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Workshop on the Paks II site characteristics

Budapest, Feb 15, 2022

Federal Ministry
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WORKSHOP ON THE PAKS II SITE CHARACTERISTICS

Assessment of the Hungarian-Austrian professional workshop on the Paks II site characteristics in Budapest, Feb 15, 2022

Kurt Decker
Christoph Grützner
Esther Hintersberger
Manfred Strecker
Alessandro Valentini

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Project Manager Franz Meister (Umweltbundesamt, Industry & Energy Supply)

Authors _EEA Expert Team:_ Kurt Decker (University of Vienna, Department of Geology), Christoph Grützner (Friedrich Schiller University Jena, Institute of Geological Sciences), Esther Hintersberger (University of Vienna, Department of Geology), Manfred Strecker (University of Potsdam, Institute of Geosciences), Alessandro Valentini (Private Consultant)

Layout Sarah Perfler

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ABSTRACT

This document reports on the *"Hungarian-Austrian Bilateral Professional Workshop on the Open Questions Raised by the Environment Agency Austria (EAA), 15th of February 2022, Budapest",* held within the framework of the bilateral nuclear expert talks under the Agreement between the Government of Hungary and the Government of Austria on Issues of Common Interest in the Field of Nuclear Safety[1].

The workshop addressed open questions raised by the Austrian delegation regarding the issue of the suitability of the Paks II site for a nuclear power plant (NPP). The bilateral discussion was initiated by a report by Decker & Hintersberger (2021)[2], in which the authors used geological data published in the Paks II Geological Site Report to conclude that the site is located on a seismotectonically active and capable fault. According to the authors, the geological data indicated a system of structurally related, SW-NE-striking active fault zones in the near region and site vicinity of Paks, including the Dunaszentgyörgy-Harta fault zone (DHFZ) that directly passes below the Paks II site and the existing NPP. Proof of active faulting include faulted Quaternary sediments, geomorphological features, and paleoseismological evidence of strong earthquakes from about 14 locations. Of these data, the most noteworthy are the results from the paleoseismological trench Pa-21-II, excavated at a fault branch of the Dunaszentgyörgy-Harta fault zone about 0.7 km from the existing NPP Paks and 1 km from the Paks II site. The trench uncovered 12 surface-breaking faults that apparently formed during two separate surface-rupturing earthquakes at about 20,000 and 19,000 years before present. Structures include a negative flower structure that is considered indicative of a horizontal surface displacement of about 0.3–0.4 m during a M≥6 earthquake. Decker & Hintersberger (2021) therefore concluded that the paleoseismological data derived from the trench Pa-21-II confirm the existence of capable faults in the site vicinity of Paks II. These capable faults are part of the DHFZ, strike into the Paks site and show evidence of repeated and significant surface displacements that occurred during the last circa 20,000 years.

The matter of surface displacement is of particular importance due to the strictness of the Hungarian Governmental Decree No. 118 of 2011, Requirement 7.3.1.1100: *"If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."* [Note: "permanent surface displacement on the site" is referred to as "fault capability" in IAEA terminology].

[1] Bilateral Meeting under the Agreement Between the Republic of Hungary and the Republic of Austria for the Exchange of Information in Case of Radiological Emergency and for the Issues of Common Interest from the Field of Nuclear Safety and Radiation Protection

[2] https://www.umweltbundesamt.at/studien-reports/publikationsdetail?pub_id=2381&cHash=7430ce7a9bc06002b5f1c4791badd0e5

During the workshop, the Austrian delegates and the EAA experts focused on clarifying the issue of capable faults at the Paks II site. Information obtained during the workshop on the site conditions of the Paks II site resulted in the following conclusions:

- Technical presentations by the Hungarian experts focused almost exclusively on historical and instrumental seismicity data and their interpretation. The EAA[3] experts regard the data presented to be insufficient to allow an assessment of fault capability.
- The EAA experts confirm their conclusions on the existence of capable faults in the vicinity of the Paks site. These capable faults, described in detail in the Geological Site Report and partly excavated in the paleoseismological trench PA-21-II, are part of the Dunaszentgyörgy-Harta fault zone, their strike continues into the site, and they reveal evidence of repeated, significant surface displacements during the last ca. 20,000 years. The information provided during the bilateral workshop and the answers to the Austrian questions do not suffice to revise these conclusions.
- The EAA experts consider the data presented during the workshop and in the Geological Site Report to be insufficient to reliably exclude the hazard of fault capability. The available paleoseismological (trenching) data are insufficient to rule out the existence of capable faults on the Paks II site. For a comprehensive assessment, other structures of the Dunaszentgyörgy-Harta fault zone with inferred near-surface faults need to be trenched. This particularly applies to near-surface faults mapped by geophysical data both in the immediate vicinity of the Paks II site and on the site itself and described in the Geological Site Report[4].
- The latter finding is of particular importance in light of the Hungarian Governmental Decree No. 118 of 201, which in Requirements 7.3.1.0800 and 78.3.1.1100[5] stipulates that investigations regarding the potential of permanent surface displacement must be sufficiently detailed to enable a substantive decision to be made on the suitability of the site, and that the site shall be deemed unsuitable if the potential of the occurrence of a permanent surface displacement on the site cannot be reliably excluded and the said displacement may affect the nuclear facility.
- To reliably assess fault capability, it is important to expand the observation periods of possible seismogenic surface faulting beyond the coverage of historical and instrumental earthquake data. In line with international scientific practice, WENRA requirements and IAEA guidance, extending the timescale to centennial and millennial observation periods cogently requires the adoption of a paleoseismological approach, especially in an intraplate setting such as Hungary.

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[3] EAA: Environmental Agency Austria

[4] Profiles Pa-21-S-Geomega; Paks-MUEL-10; Pa-22-S; Paks-MUEL-3; all documented in the Geological Site Report.

[5] http://www.oah.hu/web/v3/haeaportal.nsf/8EE55B54901CDD60C1257CDD004367CB/$FILE/118%202011%20Korm.%20Rendelet%20_7.%20k%C3%B6tet_EN_2018_04_10.pdf

Therefore, the EAA experts strongly recommend a paleoseismological documentation of the excavation pits for the Paks II NPP. The team of experts appreciates HAEA's expectation that a *"monitoring program … is expected to be part of the permit application of the preparatory phase".* It recommends, however, that HAEA issues an official regulatory decision requiring targeted paleoseismological investigations of the excavation pit, as meaningful paleoseismological documentation is not possible during standard excavation work. Robust data can only be obtained from thoroughly cleaned excavation surfaces and rigorous stratigraphic and structural logging, conditions that cannot be expected during routine earthwork. Instead, adequate time must be allowed during excavations to establish good outcrop conditions and to document the profiles in sufficient detail. Finally, a convincing data set to disprove the existence of capable faults requires trenches oriented approximately perpendicular to the strike of the DHFZ and covering, as a minimum, the entire length of the future reactor buildings and related construction relevant to safety.

To continue and intensify dialogue, the Austrian delegates suggested that the EAA experts be granted permission to visit open construction pits on the Paks II site. The Hungarian delegates responded positively to this suggestion. Despite the obvious differences in opinion regarding some key issues of fault activity and capability, this courtesy is deeply appreciated.

Although the Hungarian-Austrian bilateral workshop provided a valuable opportunity to discuss the conditions of the Paks II site, it was not possible to clarify mutual positions in a technically satisfactory manner. For this reason and in view of the relevance for nuclear safety, the EAA experts suggest continuing the dialogue at expert level and involving further international experts. Follow-up discussions should consider additional details of the earlier set of questions and address the following points:

- Clarification of the validity of the statement in the Site License: "Based on the evaluation of the research the possibility of surface displacement due to a surface-breaking fault is excluded for the site." Based on accessible data and information, the EAA experts cannot agree with this statement.
- Clarification of the validity of the statement in the Site License: "Within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100.000 years." Based on accessible data and information on the Németkér fault, the EAA experts cannot agree with this statement.
- Discrepancies between the Geological Site Report and the Site Safety Report, and HAEA's assessment of these discrepancies.
- Consideration of near-fault effects in seismic hazard assessment.

INTRODUCTION AND BACKGROUND

On October 18, 2016, the company MVM Paks II. Zrt. applied for a site license for the new nuclear power plant (NPP) Paks II to be constructed on a site next to the existing Hungarian NPP Paks. For this purpose, the license applicant had initiated a comprehensive geological exploration program that resulted in a Geological Site Report, written by a multifaceted group of experts, and a Site Safety Report, compiled by MVM Paks II. Zrt. on the basis of the Geological Site Report. Based on these reports and other technical documentation, the Hungarian Atomic Energy Agency (HAEA) granted the site license on June 30, 2017.

The geological site conditions of the existing Hungarian NPP Paks have been a matter of discussion between Hungary and Austria since at least 2011. At that time, geological and seismological data from the region in which the NPP is located was published in scientific journals that revealed evidence of active faults offsetting Quaternary sediments (Tóth & Horvath, 1997; Tóth, 2003). The topics of active faulting, seismic hazard and seismic safety of the existing NPP Paks were subsequently discussed during Hungarian-Austrian bilateral meetings (e.g., Pecs, 2011[6]) and the European Stress Tests in 2012.

The ongoing discussion of seismotectonic hazards for the Paks site and the publicly available technical reports for the siting of Paks II led the Austrian Ministry BMK[7] to request an independent expert assessment of the geological site data and the site license decision by the HAEA.

The results of the assessment were published in a peer reviewed report[8] by K. Decker and E. Hintersberger in 2021. This report (Decker & Hintersberger, 2021) concluded the following:

- The Geological Site Report identified a system of structurally related, SW-NE-striking active fault zones near the Paks II site, including the Németkér-, Bonyhád-, Kapos- and Dunaszentgyörgy-Harta fault zones, with the latter directly passing below the Paks II site and the existing NPP. Proof of active seismogenic faulting include faulted and offset Quaternary sediments (extensively shown in geophysical, geological and borehole profiles), geomorphological features indicative of surface deformation (fault scarps, displaced aeolian landforms, stream patterns) and paleoseismological evidence of strong earthquakes from about 14 locations.
- Of these data, the results from the paleoseismological trench Pa-21-II, excavated at a fault branch of the Dunaszentgyörgy-Harta fault zone about 0.7 km from the existing NPP Paks and 1 km from the Paks II site, are most

[6] Bilateral Meeting under the Agreement Between the Republic of Hungary and the Republic of Austria for the Exchange of Information in Case of Radiological Emergency and for the Issues of Common Interest from the Field of Nuclear Safety and Radiation Protection

[7] Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology

[8] The report was reviewed by five experts, including two named and one anonymous Hungarian senior expert.

notable. The trench uncovered 12 surface-breaking faults that apparently formed during two separate surface-rupturing earthquakes at about 20,000 and 19,000 years before present. Structures include a negative flower structure that, according to Decker & Hintersberger (2021), is indicative of a horizontal surface displacement of about 0.3–0.4 m during a M≥6 earthquake. Decker & Hintersberger (2021) therefore concluded that the Dunaszentgyörgy-Harta fault zone, which passes through the Paks II site, is both an active and a capable fault.

- Evidence of active faulting in the site vicinity of Paks II and of capable faults within the Dunaszentgyörgy-Harta fault zone near the Paks II site is not fully and/or correctly reflected in the Site Safety Report compiled by MVM Paks II Zrt. The Site Safety Report omits relevant data from the Geological Site Report, such as virtually all paleoseismological data from the near region of the site, and shows a location and width of the Dunaszentgyörgy-Harta fault zone at the site that differs from the data in the Geological Site Report. Not only does Site Safety Report fail to provide a comprehensive and unbiased presentation of the paleoseismological data obtained from the trench Pa-21-II, but its conclusions regarding fault activity and fault capability are inconsistent with the geological evidence described in the Geological Site Report.

In spite of the evidence of the above-mentioned geological structures and the resulting safety-relevant issues regarding fault capability, and in spite of the potential conflict with the Hungarian regulatory requirement[9] to reliably exclude the potential of for the occurrence of a permanent surface displacement by scientific evidence, the HAEA granted the site license for the NPP Paks II on June 30, 2017.

Regardless of the site license decision, Decker & Hintersberger (2021) argued that the geological and geophysical data documented in the Geological Site Report and the Site Safety Report are insufficient to reliably exclude the potential for a permanent surface displacement at the site to meet Requirement 7.3.1.1100 of the Hungarian Governmental Decree No. 118 of 2011[9]. Although successfully exposing several branch faults of the Dunaszentgyörgy-Harta fault zone, the 85 m long paleoseismological trench Pa-21-II was considered insufficient to provide a reliable and comprehensive assessment of the potential fault capability for all branches of the active fault zone, which extends over a width of about 1 km in the subsurface of the existing NPP as well as large parts of the Paks II site. The authors concluded that, on the contrary, the paleoseismological data derived from the trench Pa-21-II near the site confirm the existence of capable faults in the site vicinity of Paks II. These capable faults are part of the Dunaszentgyörgy-Harta fault zone, strike into the site, and show evidence of repeated and significant surface displacements that have occurred over the last ca. 20,000 years.

Decker & Hintersberger (2021) thus concluded that the Hungarian Governmental Decree No. 118 of 2011 on nuclear safety requirements, Requirement

[9] Hungarian Governmental Decree No. 118 of 2011, Requirement 7.3.1.1100

7.3.1.1100, is evidently not met: The potential occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidence. Consequently, the Paks II site should therefore be deemed unsuitable.

On May 14, 2021, the Austrian Ministry of Foreign Affairs forwarded the report by Decker & Hintersberger (2021) to the Hungarian side, requesting bilateral consultations on the issue. The forwarded report contained, in particular, eight questions addressed to the HAEA, which were formulated to clarify some technical contents and procedural processes leading to the site-license decision.

On July 22, 2021, the HAEA agreed to the requested bilateral consultations, which were finally held on February 15, 2022 in Budapest. On this occasion, the EAA experts presented their views on the issue of fault capability at the Paks II site, confirming the conclusions by Decker & Hintersberger (2021), that the Hungarian Governmental Decree No. 118 of 2011 on nuclear safety requirements, Requirement 7.3.1.1100, is evidently not met. The EAA experts submitted a report to the Hungarian Ministry of Foreign Affairs and HAEA on February 18, 2022 (Decker et al., 2022) summarizing the workshop results from the perspective of the EAA experts. In this report, the EAA experts stated that the information provided during the bilateral workshop was not sufficient to revise their conclusion that the Paks II site was unsuitable due to the hazard of fault capability.

On March 29, 2022, the HAEA extended the Paks II site license (HAEA, 2022, Decision number P2-HA264[10]). The decision does not include stipulations that address the issue of fault capability discussed at the bilateral meeting on February 15, 2022. With respect to fault capability, the extension of the site license considered the expert position taken by Varga (2021), who essentially reiterates the assessment set out in the site license granted on June 30, 2017: *"No offsets in sediments were demonstrated to be present in the geological survey trench excavated in the framework of the FKP* [Földtani Kutatási Program – Geological Research Program]*, meaning that any paleo-earthquakes that may have occurred in the last few ten thousands of years were unable to result in significant faults. This is highly significant for the purposes of assessing the threat of earthquakes to the survey area. The results of geologic and geomorphologic surveys also confirm this finding. This means that the area has been inactive in a longer run for seismologic purposes."* Varga (2021) includes no references to new investigations, nor evidence or data to support his expert statement. The EAA experts consider Varga's assessment (2021) to be incorrect. Contrary to his assessment, the results of the geological survey trench do not disprove significant offsets by surface faulting (see Chapter 1.1.2 below and Decker & Hintersberger, 2021, Chapter 3.3.3, for a detailed discussion). The statement by Varga (2021) further appears to misunderstand the Hungarian Governmental Decree No. 118 of 2011, Requirement 7.3.1.1100. According to 7.3.1.1100, it is not necessary to prove permanent surface displacement (fault capability) to qualify a site as unsuitable, but rather to reliably exclude through scientific evidence the potential

[10] Including the documents considered in adopting the decision: Algmagembetov, 2021; Som System KFT, 2021; Varga, 2021.

for permanent surface displacement at the site to qualify the site as suitable. The lack of stipulations regarding the exclusion of fault capability for the Paks II site in HAEA, 2022, Decision number P2-HA264 is therefore not stringent to the EAA experts.

On August 25, 2022, the HAEA granted a construction license for Paks II, blocks 5 and 6 (Decision number P2-HA0375). As in the other documents, the decision does not contain any stipulations addressing the issue of fault capability.

OBJECTIVES

This document reports on the *"Hungarian-Austrian Bilateral Professional Workshop on the Open Questions Raised by the Environment Agency Austria, 15th of February 2022, Budapest"*. The workshop was held within the framework of the bilateral nuclear expert talks under the Agreement between the Government of Hungary and the Government of Austria on Issues of Common Interest in the Field of Nuclear Safety[11]. The workshop was kindly hosted by the Hungarian Atomic Energy Authority (OAH) to address open questions raised by the Austrian delegates regarding the issue of the suitability of the Paks II site as a future nuclear power plant.

During the workshop, the Austrian delegates and the EAA[12] experts focused on the clarification of the capable fault issue at the Paks II site as described in the report by Decker & Hintersberger (2021). The matter is of particular importance due to the strictness of the Hungarian Governmental Decree No. 118 of 2011, Requirement 7.3.1.1100: *"If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."* [Note: "permanent surface displacement on the site" is referred to as "fault capability" in IAEA terminology].

This report provides summaries of the key arguments presented by the Hungarian experts to support their view on the characteristics of the Paks II site. These summaries are followed by corresponding comments by the EAA experts. Comments also consider the content of the workshop presentation by Tóth et al. (2022) and the written answers to the eight questions to the Hungarian Regulatory Authority (HAEA) that were formulated in the report by Decker & Hintersberger (2021, p. 74-78). The workshop presentation by Tóth et al. (2022) is contained within Appendix 2. Questions to the HAEA, the received answers and the assessment of the answers by the EAA experts from chapter 2 of this report.

During the meeting, the Hungarian delegates broached the issue of a possible misunderstanding of the wording of the Requirement 7.3.1.1100, which could be due to an inaccurate translation into German. The EAA experts subsequently verified that the source of the translation used in Decker & Hintersberger (2021) and the current report is the official English translation of the Hungarian text[13]. The HAEA further raised concerns about language barriers posing obstacles when discussing technical documentation written in Hungarian. It is stressed

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[11] Bilateral Meeting under the Agreement Between the Republic of Hungary and the Republic of Austria for the Exchange of Information in Case of Radiological Emergency and for the Issues of Common Interest from the Field of Nuclear Safety and Radiation Protection

[12] EAA: Environmental Agency Austria

[13] http://www.oah.hu/web/v3/haeaportal.nsf/8EE55B54901CDD60C1257CDD004367CB/$FILE/118%202011%20Korm.%20Rendelet%20_7.%20k%C3%B6tet_EN_2018_04_10.pdf (download 30.08.2022)

that the EAA and the EAA experts attached great importance to the language issue and handled the subject to the best of their knowledge (see chapter 2.9 for more detail).

By considering the printed version of the Hungarian technical presentations and HAEA's written replies this report is considered final. It replaces the report by Decker et al. (2022).

1 SUMMARIES OF KEY ARGUMENTS PROVIDED BY THE HU DELEGATES AND KEY EAA COMMENTS

1.1 Fault Capability

1.1.1 Key argument by Paks II Zrt: exclusion of fault capability

In his presentation, L. Tóth provided information on the seismological database covering the greater region of the Paks II site and its implications for the site characteristics. From the seismological data, he concluded that surface-breaking faults are not plausible in this environment. The EAA team understood this conclusion to be drawn from the argument that seismicity in the area occurs at an extremely low level and that, based on all available information, a M=6 earthquake is considered unlikely to rupture the surface in a time frame of 100,000 years.

1.1.2 Key comments by EAA experts: evidence of fault capability

The above statements by L. Tóth suggested to the EAA experts that the exclusion of fault capability at the site is mostly (or solely?) based on instrumental earthquake records. Other existing data and toolkits for the identification and analysis of capable faults were not fully utilized. This approach appears surprising, and it is contrary to the workflow generally adopted by governmental agencies and private firms when assessing seismotectonic hazards of nuclear power installations over a wide range of low-occurrence probabilities (typically 10^{-4} to 10^{-7} per year). Ignoring such an approach is inconsistent with the IAEA and WENRA guidelines (see presentation by S. Baize), which recommend the analysis of fault behaviour on long timescales for evaluating capable faults, especially in low-strain intraplate areas (i.e., Pliocene-Quaternary tectonism). Even in seismically very active plate-boundary regions with frequent earthquakes, regulators require that paleoseismological and geological data be included in hazard calculations in addition to instrumentally recorded seismicity data. It is important to stress that nowhere in the world is seismology considered the sole methodology for assessing seismotectonic hazards, including fault capability.

The approach presented to justify the statement *"a M=6 earthquake cannot rupture the surface in a time frame of 100.000 years"* is also not in line with the WENRA requirements of Safety Reference Level TU3.3 (WENRA, 2021: *"The hazard assessment shall be based on all relevant site and regional data. Particular attention shall be given to extending the data available to include events beyond recorded and historical data."* WENRA (2020b) specifies this requirement more precisely by stating that data shall include paleoseismological results.

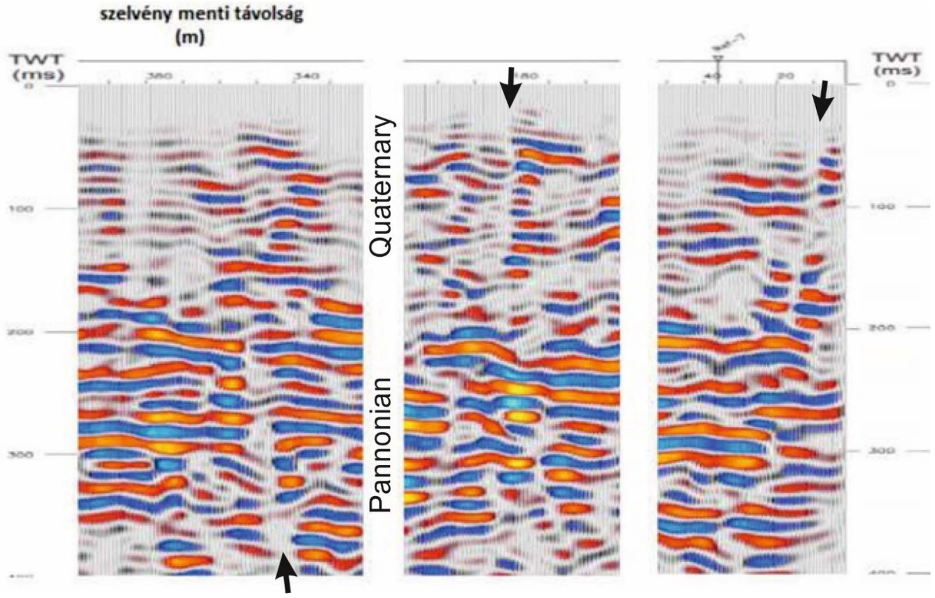
During the discussion, L. Tóth conceded that methodologies based solely on the analysis of historical and instrumentally recorded earthquakes are indeed unsuitable to reliably exclude fault capability.

In the data set provided in the Hungarian Geological Site Report, state-of-the-art shear-wave reflection seismic data unambiguously document the rupture of Late Pleistocene to Holocene sediments close to the Paks II site (profiles Pa-21-S, Pa-22-S; Geological Site Report, Ács et al., 2016, Fig. 420, Fig. 422). Fault sticks shown in the seismic profile PA-22-S reach up to depths as shallow as 50 ms shear wave TWT (Two-Way Travel Time). This TWT value corresponds to a depth of only a few meters below the surface. Importantly, some of the faults depicted by the seismic profile PA-21-S were exposed in the paleoseismological trench Pa-21-II (see below).

A grid of shear-wave reflection seismic data was also acquired within the Paks II site area (Ács et al., 2016, Attachments 4–7; Tóth, 2016, p. 96-103). Due to the limited quality of the seismic data and abundant reflection artefacts related to the anthropogenic backfill, the authors refrained from a full interpretation of the data, stating that possible tectonic offsets of Quaternary strata cannot be readily assessed (Tóth et al., 2016, p. 98). The Site Safety Report includes no description or interpretation of the data.

In a later interpretation of the same S-wave reflection profiles, T. Bodoky (2021) introduced a method for discriminating between seismic signals derived from the anthropogenic backfill and reflection patterns indicative of faults. This approach, in which "phase jumps" (sudden phase changes along a traceable seismic horizons) are reliable indicators of fault offsets, led to the identification of numerous faults cutting the top of the Pannonian strata and continuing upwards into the overlying Quaternary sediments (Figure 1). The data allow tracing faults up to a minimum depth of about 50 ms shear wave TWT (circa 7 meters according to the s-wave velocity estimated by Bodoky, 2021). Bodoky (2021, p. 212) concludes that the shear-wave reflection data makes it *"quite certain"* that Quaternary sediments are faulted. Bodoky (2021) further provided a map of the Paks II site showing the locations of faulted or fractured zones (*"töréses zavart zona"*). A tentative interpretation of the 15 S-wave reflection lines included in Ács et al., 2016, Attachments 4–7 by the EAA experts revealed similar results (Figure 2). The EAA experts only considered faults that were interpreted to affect overlying Quaternary sediments. The results of both interpretations highlight numerous fault/fracture zones (Bodoky, 2021) and fault sticks (EAA experts) within the Paks II site area (Figure 2). Fault sticks tend to line up along SW-NE- to SSW-NNE-striking structures, i.e., parallel to the strike of the Dunaszentgyörgy-Harta fault zone.

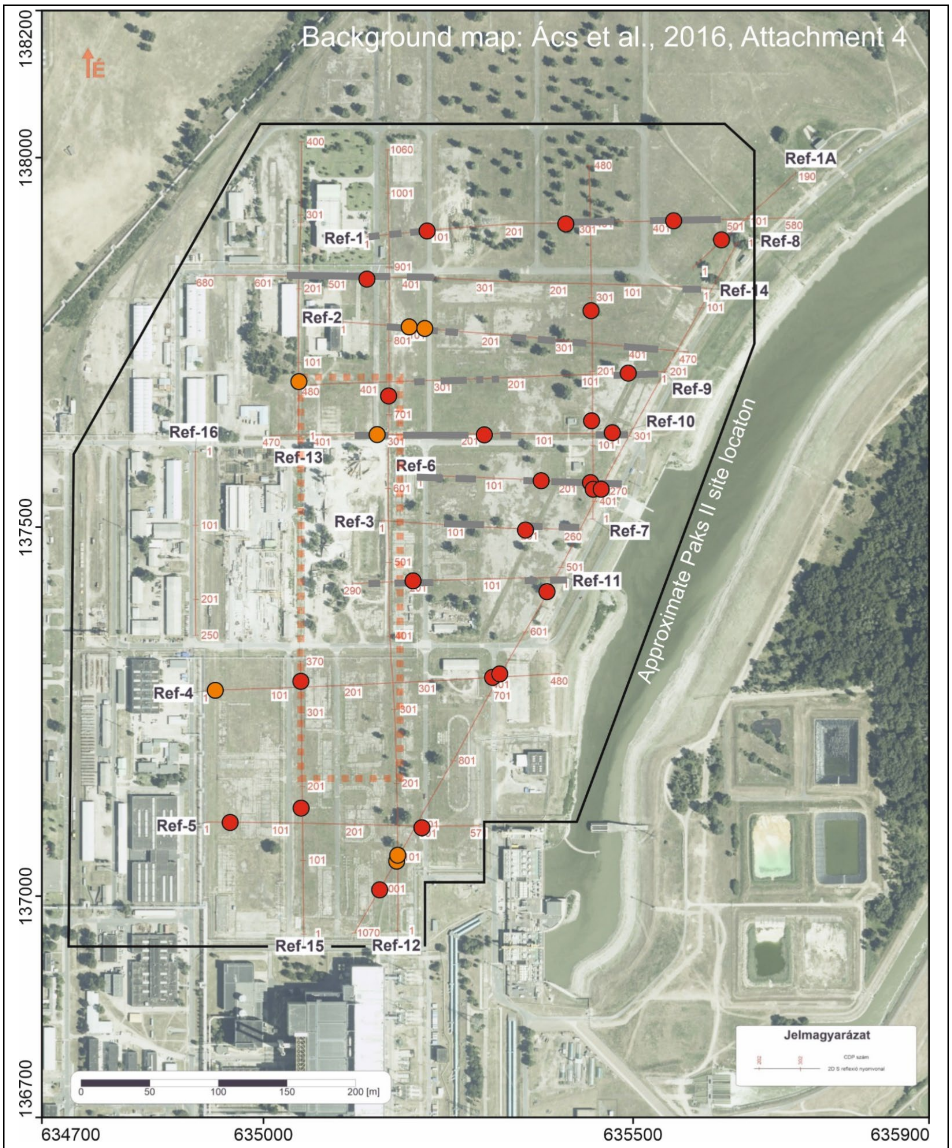
Figure 1.
Phenomena depicted by S-wave reflection seismic lines from the Paks II site that cannot be interpreted as surface noise, and thus indicate fault offsets.



Left: displacement reaching up to the Pannonian-Quaternary boundary apparently not offsetting Quaternary sediments. Center and right: offset reflectors and phase jumps (indicated by red/blue color changes along reflectors) indicating fault offsets in Quaternary sediments. Modified from Bodoky (2021), Figure 4b, by inserting arrows pointing to offset reflectors and labels denoting Pannonian and Quaternary sediments, respectively.

Source: Modified from Bodoky (2021), Figure 4b

Figure 2.
Aerial photo of the Paks II site showing the location of shear-wave reflection seismic lines and indications of faults (modified from Àcs et al., 2016, attachment 4).



Approximate outline of the Paks II site (black line) and supposed position of the reactor buildings (stippled red) added. Grey bars: faulted or fractured zones (töréses zavart zona) identified by Bodoky (2021); circles: locations of faults suggested by phase jumps in Quaternary sediments (EAA expert interpretation; red and orange circles denote high and medium confidence, respectively).

Source: Modified from Àcs et al., 2016, attachment 4 umweltbundesamt

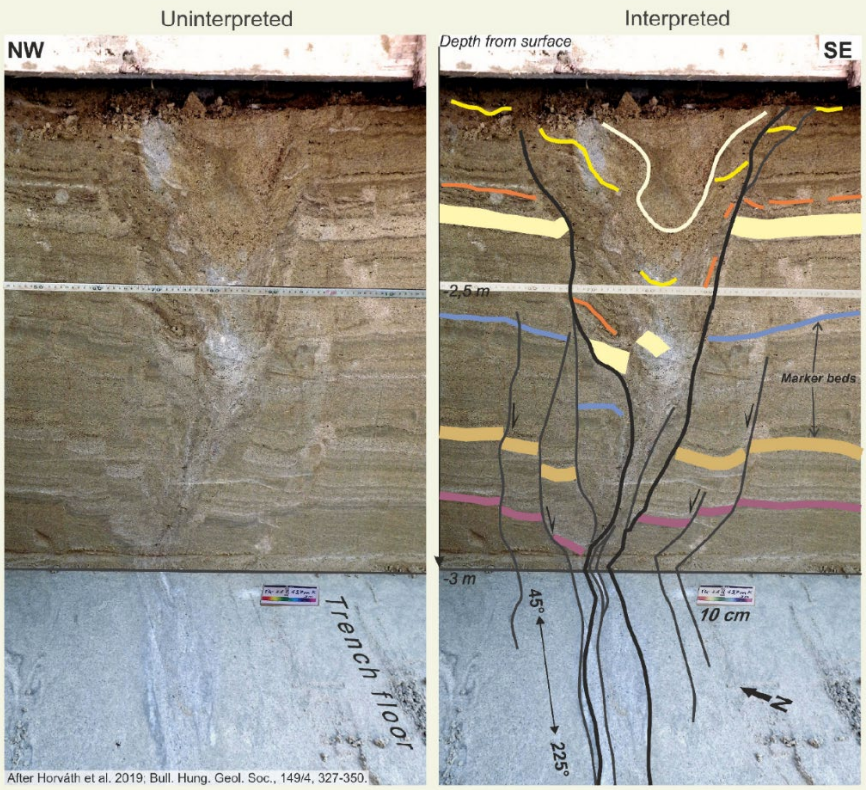
The S-wave reflection data and the interpretation by Bodoky (2021) are regarded as vitally important for assessing the seismotectonic conditions at the site: The data cover the actual construction site of the planned reactor buildings and other structures important to nuclear safety.

In addition to the data obtained from the Paks II site, road outcrops along Highway M6 about 9.7–10.5 km north of the Paks II site[14] exhibit faults that cut Late Pleistocene loessic sediments (Magyary, 2016). Magyary reported rupture ages between 5.5±1.1 ky and 7.7±1.1 ky and 13.2±1.9 ky and 14.3±2.7 ky, respectively, for two events identified by paleoseismological methods. Notably, fault patterns reported by Magyary (2016) resemble the fault orientations of surface-breaking faults and fractures caused by the 2020 Petrinja Mw=6.4 earthquake at the Županić strike-slip fault (Tondi et al., 2021).

Furthermore, in the man-made trench Pa-21-II, deformation of near-surface sediments was recorded. The identified structures offset 20-ky-old floodplain sediments (Halász et al., 2016, Attachment 2, trench log). Based on paleoseismological criteria (e.g., McCalpin, 2009, Fig. 6.34, Fig. 6.35) these structures are related to fault offsets. The arrangement of the offset strata is related to a brittle deformation process and cannot be mistaken for a sedimentological feature that might have been caused by paleoclimatic conditions under a periglacial regime (e.g., ice-wedge fill). Neither can these features be explained as liquefaction phenomena associated with the upward escape of water-saturated sediment, such as those described by Obermeier (1996) or Tuttle (1999, 2001). A tectonic interpretation of the described features by Halász et al. (2016) has also been adopted by Wórum et al. (2020). In their map of Young Geological Deformations in Hungary, Wórum et al. (2020, Fig. 3) show a structure from the trench Pa-21-II as an example of characteristic neotectonics deformation features (Figure 3).

[14] The stated distance from the Paks II site is in line with the outcrop documentation by Magyary (2016, particularly Figs. 1 and 3). The distance of ca. 20 km from the site claimed during the bilateral meeting in Budapest is apparently based on a misunderstanding of the original report.

Figure 3. Surface-breaking fault excavated in the trench Pa-21-II serving as "an example of characteristic neotectonics deformation features" in the map of Young Geological Deformations in Hungary by Wórum et al. (2020).



3. Faulting-induced paleosurface rupture trenched in Upper Pleistocene eolian sand

Pictures show structure 43.7 m from the trench Pa-21-II interpreted as a negative flower structure by Halász et al., 2016..

Source: Picture unmodified from Wórum et al., 2020, Fig. 3

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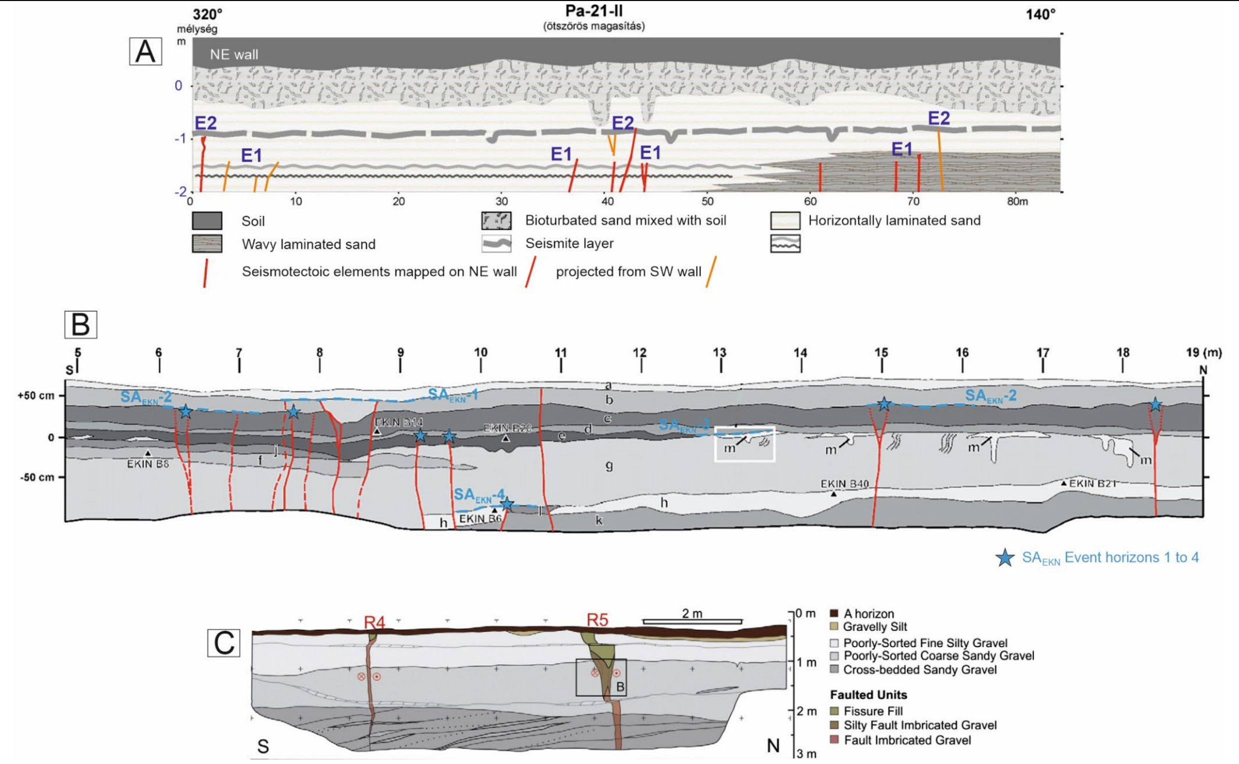
The structures observed in Pa-21-II are strikingly similar to published trench observations across strike-slip faults, such as the faults related to the 1999 Izmit (Turkey) Mw=7.4 and the 2010 Darfield (New Zealand) Mw=7.1 earthquakes (Dikbas et al., 2018; Hornblow et al., 2014): They all show very narrow sub-vertical deformation bands with no or small vertical offset distributed over the length of the respective trench walls. The faults terminate upwards in sediment-filled fissures. The similarities to the published trench studies support the interpretation of the observations in trench Pa-21-II as the result of at least two surface-breaking earthquakes along a strike-slip fault (Figure 4). In addition, both studies conclude that vertical offset observed within the trenches underrepresent the total surface offset related to the respective earthquake. Hornblow et al. (2014) even state that only approximately 30% of surface displacement that occur in strike-slip earthquakes are manifested along surface-breaking faults. Therefore, the slip estimation of only few centimeters along the Dunaszentgyörgy-Harta fault zone based on the trenching observation must be considered as an absolute minimum offset.

In addition to these concerns, the EAA experts stressed that paleoseismological investigations of a fault need to include numerous trenches at different sites along strike of the fault in order to capture the full rupture pattern and to address the problem of local variations in fault slip. In case of a fault system (as it is here the case), paleoseismological excavations must cover the full width of such a system or all individual faults. This best practice was not implemented in the case of PAKS II.

Consequently, the IAEA criterion for the identification of a capable fault is clearly met:

IAEA, 2010, SSG 9, p. 51: *"3.6. A fault shall be considered capable if … one or more of the following conditions applies: … (a) It [The fault] shows evidence of past movement or movements (significant deformations and/or dislocations) of a recurring nature within such a period that it is reasonable to infer that further movements at or near the surface could occur …".*

Figure 4. Comparison of the paleoseismological trench Pa-21-II with trenches exposing surface-breaking faults that ruptured during recent strike-slip earthquakes.



(A) Interpreted trench log of the paleoseismological trench Pa-21-II (modified from Ács et al., 2016, Fig. 250) showing upward terminations of recorded faults at the depth of the upper "marker horizon" (E2) and the seismite layer at -1 m below surface (E1). The corresponding horizons are interpreted as representing two distinct seismic event horizons. Location of the younger seismite is not indicated in the original figure. Seismotectonic elements supplemented from the trench log MÁ/PA2-16-FT-14 V2 Pa-21-II. Depth scale according to MÁ/PA2-16-FT-14 V2 Pa-21-II.

(B) Log of paleoseismological trench across the North Anatolian Fault. Faults labelled SA_{EKN}-1 moved by 2.4 m laterally during the 1999 İzmit earthquake (modified from Dikbaş et al., 2018, Fig. 10).

(C) Log of paleoseismological trench crossing the Greendale strike-slip fault showing surface-breaking faults formed by the 2010 Darfield earthquake. Note upward termination of faults (R4, R5) in tension gashes (modified from Hornblow et al., 2014). [Pa-21-II_section_Acs_Fig_250.jpg]

Source: (A) Modified from Ács et al., 2016, Fig. 250, (B) Modified from Dikbaş et al., 2018, Fig. 10, (C) Hornblow et al., 2014

1.2 Maximum Earthquake

1.2.1 Key argument by Paks II Zrt: Assumption of M=6 as a maximum earthquake magnitude at the Paks site

During the presentation by L. Toth, it was stated that the greater region of the site could be subject to a maximum magnitude M=6 earthquake (Mmax). In addition, it was claimed that such an event could affect the area on timescales of 100,000 years. Apparently, this assessment was based exclusively on instrumentally and historically recorded seismicity.

1.2.2 Key comments by EAA experts on maximum earthquake magnitude and timing

As mentioned by the presenter himself, the site region is situated in a low-strain intracontinental area, yet GPS data indicate that deformation occurs at decadal timescales (Grenerczy et al., 2005; Nocquet, 2012). For this reason, it is realistic to assume that the central Hungarian region is subject to continuing, widely distributed deformation and loading of pre-existing faults (Mid Hungarian Shear Zone; Fodor et al., 2005). Consequently, in an anastomosing network of WSW-ENE- to SW-NE-striking faults, earthquakes may be triggered under the present-day tectonic stress field, and given the structural nature of the anastomosing fault array, fault ruptures may trigger activity on adjacent, neighboring faults. Geological observations suggest that this has indeed occurred in the recent geological past (Fodor et al., 2005). Based on the present-day geodynamic setting, it has to be assumed that this process will also continue in the future. Clearly, in light of the low level of seismicity recorded in the Paks region over the past 30 years, the EAA experts note that these regional neotectonic characteristics require that the seismicity record be extended to longer timescales, i.e., the Pliocene and Quaternary periods for the site's fault evaluation (IAEA, 2010). Longer timescales have to be taken into account, because the return periods of potential ground-rupturing earthquakes exceed historical and instrumental data by several orders of magnitude. The EAA experts further note that the presented approach is not consistent with WENRA guidance on the assessment of maximum earthquake magnitudes (WENRA, 2020b, guidance on Safety Reference Levels TU3.3 and TU6.2).

A closer review of MVM Paks II. Zrt. (2016a, p. 67ff) and Tóth et al. (2022) revealed that the main conclusion *"the maximum earthquake that would be expected for the site in a 100,00-year timescale was assumed to be M=6"* most likely derived from the hazard deaggregation analysis. Deaggregation by distance and magnitude for the occurrence frequency of 10^{-5}/year at the site indicates that the most significant contribution to the total ground-motion hazard comes from nearby (5–20 km distance) earthquakes with magnitudes between M=5.5 and M=6.0 (MVM Paks II. Zrt., 2016a, Fig. 5.3.2.3.3-1; p. 92).

Under these circumstances, the assumption of a Mmax=6 earthquake and the arbitrary choice of a 100,000-year timeframe for assessing fault capability is not warranted.

Mmax values selected for the site-specific PSHA are higher than M=6 (Àcs et al., 2016, Tab. 49, 51 and 53). The three source-zone models used for the PSHA use Mmax=6.7-7.0, Mmax=5.9-6.4 and 6.1-6.4, respectively. The SHARE database lists values of maximum earthquake magnitude between 6.5 and 7.5 in Central Hungary (Woessner et al., 2015). These values are significantly higher than the value for a Mmax=6 used for assessing fault capability.

The EAA experts' estimates of the occurrence frequency of strong earthquakes in the seismic source zone that includes the Paks II site revealed that one Mw≥6 earthquake can be expected to occur every 33 to 50 years. The estimates are based on the Gutenberg-Richter (GR) relations and the GR parameters reported by MVM Paks II. Zrt. (2016a, Figs. 5.3.2.2.2.1-2, 5.3.2.2.2.2-2, 5.3.2.2.2.3-2).

According to published empirical models (Wells and Coppersmith, 1994; Takao et al., 2013), the probability of surface rupture on the principal fault due to a strike-slip M=6 event ranges from 5% to 40%. Moreover, since fault displacement has been observed for M<= 6 and for strike-slip faults, as reported by Sarmiento et al. (2021) and Baize et al. (2019) in the FDHI and SURE database, respectively, surface rupture on the principal fault and for M=6 events should by no means be excluded *a priori.* Empirical models also suggest that after a M=6 earthquake, the area affected by coseismic deformation could be wider and not only located near the principal fault. For example, using InSAR data to derive the deformed area vs Mw relationship, Serva et al. (2019) developed an empirical model that predicts a deformed area of about 340 km^2 for a M=6 earthquake. Within this area, secondary ruptures (or distributed displacement) can occur on splays of the main fault or antithetic faults.

1.3 Regional Faults

1.3.1 Key argument by Paks II Zrt and former Geological Survey: Assessment of the role of regional faults linked with the Dunaszentgyörgy-Harta fault zone

During the discussion, it was stated that regional faults with similar strike to the Dunaszentgyörgy-Harta fault zone (DHFZ) exist, but are not deemed active and kinematically linked to the DHFZ. One such case was said to be the Németker Fault, which is located more than 10 km north of both the site and the faults previously exposed in outcrops at Highway M6 (Mágyary, 2016). In addition, classified seismic reflection data were mentioned that were said not to show offsets of young (Quaternary?) geological units. Unfortunately, these data were not included in the Geological Site Report nor in the Site Safety Report.

1.3.2 Key comments by EAA experts on linked faults

The area under consideration is characterized by neotectonic structures that are related to the compressional reactivation of Miocene extensional and strike-slip fault systems (e.g., Fodor et al., 2005). Such zones are typically feature transfer structures that kinematically link different faults branches. In the present-day tectonic stress field such zones with an inherited structural framework constitute a broad zone of potential deformation with complex, anastomosing strike-slip and normal faults (Wórum et al., 2020). It is therefore conceivable that individual faults within this fault network are being loaded and will ultimately trigger failure of neighboring faults after an earthquake has occurred. Examples of such static or dynamic triggering of linked fault strands include reactivated structures characterizing the intraplate St. Lawrence lowland in North America, the North China Craton (Liu et al., 2011), and the tectonically active regions of the Walker Lane (Western USA), with the 2019 Ridgecrest, 1992 Landers, and 1999 Hector Mine earthquakes; similar conditions may have caused failure along interplate faults such as the 2016 Kaikoura earthquake (New Zealand) and the 2010 El Mayor Cucapah earthquake (Mexico)[15]. Finally, coeval surface rupture of neighboring faults has also been reported for the kinematically linked Župić and Kupa faults in Croatia during the 2020 Mw 6.4 Petrinja earthquake (Tondi et al., 2021). Earthquakes in all of these regions thus demonstrate that the build-up and seismogenic release of tectonic stresses on one fault may trigger ground-breaking earthquakes not only on adjacent but also on more distant pre-existing faults.

Although it cannot be proven with currently available data that such processes have also occurred in central Hungary, under the current tectonic stress-field conditions, the triggering or loading of adjacent faults during a potential earthquake is conceivable for the principal SE-NW-striking structures such as the DHFZ and linked subordinate structures described by Mágyary (2016). This is important for identifying ground-breaking paleo-earthquakes and the potential existence of capable faults in the context of defining capable faults as stated by IAEA (2010, SSG 9, p. 51: *"3.6. A fault shall be considered capable if, … one or more of the following conditions applies: … (b) A structural relationship with a known capable fault has been demonstrated such that movement of one could cause movement of the other at or near the surface."*)

For these reasons, a closer investigation of the spatial and temporal characteristics of the faults in the near-region of the Paks site is warranted, especially with respect to the paleoseismological results obtained from the Highway M6 outcrops (Mágyary, 2016), which are located at distances between about 9.7–10.5 km north of the Paks II site.

Unfortunately, the seismic reflection data used in the Hungarian experts' arguments against fault activity at the Paks II site were presented for the first time at the meeting in Budapest, and a critical evaluation of the imaged structures by the EAA experts was not possible. As a result, the rationale for and the validity of the exclusion of fault rupture below the outcrops at Highway M6 could not be rigorously assessed.

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[15] Most of these examples and references to original scientific papers are included in the workshop presentations by S. Baize, C. Grützner and E. Hintersberger.

2 QUESTIONS, RESPONSES AND EVALUATION OF RESPONSES

The following questions to the Hungarian Atomic Energy Authority (HAEA), formulated in the report by Decker & Hintersberger (2021), were submitted to the Hungarian Atomic Energy Agency on May 14th 2021 prior to a proposed workshop in Budapest, which took place in in February 2022.

All questions addressed additional information on the Site License for the planned NPP Paks II that was granted by HAEA in 2017 and, in particular, information on the assessment of fault capability at the site.

The background to all questions is the Hungarian regulation 7.3.1.1100 of the 7. Annex of Hungarian Governmental Decree (2011), which lists the following disqualifying circumstances for an NPP site: *"If the potential of occurrence of a permanent surface displacement on the site **cannot be reliably excluded** by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."*

HAEA's written replies were received on April 29, 2022, in the form of presentation slides (Konc et al., 2022). Replies were accompanied by slides prepared by L. Tóth and co-authors (Tóth et al., 2022[16]) and a presentation on the licensing procedure (Krutzler, 2022). The original slides of the presentation actually given by L. Tóth at the workshop on February 15, 2022 were not provided. All data are included in Appendix 2. The replies by HAEA printed in this report are the original text documents provided to the Austrian Umweltbundesamt and the EAA experts.

2.1 General statement by the HAEA:

"Nuclear safety is paramount"

Its assurance promotes not only the highest safety standards and the strictest rules and regulations, but also international cooperation, information sharing, and open discussion of any and all topics. Hungary's bi- and multilateral cooperation seeks to be at the forefront of nuclear safety as a member of the EU, IAEA, WENRA, and many other international organizations.

As part of this effort, the HAEA and the EAA (including its predecessors) have had robust and constant discussions, with a particular emphasis on amending the legal and regulatory framework, events of interest, changes in organizational structures, findings and conclusions of various activities.

[16] The presentation received on April 29, 2022 was not shown at the Budapest workshop. Slides were apparently updated after the bilateral meeting.

The HAEA as Hungary's nuclear regulatory body, promotes and facilitates nuclear safety by funding/conducting research, actively participating in the development of international standards and detailed methodological recommendations, and following and integrating international trends and advances in science and technology into the national legal and regulatory framework.

The HAEA values the cooperation between Austria and Hungary, two neighboring EU member countries. The issues and questions expressed by the Austrian counterpart are being thoroughly reviewed and considered, and the HAEA's goal as it has always been is to respond to and handle these questions and issues appropriately."

Assessment The EEA experts appreciate HAEA's introductory statement, particularly its commitment to "*the highest safety standards and the strictest rules and regulations"* in the context of international relations with WENRA and IAEA.

Final conclusion The issue does not require further information or discussion.

2.2 Question 1

Question *Did the licensee undertake sufficient efforts to investigate the site and the site vicinity (as defined by IAEA) with respect to fault capability?*

What is HAEA's position with respect to the licensee's claim that requirement 7.3.1.1100 does not require proof?

Background In volume 1 of the Site Safety Report, MVM Paks II Zrt. identifies the requirements to be examined in order to establish the basis for the permit (MVM Paks II Zrt., 2016c, p. 19-36, *"Table 2.2.4-1, Requirements for site inspection and assessment of nuclear installations"*). The first column of the table lists the NBSZ requirements, while the second column contains justifications for not considering some of the regulations in the site permit. Regulations not considered are marked by the crossed-out regulation numbers in the first column. For regulation 7.3.1.1100 of the 7th Annex of the Hungarian Governmental Decree (2011), which lists fault capability as a disqualifying hazard, the licensee states the following:

"7.3.1.1100 If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."	*"Point not requiring proof of fulfilment of a requirement, because in the case of an unfit site, no application for a site permit will be submitted."*

This suggests to us that MVM Paks II Zrt. regards the fact that the site permit has been submitted as proof for the exclusion of fault capability.

Answer by the HAEA *"The Licensee carried out detailed and extensive site evaluations to support the site license application. Even before that the Paks site was thoroughly researched and evaluated and is by far the most seismologically and geologically researched and evaluated area in Hungary. An extensive site re-evaluation program has been performed in the late eighties and early nineties under the scientific technical support of the IAEA and in compliance with the IAEA requirements and guidances. This programme has been supported by the PHARE programme of the EU. The evaluations and interpretations have been performed with the contribution of worldwide acknowledged experts. The main focus of that programme was the activity and eventual capability of the mapped faults in the vicinity of the site. In line with IAEA requirements and recommendations, a Periodic Safety Review is performed every ten years, during which site related information is re-evaluated, and additional site investigation is carried out as needed with the latest technologies and methods.*

The cited statement concerning requirement 7 3 1 1100 in Site Safety Report Book 1 has to be interpreted within the context of that chapter. It does not mean, it was not taken into account at all. It indicates, that based on the site investigation, the site has not to be declared unsuitable. Complementary to this, Site Safety Report Book 3 summarizes all relevant Nuclear Safety Code (requirements and briefly describes why the Licensee considered them handled appropriately. In this, a summarized demonstration is given concerning NSC requirement 7 3 1 1100., with reference to additional documents."

EAA expert assessment HAEA's reply leads us to conclude that the licensee rejected the necessity of proving the suitability of the site with respect to Regulation 7.3.1.1100 through appropriate scientific and technical data. Wording in MVM Paks II Zrt., 2016c, p. 19–36, *"Table 2.2.4-1, Requirements for site inspection and assessment of nuclear installations"* implies that the mere *decision* of the licensee to submit the site application was deemed sufficient to declare site suitability, rather than scientifically sound and technically robust data.

The statement *"Point not requiring proof of fulfilment"* is understood as a suggestion by the licensee to the HAEA that, based on the licensee's assessment, an in-depth evaluation of the fulfillment of regulation 7.3.1.1100 was not advisable.

Final conclusion The issue does not require further information or discussion.

2.3 Question 2

Question Did the licensee provide a safety demonstration on how to mitigate the following hazards: fault capability (N3 in WENRA 2020a), vibratory ground motion (N1 in WENRA, 2020a), and vibratory ground motion including near-fault effects on long period ground motion with very short duration (0.5–5 s) (forward directivity and fling-step ground motion observed from velocity pulses recorded in time histories) (WENRA, 2020b)? If yes: What is the basis for the assessment of hazard severity?

Background *„Die Partei wies nach, dass zur Behandlung von auf den Standort bezogenen und im Zuge der Planung zu berücksichtigenden Gefährdungsfaktoren, verwirklichte und getestete technische Lösungen existieren."* (HAEA, 2017, Punkt 1.1.c)[17]

Even if HAEA regards fault capability as screened out, near-fault effects cannot be screened out in seismic hazard assessment for vibratory ground shaking.

Answer by the HAEA *"Hungary/HAEA, as a member of WENRA, participates in the development of the WENRA Reference Levels and Safety Objectives. In accordance with its WENRA membership the WENRA Reference Levels for existing NPPs, and also Safety Objectives for new NPPs have been incorporated into the Hungarian legal framework (mostly into the NSC). At the time of the licensing (2016 2017), the 2014 revision of the RLs was implemented. WENRA performed a peer review to check the implementation of the RLs, and the results are publicly available.*

It is important to highlight, that the licensing of an NPP is a multi-step process with specific goals for every different step. The goal of the site licensing is to determine the suitability of the site and to evaluate and characterize hazards that will have to be taken into account during the design of the facility. A safety demonstration of the design is expected in subsequent licensing and permitting procedures. At the stage of the site licensing, the Licensee has to demonstrate, that there are existing technologies, which are viable to handle site conditions. The necessary design solutions will be demonstrated by the licensee and evaluated by the authority later on."

EAA expert assessment The answer confirms that the WENRA Safety Reference Levels for existing NPPs and the WENRA Safety Objectives for new NPPs have been implemented in the national legal framework.

The EAA experts are well aware that safety demonstration of the NPP is expected in subsequent licensing and permitting procedures. However, the seismic hazard assessment, on which any design solution is to be based, was part of the site licensing process (Ács et al., 2016; MVM Paks II. Zrt., 2016a, chapter 5.3). The same is true for the review of the seismic hazard results by the HAEA. The hazard factors stated in Question 2 (near-fault effects, fault directivity, fling-step) therefore should have been considered in the site assessment. Unfortunately, the answer does not include information on whether or not this has been the case. A review of the chapters on site-specific seismic hazard assessment in Ács et al. (2016) and MVM Paks II. Zrt. (2016a) revealed no evidence that the effects listed by WENRA (2020a, b) were considered.

Final conclusion The question remains open. The EAA experts recommend requesting additional information and discussing the issue in the context of seismic ground-motion hazards.

[17] "The party demonstrated that implemented and tested technical solutions exist for the treatment of site-related risk factors to be taken into account in the course of planning." (HAEA, 2017, point 1.1.c)

2.4 Question 3

Question Did HAEA fully delegate the assessment of the geological suitability of the site and site suitability with respect to seismotectonic hazards (including fault capability) to the Mining Authority[18], or did HAEA also review the geological contents of the Site Safety Report (MVM PAKS II. ZRT., 2017) based on its own expertise?

Background *„Die Bergbauaufsicht – auch das Gutachten der unabhängigen Sachverständigen berücksichtigend – bestimmt, dass die im Programm festgelegten Zielsetzungen mit der Durchführung des genehmigten Standortuntersuchungs- und Bewertungsprogrammes erfüllt wurden. Die Bergbauaufsicht akzeptiert die Feststellungen* [des Lizenzwerbers] *bezüglich der Bewertung der Eignung des Standortes, …"*

„Den Nachweis annehmend, dass geologische Standortcharakteristika, die eine Errichtung ausschließen (würden) fehlen, bestimmt die Bergbauaufsicht, dass der Standort aus geologischer Sicht für das Errichten einer Nuklearen Anlage geeignet ist." (Punkt 1.12).[19]

It appears that HAEA relied entirely on the external decision by the Mining Authority without carrying out its own assessments.

Answer by the HAEA *"In the Hungarian regulatory framework, the review of certain specialized expert areas is delegated to co authorities during licensing and permitting activities. HAEA has to take into account the decision of its co authorities during the licensing procedures. Regardless, in line with IAEA recommendations, HAEA, as the main licensing authority, performed its own assessment on all relevant NSC requirements, including on those delegated to the Mining Authority.*

Before the site licensing procedure HAEA and the Mining Authority agreed on which NSC requirements will be evaluated in depth by each organization.

On the subject raised in the question, the HAEA and the Mining Authority both carried out their reviews independently and reached the same overall conclusion."

EAA Expert assessment The question has been fully answered.

Final conclusion The issue does not require further information or discussion.

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[18] Baranya Megyei Kormányhivatal Műszaki Engedélyezési és Fogyasztóvédelmi Főosztály Bányaszati Osztálya

[19] "The Mining Supervision – also taking into account the report of the independent experts – determines that the objectives set out in the program have been met with the implementation of the approved site investigation and assessment program. The Mining Authority accepts [the license applicant's] findings regarding the site suitability assessment,…" "Assuming evidence that geological site characteristics that (would) rule out construction are missing, the mining supervisory authority determines that the site is geologically suitable for the construction of a nuclear facility." (Item 1.12).

2.5 Question 4

Question Did the Mining Authority[18] base its assessment of the geological suitability of the site (including fault capability) exclusively on the Site Safety Report (MVM PAKS II. ZRT., 2016), or did the Mining Authority also consult the geological reports that had been prepared for the license applicant, in particular the paleoseismological reports by Halász, Konrád & Sebe (2016) and Magyari (2016)?

Background It appears that the summary of the geological data provided in the Site Safety Report compiled by MVM PAKS II. ZRT. (2016) is the exclusive basis for the licensing decision. However, point 1.12. of the justification and legal basis of the administrative statement (*"Az OAH döntése és elöírt feltételinek indololása, jogalapja, A rndelkezö Réz 1.12. pontjához"*) indicates that the Mining Authority based its decision on the following:

- *"copy of the application;*
- *Site Safety Report (TBJ);*
- *final report of the geological research programme;*
- *contents of the Site Safety Report belonging to the subject area under the influence of the authority;*
- *independently reviewed material in the Site Safety Report;*
- *confirmation of payment of the administrative fee."*

Answer by the HAEA "The indicated reports and more have been part of the documentation available for and subjected to review. The Site Safety Report is based on the complex synthesis where paleoseismic findings were taken into account.

It is important to mention, that the authors of said reports have also participated in developing the relevant chapters of the Site Safety Report and its background documents, and they are listed as authors.

Furthermore, the Site Safety Report was only one component of the application for a site license. It also contained dozens of background reports supplementing the Site Safety Report. During their decision making process, the HAEA and the Mining Authority considered the full range of documents."

EAA expert assessment The HAEA confirms that the entire range of documents in the Geological Site Report and the Site Safety Report was considered in the site licensing procedure.

In light of this, it is remarkable that neither the HAEA nor the Mining Authority identified or questioned the discrepancies between the contents and conclusions of the Geological Site Report and the Site Safety Report highlighted by Decker & Hintersberger (2021). The most significant and obvious inconsistencies between the two reports, highlighted by the authors cited, concern the following issues:

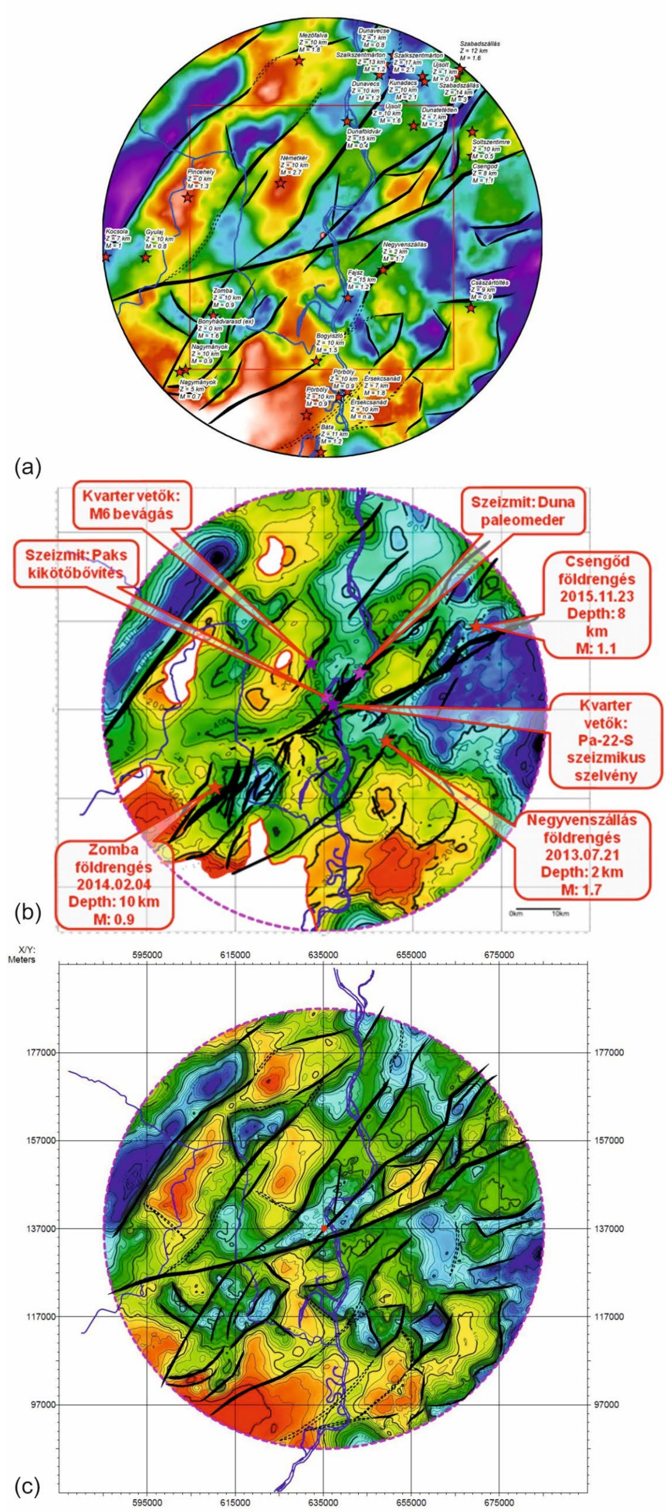
- the deletion of data proving active (Quaternary) deformation of the Dunaszentgyörgy-Harta fault zone (DHFZ) as shown by comparison of Tóth et al., 2016, Fig. 57; Ács et al., 2016, Fig. 427; and MVM Paks II ZRT., 2016a, Fig. 5.2.1.2.1–6 (Figure 5).

- the location and extent of the DHFZ below the Paks II site as shown by Ács et al., 2016, Fig. 418; and MVM Paks II ZRT., 2016a, Fig. 5.2.1.2.6–1 (Figure 6).
- the disregard of paleoseismological evidence for the occurrence of ground-rupturing earthquakes in the last 30,000 years included in different parts of the report by Ács et al. (2016; for a compilation of the data and references see Decker & Hintersberger, 2021, Tab. 1)

Final conclusion The question has been answered.

The EAA experts still recommend requesting additional information on how the HAEA and the Mining Authority dealt with the documented discrepancies between the cited reports.

Figure 5. Comparison of maps showing fault locations within a 50 km radius of the Paks II site on the background of a depth structure map.



(a) Ács et al., 2016 (Fig. 427) show earthquakes epicenters (red stars) registered between January 1, 1995, and May 31, 2016. (b) Tóth et al., 2016 (Fig. 57) provides summary information of data indicative of Quaternary tectonics. Balloons refer to earthquakes (földrenges), Quaternary faults (kvater vetök) and seismites (szeizmit). (c) None of the data shown in (a) and (b) is included in MVM Paks II ZRT., 2016a, Fig. 5.2.1.2.1-6.

Source: (a) Ács et al., 2016 (Fig. 427), (b) Tóth et al., 2016 (Fig. 57), (c) MVM Paks II. Zrt., 2016a

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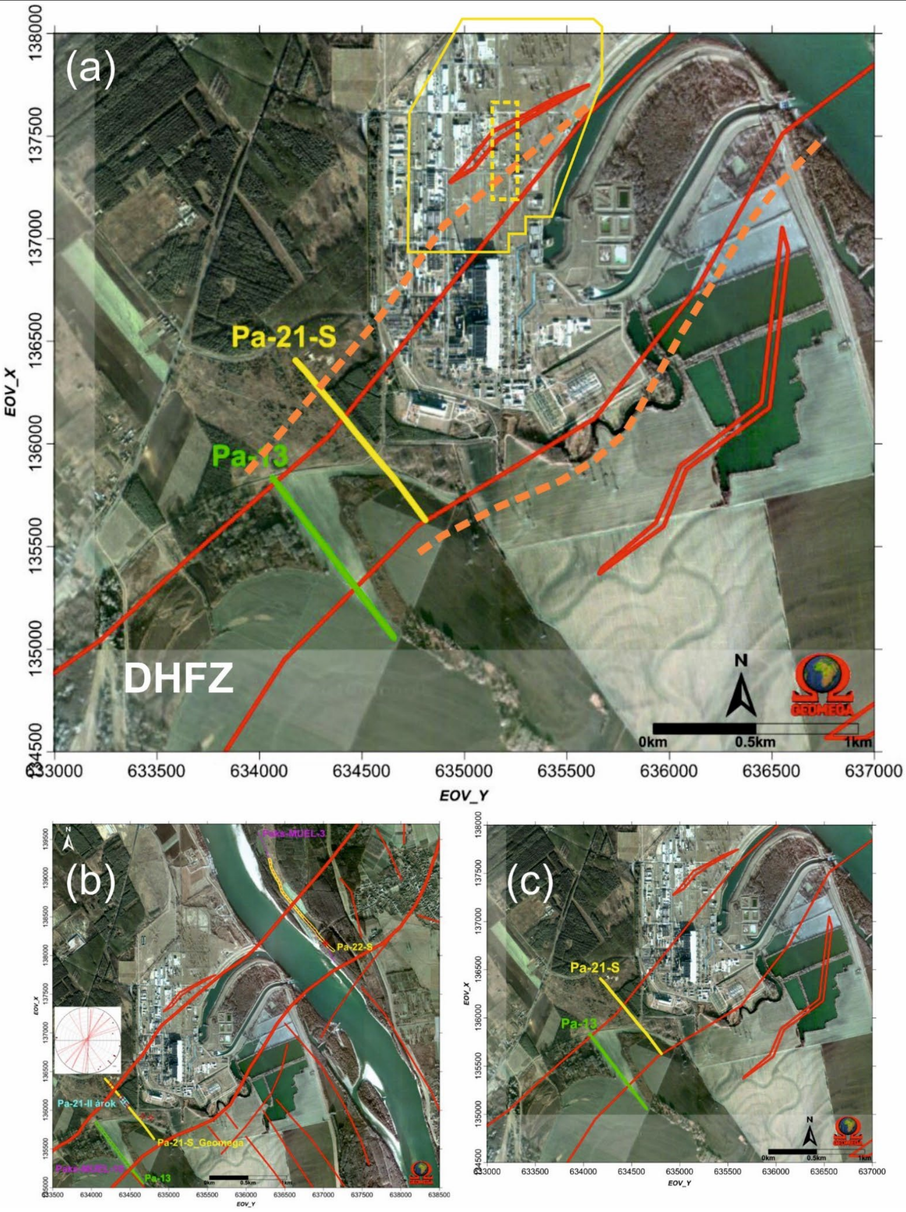
Figure 6. Comparison of the location of the Dunaszentgyörgy-Harta fault zone (DHFZ) and accompanying branch faults (red polygons) shown by Paks II Zrt., 2016a



(a) Comparison of the location of the Dunaszentgyörgy-Harta fault zone (DHFZ) and accompanying branch faults (red polygons) shown by Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1. (red lines) and Ács et al., 2016, Fig. 418, p. 700 (orange broken line). The width of the fault zone indicated by Ács et al. (2016) extends farther north into the perimeter of the new reactor blocks. The yellow polygon denotes the site of Paks II according to the geographic coordinates listed in HAEA (2017). The yellow broken line indicates the approximate position of the reactor blocks of Paks II (from https://www.paks2.hu/kozerthetoen-a-letesitesi-engedelyezesrol). Unmodified maps are shown in (b) and (c): (b) Location and extent of the DHFZ indicated in the Geological Site Report, Ács et al., 2016, Fig. 418, p. 700. (c) Location and extent of the DHFZ shown in the Site Safety Report, MVM Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1. [Paks_II_site_map_fault_location_MVM_Paks.jpg]

Source: Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1 and Ács et al., 2016, Fig. 418, p. 700

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2.6 Question 5

Question The site application by MVM Paks II. Zrt. is dated October 18, 2016. The final paleoseismological report to MVM Paks II. Zrt., which includes the full documentation and interpretation of the paleoseismological results obtained from the site by Halász, Konrád & Sebe (2016), is dated October 27, 2016. The paleoseismology report contains data and conclusions that, in the view of the cited authors, support the existence of a surface-breaking fault at the site.

How confident are HAEA and the Mining Authority that the licensee included all the paleoseismological results that are relevant for assessing the suitability of the site according to NSC 7.3.1.1100 of the 7th Annex of the decree, considering that the paleoseismology report was not yet completed at the time of the application? Did HAEA and the Mining Authority take into account the complete results of Halász, Konrád & Sebe (2016) in their decision, or only the summary provided by MVM Paks II Zrt., which was completed before the final paleoseismology report was available to the license applicant?

Background It appears that the Mining Authority based its decision on the Site Safety Report, the final report of the geological research program and an expert review of the Site Safety Report. In its conclusion, the authority states that *"based on the geological assessment of the site and its surrounding … it is evident, that no [site] exclusion factors exist, which could endanger the construction and licensing of the new units"* (pp. 24–25 of the translated text).

Auch der Sachkundige sagt in seinem Gutachten, dass „anhand der geologischen Bewertung des Standortes und seiner Umgebung … erkennbar ist, dass es keinen solch ausschließenden Faktor gibt, welcher die Erbauung und Freigabe der neuen Blöcke gefährden könnte". … "Im Falle der Auswahl und Anwendung der entsprechenden „bewährten technischen Lösung" sind die im Zuge der Untersuchung und Bewertung des Standortes aufgedeckten Gefahren behandelbar." (Zu Punkt 1.12. des Bestimmungsteiles, Begründung und Rechtsgrundlage der fachbehördlichen Stellungnahme)[20]

Answer by the HAEA *"As described previously, the authors of the said report have also participated in developing the relevant chapters of the Site Safety Report and its background documents, and they are listed as authors. Although the mentioned report was not part of the site license application, information from the said report is in line with the information presented in the Site Safety Report.*

Regarding the specifics of Halász Konrád Sebe 2016 paper which fully supported the claims made by the licensee in the siting license the ten day gap between the Site Safety Report's release date and the mentioned paper is a minor technicality. The

[20] *"The expert also says in his report that "based on the geological evaluation of the site and its surroundings … it can be seen that there is no such excluding factor that could jeopardize the construction and licensing of the new blocks". … "If the appropriate "proven technical solution" is selected and applied, the hazards identified in the course of the investigation and assessment of the site can be handled." (Regarding point 1.12. of the determination part, justification and legal basis of the official statement)"*

same information and conclusions are found in both reports, which were written by the same authors."

EAA expert assessment The EEA experts do not agree with the statement a *"ten-day gap between the Site Safety Report's release date and the mentioned paper is a minor technicality"* considering that Halász, Konrád & Sebe (2016) constitutes a major data set for assessing potential surface rupture at the site and thus the suitability of the site.

All but one of the reports in the Geological Site Report[21] including the Final Report of the Geological Research Program (Zárójelentése; Ács et al., 2016) were completed *before* the Site Safety Report (MVM Paks II. Zrt., 2016a, b; October 18, 2016) and *before* the site application by MVM Paks II. (the confirmed date is October 18, 2016). This should also be expected for the report by HALÁSZ, KONRÁD & SEBE (2016), which contains data that make it impossible to *"reliably exclude the potential of occurrence of a permanent surface displacement by scientific evidence"* as required by the Hungarian Governmental Decree No. 118 of 2011, Requirement 7.3.1.1100 (see Decker & Hintersberger, 2021, for a detailed discussion). Data provided in the report therefore had the potential to render the site unsuitable for a new NPP.

The observed discrepancy in the timeline means that it cannot be ruled out that the contents and conclusions of the report by Halász, Konrád & Sebe (2016) were modified after the submission of the site application to fit the documents of the license application.

Final conclusion The issue does not require further information or discussion.

2.7 Question 6

Question In their report to MVM Paks II. Zrt., HALÁSZ, KONRÁD & SEBE (2016) describe the following paleoseismological results: *"The seismotectonic structures excavated in trench Pa-21-II are faults which are parts of a negative flower structure of a strike-slip fault system. Displacements along the faults could be proved in two cases: at 41 meter [of the trench profile] with 1 cm vertical, at 37 meter with 2,5 cm horizontal [displacement] component [etc.]."*[22] Do HAEA and the Mining Authority regard this scientific result to reliably exclude permanent surface displacement at the site as required by NSC 7.3.1.1100?

[21] Date stampings of the Geological Site Report are as follows: Tóth et al. (Geophysics): 16.06.2016; Monus et al. (Spaeleoseismology): 31.01.2016; Lab analysis: between 06.07.2013 and 31.07.2016; Magyari (Paleoseismology): 18.09.2016; Ács et al. (Final Report), 20.09.2016.

[22] Chapter 1.1.6. Summary, page 52 of the cited report.

Answer by the HAEA *"The neotectonical interpretation is based on all the available information including the observations in Quaternary sediments of Magyari 2016. The basis of exclusion for the fault capability at the Paks site is the internationally accepted significance criterion presented in Gürpinar et al 2017. Based on the results of the geological surveys the fault displacement value extrapolated to the 1.00E-05/y occurrence frequency is well below the 0.1 m significance limit* **[1]**[23] *(and well below the minimal requirements for "normal" tilting ergo has to be covered by the margins in the design basis) even when applying conservative assumptions, hence rendering the fault insignificant. Since no significant fault was identified* **[2]** *on site, there was no basis to invoke regulation 7 3 1 1100 of the Hungarian NSC Volume 7.*

As for the document referenced in the background section Halász Konrád Sebe 2016 of the question it should be highlighted that the authors made the following observations in their report **[3]***: "Observations supporting the presence of horizontal or vertical fault displacement parallel to the fractures were not identified In the immediate vicinity of the fractures (within 1 2 dm a few layers bent mostly downwards and in some cases upwards, these structures are local deformations not fault displacements and are not present consistently along the fracture".*

Trenches Pa 21 I and II at the Paks site revealed plastic deformations and fractures from seismic origin Deformations observed in the loose sediment may have been caused by earthquakes with a magnitude 5 or higher which were estimated to have occurred with a frequency in the order of 1000 years in the late Pleistocene era based on the OSL measurements and can be connected to the activity of the Dunaszentgyörgy Harta faulting system. In the immediate vicinity of the fractures, local deformations of a few cm of the sand structures were observed as well as dilatation up to a few cm however no indication of horizontal or vertical displacement was detected on the two sides of the fractures within the sand layers The majority of the documented fissures probably aren't the continuation of the fault displacement branches approaching the surface but an indirect result of seismic waves causing extensional fissure and lode intrusion."

While this did not have an impact on the licensing, it is worth noting that later studies by the same authors Konrád Sebe Halász 2021 backed up their findings:

"In the immediate vicinity of the fractures, local deformation of the sand layers of a few cm can be observed, and dilatation of up to a few cm may have occurred along with the fractures. However, neither the horizontal displacement nor the vertical displacement of the sand bodies on either side of the fracture was not detectable. This can be explained by the fact that the deformation of the fault zone, which still causes a clear displacement in the bedrock and older Cenozoic rocks, is absorbed by unconsolidated sediments near the surface so that the surface is no longer seen deformed. Most of the documented fractures are probably not a direct continuation of the fault branches to the surface **[4]***, but an indirect extensional fissure and lode intrusion caused by earthquake waves."*

[23] Bold fonts and numbers in brackets were inserted to link to the EEA assessment below.

EAA expert assessment

The question has not been answered. It remains open how the paleoseismological evidence provided by Halász et al. (2016) can reliably exclude permanent surface displacement at the site, as required by NSC 7.3.1.1100.

The EEA experts therefore repeat their previous assessment, stressing that the paleoseismological data by Halász et al. (2016) confirm the existence of capable faults in the site vicinity of Paks II.

[1] Fault displacement value extrapolated to the 10.0 E 05/y below 0.1m

The HAEA claims that the fault displacement value extrapolated to an occurrence probability of 10^{-5} per year is less than 0.1m; unfortunately, this statement was made without reference to the type of analysis or data confirming these values.

Careful reexamination of the publicly available Geological Site Report and the Site Safety Report documents did not reveal that adequate analyses were available at the time of site licensing.

[2] Significance of the identified fault

The Hungarian regulation NSC 7.3.1.1100 requires to reliably exclude the potential of occurrence of a permanent surface displacement on the site by scientific evidence, and the displacement may affect the nuclear facility. No reference is made to a potential magnitude or probability of ground displacement or fault slip. The requirement of NSC 7.3.1.1100 is therefore in line with the WENRA requirement for new NPPs to *"practically eliminate scenarios which would lead to early or large* [radioactive] *releases"* (WENRA, 2010, Safety Objective O3; WENRA, 2013) and with WENRA's expectation on the application of practical elimination (WENRA, 2019)[24].

According to WENRA, practical elimination can be demonstrated by showing that a scenario is physically impossible or by demonstrating that the scenario is extremely unlikely with a high degree of confidence[25]. WENRA (2019) is very explicit in ranking the two possibilities to demonstrate practical elimination stating: *"Physical impossibility is the preferred way to demonstrate practical elimination of a scenario because it rules out its occurrence"* (WENRA, 2019, p. 15).

WENRA (2019, p. 15–16) explains that physical impossibility of a fault scenario can be achieved by the complete absence of unacceptable loads or by demonstration that the maximum load is significantly lower than the minimum resistance of relevant systems, structures and components (SSCs). It is further stated that *"mathematical models of physical processes … can only be used in the*

[24] In the answer to Question 2, the HAEA confirms that WENRA Reference Levels for existing NPPs and also Safety Objectives for new NPPs have been incorporated into the Hungarian legal framework.

[25] Accident sequences with a large or early release can be considered to have been practically eliminated: (1) if it is physically impossible for the accident sequence to occur or (2) if the accident sequence can be considered with a high degree of confidence to be extremely unlikely to arise (WENRA, 2013, p. 29).

demonstration of physical impossibility if both: (a) the maximum range in their uncertainty can be reliably determined, taking into account all relevant factors, and (b) they can be shown to cover the worst case possible." The EAA experts are not aware of a generally recognized method to reliably determine the maximum load or worst case in terms of surface offset for the hazard of fault capability.

The EEA experts regard the Hungarian regulation NSC 7.3.1.1100 to be in line with the WENRA Safety Expectations for new NPPs. A weakening of the regulation by relating it to a *"significance criterion"* is neither in line with the wording of NSC 7.3.1.1100 nor the notion of WENRA concerning practical elimination.

Ad [3] Invoking regulation 7.3.1.1100.

The HAEA states that: *"Since no significant fault was identified on site, there was no basis to invoke regulation 7.3.1.1100 of the Hungarian NSC Volume 7."* Contrary to this assessment, regulation 7.3.1.1100 does not require identifying *"a significant fault"* but reliably excluding the potential of surface displacement, stating: *"If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."*

The EEA experts therefore cannot share HAEA's interpretation of regulation 7.3.1.1100.

The HAEA's answer repeats the wording by Halász et al. (2016) and introduces a later publication by Konrád et al. (2021), which, based on its publication date, could not have constituted a basis for the site-license decision and does not include any new paleoseismological data beyond those available for the report completed in 2016. Neither the text cited in the question ("*The seismotectonic structures excavated in trench Pa-21-II are faults which are parts of a negative flower structure of a strike-slip fault system."* Halász et al., 2016) nor the statements cited in quotation marks in the answer exclude the presence of a capable fault.

It must be noted that the texts that the HAEA quoted from Halász et al. (2016) and Konrad et al. (2021) contradict the following conclusions that the same authors formulated in other parts of their 2016 report:

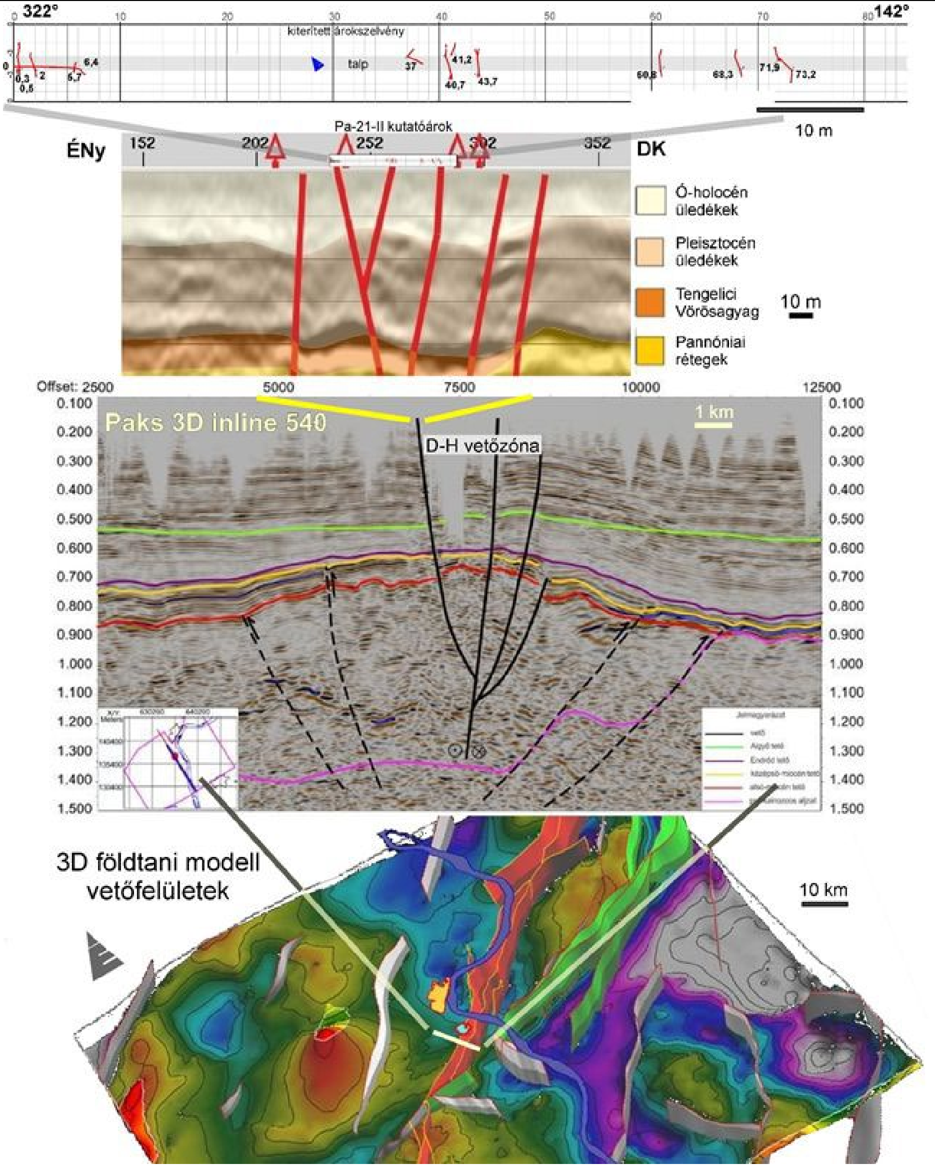
Halász et al. 2016, page 48: Structures at 41.3m and 43.7m of the trench Pa-21-II are clearly identified as faults although the term "fault" is avoided: *"2. At 41.3 meters and 43.7 meters, both sidewalls and the bottom of the trench revealed structures that, based on their strike, slope and accompanying normal faults (Figure 35; Figure 36), are clearly related to the flower structure known in the subsurface (of the nature of a transtensional negative flower structure) lateral displacements."*

Halász et al. 2016, page 50: The description and figures referenced in the text unequivocally identify faults and fault offset, even though the term "fault" is substituted by "tectonic fracture": *"After considering all these difficulties of interpretation, the conservative approach requires a classification as tectonic fractures. The contradictions detailed above are resolved if the layer deformation phenomena of uncertain origin are interpreted as deformation caused by the displacements of* *the transtensional flower structures. In this case, the en-echelon pattern documented at 37 meters indicating left shear (Figure 32) indicates a minimum horizontal displacement of 2.5 cm based on the width of the fissures.* [Etc.]".

[4] Faults in the trench Pa21-II are not direct continuations of the fault branches at depth.

The statement by Konrad et al. (2021) contradicts the earlier interpretation of the same authors illustrated and described in Halász et al. (2016), page 51, Figure 45. The cited figure explicitly links the faults in trench Pa-21-II with the deep structure of the Dunaszentgyörgy-Harta fault zone (Figure 7):

Figure 7. Location of the trench Pa-21-II above the Dunaszentgyörgy-Harta fault zone (DHFZ) shown in Halász et al. (2016), Figure 45.



The figure caption by Halász et al. (2016), page 51 reads: "Figure 45. Correspondence of the seismotectonic elements discovered in the Pa-21-II research trench with the Dunaszentgyörgy-Harta fault zone. … When placing the tectonic detection profile of the research trench over the reinterpreted shallow seismic profile based on the Pa-21 prospecting drillings, it is striking that the documented seismotectonic structures are located above the faults defined on the shallow seismic profile, and their strike and slope are the same."

Source: Halász et al. (2016), Figure 45

Final conclusion The issue requires further information and discussion.

2.8 Question 7

In their explanatory statement to para. 1.12. of the Site License, bullet 3, HAEA and the Mining Authority state the following (p. 26 in the German translation): *"Faults in the geotectonic vicinity of the planned site (particularly considering the NE-SW-striking Dunaszentgyörgy-Harta Fault Zone, which is proven below a part of the site) can dissect the Pannonian strata and touch the near-surface parts of the Quaternary sediments. However, based on the results of the complex research (drillings, trench, geodesy/space-born geodesy, geomorphological mapping) it can be concluded, that faults, which are associated with 100.000 years earthquakes with magnitude Mw<6 and a focal depth of 8-12 km, do not reach the surface and that these faults cannot lead to tectonic surface deformation. Based on the evaluation of the research the possibility of surface displacement due to a surface breaking fault is excluded for the site.* **Surface displacement cannot be proved at the site [1]**. *The conditions to exclude the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree do not exist for the investigated site.*

The complex investigations confirm, that at the investigated site and ***within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100.000 years [2]****. Conditions for denying the suitability of the site according to paragraph 7.3.1.1100 of the 7. Annex of the decree neither exist for the investigated site nor for its surrounding within a distance of at least 10 km."*

Question What is the evidence confirming that *"surface displacement cannot be proved at the site"* [1], and what is the evidence for statement [2]?

Background Statement [1] seems nonfactual considering the observations of displaced Late Pleistocene sediments described in the paleoseismology report from the site by Halász et al. (2016).

Statement [2] seems nonfactual considering the paleoseismological report by Magyari (2016), who shows faults displacing Holocene sediments from outcrops along Highway M-6. At two locations, at distances of 10.7 km and 7.5 km from the existing NPP Paks, the cited author describes two surface-breaking faults with a displacement of up to 0.6 m. Surface displacements occurred between circa 14,000 and 5,000 years ago.

Answer by the HAEA **[1]**[26] *"All the collected evidence (geological survey, as well as the space surveying, GPS data assessment which identified a crustal movement below 0.1 mm/y) support the claim that no significant fault displacement is present on a 1,00E-05 /y occurrence frequency basis at the site. Furthermore, as it was explained in the previous answers the 1 cm vertical and 2 4 cm horizontal fault displacement finding at the Pa 21 trench is considered as a fault displacement only as a conservative assumption and even as a conservative assumption it is well below the significance limit.*

Additionally, regulation 7 3 1 1100 from the Hungarian NSC Volume 7 states the following: "If the potential of occurrence of a permanent surface displacement on the

[26] Bold fonts and numbers in brackets were inserted to link to the EEA assessment below.

*site cannot be reliably excluded by scientific evidences****, and the displacement may affect the nuclear facility*** *the site shall be qualified as unsuitable."*

The detected and calculated fault displacement (which again is considered a fault displacement only as a conservative assumption since the evidence indicates that it is a local soil disruption) values on site were not just insignificant according to the accepted international standards but were also well below the design requirements for "normal" tilting due to uneven subsidence of the civil structures. As a result these values further supported the claim that the detected fault displacement is insignificant by international standards and due to being already covered by the safety margins with engineering and design solutions for majoring effects, therefore the displacement cannot affect the safety of the site.

Regarding the question on the displacement found at the M 6 highway engineering survey some information in the study may have been misinterpreted, some may have been excluded from the scope of the review of the EAA and some information may not have been presented in the referred documents but in other documents. It is assumed that these reasons might have led to the question. In order to facilitate the understanding of these findings the following clarification can be given:

[2] *The document/study Magyari 2016 does not refer to the Paks NPP site when claiming that fault displacement was detected 8 10 km to the North North-West from Paks but the Northern edge of the city of Paks which is several km away from the Paks NPP to the South. In fact, the study states the following:*

"We examined four vertical sections showing the most characteristic developments in the area as well as their horizontal relations and structural changes The site of the evaluation is located 8 10 km North Northwest from the city of Paks"

The evaluation of late Pleistocene sedimentological neotectonic and paleoseismological observations was conducted in the wider area of the Paks site, which also included data from the Gyapa exploration as part of the Geological Site Investigation Program, in accordance with the comprehensive and conservative approach generally required in the nuclear industry.

The fault line going through the detection point at Gyapa and the one going through the Paks NPP site are two different and separate fault lines. Studies in the Geological Survey proposed this fault line to be part of the Németkér line and no evidence can support the assumption that the two fault lines are in direct connection with the fault line going through the Paks site. Based on Figure 2 page 19 of the EAA study, this appears to be accepted by the EAA as well. As it was explained earlier the regulations of the Hungarian NSC refer to fault lines that can reach or somehow affect the nuclear safety of the nuclear facility due to displacement not just fault lines in general. This requirement is not met by a fault line that is several kilometers away from the site of the NPP and has no connection to the site.

It was stated by the IAEA during its previous missions at the Paks site (e. g., Seismic Safety Review Mission for the Review of Tectonic Stability and Seismic Input for the Paks NPP) that:

"The most direct evidence to establish whether a tectonic feature should be considered active is seismicity."

In compliance with the recommendations of the IAEA the Hungarian counterparts commissioned an earthquake monitoring system that was capable of locating earthquakes as small as magnitude 2 0 within about 100 km of the Paks NPP site. This was later upgraded to be able to detect earthquakes down to 1 Mw. The observations made by this monitoring system is freely available online and it can be of advantageous service for the neighboring countries as well.

While the monitoring system is extremely sensitive in the last 30 years (since its commission) literally zero earthquake events have been registered that originated from the region of the Paks site, not even in the 1 Mw magnitude range."

EAA expert assessment

[1] Fault displacement detected in trench Pa-21-II insignificant to affect the nuclear facility

HAEA argues that the 1 cm vertical and 2.4 cm horizontal fault displacement detected in the trench Pa-21-II are insignificant to pose a threat to the planned NPP as such displacements are enveloped by the *"design requirements for 'normal' tilting due to uneven subsidence of the civil structures".*

In this context it must be noted that:

- The small displacement reported by the HAEA are challenged by scientifically defendable alternative interpretations that arrive at much larger displacements. Decker & Hintersberger (2021) presented a quantitative model indicating a strike-slip displacement of about 0.3–0.4 m for the fault observed at 43.7 m in the trench Pa-21-II. Their interpretation is corroborated by comparing the structures exposed in trench Pa-21-II with trenching results from other strike-slip faults (Hintersberger & Grützner, 2022[27]).
- Trench Pa-21-II only exposes sediments from approximately the last 20 ky, which is too short a time window to assess fault activity and fault capability in intraplate settings with low deformation rates[28]. Trenching results therefore fail to prove that no surface displacements in excess of a few centimeters can occur at timescales appropriate for fault analysis in intraplate settings (i.e., Pliocene to Holocene), even if the interpreted 2.4 cm offset is considered representative for the last, approximately 20 ky.

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[27] See Attachment 3, workshop presentation "Examples for surface breaking earthquakes and their paleoseismological record."

[28] IAEA (2022), Para. 7.4 (a): In highly active areas, where both seismic and geological data consistently reveal short earthquake recurrence intervals, evidence of past movements in the Upper Pleistocene to the Holocene (i.e., the present) might be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods (e.g., the Pliocene to the Holocene (i.e., the present) are appropriate. In areas where the observed activity is between these two rates (i.e., not as highly active as plate boundaries and not as stable as cratonic zones), the length of the period to be considered should be chosen on a conservative basis (e.g., the Quaternary with possible extension to the Pliocene, depending on the area's tectonic activity level).

- The 85-m-long paleoseismologial trench Pa-21-II exposes only a small portion of the approximately 1-km-wide Dunaszentgyörgy-Harta fault zone south of the Paks II site. Fault strands continuing into the Paks II site were not adequately investigated, although state-of-the-art shear-wave reflection seismic, borehole and electrical resistivity tomography data in the Geological Site Report unambiguously document the offset of Quaternary sediments.

The EAA experts conclude that available data cannot reliably exclude the potential of occurrence of a permanent surface displacement at the site. This also pertains to offsets with displacements large enough to affect the safety of the nuclear facility.

[2] Lack of fault segments that led to surface displacement by faulting in the last 100,000 years within at least 10 km of the surroundings of the site

Magyary (2016) documented unequivocal evidence of surface displacement from outcrops at the Highway M6 north of Paks, most importantly from locations labeled Gyapa-Cece Points 1 and 4. Data from these outcrops prove vertical surface offsets of about 0.6 m and 0.1 m, respectively (Magyari, 2016, Figure 5; Figure 15). OSL dating revealed ages between 7.7±1.1-5.5±1.1 and 14.3±2.7-13.2±1.9 ky for the two events (Magyary, 2016, p.8–9). Surface offsets indicate magnitudes of circa M=6.5 for the event leading to about 0.6 m of displacement and M>6 for the second paleo-earthquake (see Decker & Hintersberger, 2021, chapter 3.2 for a detailed assessment of the data).

The locations of Gyapa-Cece Points 1 and 4 are indicated in Figures 1 and 3 by Magyari, 2016. A repeated check of the outcrop locations and their distance from the Pacs II site confirms distances of about 9.5 to10 km from the site. The distance of the outcrops from the city limits of Paks is less than 5 km.

Plotting Gyapa-Cece Points 1 and 4 on the tectonic maps shown in the Site Safety Report (MVM Paks II Zrt., 2016b, Fig. 5.2.1.2.1-6, Fig. 5.2.1.2.6-3) indicates that both are located at the Némétker fault. The closest distance of the Némétker fault to the Paks II site, measured in the direction perpendicular to the strike of the fault, is about 6 km as estimated from the cited figures.

The statement by HAEA and the Mining Authority "*within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100.000 years*" (explanation to para. 1.12. of the Site License, bullet 3) is therefore wrong.

The answer by the HAEA apparently does not recognize the importance of the implications of the paleoseismologial data by Magyary (2016):

(1) Data unequivocally proves that the Némétker fault is a capable fault as defined by IAEA and the Hungarian regulations (see Decker & Hintersberger, 2021, for a thorough review of the definitions of the term "capable fault").
(2) The two M>6 paleo-earthquakes that occurred in the site vicinity disprove the assumption that *"faults, which are associated with 100.000*

years earthquakes with magnitude Mw<6 and a focal depth of 8-12 km, do not reach the surface" as claimed in the Site License (explanatory statement to para. 1.12. of the Site License, bullet 3).

(3) The magnitude of the event leading to a surface offset of about 0.6 m challenges the validity of the maximum earthquake magnitude (Mmax) assumed for the site in the PSHA.

(4) The Németkér fault has a close structural relationship with the Dunaszentgyörgy-Harta fault zone. This is important for the identification of ground-breaking paleo-earthquakes and IAEA's capable fault definition (2010, SSG 9, p. 51: *"3.6. A fault shall be considered capable if, ... (b) A structural relationship with a known capable fault has been demonstrated such that movement of one could cause movement of the other at or near the surface."*). For these reasons, a closer investigation of the spatial and temporal characteristics of the faults within the near-region of the Paks site is warranted (see chapter 1.3 for detailed discussion).

Final conclusion This issue requires further information and discussion.

2.9 Question 8

Question Recent information indicates that the Hungarian government has granted permission to start earthwork to excavate on the building site[29]. Has HAEA been involved in granting this permission, and has HAEA agreed to this permit? Has HAEA ensured that excavation works are accompanied by adequate paleoseismological documentation?

Background Geological data and the assessments in the Geological Site Report and the Site Safety Report by MVM Paks II Zrt. consistently report the Dunaszentgyörgy-Harta fault zone as an active fault that extends into the site area of Paks II (MVM Paks II Zrt., 2016a, Fig. 5.2.1.2.6-1.; ÁCS et al., 2016, Fig. 418; Figure 4 and Figure 10 in Decker & Hintersberger, 2021). The data further indicate that a splay fault of the fault system extends into the perimeter of the planned new reactors.

Answer by the HAEA *"So far HAEA issued permits for in situ testing (soil stabilization, cut off wall), and for the first stage of the foundation pit excavation (above the groundwater level, up to 5 meters down from the site surface).*

Concerning the latter permit, it is important to mention, that the site of Paks II is artificially backfilled (executed during the construction of the current NPPs). The first phase of the foundation pit excavation will almost exclusively affect the artificial backfill. The original, natural soil layers are not expected to be disturbed at this stage. A monitoring program, including an initial or „zero" state screening is expected to be part of the permit application of the preparatory phase.

[29] https://www.direkt36.hu/addig-nyomultak-az-oroszok-hogy-nekik-kedvezoen-utemeztek-at-paks-2-t/ (in Hungarian) (download December 2020)

Since the position of the EAA study is different from the results of the review of the Siting License Application carried out by the HAEA and the Mining Authority, the reason behind these differences shall be explored and identified if possible The HAEA believes that these differences could include (but are not limited to) the following:

- **[1]**[30] *Specifically the HAEA has access to far more documentation and information than the EAA study (e g complete documentation and as required by law external peer review of the Geological Research Program and its implementation, as well as full documentation of the IAEA's "Site and External Events Design Review Service" (SEED) mission, etc.). It should be obvious that the results (as well as their validity) of such reviews are in accordance with the available data, and that conservative assumptions filling in the gaps of non-available data can lead to widely disparate conclusions.*
- **[2]** *The loose sedimentary layers covering the Paks site as well as the geological features of the site (moderately seismic zone in intraplate condition, etc.) behave very differently from the areas where permanent surface displacement due to faulting typically occur (e. g., Japan, California New Zeeland, etc.). Such areas have much larger earthquake intensity at the same occurrence frequency level, with different focal depths, different energy release mechanisms and much harder soil or crystalized layers covering them that are able to conduct the crustal breaking to the surface without attenuation. It should be highlighted that the Paks site is also very different in terms of geology, faulting/earthquake behaviour from the surrounding regions in the neighboring countries. In general, it can be stated that the empirical models and evaluation methods developed for areas with completely different tectonic and soil properties from the Paks site lead to a largely overestimated result and therefore incorrect/ultra conservative conclusions. This may especially be the case if the specifics of the Paks site are not taken into consideration (e g the damping/dissipating effects) when applying these modelling techniques.*
- **[3]** *The language barrier may pose a serious obstacle when reviewing/discussing scientific/technical documentation written in Hungarian (but it is generally true for any language). Certain nuances in the text may be difficult to express in other languages, causing the overall meaning of the statements to change or diverge.* **[4]** *A typical example of such is the “exclusion of the fault”, which were considered as neglecting the effect by the experts of the EAA, but the term “exclusion of the fault”, in Hungarian refer to two different things. The term “exclusion” can be used as exclusion from the realm of possibilities (e g physical impossibility) and as exclusion from the design basis and from the scope of detailed effect assessment. For a Hungarian expert the difference is trivial based on the context, but this difference may be lost during translation. Exclusion in the case of the faulting refers the later. It is insignificant and excluded as an effect not as a possibility, which is based on international standards and because there is a majoring effect (a hazard/phenomena with similar effect but larger amplitude/magnitude) required to be considered in the design which means that the effect of faulting (e g tilting of the reactor island) is already required to be covered with a large safety margin.”*

[30] Bold fonts and numbers in brackets were inserted to link to the EEA assessment below.

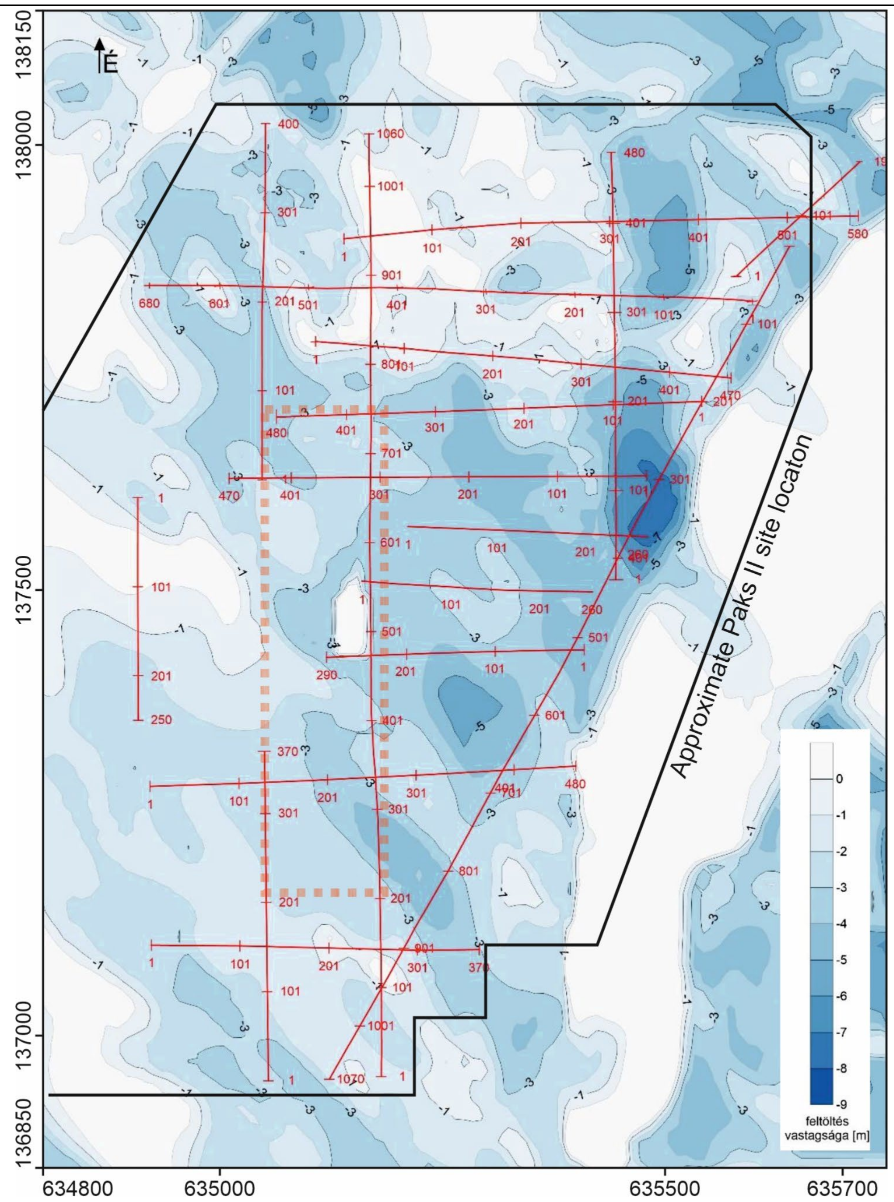
EAA expert assessment

Question 8 has not been sufficiently answered. It remains to be seen if the HAEA will require paleoseismological documentation of the excavations for the Paks II NPP. The EEA experts are unable to judge whether the HAEA's expectation that a *"monitoring program, including an initial or 'zero' state screening is expected to be part of the permit application of the preparatory phase"* is equivalent to a regulatory decision requiring targeted paleoseismological investigations in the future excavation pit.

The EEA experts caution that a meaningful paleoseismological documentation cannot be achieved by monitoring excavation work alone. Robust data can only be obtained from excavations with thoroughly cleaned and logged trench-wall surfaces, a requirement which cannot be expected from routine earthwork. The planning of earthwork needs to account for the time required to establish such outcrop conditions and documentation of the profiles with a level of detail comparable to those for the trench Pa-21-II (Hálasz et al., 2016). A convincing data set to disprove the existence of capable faults will require trenches trending approximately perpendicular to the strike of the Dunaszentgyörgy-Harta fault zone and covering, as a minimum, the whole length of the future reactor buildings and other SSCs relevant to safety.

Tóth et al. (2016, Fig. 77) provide a thickness map of the anthropogenic fill at the Paks II site, which shows that backfill covering natural soil is in some places much less than 5 m thick (Figure 8). It thus seems that the first phase of excavation will also affect the uppermost and youngest layers of sediments deposited as a result of natural processes. Documenting whether the latter layers are undeformed or penetrated by faults is of utmost importance for a rigorous paleoseismological assessment. Proper documentation should therefore be required from the very early stages of excavation.

Figure 8. Thickness map of backfill at the Paks II site



Color code denotes filling thickness (feltöltes vastagsaga). Modified from Tóth et al., 2016, Fig. 77, by adding the approximate location of the Paks II site and the expected locations of the reactor buildings. [Toth_Fig_77_thickness_antropocene.jpg]

Source: Modified from Tóth et al., 2016, Fig. 77 umweltbundesamt

[1] Access to documentation and information

The EEA experts regarded the bilateral workshop in Budapest as an excellent occasion to present information and learn about new data for excluding the possibility of permanent surface displacement, which can be integrated into the material in the Geological Site Report and the Site Safety Report. Unfortunately, the participating Hungarian experts did not use the opportunity to present convincing evidence that could challenge the EEA's assessment. The Hungarian technical presentations were essentially limited to seismological data, which were not useful for clarifying the fault capability issue, particularly in the context of timescales that are characteristic of fault rupture in intra-continental regions.

[2] Uniqueness of the Paks II site

The physics of fault ruptures is universally applicable to all sites, irrespective of their location. This also pertains to the applicability and interpretation of paleoseismological techniques. A detailed assessment of [2] is included in chapter 1 of this report.

[3] Language barriers

The EEA expert assessments are based on translations of the relevant parts of the Geological Site Report and the Site Safety Report provided by bilingual (Hungarian–German and/or Hungarian–English speaking) geoscientists who had both the necessary language skills and geological expertise to comprehend the full context of the technical content.

The report by Decker & Hintersberger (2021) was reviewed by five experts, including two named experts and one anonymous Hungarian senior expert. This included a review of the correct use of data from the Geological Site Report and the Site Safety Report for the Paks II site. The rigor of the review exceeded the effort usually expended for high-ranking international peer-reviewed earth-science journals.

[4] Incorrect translation of Regulation 7.3.1.1100 and misunderstanding of the term "exclusion"

The source of the translation used in Decker & Hintersberger (2021) and the current report is the official English translation of the Hungarian wording published by the HAEA in 2018[31]. The translation used is therefore considered correct.

Regulation 7.3.1.1100 is part of Annex 7 of the Governmental Decree No. 118/2011 (VII. 11.) of the (Hungarian) Nuclear Safety Code Volume 7. Chapter 7,1 of Annex 7 defines the purpose of the regulation collected in the Annex as follows:

"7.1.1.0100. The purpose of the regulation is to identify the nuclear safety requirements for the site and for the identification of the characteristics of the site of nuclear facilities" [etc.].

Regulation 7.3.1.1100 is therefore clearly introduced in the context of site characterization and not in the context of design. The EEA experts are therefore unable to follow HAEA's argumentation, which asserts that *"in the case of the* [surface] *faulting consideration of the effect should be considered in the design."*

Final conclusion The issue does not require further information or discussion.

[31] http://www.oah.hu/web/v3/haeaportal.nsf/8EE55B54901CDD60C1257CDD004367CB/$FILE/118%202011%20Korm.%20Rendelet%20_7.%20k%C3%B6tet_EN_2018_04_10.pdf (download 30.08.2022)

3 CONCLUSIONS AND RECOMMENDATIONS

The information obtained during the first workshop on the site conditions of the Paks II site lead the EAA experts to the following conclusions:

- The EAA experts confirm their conclusions on the existence of capable faults in the vicinity of the Paks site. These capable faults, described in detail in the Geological Site Report and partly excavated in the paleoseismological trench PA-21-II, are part of the Dunaszentgyörgy-Harta fault zone, their strike continues into the site, and they reveal evidence of repeated, significant surface displacements during the last ca. 20,000 years. The information provided during the bilateral workshop and the answers to the Austrian questions do not suffice to revise these conclusions.
- The EAA experts regard the presented data on seismicity insufficient to allow a reliable assessment of capable faults (*"7.3.1.0800. The potential occurrence of a permanent surface displacement on the site shall be analyzed and evaluated. The examination must be sufficiently detailed to enable a substantive decision to be taken on the question of the possibility of discarding the site by the occurrence of permanent surface displacement."*)[32]
- The available paleoseismological (trenching) data are not sufficient to exclude fault capability. For a comprehensive assessment, other linked structures with inferred near-surface faults need to be trenched. This particularly applies to near-surface faults mapped by geophysical data in the immediate vicinity of the Paks II site (profiles Pa-21-S-Geomega; Paks-MUEL-10; Pa-22-S; Paks-MUEL-3; etc.).
- The latter conclusion is particularly important with regard to the Hungarian Governmental Decree No. 118 of 2011, Requirement 7.3.1.1100: *"If the potential of occurrence of a permanent surface displacement on the site cannot be reliably excluded by scientific evidences, and the displacement may affect the nuclear facility, the site shall be qualified as unsuitable."*[33].
- To reliably assess fault capability, it will be important to expand the observation periods of possible seismogenic surface faulting beyond the coverage of historical and instrumental earthquake data. In line with international scientific practice and WENRA requirements, the expansion of the timescale to centennial and millennial observation periods cogently requires the adoption of a paleoseismological approach, especially in an intraplate setting such as Hungary.
- The EAA experts strongly recommend a paleoseismological documentation of the excavation pits for the Paks II NPP. The team of experts appreciates HAEA's expectation that a *"monitoring program … is expected to be part of the permit application of the preparatory phase".* It recommends that HAEA issues an official regulatory decision requiring targeted paleoseismological

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32 http://www.oah.hu/web/v3/haeaportal.nsf/8EE55B54901CDD60C1257CDD004367CB/$FILE/118%202011%20Korm.%20Rendelet%20_7.%20k%C3%B6tet_EN_2018_04_10.pdf

33 http://www.oah.hu/web/v3/haeaportal.nsf/8EE55B54901CDD60C1257CDD004367CB/$FILE/118%202011%20Korm.%20Rendelet%20_7.%20k%C3%B6tet_EN_2018_04_10.pdf

investigations of the excavation pit. The EEA experts furthermore suggest that a meaningful paleoseismological documentation cannot be achieved by merely *"monitoring"* excavation work. Robust data can only be obtained from excavations with thoroughly cleaned trench-wall surfaces and rigorous stratigraphic and structural logging. Such conditions cannot be expected from routine earthwork and excavations reaching below the groundwater table. Excavations therefore need to provide adequate time for establishing such outcrop conditions and documenting the profiles in sufficient detail. A convincing data set to disprove the existence of capable faults will require trenches trending approximately perpendicular to the strike of the Dunaszentgyörgy-Harta fault zone and covering, as a minimum, the whole length of the future reactor buildings and other infrastructure relevant to safety.

Thickness maps of anthropogenic backfill and the existing HAEA permit to excavate to a depth of 5 m below surface suggest that the top layers of naturally occurring soil will already be removed during an early phase of the excavations. Proper paleoseismological documentation should therefore start as soon as possible.

Although the workshop provided a valuable opportunity to exchange opinions on the conditions of the Paks II site, it was not possible to agree on a technically satisfactory outcome. For this reason and in view of the relevance for nuclear safety, the EAA experts suggest continuing the dialogue at the expert level and involving further international experts. Follow-up discussions should consider additional details of the earlier set of questions and address the following points:

- Question 2: Consideration of near-fault effects in seismic hazard assessment.
- Question 4: Discrepancies between the Geological Site Report and the Site Safety Report, and HAEA's assessment of these discrepancies.
- Question 6: Clarification of the validity of the statement in the Site License: "Within at least 10 km of its surrounding no fault segment exists, which led to surface displacement by faulting in the last 100.000 years." Based on accessible data and information on the Németkér fault, the EAA experts cannot agree with this statement.
- Question 7: Clarification of the validity of the statement in the Site License: "Based on the evaluation of the research the possibility of surface displacement due to a surface breaking fault is excluded for the site." Based on accessible data and information, the EAA experts cannot agree with this statement.

Questions 6 and 7 are considered highest priority. Due to the safety relevance for the new NPP, these questions should be clarified as soon as possible.

To continue and intensify dialogue, the Austrian delegates suggested that the EAA experts be granted permission to visit open construction pits on the Paks II site. This would enable the experts to make first-hand observations of the geological site conditions and would foster confidence building. The Hungarian delegates responded positively to the Austrian suggestion. Despite the obvious differences of opinion regarding some of the key issues of fault activity and capability, this courtesy is deeply appreciated and underscores the open and positive spirit of the meeting.

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