculated. This updating process can be performed after each excavation if required, until the failure frequency for the respective ECDA region is sufficiently low. This allows the integrity manager to minimize the number of excavations required;
- Finally, in the post-assessment the ECDA module can be used to calculate an appropriate reassessment interval for the pipeline.

Overall, the KEMA ECDA solution gives the benefit of easy access to all relevant data from the pipeline under investigation, as well as from other pipelines. It offers considerable time-saving, increased transparency and better reproducibility throughout the ECDA process. In addition, it enables quantification of each mitigating activity to the overall integrity of the pipeline, thereby minimizing the overall cost of mitigating measures. And finally, the DA module accounts for most of the uncertainties generally encountered within the ECDA process.

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