Deliverable D6.2:
Implementation of the software

WP6: Development of the open Access TeaM Cables tool and integration of models

Grant Agreement number: 755183	NFRP-2016-2017-1
Euratom programme	Research and Innovation Action
Start date of project: 1st September 2017	Duration: 54 months
Lead beneficiary of this deliverable:	FRA-G
Dissemination Level: Public	Document type: Report
Due date of deliverable: 30/04/2019	Actual submission date: 20/05/2019

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Description: Report describing the software structure in more detail (e.g. displayed graphically) and a preliminary version of the software tool, based on Revision A of specifications.

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Glossary

Abbreviation/ acronym	**Description**
[POOP]	polymer free radical oxidized
A	free-radical antioxidant
AH	Antioxidant
COMSY	Condition Oriented Monitoring and Plant Management System (Software)
ECS	EDF Coding System
EDF	Électricité de France
ENSAM	École Nationale Supérieure d'Arts et Métiers
FRA-G	Framatome GmbH
GUI	Graphical User Interface
HW	Hardware
KKS	Kraftwerk-Kennzeichensystem
LOCA	Loss Of Coolant Accident
MS	Microsoft
O2	oxigen
OS	Operating System
P	polymer free radical
PE	Polyethylene
PO2	polymer free-radical oxidized
POOH	hydroperoxides
PVC	Polyvinylchloride
SW	Software
Tbd	To be defined
TID	Total Integrated Dose
TMC	TeaM Cables
VM	Virtual Machine

VP	Virtual Polymer (Software)
WP	Work Package
XLPE	Cross-linked polyethylene

1 Executive Summary

In this deliverable the progress achieved in WP6 for the implementation of the TeaM Cables (TMC) Tool is presented to document the project evolution and decisions taken in the course of the software (SW) implementation works in order to achieve the TMC objectives.

The TeaM Cables Tool intends to combine COMSY (Condition Oriented Monitoring and Plant Management System), developed by Framatome GmbH, and VP (Virtual Polymer), developed by EDF.

A first specification of the TeaM Cables Tool was drafted in [1]; the deliverable was submitted to TMC project in September of 2019.

2 Introduction

COMSY is the front-end software running on Windows OS platform at the customer; all data is stored in an MS Access or MS SQL Server database. For the TeaM Cables Tool, the electrical module of COMSY will be used. In the TeaM Cables Tool, the currently implemented ageing/degradation algorithms for assessment/management of the lifetime for XLPE insulated cables (as part of passive electrical systems) will be replaced/extended with the evaluation of calculation results from VP, using algorithms to be developed and validated within the framework of the TeaM Cables project.

VP is the back-end software running on Linux OS: it is a one-dimension modelling platform composed of a model data base and different calculation components. The chaining of the different parts makes it possible to develop a multi scale and multi physic modelling of the polymer ageing process. The further development and validation of the multi scale and multi physic modelling of the ageing process of XLPE in dependence of specific material properties and environmental conditions is the main objective of the TeaM Cables project.

The features required in the TeaM Cables Tool were identified in [1] as the following:

- the graphical user interface (GUI) needed for cable data entry and display,
- generates the data needed for degradation calculations in VP,
- receives the calculation results (abacus/solver matrix) from VP,
- allocation/mapping of VP results to the individual cables,
- display of results, calculation of residual life time.

This intermediate report presents the activities made and progress achieved in WP6 for the implementation of the TeaM Cables Tool in order to document the project evolution and decisions made in the course of the SW implementation works in order to achieve the TMC objectives.

In order to test the handling of data formats between VP and COMSY, a first data exchange was made with calculation data genetrated by EDF from the existing (preliminary) calculation model of VP. The data is presented in section 3 in more detail.

Based on information exchanged in a telephone conference held end of January 2019, the data was analysed and used to implement the first TeaM Cables Tool features into COMSY. These features will be briefly presented in section 4.

3 VP Data

3.1 VP data received

Framatome received data from a (preliminary) calculation run in VP. The content was discussed in a telephone conference on the 28th of January 2019.

The following files were received:

- **generate_input_with_openturns.py,** this file contains the addressing parameters for VP run (python commandos)
- **experimental_design_for_vp.txt,** this file contains the 10 couples of temperatures in Kelvin and dose rates in Gy/s for the calculation run
- **c_solver_stiff_ode_1d_cas_0000.metadata.txt,** this file contains explanations for the VP abacus (e.g.):
    - field_name = chemical products concentration
    - producer = c_solver_stiff_ode_1d
    - data_shape = (7,)
    - component_names = ['POOH', 'P', 'PO2', 'O2', '[POOP]cage', 'A', 'AH']
    - component_units = ['mol/l', 'mol/l', 'mol/l', 'mol/l', 'mol/l', 'mol/l', 'mol/l']
- **c_solver_stiff_ode_1d_cas_0000.txt through c_solver_stiff_ode_1d_cas_0009.txt,** these files contain the the results of the VP calculation run of the 10 couples in abacus form with:
    - temps: time in hour
    - X: number of discretization nodes.
    - POOH: concentration of the hydroperoxides which are breakdown products [mol/l]
    - P: concentration of the polymer free radical [mol/l]
    - PO2: polymer free-radical oxidized concentration [mol/l]
    - O2: oxigen concentration per node as a function of time [mol/l]
    - [POOP]cage: concentration of stabilized polymer free radical oxidized species [mol/l]
    - A: free-radical antioxidant concentration [mol/l]
    - AH: antioxidant concentration [mol/l]

More details are included in the working document [2].

3.2 VP data analysis and clarifications

In the telephone conference in January 2019 it was mentioned that PO2 concentration is typically used to trace ageing (degradation) in XLPE. In consequence, some PO2 over time diagrams were generated for visualization purposes. The diagrams, including remarks and clarification results from a second telephone conference held in April 2019 are included in the working document [2].

Clarification results:

1. units in "**experimental_design_for_vp.txt**" appear to be wrong; the correct units for the couples in VP should be [K] for temperature and [Gy/h] for dose rate, [Gy] for integral dose
2. model used in the first VP run is a material sheet with free surfaces
3. PO2 is radical, not an end product – not suitable for the establishment of an end-of-life criteria
4. Interaction between XLPE and conductor material is not investigated in the TeaM Cables project (there might be some hints from the experimental investigations)
5. The current VP calculation model is a preliminary version. ENSAM will develop the calculation model within the TeaM Cables project; this will be implemented in VP.

6. The final VP output might differ from the preliminary version. This means that other and/or additional calculation outputs than the parameters already included in the **c_solver_stiff_ode_1d_cas_**xxxx**.txt** might be selected for degradation over time evaluations of the XLPE material (aim is the correlation of chemical, mechanical and electrical parameters over time). It is expected that further parameters will be added to and delivered in the abacus of VP to COMSY.

4 SW-Implementation in COMSY

4.1 Data handling

The first files from VP were used as play data for implementation and testing of file handling.

The import of the VP data files into COMSY is possible.

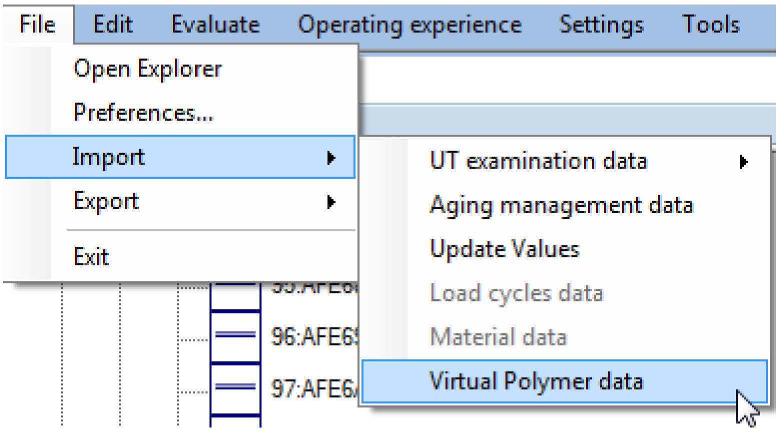

Figure 1: GUI for the import of VP data

From a demonstration data-base it is possible to create data files for VP.

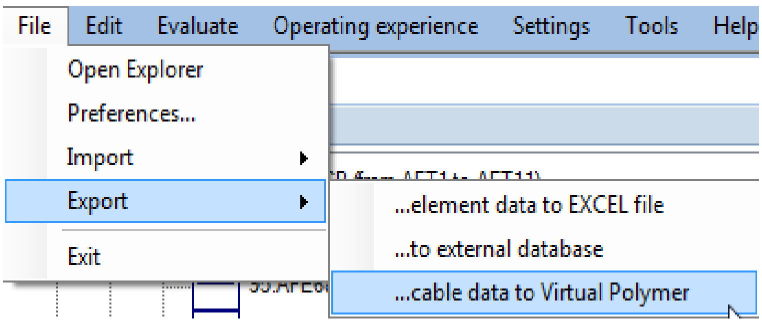

Figure 2: GUI for the export of data to VP

One XLPE "cable type" was generated (no differentiation needed for data handling tests). For this one cable type, the data files required by VP can be created including the "**metadata.txt**" file, if necessary.

```
Case_000.txt - Editor
Datei Bearbeiten Format Ansicht ?
3,130000000000000000e+02 2,500000000000000000e-04
3,130000000000000000e+02 7,400000000000000000e-04
3,130000000000000000e+02 9,000000000000000000e-04
3,130000000000000000e+02 1,200000000000000000e-03
3,130000000000000000e+02 1,300000000000000000e-03
3,130000000000000000e+02 2,360000000000000000e-03
3,130000000000000000e+02 3,000000000000000000e-03
3,130000000000000000e+02 3,200000000000000000e-03
3,130000000000000000e+02 7,200000000000000000e-03
3,130000000000000000e+02 3,500000000000000000e-02
3,180000000000000000e+02 3,300000000000000000e-03
3,220000000000000000e+02 1,100000000000000000e-01
3,220000000000000000e+02 2,200000000000000000e-01
3,220000000000000000e+02 5,500000000000000000e-01
3,220000000000000000e+02 2,200000000000000000e+00
3,400000000000000000e+02 0,000000000000000000e+00
```

Figure 3: Example for Case-file (environmental parameters for VP)

```
case_000.metadata.txt - Editor
Datei Bearbeiten Format Ansicht ?
grid_name = cas_0000
grid_unit = -
grid_discretisation = (10,)
grid_steps = (1.0,)
grid_origin = (0.0,)
field_name = chemical products concentration
producer = c_solver_stiff_ode_1d
data_shape = (7,)
component_names = ['POOH', 'P', 'PO2', 'O2', '[POOP]cage', 'A', 'AH']
component_units = ['mol/l', 'mol/l', 'mol/l', 'mol/l', 'mol/l', 'mol/l', 'mol/l']
time_list = [0.0, 8.888888888888891e-10, 1.777777777777781e-09,
2.663711140511862e-09, 3.568416110373 4495e-09, 4.480936804518 47e-09,
5.419074652498028e-09, 6.380589180890885e-09, 7.374752672681638e-09,
8.404084562745196e-09, 9.474562967801136e-09, 1.05906314951528e-08,
1.1757924567194668e-08, 1.2982400722288632e-08, 1.427108764623423e-08,
1.5632227793726203e-08, 1.7075672206186323e-08, 1.861324139674562e-08,
2.0259138197677122e-08, 2.203038642462684e-08, 2.394726587699354e-08,
2.603367026573127e-08, 2.831724021224131e-08, 3.082904171605316 6e-08,
3.360252658226593e-08, 3.667166657555 3685e-08, 4.00686492781612e-08,
4.382225310433284e-08, 4.795838062629296e-08, 5.250363183963 8895e-08,
5.749170159042785e-08, 6.297218393453263e-08, 6.902312962174125e-08,
7.577358313547392e-08, 8.345710759565033e-08, 9.258680516735338e-08,
1.0487497693059117e-07, 1.1674153126865321e-07, 1.3125044660282902e-07,
1.4407610950662462e-07, 1.5966239889681297e-07, 1.752486882870013e-07,
1.957262824921 35e-07, 2.142092365621 4238e-07, 2.398460505907493e-07,
2.654201637054642e-07, 2.986104330614551e-07, 3.260948036880 3865e-07,
3.484947537511851e-07, 3.718892625902603e-07, 3.973510431316653e-07,
4.235505459504 2403e-07, 4.503341637743769e-07, 4.777954464127702e-07,
5.060434757514 32e-07, 5.351782983783046e-07, 5.652955219316918e-07,
5.964915597234 92e-07, 6.288674927931074e-07, 6.625321823640827e-07,
6.976051372434034e-07, 7.342194549614723e-07, 7.725250785942972e-07,
8.126925920272741e-07, 8.549178057376978e-07, 8.994274376737076e-07,
9.464862995677404e-07, 9.964065501592834e-07, 1.049559816209066e-06,
1.106393346276164e-06, 1.167451936580053 6e-06, 1.233408300633184e-06,
1.3051060824955935e-06, 1.3836223421986965e-06, 1.4703610033838705e-06,
1.567197420227828e-06, 1.676711080784275e-06, 1.802578333352144e-06,
1.950274427637906e-06, 2.1284209787872056e-06, 2.3516142657458795e-06,
2.6470787357498305e-06, 3.0725646732548228e-06, 3.7607936216495617e-06,
4.796091322967029e-06, 6.070749699774808e-06, 7.483336472737 6405e-06,
```

Figure 4: Example for Metadata-file

From COMSY it is possible to exchange data by an automatic e-mail; send the files to a url; copy them to a specified location.

4.2 Next steps

In COMSY a demonstration data base is used. For data handling the creation of single cable type (XLPE) was made. The data for VP contain the real in-service condition parameters (temperatures/dose rates mapped over all installation locations in the plant).

The abstraction is made in one direction only: real XLPE cables→ XLPE cables type → VP.

In the second step the other direction has to be realised: VP calculation results → COMSY where the calculation results have to be interpreted and mapped/allocated to the real XLPE cables (individual ECS/KKS codes).

For this the following is required:

- A (preliminary) algorithm for VP abacus evaluation in COMSY,
- One (preliminary) end-of-life criteria to be used in the assessment of single cables,
- VP results using more realistic parameters.

These items were discussed in the telephone conference held in April 2019, more details are included in the working document [2].

The following decisions were made:

1. Second VP run for more representative results
2. For a first (preliminary) evaluation, the proposal is to use “AH: antioxidant concentration [mol/l]” values as indicator for end-of-life criteria for evaluation and reallocation of VP results to “real” cables in COMSY
3. Use of different end-of-life criteria for “non-LOCA[1]” and “LOCA” cables (e.g. 30% and 50% - to be discussed further).

[1] “LOCA” refers to the classification of the application/system in which the cable is used. In case the application/system is required to perform functions related to safety in the case of a **L**oss **O**f **C**oolant **A**ccident, the cable is also required to withstand and function under these postulated accident environmental loads.

5 Remarks and background information

5.1 Remarks

The parameter couples used in the first VP run are not realistic for operational conditions; in general the temperatures were too low and dose rates were too high.

FRA-G proposes to use parameters from the EPR design in the ageing calculation runs. E.g. Ambient temperature in the range of 15 to 55 °C and dose rate in the range of 10 to 100 mGy/h.

Table 1: proposed parameter range for additional VP run

T [K]	DR [Gy/s]	T [°C]	DR [Gy/h]	TID [Gy/1a]	TID [kGy/60a]
308	2,78E-07	15	1,00E-03	8,76E+00	0,53
313	5,56E-07	20	2,00E-03	1,75E+01	1,05
318	1,39E-06	25	5,00E-03	4,38E+01	2,63
323	2,78E-06	30	1,00E-02	8,76E+01	5,26
328	5,56E-06	35	2,00E-02	1,75E+02	10,51
333	1,39E-05	40	5,00E-02	4,38E+02	26,28
338	2,78E-05	45	1,00E-01	8,76E+02	52,56
343	5,56E-05	50	2,00E-01	1,75E+03	105,12
348	1,39E-04	55	5,00E-01	4,38E+03	262,80

From the TMC project point of view it may be interesting to make a VP run using parameters from the ageing of samples. This would be a first possibility for the researchers to compare data from VP simulation to experimentally obtained data. The environmental parameters used in the TMC project can be taken from [3].

5.2 Background information

Design classification of radiation zones (rooms) is done using the scheme shown in the following table. It has to be noted that the room classification is done for personal protection (accessible / non-accessible areas), therefore room classification is always conservative and the radiation loads onto the equipment is usually much lower. The column TID was added to show the resulting total integrated dose resulting from the power operation of the plant.

Table 2: proposed parameter range for additional VP run

Radiation Zone	Dose Rate Class	Boundary Dose Rate[2] [Gy/h]	TID (60a/0,9)[3] [Gy]
Green	A	1,00E-05	5
Green	2.5A	2,50E-05	12
Orange	B	1,00E-04	47
Orange	2B	2,00E-04	95
Orange	C	1,00E-03	473
Red	2C	2,00E-03	946
Red	D	1,00E-02	4730
Red	3D	3,00E-02	14191
Red	E	1,00E-01	47304
Red	3E	3,00E-01	141912
Red	F	1,00E+00	473040
Red	3F	3,00E+00	1419120
Red	G	1,00E+01	4730400
Red	…	…	…

Each capital letter alphabetically ordered corresponds to a dose rate decade starting with an 'A' which refers to a dose rate band up to 10 µSv/h. Intermediate values are defined by a digit in front of the letter for multiplying the decade represented by this capital letter, e.g. the class '2B' corresponds to a dose rate band up to an upper limit of 2×10^2 µSv/h = 200 µSv/h.

For example, in the nuclear qualification program performed for OL3 EPR, the TID of 50 kGy (based on dose rate class E) was chosen as representative requirement for cable ageing. Considering the potential dose rate effects (qualification vs. operational dose rate) by application of the power law (in case the dose rate exponent is known for the material) the actual qualification TID is higher. In RCC-E a factor of 4 is used resulting in a TID of 200 kGy for ageing (so the basis is also 50 kGy).

2 Upper limit.
3 Total integrated dose for a life time of 60 years with a power factor of 0.9.

6 References

[1]. TeaM Cables D6.1 deliverable, First revision of specifications (of the TeaM Cables Tool), 2018

[2]. TeaM Cables WP6 Interface between VP and COMSY_4_D6.2 (working paper between EDF and FRA-G), 2019

[3]. TMC-D2.2-SPECIFICATIONS_OF_tests-F2, 2018