Progress on Spent Fuel Data Compilations for PWRs

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   II.2 Genkai-1 (by I. García)
   II.3 Gösgen (by P. Díaz)
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   II.5 Mihama-3 (by A. Sabater and I. Fernández)
   II.6 Neckarwesthein-GKN II (by A. López)
   II.7 Obrigheim NPP (ICE) (by L. Cevallos and M. García)
   II.8 Obrigheim (by A. Uruburu and R. Pérez)
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   II.10 Turkey Point (by C. Israelsson)
   II.11 Vandellós-II (by J. Garrido and P. Romojaro)
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III. Summary and conclusions
A “Collaborative Agreement” involving the **collective participation of our students** in their last year of our “Nuclear Engineering Master Degree Programme” for: “the review and capturing of selected spent fuel isotopic assay data sets to be included in the new SFCOMPO database”.

**SFCOMPO / UPM Collaboration:** (F. Michel-Sendis visited Madrid, April 25th, 2013)

- Data capturing
- Data verification
- SFCOMPO Tool functionalities “beta testing”
- Feedback:
  - *Required developments*
  - “Template Format testing”
  - Uniformization / conversion of units

- Agenda: May-July 2013
- NEA Data Bank financial support for this task
Nuclear Energy Education at UPM

- Industrial Engineering (Energy/Nuclear Branch)
  ABET (Accreditation Board for Engineering and Technology) in 2010
- Master in Nuclear Science and Technology
  Mention of Quality & with the verification of General Direction of Universities
- Master in Energy Engineering (Nuclear Branch)
- Master in Technologies for Electrical Power Plants
  (DIN&ETSIIM&Tecnatom)

Figure 1: Nuclear Engineering Department

Web site: (www.din.upm.es)
We have introduced current computational methodologies and codes for reactor nuclear designs

For students, the understanding in a comprehensive way of these codes (JANIS, NJOY, WIMSD, MCNP, ORIGEN/ACAB, COBRA-TF, SEANAP, ...) is an important value in simulation, design and advanced analysis both in the research activities and in the professional work.

Methodology: “working in group”

- Classes: 14 weeks; 5 hours/week
- 15/20 students/year
- Documentation:
  - Theory and tests
  - Hands-on work
- Extra seminars:
  - J.C. Kuijper (2007)
  - R. Sanchez (2008)
  - Ivo Kodeli (2008)
  - Kostadin Ivanov (2009)
  - Enrico Sartori (2010)
  - Roberto Capote (2010)
  - J.C. Neuber (2011)
  - Y. Rugama (2012)
  - I. Gauld (2013)
  - ...
DROPBOX:
“shared area by students”

How to …?
## Reactor and Review Assignments

<table>
<thead>
<tr>
<th>ALUMNO</th>
<th>1st Task: &quot;Reactor Assignment&quot;</th>
<th>2nd Task: &quot;Review Assignment&quot;</th>
</tr>
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<tbody>
<tr>
<td>1) R. Ruiz</td>
<td>Ohi</td>
<td>H.B.Robinson-2</td>
</tr>
<tr>
<td>2) C. Israelsson</td>
<td>Turkey Point</td>
<td>Neckarwestheim GKN</td>
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<td>3) A. Uruburu</td>
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<td>OBRIGHEIM-2</td>
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<td>4) R. Pérez</td>
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<td>Gosgen</td>
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<td>11) G. López</td>
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<td>12) J. Garrido</td>
<td>Vandellos</td>
<td>Yankee</td>
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<td>13) P. Romojaro</td>
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<td>Yankee</td>
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<td>14) R. Rey</td>
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<td>Mihama-3</td>
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<td>17) A. Sabater</td>
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<td>18) A. García</td>
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<tr>
<td>19) Á. Burgos</td>
<td>H.B.Robinson-2</td>
<td>Ohi</td>
</tr>
</tbody>
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Reactor and Review Assignments
1. Beznau-I
(by E. Morgado and G. López)

- Description of the work:
  - PWR Westinghouse (Switzerland)
  - Assembly M109 → 4 samples from 2 rods: B6, D3
    - Due to problems during transportation (cask rotation) samples for analysis were extracted from mistaken rods
  - Assembly M308 → 2 samples from rod K7
    - This analysis was introduced due to the unexpected cask rotation problem with M109
Problems:

- Results from one laboratory were rejected due to the overestimation of U content
- A cross-check analysis was performed on two samples to provide recommended values for each isotope. Used for its implementation in SFCOMPO
- Isotopes with significant decay or buildup during the period from end of fuel operation (EOL) to last measurement were corrected

Problems in the implementation of data in SFCOMPO:

- Add “new” units for some of the measurements performed in the laboratories as well as the corrected EOL calculations
- It was difficult to address the cask rotation problem in the SFCOMPO application, but this was solved with the “Comment Tool” implemented in the latest stage of development

Main References:


2. Genkai-1
(by I. García)

- Description of the work

Two samples were taken from the JPNNG1SFA1 assembly irradiated in the Genkai Unit 1 PWR reactor.

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>Sample Name</th>
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<tr>
<td>JPNNG1PWR-1</td>
<td>87H01</td>
</tr>
<tr>
<td>JPNNG1PWR-2</td>
<td>87H05</td>
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</tbody>
</table>

The results obtained from the post irradiation examination conducted by JAERI were sorted out in a spreadsheet that was then uploaded to the application.

Reactor characteristics (screenshot from SFCOMPO)
2. Genkai-1 (by I. García)

Assumptions

- Dummy reference dates were used, because no records about measurements dates
- Power density through the reactor’s operation history was assumed constant.
2. Genkai-1 (by I. García)

- **Problems**
  - Reactor’s assembly type is **14x14**, old type even in the 1990's.
  - The data set of Genkai-1 reactor includes **only two points**, clearly less than other reactors.
  - The location of the Genkai-1 sample/assembly was reported **classified** (neither a pin map nor an axial zoning graph could be generated on the SF.COMPO Java application).

- **Main References**
Description of the work

- 3 assemblies containing 4 samples

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Rod</th>
<th>Sample</th>
<th>Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>1240</td>
<td>14H13</td>
<td>GU1 &amp; GU2</td>
<td>12-13-14-15</td>
</tr>
<tr>
<td>1601</td>
<td>16B05</td>
<td>GU3(‘) &amp; GU4</td>
<td>16-17</td>
</tr>
<tr>
<td>1701</td>
<td>16B05</td>
<td>GU3(‘) &amp; GU4</td>
<td>18</td>
</tr>
</tbody>
</table>

- Assembly 1240
  - Implementation in function of the irradiation cycles because some fuel rods surrounding the sample rod were changed

- Measurements for GU2 were rejected, so it was not implemented into SFCOMPO.
- The fuel rod 16B05 was irradiated for cycles 16 and 17 in assembly 1601 and then transferred for cycle (18) in assembly 1701.
- Sample GU3 can be considered as two samples, GU3 and GU3’. They have been implemented into SFCOMPO as independent samples.
Description of the work

- Assemblies 1601 and 1701
  - Fuel assemblies 1601 and 1701 share the same samples (GU3, GU3' and GU4). The samples were irradiated for cycles 16-17 in assembly 1601 and then transferred to assembly 1701
  - The assemblies were implemented in SFCOMPO separately

Problems

- SFCOMPO only admits one pin map per assembly
- Difficult to incorporate the replaced rods burnup in assembly 1240

Main References

4. H.B.Robinson Unit-2
(by A. Burgos and A. García)

- Description of the work

Study of six different samples:
  - ROD N9: 4 samples
  - ROD P8: 2 samples

Data:
  - Concentrations
    - Measurements → Divided in Ratios
    - Burn-up
  - Operation cycles → Temp & Power of each cycle
  - Core design and shape and size of the rods

Problems:
  - Some difficulties with the units and the nomenclature of special ratios
  - Operation information was collected from different reports

References

[5] SFCOMPO97 : The isotopic compositions database ...
[7] Pub23359: SCALE 5.1 Predictions of PWR Spent Nuclear ...
### Measurement Information

**SF COMPO Database**

#### Reactor Type: PWR
- **Reactor: H.B. Robinson Unit-2**
- **Organization:** (by A. Burgos and A. García)

#### Sample Characteristics

<table>
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<th>Parameter</th>
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<tr>
<td>Fuel type</td>
<td>Type</td>
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<td>Enrichment (%)</td>
<td>2.58%</td>
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<tr>
<td>Rod identifier</td>
<td>PSU-2</td>
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<tr>
<td>Axial position from bottom of fuel stack</td>
<td>0.2 m</td>
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<tr>
<td>Axial length (m)</td>
<td>25.2</td>
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</table>

#### Measurement Data

<table>
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<th>Measurement Item</th>
<th>Value</th>
<th>Unit</th>
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<tr>
<td>Operating History</td>
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<tr>
<td>Sample code</td>
<td>SFCOMPO-1</td>
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<tr>
<td>Type</td>
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<td>Unit*</td>
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</tr>
<tr>
<td>Date reference</td>
<td></td>
<td>01/01/2015</td>
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</table>

#### References

- ASTM E-723
- ASTM E-482
- EPA-8210
- EPA-8210
- EPA-8210
- EPA-8210
- EPA-8210
- EPA-8210
- EPA-8210
- EPA-8210
- EPA-8210
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- EPA-8210
- EPA-8210
- EPA-8210

**Notes:**

- SF Compo Database
- Measurement information

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*EGADSNF – Paris (France), October 18-12, 2013*
Description of the work

An important part of the required information was found in the former SFCOMPO data base, but also important information about the cycles (burnup, power) and isotopic concentration was found in “SAS2H document”.

Problem

There is not information about axial position of the sample in the rod

Main References

[1] Post Irradiation Examination For the Spent Fuel Samples. Old SFCOMPO
[2] Corrections to the Nd method of evaluation of burnup for the PIE samples from Mihama-3 and Genkai-1 reactors.
6. Neckarwestheim-GKN II
(by A. López)

- Pressurized Water Reactor – 18x18
- Sample M11 from assembly 419 (UO₂)
- Enrichment 3.8 wt %
- The analyses were performed at SCK-CEN, and depending on the measured isotope, the laboratory used:
  - α-spectrometry
  - γ-spectrometry
  - Thermal Ionisation mass spectrometry (TIMS)
  - Inductively coupled plasma mass spectrometry (ICP-MS)
- M11, irradiation: 5 cycles (1445.4 days)
- Only separation date for Am-241, Am-242m and Am-243
Main References


7. Obrigheim-1
(by M. García and L. Cevallos)

- **Description of the work**

  - **20 samples** at different heights were taken from 6 rods and 2 fuel assemblies of different enrichment, and explored via gamma spectrometry and radiochemical analyses amongst other techniques.

- Information was collected from different sources and added to the one already available in the previous SFCOMPO version. Most of the data were retrieved from document EUR 6589en, complemented with ORNL/TM-2010/44 when something was missing.
Difficulties were found regarding the following aspects:

1) Measurements of \((\text{Pu}_{238} + \text{Am}_{241})/(\text{Pu}_{239} + \text{Pu}_{240})\) and \(\text{Pu}_{238}/(\text{Pu}_{239} + \text{Pu}_{240})\) in the same sample are supposed to be taken in that order, before and after the chemical separation of Am241. That information is recorded in P. 153 Table VII in document EUR6589en.

   - Some of the measurements after separation have an associated date previous to the data before separation. Example: OBR1|BE124|D1|P2.

2) Some information present in the bibliography was worthy of inclusion but the present format of the SFCOMPO java application is not able to deal with it. It is suggested to enlarge the capability of handling the data in order to offer this and other additional data:

   - Moderator Temperature and Density, as shown in P. 94, Table 56 in ORNL/TM-2010/44
   - Comparison between the relative results obtained by different experimental techiques at different laboratories, as shown in P. 159-168 in EUR6589en

3) It should be noted that document EUR6589en has some of its pages unordered. Page 166 should follow page 159.
Main references


8. Obrigheim-ICE
(by A. Uruburu and R. Pérez)

- **Description of the work**
  - PWR, 345 Mwe, 1050 MWth, 121 fuel assemblies
  - Fuel assembly: square, 14 x 14, 180 fuel rods, enrichment 3.13% U-235
  - Fuel irradiated from **9/1972** to **6/1975**. Operating cycles 3, 4 and 6
  - ICE measurements **1977-1978**
  - Isotopic Correlation Experiment -ICE- measurements performed independently at:
    - European Institute for Transuranium Elements (ITU)
    - Institute for Radiochemistry at Karlsruhe (IRCh)
    - Karlsruhe Reprocessing Plant (WAK)
    - International Atomic Energy Agency (IAEA)

*But,*

- Original measurements not available: “lack of info”
- Data obtained from several reports referring ICE
- Many data graphically determined from figures
- Slightly different values between reports
8. Obrigheim-ICE  
(by A. Uruburu and R. Pérez)

Description of the work

Samples (some differences from other reactors)

- 5 fuel assemblies analysed:
- Each assembly divided lengthwise and analysed in two batches

SFCOMPO structure:  ASSEMBLY/ROD/SAMPLE

Samples structure:  BE168 / Half-top / 86

- there is no rod identifier for samples: "virtual" rod defined: “Half-top”…-

“Assembly average data included “:

BE168 / Full-length / 86+87
Description of the work

- Power history: Full/Zero Load operation
- Final Burnup: 26.9 - 30.1 GWd/tHM
- Sample temperature: average value
- Moderator temperature and density: average value for all fuel assemblies and cycles
- Boron concentration: average value: 450 ppm

Main References


9. Ohi-1 and Ohi-2 (by R. Ruiz)

Description of the work

<table>
<thead>
<tr>
<th>PWR Reactor Name</th>
<th>Ohi-1</th>
<th>Ohi-2</th>
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</thead>
<tbody>
<tr>
<td>Assembly Name</td>
<td>G13</td>
<td>I7G</td>
</tr>
<tr>
<td>Fuel Assembly Rod Array</td>
<td>17×17</td>
<td>17×17</td>
</tr>
<tr>
<td>Nº of Irradiation Cycle</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Sample Name</td>
<td>91E07</td>
<td>89G01</td>
</tr>
<tr>
<td>Fuel Pin Position in the Assemblies</td>
<td>N13</td>
<td>C5</td>
</tr>
<tr>
<td>Fuel Type of Sample</td>
<td>UO₂</td>
<td>UO₂-Gd₂O₃</td>
</tr>
<tr>
<td>²³⁵U enrichment [wt%]</td>
<td>3.2</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Main References


9. Ohi-1 and Ohi-2
(by R. Ruiz)
10. Turkey Point (by C. Israelsson)

- **Description of the work**
  
  From the "Destructive Examination of 3-cycle LWR fuel rods from Turkey Point Unit 3 for the CLIMAX-Spent Fuel Test, HEDL-TME 80-89" conducted in the early 1980’s: 8 samples for hydrogen analysis, **5 samples for fuel burnup** and 12 samples for metallographic examination.

- This figure shows the transversal section of one of the two (D01 and D04) Turkey Point’s assemblies and the place of examined fuel rods, as seen in the SFCOMPO Database.
Figure on the right illustrates where the samples were taken.

Figure below shows how Fuel Rod H09 is showed in SFCOMPO database.


- Some data, such as isotopic concentrations, are not consistent: “different results in the references”
- No information about “the localization of assemblies in each irradiation period”
- Some information (fission gas analysis, void volume determination) is not represented in the database since it is not related to any definite sample

**Main References**

[1] S. D. Atkin Destructive examination of 3-Cycle LWR fuel rods from Turkey Point Unit 3 for the CLIMAX - Spent fuel test Hanford Engineering Development Laboratory


Samples description: Vandellós II

- Many pellets were moved inside the reactor with the intention of performing a high burnup isotope inventory evaluation.
- Nine samples were extracted from some rods at different fuel heights by Studsvik Laboratory in Sweden.

Assembly movement inside the core

Rod movement inside the assembly
11. Vandellós-II
(by J. Garrido and P. Romojaro)

- Java application screenshot
Problems found and hypotheses

1) Isotope ‘Zirlo’ has been defined as a new element

2) Pincell ‘B’ has been added to differentiate the enrichments of each fuel assembly

3) In “Complementary Rod Type DI” the instrumentation tube characteristics are unknown

4) In “Measurement” sheet, the following hypotheses have been assumed:
   4.1) Isotopes where the corresponding ratio is “less than the specified value”, no uncertainty value has been used.
   4.2) Confidence of the measurements is unknown, so it has been set to 1σ.
   4.3) In some samples, there was no specified date of the month in which the measurement was taken, so the first day of the month has been chosen as the date to define that situation.
   4.4) The second experiment performed to determine the ratio of Pu and Am have been considered for samples E58-257 and WZtR160-800.

5) In “Operating history” sheet, some information has been erased owing to an unresolved failure in “Sample” column when the file was imported to the SFCOMPO database. **To be updated.**
   - After definition of the new label: “FULL_SAMPLE_REF”
   - A “Sample” (e.g. EF05|WZR0058|E58-88 ) can not be defined in two different Assemblies
Ref. “Irradiation data of the three fuel rods for high burnup fuel isotope determination”. ENUSA Report COM-006998 Rev.2, 2010-12-02

### Tabla 0.5
Moderator Density and Temperature

<table>
<thead>
<tr>
<th>Sample</th>
<th>Cycles 7-8-9</th>
<th>Cycle 10</th>
<th>Cycle 11</th>
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<tr>
<td>WZtR165</td>
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<tr>
<td>$\rho$ (g/cm$^3$)</td>
<td>$T$ (°K)</td>
<td>$\rho$ (g/cm$^3$)</td>
<td>$T$ (°K)</td>
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<td>WZR0058</td>
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</tr>
<tr>
<td>$\rho$ (g/cm$^3$)</td>
<td>$T$ (°K)</td>
<td>$\rho$ (g/cm$^3$)</td>
<td>$T$ (°K)</td>
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<td>5</td>
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</table>

“Included in SFCOMPO for all the samples”
References

Complementary reactor DI : Ref. 1 page 10.
Assembly type : Ref. 1 pages 3 and 10.
Rod type : Ref. 1 page 10
Complementary Rod Type : Ref. 1 page 10
Rod : Ref. 1 page 3
Compound : Ref. 2 pp.6, Ref. 3 pp.21
Compound composition : Ref. 1 pages 6 and 10
Rod axial zone : Ref. 1 page 10
Pin map ij : Ref. 3 page 19
Sample : Ref. 1 pp. 6, Ref. 4 pp. 4 and Ref. 5 pp.5
Measurement : Ref. 6 pages 6-9 and Ref. 5 pages 18-25
Reactor irradiation cycle : Ref. 1 page 2
Assembly irradiation cycle : Ref. 1 page 3
Operating history : Ref. 1 pages 4, 9, 11 and 12


Reactor and samples description

Yankee Core follow program was supported jointly by the Westinghouse Electric Corporation and the Yankee Atomic Electric Company. It was an 100 MWe experimental reactor. The analyzed samples belong to the assembly that occupied E6 position during cycles I, II and IV.

They were captured 9 samples from 3 rod positions: rod C-F6 (5 samples), rod SE-C2 (2 samples) and rod SE-E4 (2 samples).

Among C-F6 samples, two of them (T-177 and N-26) are measures of an only one sample, making up to an interlaboratory crosscheck analyses.
### Problems and remarks

- It was necessary to introduce Pu-236 atomic weight in data sheet
- Two rod pitch data in ref. : 0.422 and 0.456. That is because the greatest one belongs to rods aligned with control vanes to permit clearance for control blades. Only introduced the smallest one in SFCOMPO
- The information in references for measurements uncertainties is quite limited. Only uncertainties for Pu-236, Pu-238 and Cs-137 measurements are accurately specified. However, uncertainties of main U and Pu chains are not specified. It is only indicated that uncertainties are located between 0.2 and 0.9 %
- Power level data were captured using an application for extracting points from a chart

### Main References

2. R. J. Nodvick and et al.: “Supplementary report on evaluation of mass spectrometric and radiochemical analyses of Yankee Core I spent fuel, including isotopes of elements thorium through curium” (WCAP- 6086), August 1969
III. Summary and conclusions

- UPM contribution to SFCOMPO: 12 PWRs-“Spent Fuel Data Compilations”
- UPM team as SFCOMPO “beta testing” to check “Tool functionalities”
- Feedbacks and needs are documented
- Future work:
  - Additional “Spent Fuel Data Compilations”
  - Modelization of some BWR or PWR compilation: SCALE or MCNP

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“UPM team”