

TECHNICAL REPORT

**PROBABILISTIC
FAULT
DISPLACEMENT
HAZARD ANALYSIS**

**KRŠKO EAST AND
WEST SITES**

**PROPOSED KRŠKO 2
NUCLEAR POWER
PLANT**

KRŠKO, SLOVENIA

REVISION 1

Engineering & Construction Management
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**PROJECT No. 11-4546
13 MAY 2013**

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ANALYSIS
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Krško East and West Sites
Proposed Krško 2 Nuclear Power Plant
Krško, Slovenia


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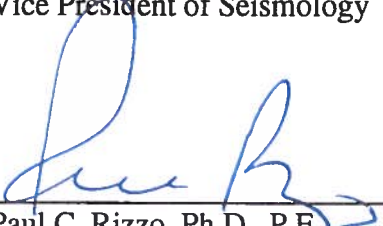
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Proposed Krško 2 Nuclear Power Plant
Krško, Slovenia

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TABLE OF CONTENTS

	PAGE
LIST OF TABLES	ii
LIST OF FIGURES	iii
1.0 INTRODUCTION	1
2.0 GEOLOGIC AND TECTONIC SETTING	4
3.0 PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS	6
3.1 PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS METHODOLOGY	6
3.2 HAZARD ANALYSIS INPUTS.....	8
3.2.1 Inputs Working Meeting.....	9
3.2.2 Additional Inputs	12
3.3 FAULT DISPLACEMENT HAZARD	18
4.0 SUMMARY AND CONCLUSION	21
REFERENCES	
TABLES	
FIGURES	
APPENDIX A	PEER REVIEW LETTER REPORT

LIST OF TABLES

TABLE NO.	TITLE
TABLE 1	FAULTS CONSIDERED IN THE PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS FOR THE KRŠKO EAST AND WEST SITES
TABLE 2	FAULT PROBABILITIES OF ACTIVITY
TABLE 3	LOGIC TREE FOR FAULT LENGTH
TABLE 4	LOGIC TREE FOR FAULT SLIP RATE
TABLE 5	SUMMARY OF FAULT DEPTH AND DIP ASSESSMENT
TABLE 6	LOGIC TREE FOR FAULT MAXIMUM MAGNITUDE
TABLE 7	LOGIC TREE FOR B-VALUE
TABLE 8	LOGIC TREE FOR DISPLACEMENT MODELS
TABLE 9	TOTAL SURFACE FAULT DISPLACEMENT HAZARD FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP

LIST OF FIGURES

FIGURE NO.	TITLE
FIGURE 1	REGIONAL TECTONIC AND GEOLOGIC SETTING OF THE KRŠKO 2 NPP SITES
FIGURE 2	STRUCTURAL GEOLOGIC MAP OF THE KRŠKO BASIN AND SURROUNDING AREA
FIGURE 3	STRATIGRAPHY OF THE KRŠKO BASIN
FIGURE 4	RELATIONSHIP AMONG VARIABLES USED IN THE FAULT DISPLACEMENT HAZARD ANALYSIS
FIGURE 5	FAULTS INCLUDED IN THE PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS
FIGURE 6	FAULTS CLOSEST TO THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 7	PROBABILITY OF SURFACE RUPTURE AS A FUNCTION OF MOMENT MAGNITUDE USING WELLS AND COPPERSMITH (1993)
FIGURE 8	200 × 200 METER CELL USED IN PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 9	TOTAL SURFACE DISPLACEMENT HAZARD FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 10	ON-FAULT AND OFF-FAULT CONTRIBUTIONS TO TOTAL HAZARD FOR THE EAST SITE BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 11	ON-FAULT AND OFF-FAULT CONTRIBUTIONS TO TOTAL HAZARD FOR THE WEST SITE BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 12	CONTRIBUTIONS TO ON-FAULT DISPLACEMENT HAZARD FROM THE VARIOUS SURFACE DISPLACEMENT MODELS FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 13	CONTRIBUTIONS TO OFF-FAULT DISPLACEMENT HAZARD FROM THE VARIOUS SURFACE DISPLACEMENT MODELS FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP
FIGURE 14	CONTRIBUTIONS TO TOTAL DISPLACEMENT HAZARD BY SOURCE FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP

**TECHNICAL REPORT
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EAST AND WEST SITES
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KRŠKO, SLOVENIA**

1.0 INTRODUCTION

Two Sites adjacent to the existing Krško 1 Nuclear Power Plant (NPP) are being considered for a proposed Krško 2 NPP. One potential Site lies immediately to the east of the existing NPP and the other lies immediately to the west. In assessing these potential Sites, one issue being considered is whether they are intersected by any “capable” faults.

The International Atomic Energy Agency (IAEA), in their Specific Safety Guide No. SSG-9 (Seismic Hazards in Site Evaluation for Nuclear Installations) (IAEA, 2010), states that Sites should be free of capable faults that affect the safety of a nuclear facility. IAEA defines a capable fault as one that:

- Shows evidence of past movement within a period of time such that it is reasonable to conclude that further movement at or near the surface may occur.
- Shows a structural relationship to a known capable fault, such that movement on the known capable fault might cause movement on the other fault at or near the surface.
- Has an assessed maximum potential earthquake that is sufficiently large and at such depth that it is reasonable to conclude movement may occur at or near the surface.

A probabilistic fault displacement hazard analysis (PFDHA) is recommended by IAEA as an approach to assessing the potential impact of fault displacement hazard for existing sites (IAEA, 2010, Paragraph 8.10). A PFDHA provides information that can be used to assess potential affects to safety of a nuclear facility and to make a risk-informed decision regarding site suitability when geologic investigations are inconclusive.

One fault – the Libna Fault – and one postulated fault – the Stara Vas Fault – are inferred to lie near or intersect the boundary of the East or West Sites for the proposed Krško 2 NPP. Thus, these features have become the focus of investigations to evaluate whether or not they exist and, if they exist, are capable.

The Libna Fault has been studied since about 1995, when high resolution seismic (HRS) lines revealed anomalies that were interpreted to represent a possible fault. To evaluate whether the postulated fault exists and is capable, beginning in 2008 additional studies were carried out, including acquisition of additional HRS reflection data, trenching across the postulated fault trace, test pits, ground penetrating radar, resistivity, and other surveying techniques. These in-depth studies uncovered some additional field evidence of the near surface expression of the Libna Fault, but definitive indication of post-Miocene activity has not been confirmed. The feature observed in the Libna Hill trench suggests a fault zone approximately 100 meters (m) wide, striking northwest and dipping to the east approximately 80 degrees (Geološki Zavod Slovenije [GeoZS], 2011). The inferred surface trace of the Libna Fault lies outside of the East and West Sites being considered for a proposed Krško 2 NPP.

The postulated Stara Vas Fault was first described in about 1997 and is characterized as a strike-slip fault parallel to and west of the Libna Fault. Field evidence observed to the north of the Site includes a steeply dipping (80 degrees), north-northwesterly striking fault plane and a fault surface exhibiting slickensides (Bavec, 2010a). Geophysical evidence of the postulated fault dies out northwest of the Site and similar to the Libna Fault, evidence for post-Miocene activity has not been identified. Although there is no evidence for the Stara Vas Fault at the East or West Site, a hypothetical extension of the fault into the East Site is considered in this analysis.

To provide additional information for assessment of the potential for these postulated capable faults to affect the safety of an NPP at the East or West Site, RIZZO carried out a PFDHA. The output of this analysis gives the annual probability of exceeding various levels of displacement for the area of interest. The analysis takes into account the locations of the faults, the rate of slip on each fault, the largest earthquake assessed to be possible on each fault, and uncertainty in these values. In addition, the probability that each fault exists and is active is included in the analysis. The analysis also incorporates, for a given magnitude earthquake, the likelihood of various levels of principal and distributed surface displacement. Principal (on-fault) displacement occurs along the main, continuous fault whose movement causes an earthquake or within several meters of the main fault. Distributed (off-fault) displacement typically occurs as discontinuous ruptures and shears located tens of meters to a few kilometers away from the principal fault. Distributed displacements are caused by secondary movements off of the principal fault.

A PFDHA is appropriate for assessing fault displacement hazard for the East and West Sites, especially given the uncertainties in the existence and characterization of faults in the

vicinity. The probabilistic approach allows the uncertainties to be incorporated in a rational framework. Using the probabilistic approach, it is possible to see the effect of modeled faults, such as the postulated Stara Vas Fault, that in the vicinity of the Site are speculative. By examining the contributions to the overall displacement hazard from each modeled fault, those which have a significant contribution to the hazard at the Site can be identified. The results can also be used to examine what uncertainties have a significant impact on the overall hazard. Such information aids in assessing whether additional characterization is necessary. Also, if refinement of fault characterization is desired, the results point to which uncertainties are most important to reduce.

In January 2013, the work described in Revision 0 of this report was presented to a Peer Review Panel for their comment and feedback. Based on the Peer Review Panel Report (*Appendix A*), the fault model was updated and forms the basis for the results presented herein.

Following this introduction, the Report provides an overview of the geology and tectonic setting for the Krško Site. Next, the PFDHA is described, including its methodology, inputs, and results. The Report concludes with a summary of findings.

2.0 GEOLOGIC AND TECTONIC SETTING

The Krško NPP Site is located on the northern bank of the Sava River, 2 kilometers (km) east of the town of Krško. The major tectonic elements in the region are the Alps, the Dinarides, and the Pannonian Basin (Ward, 1994). The Site is on the northeastern part of the Adriatic microplate. The East Alpine-Western Carpathian-Northern Pannonian tectonic block lies to the north, and the Tisza microplate lies to the east. These plate boundaries developed in a convergent margin/collision tectonic setting during the Alpine orogeny (late Tertiary).

Geologically, the Krško Basin lies at the southern edge of the Sava Compressional Wedge (*Figure 1*). The Basin, which extends northeast-southwesterly for more than 40 km and is about 10 km wide, is a folded and faulted structural syncline. Near the Krško NPP Sites, the syncline is referred to as the Krško syncline (feature “g” on *Figure 2*). Approximately 2,000 m of Neogene sediments are covered by Plio-Quaternary and Quaternary sediments possessing an average thickness of 15 m to 20 m, with localized thickness up to 150 m. Along the syncline, late Neogene and Quaternary sediments have been locally deformed (Placer, 1999) (*Figure 3*).

Seismically, the Krško Basin is an active area within Eastern Slovenia, though less active than Western Slovenia with the Julian Alps and the Idrija Fault Zone. The average depth of earthquakes is about 7 km and the depths of the stronger events are typically between 9 and 20 km. Focal mechanisms make it clear that the governing, modern day compressive stress is oriented approximately north-south. Strike-slip and reverse faults, likely connected with southward thrusting, are common, but normal faulting also is present (Ward, 1994).

The structural evolution of the Krško Basin during the Mesozoic and Cenozoic is based upon the results of detailed geologic and geophysical investigations in the near region and site vicinity. Three major groups of structures are present in the Krško Basin area. The oldest (Dinaric) group of structures exhibits predominantly NW – SE strikes and includes large folds (several km) and related faults, such as the Hrastnik and Letus Faults. Dinaric Domain structures observed in the Mesozoic formations and buried by the Neogene deposits are considered of Paleogene age. Some of these Paleogene faults were also reactivated later in the Neogene. The second group of structures (Balaton Domain structures) are observed in the Neogene (and older) rocks. They mostly exhibit NE – SW and ENE – WSW strike and correspond to the strike of the Zagreb, Sveta Nedelja, Orlica, Artiče and other faults (Prelogović et al., 1998). Earlier interpretations of faults associated with the Balaton Domain in the Krško basin (e.g., Gosar, 1998; Verbic 1993, 2005) are incorporated or updated based

on more recent investigations into the current synthesis of a seismotectonic model (Bavec, 2010a).

The left-lateral Orlica Fault exhibits a stepover structure as it deviates from its northeast strike, typical of Balaton Domain faults, into an east-west trending fault, and then continues again in the northeast direction. The Artiče structure also exhibits an east-west trend between the Močnik Fault and the Sotla River, but toward the northeast, the structure trace regains northeast trend of a Balaton Domain fault, similar to the Orlica Fault. The Artiče structure also includes a south-verging reverse fault observed in the KK-03/99 seismic line. The area between the Artiče and Orlica faults is a restraining bend, dissected by north-south to northwest-southeasterly trending faults (known in this study as the Globoko Hills Faults), including the Libna and Stara Vas Faults. To the North, these faults end at the Orlica Fault, while their southernmost extent is currently unknown. It is assumed that these faults end at one of the Balaton faults to the South. In the center of the Globoko Hills, uplifting is observed north of the Artiče Fault. The faults in the area of the uplift (e.g., Sromljica and Gabrnica Faults) exhibit oblique movement, with components of both reverse and right-lateral strike-slip faulting. This is accomplished through uplift of the Globoko Hills coupled with counterclockwise rotation of the fault blocks in response to its positioning between the left-lateral Orlica and Artiče Faults (Bazargan-Sabet, 2010).

Buried faults associated with the Balaton Domain are interpreted within the Krško Basin, south of the potential Krško 2 NPP Sites, from seismic reflection data (Verbič, 2005; Gosar, 1998). These faults appear to occur within the thick Miocene carbonate sequence. Continuation of these faults into the Plio-Quaternary deposits has not been established.

3.0 PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS

A PFDHA is carried out to assess the likelihood of exceeding various levels of surface displacement at the East and West Sites being considered for the Krško 2 NPP. First the methodology used to calculate the surface displacement hazard is described. Next the inputs to the analysis are presented. Then the results of the PFDHA are discussed.

3.1 PROBABILISTIC FAULT DISPLACEMENT HAZARD ANALYSIS METHODOLOGY

Calculation of fault displacement hazard conceptually follows the same approach as for ground motion hazard. Youngs et al., (2003) developed a methodology consisting of two approaches: an approach based on the occurrence of earthquakes producing primary and secondary displacement (the “earthquake approach”) and an approach based on observed displacement characteristics at a site of interest (fault, minor shear, fracture, unbroken ground) without specifying their cause (the “displacement approach”). The methodology was implemented for normal faulting in an extensional regime at Yucca Mountain, Nevada, USA. Both “principal displacement” and “distributed displacement” were considered in determining the hazard. Principal displacements occur along the main fault plane that generates the earthquake. Distributed displacements occur away from the principal fault on other discontinuities (e.g., faults, shears, fractures), or in previously unbroken ground. Principal displacement typically is observed within several meters from the fault. Distributed displacement occurs over a zone that may extend outward tens of meters to kilometers from the principal fault. Inclusion of principal and distributed displacement is consistent with guidance in IAEA Specific Safety Guide SSG-9 (IAEA, 2010, Paragraph 8.11) regarding consideration of primary and secondary displacement.¹

Petersen et al., (2011) extended the earthquake approach of Youngs et al., (2003) to strike-slip faulting and included the accuracy of fault mapping and fault complexity in their formulation. The PFDHA carried out for the Krško 2 Sites follows the implementation of Petersen et al., (2011).

Petersen et al., (2011) define the rate of fault displacement exceedance as:

¹ Note that IAEA SSG-9 (IAEA, 2010) indicates that an example of secondary displacement is “triggered slip on an existing fault or a bedding plane from an earthquake on another fault.” In this Report, triggered slip on an existing fault from an earthquake on another fault is not addressed explicitly. Rather it is included implicitly by including the existing fault in the fault source model and including the observed displacement (including any from triggered earthquakes) in the assessment of slip rate for the existing fault.

$$\lambda(D \geq D_0)_{xyz} = \alpha(m) \int_{m,s} f_{M,S}(m,s) P[sr \neq 0|m] \\ \times \int_r P[D \neq 0|r, z, sr \neq 0] \times P[D \geq D_0|l/L, m, D \neq 0] f_r(r) dr dm ds$$

for principal-fault contributions, and

$$\lambda(d \geq d_0)_{xyz} = \alpha(m) \int_{m,s} f_{M,S}(m,s) P[sr \neq 0|m] \\ \times \int_r P[d \neq 0|r, z, sr \neq 0] \times P[d \geq d_0|r, m, d \neq 0] f_r(r) dr dm ds$$

for distributed-fault contributions. In these equations:

x,y	are the Site coordinates
z	is the dimension of the area (z^2) for which fault displacement hazard is assessed
r	is the closest distance from the fault surface trace to the Site
l/L	is the on-fault distance ratio in which l is the along-fault distance from the point on the fault nearest to the Site to the closest end of the rupture and L is the total rupture length
s	is the distance from the end of the rupture to the end of the fault
D	is principal-fault (on-fault) net displacement in meters
d	is net displacement away from the principal fault (off-fault) in meters
sr	is surface rupture
$f_{M,S}(m,s)$	is a probability density function (PDF) that characterizes earthquake magnitude and the location of ruptures along a fault
$f_r(r)$	is a PDF that characterizes the distance from the Site to potential ruptures
$P[D \neq 0]$	is the probability of having surface rupture on a principal fault
$P[d \neq 0]$	is the probability of having surface displacement off the principal fault
$P[sr \neq 0]$	is the probability of having surface rupture

In addition, Petersen et al., (2011) define two additional PDFs. The PDF $f_D(l/L, m)$ gives net slip on principal faults a distance l/L along the fault for a given earthquake magnitude, m . The PDF $f_d(r, m)$ provides net distributed slip a distance r from a principal fault for a given earthquake magnitude, m .

The probabilities are determined by integrating over a lognormal distribution whose mean and standard deviation are determined from regression analyses. The spatial relation among

the defined variables is shown on **Figure 4**. On **Figure 4**, the case in which $r=0$ is the on-fault/principal faulting case.

The PDF $f_R(r)$ includes both epistemic and aleatory uncertainties. Aleatory uncertainty derives from ruptures occurring on different fault traces in different earthquakes through geologic time. Epistemic uncertainty is related to fault mapping accuracy and fault complexity. Fault displacements on and off the principal fault are also subject to epistemic and aleatory uncertainties related to measurement errors and natural variability, respectively.

This approach is consistent with the guidance in IAEA SSG-9 (IAEA, 2010, Paragraphs 8.12 and 8.13).

Petersen et al., (2011) develop regression relations and PDFs for:

- Displacements as a function of magnitude and distance (multivariate).
- Normalized displacements along the main fault that are a function of average displacement.

Displacement is the net displacement across the fault, including both the vertical and horizontal components.

For normalized displacements the following equations relate displacement on and off the main fault to average displacement (D_{ave}) (Petersen et al., 2011):

$$P[D \geq D_0 | l/L, m, D \neq 0] = \int_{D_{ave}} P[D \geq D_0 | l, L, D_{ave}(m), D \neq 0] \times f_{D_{ave}}[D_{ave}(m)] dD_{ave}$$

and

$$P[d \geq d_0 | l/L, m, d \neq 0] = \int_{D_{ave}} P[d \geq d_0 | l, L, D_{ave}(m), d \neq 0] \times f_{D_{ave}}[D_{ave}(m)] dD_{ave}.$$

The Petersen et al., (2011) methodology is implemented in the software code RIZZO-HAZARD and used to compute fault displacement hazard for the Krško 2 proposed Sites. The implementation of the approach in the software has been verified and validated in accordance with RIZZO quality assurance procedures.

3.2 HAZARD ANALYSIS INPUTS

Inputs to the PFDHA for the Krško 2 Sites are based on available information (as of May 2011) regarding the faults in the area. Alternative interpretations that are allowed by the data

are characterized and included in the analysis. Inputs are based primarily on Bavec (2010a) for faults in the area around the Krško Sites and on Petersen et al., (2011) for characterization of on-fault and off-fault displacement as a function of magnitude and distance.

3.2.1 Inputs Working Meetings

The inputs were originally discussed and finalized during a Working Meeting held in Pittsburgh, PA, USA on 10-12 May 2011 for Revision 0 of this report. Participants at this first meeting included:

- Paul C. Rizzo Associates, Inc. (RIZZO) – Richard Quittmeyer, Erich Zorn, Rigobert Tibi, Ali Fatehi, and Jose Blanco
- Consultants – Miloš Bavec and Igor Riznar

Following comment and feedback by a Peer Review Panel (*Appendix A*), fault characterization inputs were updated during an additional Working Meeting held in Pittsburgh, including participants in Slovenia by videoconference, on 08 March 2013. Participants at this second meeting were:

- RIZZO – Richard Quittmeyer, Ali Fatehi, K. Michael Cline, M. Logan Cline, and Arash Zandieh
- Slovenian Geological Survey (GeoZS) – Miloš Bavec (by videoconference)
- Mojca Borse (GEN) also attended the second meeting as an observer.

Dr. Quittmeyer facilitated the meetings. The discussion below describes the combined assessment from the two Working Meetings and represents the final base-case fault characterization model.

The goal of the meetings was to develop the inputs to the PFDHA using a logic tree framework to represent uncertainties. First, an overview of PFDHA was presented to clarify what inputs were required. Then the discussion turned to evaluation of faults at or near the Krško Sites area that were relevant to determining hazard displacement. While it was anticipated that the closest faults would be the most important contributors, more distant faults were also included for completeness and to verify their hazard contribution. The goal of the second meeting was to review and update the inputs to the PFDHA based on comments from the Peer Review Panel.

The fault discussion began with an assessment of the tectonic framework. Two alternatives were considered. In one, the Globoko Hills Faults are secondary structures related to movement on Balaton Domain Faults (e.g., Orlica, Artiče). In the alternative interpretation, the Globoko Hills Faults are related to Dinaric Domain Faulting. The first interpretation is much more strongly supported by the data and, thus, the alternative interpretation was dropped because it would have been assessed a low weight and, therefore, have an insignificant impact on hazard.

With respect to fault displacement hazard at the Krško East and West Sites, the Globoko Hills Faults are of interest. In particular, the Libna Fault trends north-northwesterly and has an inferred mapped trace just outside the proposed boundary of the East Site. A second Globoko Hills Fault, the postulated Stara Vas Fault, is inferred to run in a south-southeast direction west of the Libna Fault. Although there is no evidence that the postulated Stara Vas Fault extends to the East and West Sites, a speculative extension that reaches the Site is included in the analysis. While geophysical data do not support this interpretation, it is included for conservatism.

In addition to the Libna Fault and the postulated Stara Vas Fault, other faults considered for inclusion in the PFDHA are the Orlica Fault, Artiče Fault, Gorica Fault, Hrastnik Fault, and Letuš Fault. The Orlica and Artiče Faults are related to the Balaton Domain fault system and the Hrastnik and Letuš Faults are related to faults of the Dinaric Domain. The Gorica Fault is included to represent the possibility that such Balaton Domain faults lie buried beneath the basin sediments (e.g., Gosar, 1998; Verbič, 2005). Its location is defined on the basis of an interpreted buried fault about 2 km south of the Sites (Gosar, 1998; Bavec, 2010a), but other characteristics are assumed from analogy to other Balaton Domain faults. Also, additional Globoko Hills Faults similar to the Libna Fault and the postulated Stara Vas Fault, but farther east from the Krško Sites were considered. **Table 1** lists the faults and postulated faults considered for inclusion in the PFDHA. Fault sources comprising the final model are shown on **Figures 5 and 6**.

For the faults considered for inclusion in the PFDHA, the next assessment was their probability of being active. The Libna Fault was evaluated to have a probability of activity of 1.0. While there is uncertainty regarding the age of most recent movement along the fault and the degree to which the amount and age of displacement may be affected by mass wasting and karst features (RIZZO 2012), a value of 1.0 is conservatively assessed given its proximity to the Sites. The postulated Stara Vas Fault, because it lacks any geomorphic expression and is much more poorly defined than the Libna Fault (RIZZO 2012), was assessed to have a probability of activity of 0.3. The other Globoko Hills Faults were

evaluated to have a 50 percent likelihood of being active. This evaluation was based on lack of definitive evidence for Quaternary-age movement and their generally inferred rather than mapped nature. The Gorica Fault is assessed to have a 0.9 probability of activity. While consistent with the tectonic model of the Site vicinity and supported by interpreted offsets in seismic reflection data (e.g., Gosar, 1998), it is given a probability of activity slightly less than 1.0 because it exhibits no geomorphic expression and there is no evidence of offset of Plio-Quaternary deposits (RIZZO, 2012). The Letuš Fault was evaluated to have a zero percent probability of activity and was dropped from further consideration. All other faults were assessed to be active with 100 percent probability (*Table 2*).

During the working meetings, the participants also evaluated the length of the various faults and concluded that there was generally uncertainty in that parameter. Thus, using a logic tree framework, alternative lengths, and weights expressing their support in the data, were assessed for most faults (*Table 3*). Lengths were assessed based on the available geological and geophysical data. For the Orlica North and Hrastnik Faults, although the working meeting participants assessed uncertainty in their lengths, in the PFDHA only the longer length is included. This conservative step is taken to simplify the fault model for these faults that are more distant from the Krško Sites.

Single-event fault displacement data are not available to estimate earthquake magnitudes and recurrence rates for any of the faults included in the model. Also, instrumentally recorded seismicity is insufficient to assess the rate of earthquake occurrence associated with the faults. Thus, recurrence rates are inferred from long-term net slip rates determined for the faults from available geologic data (e.g., offset marker horizons and age constraints) (Bavec, 2010a).

Participants at the Working Meetings evaluated data on the long-term net slip-rate for faults considered in the PFDHA. Uncertainty in the age and offset of marker horizons leads to uncertainty in the assessed slip rates. As for fault length, a logic tree framework is used to represent the fault slip rates and their uncertainties (*Table 4*). Slip rates for the Orlica, Artiče, Hrastnik, and Libna Faults are considered on an individual basis. As no direct measurements are available for the Gorica Fault, its slip rate is taken as one-half that determined for the Artiče Fault based on its similar tectonic setting but lack of fault displacement expression. Similarly, the slip rate determined for the postulated Libna Fault is applied to all the other modeled Globoko Hills Faults for which direct evidence is unavailable. For this case, the basis is a similar tectonic setting and a similar degree of expression. For the postulated Stara Vas Fault, although it is not as well expressed as the other Globoko Hills Faults that are included in the PFDHA, the Libna Fault slip rate is also applied as a conservative assessment.

Working meeting participants also assessed the depth of faulting and fault orientation for the faults considered for the PFDHA (*Table 5*). This assessment supports evaluation of maximum magnitude using empirical relations between rupture area and M_W (*Section 3.2.2*). It could also be used to evaluate the probability of surface rupture given the occurrence of a given magnitude earthquake on a fault. Ultimately, however, the probability of surface faulting for a given magnitude earthquake was treated following the approach of Petersen et al., (2011), which is summarized in *Section 3.2.2*.

3.2.2 Additional Inputs

In addition to the inputs derived from assessments at the working meetings, additional inputs are required to carry out the PFDHA. These consist of the maximum magnitude (M_{max}) that can occur on each fault; the b-value for an exponential magnitude frequency distribution describing earthquake occurrence on each fault; the probability that a given moment magnitude (M_W) earthquake will produce a surface rupture; the distribution of the amount of surface displacement along a fault rupture as a function of M_W ; and the distribution of surface displacement away from a primary fault as a function of M_W and distance from the fault.

Maximum Magnitude

The M_{max} for each modeled fault is used along with the slip rate and b-value to assess the frequency of different magnitude earthquakes occurring on the fault following the approach of Youngs and Coppersmith (1985). M_{max} is determined using empirical relations between rupture length and M_W and rupture area and M_W (Wells and Coppersmith, 1994). M_W values are determined following each approach (i.e., based on rupture length or based on rupture area) using the assessments of maximum rupture length, fault orientation, and the thickness of the seismogenic zone, as appropriate. Then the estimates are combined into an overall M_{max} distribution for use in the PFDHA. The final M_{max} distribution for each fault is determined subjectively taking into account the estimates of M_W from the two approaches and their weights based on the assessed uncertainties.

For the rupture length approach, because the faults are generally short in length (all except the Hrastnik fault have lengths of 25 km or less), the rupture length is taken to be equivalent to the estimated fault length. That is, each alternative interpretation of the fault is assumed to be capable of rupturing its entire estimated length in a single earthquake. Typically earthquakes rupture only a portion of a fault's total length, so this approach provides a conservative estimate of M_{max} . The Wells and Coppersmith (1994) empirical relation for the assessed style of faulting is used. For each fault, M_{max} determined from rupture length is

described by a discrete probability distribution to represent uncertainty in the parameter. The mean M_W value and the mean ± 1 standard deviation values form the distribution with weights of 0.6, 0.2, and 0.2, respectively (*Table 6*).

For modeled Globoko Hills Faults other than the postulated Libna and Stara Vas Faults, which are closest to the potential Krško 2 NPP Sites, M_{max} is based only on the longest assessed length for each fault. This assessment is conservative for the shorter assessed length, but because these faults are farther from the Sites of interest they have a smaller contribution to hazard. Thus the simplified uncertainty representation is used. This approach is also used for the Orlica North Fault and the Hrastnik Fault, which are also relatively distant from the Sites.

For the rupture area approach, M_{max} is determined using the same rupture lengths as discussed above. Rupture width is determined using the assessed fault dip and depth of faulting. Uncertainty in depth of faulting results in a range of rupture widths. When combined with the rupture length, this gives a range of rupture areas. The range of M_W determined from the range of rupture areas using the Wells and Coppersmith (1994) mean values is taken as the representation of uncertainty in M_{max} from the rupture area approach. Each value can be associated with a weight based on the probabilities of the rupture length and depth of faulting leading to a given rupture area.

The final M_{max} distribution is determined subjectively based on the distributions from the rupture length and rupture area approaches, giving each approach equal weight. Four discrete values with associated weights comprise the final distribution (*Table 6*).

b-value

The slope of the exponential magnitude frequency relation, which is used with the slip rate and M_{max} to determine the rate of occurrence of different magnitude earthquakes, is taken from an existing probabilistic seismic hazard analysis (PSHA) for ground motion at the Site (PSR-NEK-2.7.2, 2004). In the previous PSHA, b-value was assessed to be an uncertain parameter represented by values of 0.97 and 1.49 with equal weight. The same distribution is used in the PFDHA (*Table 7*).

Probability of Surface Rupture

In analyzing the hazard of surface displacement it is necessary to model the likelihood that an earthquake with a given M_W will rupture to the surface. In the PFDHA, following Petersen et

al., (2011), the regression of Wells and Coppersmith (1993) is used. They used a logistic regression model that provides the conditional probability of surface rupture given an M_W :

$$P[sr \neq 0|M_W] = \frac{e^{(a+bM_W)}}{1 + e^{(a+bM_W)}}$$

in which a and b are constants. Wells and Coppersmith (1993) determined $a = -12.51$ and $b = 2.053$ based on their dataset. This relation gives about a 10 percent probability for a M_W 5 earthquake to rupture the surface and about a 90 percent probability for a M_W 7.25 earthquake (*Figure 7*).

Distribution of Principal Faulting Surface Displacement

The distribution of surface displacement along a fault rupture is modeled in the PFDHA following Petersen et al., (2011). They analyzed a worldwide dataset of net displacement from earthquakes producing strike-slip surface rupture. The dataset consists of displacement data from strike-slip earthquakes in California, USA (7 earthquakes), Turkey (6), Japan (3), Alaska, USA (1), Guatemala (1), Iran (1), Philippines (1), and China (1). These earthquakes occurred in active tectonic zones. The earthquakes range in M_W from 6.4 to 7.9, with most earthquakes having M_W greater than 7. This dataset is the best available for characterizing displacements from strike-slip earthquakes.

While the earthquakes in the Petersen et al., (2011) database have strike-slip mechanisms, the observed surface displacements sometimes include a normal component of slip. For the regression analyses, Petersen et al., (2011) use net surface displacement. For most data points in the Petersen et al., (2011) database, observed surface displacement was strongly strike-slip; but for about 10 percent of the observations oblique displacement was measured. For some observations the normal component of displacement exceeded the strike-slip component.

While the strike-slip component of displacement is generally dominant in the Krško vicinity (Bavec, 2010a), detailed information on the ratio of strike-slip to normal displacement for surface rupture in is unavailable. However, given the general strike-slip faulting environment in the Krško vicinity, with oblique movement expected on some secondary structures, and the inclusion of oblique-slip data in the Petersen et al., (2011) database that was used to develop displacement regression relations for strike-slip faulting, it is reasonable to apply the Petersen et al., (2011) relations in the Krško PFDHA.

Note that the M_{\max} values assessed for faults modeled in the PFDHA are largely less than M_w 6.4 (**Table 6**), the lower bound of the Petersen et al., (2011) dataset. Thus, for many of the earthquakes modeled in the PFDHA, the Petersen et al., (2011) relationships are applied below the magnitude range in which they are constrained by the worldwide observations. This potential limitation is mitigated, however, because smaller earthquakes are less likely to produce surface displacement (**Figure 7**). Also, there is no suggestion in the regression residuals from Petersen et al., (2011) that the fit of the data to the regression curve degrades at lower magnitudes.

The Petersen et al., (2011) regression relations are chosen for the PFDHA because most of the faults near the Krško East and West Sites are characterized as strike-slip faults. Two of the local faults (Artiče and Gorica) are thought to be predominantly reverse faults. Nevertheless, the results from Petersen et al., (2011) are used for those faults also as fault displacement relationships for reverse faulting have not been developed. Uncertainty in the applicability of the Petersen et al., (2011) relations to these two faults is unlikely to have an impact on the computed hazard because these faults are not dominant contributors to the fault displacement hazard at the two Sites.

Surface fault displacement data from the Krško area or the Slovenia region are not available to test the Petersen et al., (2011) relationships for local applicability. The Petersen et al., (2011) relationships are used based on their development using available surface rupture data from tectonic regimes around the world in which strike-slip faulting is predominant, similar to the Krško area.

To characterize the distribution of principal faulting surface displacement Petersen et al., (2011) used two approaches. In one approach, they developed least-squares best-fit regression relations relating the natural logarithm of displacement to magnitude and distance in a multivariate analysis. In the second approach, they also analyzed the displacement data normalized by average displacement as a function of distance. In this model magnitude is not directly considered, but is implicitly included through the average displacement, which is calculated from M_w using Wells and Coppersmith, (1994). They considered three models to represent the principal fault displacements in the multivariate analysis: bilinear, quadratic, and elliptical. For the normalized displacement approach, they used a power law model. Their regression equations are summarized in **Table 8**.

Petersen et al., (2011) found that the three models from the multivariate analysis resulted in similar aleatory uncertainties and did not find a basis to prefer one over the others. Thus, in the PFDHA all three models are used with weights of 0.34, 0.33, and 0.33, respectively.

Petersen et al., (2011) did prefer the results of the multivariate analysis over the normalized analysis. In the PFDHA, results of both approaches are used, but the results of the multivariate model are given a weight of 0.6 versus a weight of 0.4 for the results of the normalized approach. For the normalized approach, aleatory uncertainty related to the calculation of average displacement from M_W using Wells and Coppersmith (1994) is added to the aleatory uncertainty from the Petersen et al., (2011) regression results.

Distribution of Distributed Faulting Surface Displacement

In addition to the regressions of displacement amplitude for principal faulting, Petersen et al., (2011) also provide regression results for distributed (off-fault) rupture. To analyze the distributed faulting data, they used a power law relation. Results of the multivariate and normalized approaches are summarized in **Table 8**. Both approaches are used in the PFDHA. Following Petersen et al., (2011), the results of the multivariate analysis are given a weight of 0.6; the results of the normalized analysis are used with weight 0.4.

Probability of Distributed Surface Displacement

Petersen et al., (2011) also used their data set to examine the probability that distributed faulting will occur in a given area as a function of distance from the principal fault. These results are modeled using a power law formulation and consider cells ranging from 25 by 25 m to 200 by 200 m. Their regression results are summarized in **Table 8** and are used in the PFDHA. Petersen et al., (2011) note that at distances within a few hundred meters of the principal fault the power law does not extrapolate well. Therefore, they provide an alternative interpolation method for use near the principal fault. These results are used in the PFDHA.

Uncertainty in Distance

There is often a difference between the mapped location of a fault and the location of surface rupture during an earthquake. This difference can result from an aleatory component of fault rupture. Especially in a complex fault zone, the strand of the fault that ruptures during any specific earthquake has a random aspect. Additionally, there is uncertainty in the location of a mapped fault based on the quality of the mapping and the ability of the fault to be discerned using available geologic and geophysical data. For example, the fault may be concealed by recent sedimentary deposits. These aspects of fault complexity and mapping accuracy are addressed in the PFDHA methodology developed by Petersen et al., (2011). Fault location uncertainty is represented by the standard deviation of the normal probability distribution for

distance. They include fault location uncertainty according to four mapping accuracy categories: accurate, approximate, concealed, and inferred, in order of increasing uncertainty. In addition, for the concealed and inferred categories, the fault is classified as either simple or complex.

Because the faults in the vicinity of the East and West Sites for the proposed Krško 2 NPP have little or no surface expression and are based primarily on geophysical data, in the PFDHA the most uncertain category is assumed (inferred and complex). This may introduce some element of conservatism, but given the available data it is deemed to be appropriate. The two-sided distribution is used and has a value of 116.35 m.

Site Area Footprint

Fault displacement hazard is a function of the area of the footprint (cell size) for which hazard is being assessed. As expected, the larger the footprint being evaluated, the larger the area available to be affected by surface displacement and, thus, the higher the hazard. Petersen et al., (2011) gives the probability of off-fault rupture for cell sizes of 25×25 square meters (m²), 50×50 m², 100×100 m², 150×150 m², and 200×200 m². In this analysis, fault displacement hazard is determined for a 200×200 m² cell size centered at the assumed site of the nuclear island for the East (45.9361N, 15.52253 E) and West (45.94037 N, 15.50745 E) Krško Sites (*Figure 8*). While a 100×100 m² cell would cover the footprint of the potential nuclear island, the larger cell size is used for conservatism.

Minimum Magnitude of Integration

The minimum magnitude for fault displacement hazard integration is taken as M_W 5.0 for most faults. The relation of Wells and Coppersmith (1993) between M_W and probability of surface fault displacement indicates that earthquakes less than M_W 5.0 have only a 10 percent likelihood of rupturing the surface. In addition, predicted surface displacements for earthquakes of M_W less than 5.0, conditional on surface displacement occurring, are small and do not contribute significantly to displacement of engineering significance. For faults with a M_{max} of 5.0 or less the minimum magnitude of integration is taken as M_{max} minus 0.5 magnitude units. Implicit in this choice is the assumption that the regression relations of Petersen et al., (2011) and Wells and Coppersmith (1993) can be extrapolated to magnitudes lower than those of the earthquakes providing the fault displacement data on which they are based.

Consideration of Probabilistic Seismic Hazard Analyses (PSHA)

The most recent PSHA for the Krško site was carried out in 2003-2004 based on an assessment of the seismotectonic model for the area (Swan et al., 2004). Alternative models were developed and formed the basis for characterization of seismic sources, including uncertainty.

Since development of that seismic source model, additional investigations were carried out and some are ongoing. The most recent seismotectonic model for the Krško vicinity is documented in Bavec (2010a). An updated seismic source model based on Bavec (2010a) is described in Bavec (2010b). This updated seismic source model consists primarily of alternative areal source zone configurations. One alternative, however, includes some fault sources. Within 10 km of the Krško site, the fault sources consist of the Hrastnik Fault, the Lokavec Fault, the Orlica Fault, and the Artiče Fault.

The fault source model for the PFDHA is consistent with these faults because they are based on the same seismotectonic model. In the PFDHA, the Hrastnik and Lokavec faults are treated as a single feature. Additional faults included in the PSHA are more distant from the Krško site and thus are not expected to contribute to fault displacement hazard. The PFDHA source model includes faults that are not explicitly included in the PSHA source model. Because displacement hazard is sensitive to nearby faults, and because the displacement hazard is very low at the site, small, nearby faults are included in the PFDHA to determine their hazard contribution. While these sources contribute to the displacement hazard, for ground motion hazard they are encompassed by the areal source zone that hosts the site and are not treated explicitly. The PFDHA and PSHA models are consistent, but because they deal with different earthquake hazards (surface fault displacement and vibratory ground motion, respectively), they are not identical.

3.3 FAULT DISPLACEMENT HAZARD

Probabilistic fault displacement hazard is calculated following the approach of Petersen et al., (2011) (*Section 3.1*) as implemented in the RIZZO computer code RIZZO-HAZARD (Version 1.1) and using the inputs described in *Section 3.2*. The implementation of the Petersen et al., (2011) approach in RIZZO-HAZARD is verified and validated (RIZZO, 2011a; 2011b) in accordance with RIZZO procedure QP-7, Control of Design and Analysis Software.

As displacement probabilities in the Petersen et al., (2011) formulation are a function of the location of the surface rupture (L on **Figure 4**), the locations of the inferred surface traces provide the spatial description of faults in the analysis. The inferred three-dimensional orientation of ruptures is used in assessing M_{\max} , but does not enter into the hazard calculation. The rate of future earthquakes as a function of magnitude is based on the assessed slip rates using the slip-rate constrained recurrence formulation of Youngs and Coppersmith (1985). The distribution of ruptures along the fault is taken to be uniform. Integration is carried out from a minimum magnitude of either 5 (M_W) or the lower bound of the M_{\max} distribution minus 0.5 magnitude units, whichever is smaller. Annual frequencies of exceedance are calculated for a range of displacement values from 0.001 m to 4 m.

Following the Petersen et al., (2011) approach, displacement hazard from triggered earthquakes is not included. Triggered displacement occurs when an earthquake on one fault causes an earthquake to occur on another nearby fault. However, while not included explicitly, to the extent that triggered displacement has occurred on faults in the Krško area in the past, the contribution of such events to the cumulative displacement on the faults is included in the estimates of slip rate.

Mean annual frequencies of net fault displacement exceedance for the East and West Krško Sites are very low (**Table 9, Figure 9**). Surface fault displacement of 0.001 m (1 millimeter [mm]) has a mean annual probability of exceedance of about 10^{-6} or less. Hazard for the East and West Sites is about the same for displacements of 0.001 m. As the displacement level increases, the mean annual frequency of exceedance for the West Site drops at a faster rate than for the East Site, resulting in hazard for the East Site exceeding that for the West Site by about a factor of 4 for a displacement level of 0.100 m (10 cm). For displacements greater than about 0.050 m (5 cm), mean annual frequencies of exceedance are lower than about 10^{-8} .

These low values reflect the fact that the faults included in the model generally do not intersect the Site area (except for the speculative long version of the Stara Vas Fault), have assessed values of M_{\max} that are not associated with large on- or off-fault surface displacements, have low slip rates, and are characterized in many cases by uncertainty regarding whether they are active. There is no basis to partition net displacement exceedance into vertical and horizontal components, so only the net displacement exceedance is reported.

Total hazard at each site is dominated by off-fault (secondary) displacement contributions for small displacement levels (< 0.010 m or 1 cm). As displacement level increases, for the East Site on-fault displacement becomes more important and starts to dominate at about 0.050 m (5 cm) (**Figure 10**). For the West Site, off-fault displacement contributions dominate for all

displacement levels (*Figure 11*). This result is expected because the modeled faults lie closer to the hazard calculation cell for the East Site (*Figure 8*), although the probability of activity and weight for each fault length alternative also influence the hazard.

Evaluation of the contributions to on-fault displacement hazard from the various fault displacement models developed by Petersen et al., (2011) shows that the alternative models give similar results (*Figure 12*). The hazard contributions generally reflect the weights given to the multivariate (0.6) versus normalized (0.4) approaches. As the displacement level of interest increases, the relative contribution to hazard increases slightly for the displacement regression relations based on the normalized approach. For off-fault hazard, the multivariate model dominates (*Figure 13*).

Hazard at the East and West Sites reflects relative contributions from different faults in the model. As discussed above, for the East Site off-fault displacement dominates for displacement levels less than about 0.020 m (2 cm) (*Figure 10*). For this component of the hazard, no single fault dominates. Important contributors to off-fault hazard are the Orlica South, the postulated Gorica, the Libna, and the Artiče faults (*Figure 14*). While none of these faults dominates the hazard individually, their combined off-fault contribution exceeds on-fault hazard by an order of magnitude. For displacement levels greater than about 0.020 m, the on-fault component of hazard starts to dominate (*Figure 10*), with the postulated Stara Vas B Fault being the primary contributor even though this longer interpretation is assessed a weight of only 0.1 (*Figure 14*). At these larger displacement levels, hazard contributions from the A and B versions of the Libna Fault are each about an order of magnitude less.

For the West Site, where off-fault displacement dominates the hazard (*Figure 10*), the most important contributions are from the Orlica South, the postulated Gorica, and the Long and Extended-West interpretations of the Artiče fault (*Figure 14*). The relative contributions from the different sources do not vary substantially as a function of displacement level.

While fault displacement hazard is analyzed in this study for the East and West Sites, because the existing Krško 1 NPP site is located between the East and West Sites, the general results from this study also apply at the Krško 1 NPP site. Fault displacement hazard at the existing NPP is of the same order as obtained for the studied Sites.

4.0 SUMMARY AND CONCLUSION

A probabilistic fault displacement analysis for the East and West Sites being considered for the Krško 2 NPP indicates that the probability of exceeding surface displacement of engineering significance is very low. For a surface offset of 0.001 m (equivalently 0.1 cm or 1 mm), the mean annual probability of exceedance is about 10^{-6} for both Sites. For surface displacements of engineering significance (i.e., on the order of 5 centimeters [cm]) the mean annual probabilities of exceedance are less than about 10^{-7} with the hazard at the East Site being slightly greater than at the West Site. Because the existing Krško 1 NPP is located between the East and West Sites considered in this evaluation, the results are also applicable to that site.

Analysis of the fault displacement hazard for the Krško 2 Sites is subject to uncertainties. Through the probabilistic approach, these uncertainties have been explicitly incorporated. For example, uncertainties in the lengths of faults, their slip rates and maximum magnitudes, and the models used to predict on-fault and off-fault displacement were assessed and included through the use of weighted alternatives.

Because surface faulting earthquakes in the Krško area have not occurred recently or historically, the characteristics of such potential events are unknown. Thus, models of on-fault and off-fault displacement developed from available data collected elsewhere are adopted. Because the models are based on strike-slip earthquakes– the style of faulting that dominates the Krško Basin, they should be representative of displacements that might occur at the Krško 2 Sites if capable faults are at or near the site. However, these models cannot be tested with site-specific data.

In the analysis, some conservative assumptions are included. Specifically:

- It is assumed that there is no uncertainty that the Libna Fault is active.
- While there is no conclusive evidence that the postulated Stara Vas Fault extends near the East or West Site, a low-weighted alternative configuration for that source brings it within the Sites and very close to the hazard calculation cell for the East Site.
- The slip rate distribution assessed for the Libna fault is also used for the Stara Vas source, even though the Stara Vas source is a much less well-defined feature.
- The cell size for which the displacement hazard is calculated ($200 \times 200 \text{ m}^2$) is larger than the nuclear island footprint (typically on the order of $100 \times 100 \text{ m}^2$).

For the East Site, hazard contribution from the postulated Stara Vas Fault is important for displacement levels greater than about 0.050 m. For these displacement levels, the on-fault contribution from the long version of the Stara Vas Fault dominates. At smaller displacement levels, off-fault contributions from the Orlica South, the postulated Gorica, the Libna, and the Artiče faults combine to yield the total hazard.

For the West Site, hazard is dominated by off-fault contributions; on-fault hazard is negligible. Off-fault contributions from the Orlica South and postulated Gorica Faults, and from interpretations of the Artiče Fault that bring it closer to the Sites, are important.

The stiffness of the material underlying a site can have an impact on the propagation of fault rupture displacement to the surface. Softer materials can absorb some of the displacement as it propagates upward. Moss et al., (2013), however, demonstrate that the dependence of surface displacement on material stiffness varies with fault rupture mechanism. While for reverse faulting they find displacement is generally lower for a given magnitude earthquake that ruptures softer material, the effect is not observed for strike-slip faults. Because the Krško site lies in a primarily strike-slip tectonic environment, the stiffness of the material at the site is not likely to have a strong influence on the level of displacement hazard. The reported results should not be reduced for this potential effect.

The PFDHA indicates that surface fault displacement of engineering significance is highly unlikely at the Krško Sites. This is because the likelihood that active faults pass through the Sites is low and off-fault displacement from faults outside the Sites diminishes quickly with distance. Also, rates of activity are assessed to be low.

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TABLES

TABLE 1
FAULTS CONSIDERED IN THE PROBABILISTIC FAULT DISPLACEMENT
HAZARD ANALYSIS FOR THE KRŠKO EAST AND WEST SITES

FAULT NAME
Orlica
Artiče
Gorica
Stara Vas
Libna
Močnik 1
Močnik 2
Sromljica
Gabrnica
Hrastnik
Letuš

Source: RIZZO, (2013a)

TABLE 2
FAULT PROBABILITIES OF ACTIVITY

FAULT	PROBABILITY OF ACTIVITY
Orlica	1.0
Artiče	1.0
Gorica	0.9
Stara Vas	0.3
Libna	1.0
Močnik 1	0.5
Močnik 2	0.5
Sromljica	0.5
Gabrnica	0.5
Hrastnik	1.0
Letuš	0.0

Source: RIZZO, (2013a)

TABLE 3
LOGIC TREE FOR FAULT LENGTH

FAULT	LENGTH (km)	WEIGHT
Orlica North	25	1.0
Orlica South	15	1.0
Artiče Short	11.6	0.5
Artiče Long	16.4	0.1
Artiče Extended-East	19.7	0.3
Artiče Extended-West	24.5	0.1
Gorica A	9.3	0.6
Gorica B	12.1	0.4
Stara Vas A	1.0	0.9
Stara Vas B	2.5	0.1
Libna A	4.6	0.5
Libna B	5.9	0.4
Libna C	10.5	0.1
Močnik 1	4.8	1.0
Močnik 2A	6.6	0.6
Močnik 2B	7.3	0.4
Sromljica A	5.5	0.6
Sromljica B	6.3	0.4
Gabrnica A	4.4	0.6
Gabrnica B	5.8	0.4
Hrastnik	51	1.0

Note:

For the Orlica North and Hrastnik Faults, uncertainty in fault length was assessed, but is not included in the fault model used in the PFDHA. Uncertainty in the length of the Orlica North Fault is assessed as 15 km and 25 km with weights of 0.8 and 0.2, respectively. Uncertainty in the length of the Hrastnik Fault is assessed as 44 km and 51 km with weights of 0.8 and 0.2, respectively.

Source: RIZZO, (2013a), RIZZO, (2013b)

**TABLE 4
LOGIC TREE FOR FAULT SLIP RATE**

FAULT	SLIP RATE (mm/yr)	WEIGHT
Orlica North	0.100	0.5
	0.050	0.5
Orlica South	0.100	0.5
	0.050	0.5
Artiče Short, Artiče Long, Artiče Extended-East, and Artiče Extended-West	0.12	0.5
	0.06	0.5
Gorica A and Gorica B	0.06	0.5
	0.03	0.5
Stara Vas A and Stara Vas B	0.143	0.1
	0.020	0.4
	0.010	0.4
	0.004	0.1
Libna A, Libna B, and Libna C	0.143	0.1
	0.020	0.4
	0.010	0.4
	0.004	0.1
Močnik 1	0.143	0.1
	0.020	0.4
	0.010	0.4
	0.004	0.1
Močnik 2A and Močnik 2B	0.143	0.1
	0.020	0.4
	0.010	0.4
	0.004	0.1
Sromljica A and Sromljica B	0.143	0.1
	0.020	0.4
	0.010	0.4
	0.004	0.1
Gabrnica A and Gabrnica B	0.143	0.1
	0.020	0.4
	0.010	0.4
	0.004	0.1
Hrastnik	0.100	0.5
	0.043	0.5

Source: RIZZO, (2013a)

TABLE 5
SUMMARY OF FAULT DEPTH AND DIP ASSESSMENT

FAULT	SEISMOGENIC DEPTH (km)	WEIGHT	DIP (DEG)	WEIGHT
Orlica North	5	0.5	90	0.75
	10	0.5	60	0.25
Orlica South	5	0.5	90	0.75
	10	0.5	60	0.25
Artiče Short, Artiče Long, Artiče Extended-East, and Artiče Extended-West	5	0.6	60	0.6
	10	0.4	30	0.4
Gorica A and Gorica B	5	0.6	60	0.6
	10	0.4	30	0.4
Stara Vas A and Stara Vas B	3	0.4	80-90 to 2 km 60 to seismogenic depth	1.0
	5	0.4		
	7	0.2		
Libna A, Libna B, and Libna C	3	0.4	80-90 to 2 km 60 to seismogenic depth	1.0
	5	0.4		
	7	0.2		
Močnik 1	3	0.4	80-90 to 2 km 60 to seismogenic depth	1.0
	5	0.4		
	7	0.2		
Močnik 2A and Močnik 2B	3	0.4	80-90 to 2 km 60 to seismogenic depth	1.0
	5	0.4		
	7	0.2		
Sromljica A and Sromljica B	3	0.4	80-90 to 2 km 60 to seismogenic depth	1.0
	5	0.4		
	7	0.2		
Gabrnica A and Gabrnica B	3	0.4	80-90 to 2 km 60 to seismogenic depth	1.0
	5	0.4		
	7	0.2		
Hrastnik	5	0.7	90	0.5
	10	0.3	60	0.5

Source: RIZZO, (2013a)

**TABLE 6
LOGIC TREE FOR FAULT MAXIMUM MAGNITUDE**

FAULT	STYLE OF FAULTING	M_w FROM RUPTURE LENGTH	WEIGHT	M_w FROM RUPTURE AREA	WEIGHT	MAXIMUM MAGNITUDE (M_w)	WEIGHT
Orlica North	Strike-slip	6.7	0.600	6.1	0.375	6.1	0.25
		6.4	0.200	6.2	0.125	6.4	0.35
		7.0	0.200	6.4	0.375	6.7	0.30
				6.5	0.125	7.0	0.10
Orlica South	Strike-slip	6.5	0.600	5.9	0.375	5.9	0.25
		6.2	0.200	6.0	0.125	6.2	0.35
		6.8	0.200	6.2	0.375	6.5	0.30
				6.3	0.125	6.8	0.10
Artiče Short	Reverse	6.3	0.600	6.0	0.360	6.0	0.28
		6.0	0.200	6.2	0.240	6.2	0.24
		6.5	0.200	6.2	0.240	6.3	0.30
				6.5	0.160	6.5	0.18
Artiče Long		6.7	0.600	6.3	0.360	6.3	0.28
		6.4	0.200	6.5	0.240	6.5	0.24
		6.9	0.200	6.5	0.240	6.7	0.30
				6.8	0.160	6.9	0.18
Artiče Extended-East		6.5	0.600	6.2	0.360	6.2	0.18
		6.2	0.200	6.4	0.240	6.4	0.22
		6.8	0.200	6.5	0.240	6.6	0.42
				6.7	0.160	6.8	0.18
Artiče Extended-West		6.5	0.600	6.1	0.360	6.1	0.18
		6.2	0.200	6.3	0.240	6.3	0.22
		6.7	0.200	6.4	0.240	6.5	0.42
				6.6	0.160	6.7	0.18

**TABLE 6
LOGIC TREE FOR FAULT MAXIMUM MAGNITUDE
(CONTINUED)**

FAULT	STYLE OF FAULTING	M_w FROM RUPTURE LENGTH	WEIGHT	M_w FROM RUPTURE AREA	WEIGHT	MAXIMUM MAGNITUDE (M_w)	WEIGHT
Gorica A	Reverse	6.2	0.600	5.9	0.360	5.9	0.28
		5.9	0.200	6.1	0.240	6.1	0.12
		6.4	0.200	6.2	0.240	6.2	0.42
		6.4	0.200	6.4	0.160	6.4	0.18
Gorica B		6.3	0.600	6.0	0.360	6.0	0.18
		6.1	0.200	6.2	0.240	6.2	0.22
		6.6	0.200	6.3	0.240	6.3	0.42
		6.6	0.200	6.5	0.160	6.6	0.18
Stara Vas A	Strike-slip	5.2	0.600	4.5	0.400	4.5	0.20
		4.9	0.200	4.7	0.400	4.7	0.20
		5.4	0.200	4.9	0.200	4.9	0.20
Stara Vas B		5.3	0.600	4.9	0.400	4.9	0.20
		5.3	0.200	5.1	0.400	5.1	0.20
		5.9	0.200	5.3	0.200	5.3	0.20
		5.9	0.200	5.3	0.200	5.7	0.40

**TABLE 6
LOGIC TREE FOR FAULT MAXIMUM MAGNITUDE
(CONTINUED)**

FAULT	STYLE OF FAULTING	M_w FROM RUPTURE LENGTH	WEIGHT	M_w FROM RUPTURE AREA	WEIGHT	MAXIMUM MAGNITUDE (M_w)	WEIGHT
Libna A	Strike-slip	5.9	0.600	5.2	0.400	5.2	0.20
		5.6	0.200	5.4	0.400	5.4	0.20
		6.2	0.200	5.6	0.200	5.6	0.20
						6.0	0.40
Libna B		6.0	0.600	5.3	0.400	5.3	0.20
		5.7	0.200	5.5	0.400	5.5	0.20
		6.3	0.200	5.7	0.200	5.7	0.20
						6.1	0.40
Libna C		6.3	0.600	5.5	0.400	5.5	0.20
		6.0	0.200	5.8	0.400	5.9	0.40
		6.6	0.200	5.9	0.200	6.3	0.30
						6.6	0.10
Močnik 1	5.9	0.600	5.2	0.400	5.2	0.20	
	5.6	0.200	5.4	0.400	5.4	0.20	
	6.2	0.200	5.6	0.200	5.6	0.20	
				6.0	0.40		
Močnik 2A and Močnik 2B	6.1	0.600	5.4	0.400	5.4	0.20	
	5.8	0.200	5.6	0.400	5.6	0.20	
	6.4	0.200	5.8	0.200	5.8	0.20	
				6.2	0.40		
Sromljica A and Sromljica B	6.1	0.600	5.3	0.400	5.4	0.20	
	5.8	0.200	5.5	0.400	5.6	0.20	
	6.3	0.200	5.7	0.200	5.8	0.20	
				6.2	0.40		

TABLE 6
LOGIC TREE FOR FAULT MAXIMUM MAGNITUDE
(CONTINUED)

FAULT	STYLE OF FAULTING	M_w FROM RUPTURE LENGTH	WEIGHT	M_w FROM RUPTURE AREA	WEIGHT	MAXIMUM MAGNITUDE (M_w)	WEIGHT
Gabrnica A and Gabrnica B	Strike-slip	6.0	0.600	5.3	0.400	5.3	0.20
		5.7	0.200	5.5	0.400	5.5	0.20
		6.3	0.200	5.7	0.200	5.7	0.20
						6.1	0.40
Hrastnik	Strike-slip	7.1	0.600	6.4	0.35	6.4	0.35
		6.8	0.200	6.5	0.35	6.7	0.25
		7.4	0.200	6.7	0.15	7.1	0.30
				6.8	0.15	7.4	0.10

Source: RIZZO, (2013a)

**TABLE 7
LOGIC TREE FOR B-VALUE**

FAULT	B-VALUE	WEIGHT
Orlica North Orlica South Artiče Short, Artiče Long, Artiče Extended-East, and Artiče Extended-West Gorica A and Gorica B Stara Vas A and Stara Vas B Libna A, Libna B, and Libna C Močnik 1 Močnik 2A and Močnik 2B Sromljica A and Sromljica B Gabrnica A and Gabrnica B Hrastnik	0.97 1.49	0.5 0.5

Source: RIZZO, (2013a)

**TABLE 8
LOGIC TREE FOR DISPLACEMENT MODELS**

SURFACE DISPLACEMENT TYPE	ANALYSIS TYPE	WEIGHT	MODEL	WEIGHT
Principal Fault Displacement	Multivariate	0.6	Bilinear: $\ln(D) = 1.7969M_W + 8.5206 \left(\frac{l}{L}\right) - 10.2855 \quad \sigma_{ln} = 1.2906 \quad \frac{l}{L} < 0.3$ $\ln(D) = 1.7658M_W - 7.8962 \quad \sigma_{ln} = 0.9624 \quad \frac{l}{L} \geq 0.3$	0.34
			Quadratic: $\ln(D) = 1.7895M_W + 14.4696 \left(\frac{l}{L}\right) - 20.1723 \left(\frac{l}{L}\right)^2 - 10.54512 \quad \sigma_{ln} = 1.1346$	0.33
			Elliptical: $\ln(D) = 3.3041 \sqrt{1 - \frac{1}{0.5^2} \left[\left(\frac{l}{L}\right) - 0.5\right]^2} + 1.7927M_W - 11.2192 \quad \sigma_{ln} = 1.1348$	0.33
	Normalized	0.4	Bilinear: $\ln(D/D_{avg}) = 8.2525 \left(\frac{l}{L}\right) - 2.3010 \quad \sigma_{ln} = 1.2962 \quad \frac{l}{L} < 0.3008$ $\ln(D/D_{avg}) = 0.1816 \quad \sigma_{ln} = 1.0013 \quad \frac{l}{L} \geq 0.3008$	0.34
			Quadratic: $\ln(D/D_{avg}) = 14.2824 \left(\frac{l}{L}\right) - 19.8833 \left(\frac{l}{L}\right)^2 - 2.6279 \quad \sigma_{ln} = 1.1419$	0.33
			Elliptical: $\ln(D/D_{avg}) = 3.2699 \sqrt{1 - \frac{1}{0.5^2} \left[\left(\frac{l}{L}\right) - 0.5\right]^2} - 3.2749 \quad \sigma_{ln} = 1.1419$	0.33

TABLE 8
LOGIC TREE FOR DISPLACEMENT MODELS
(CONTINUED)

SURFACE DISPLACEMENT TYPE	ANALYSIS TYPE	WEIGHT	MODEL	WEIGHT
Distributed Fault Displacement	Multivariate	0.6	Power Law: $\ln(d) = 1.4016M_W - 0.1671 \ln(r) - 6.7991 \quad \sigma_{ln} = 1.1193$	1.0
	Normalized	0.4	Power Law: $\ln(d/D_{avg}) = -0.1826 \ln(r) - 1.5471 \quad \sigma_{ln} = 1.1388$	1.0
Probability of Ground Rupture for Distributed Faulting	NA	NA	Power Law: $\ln(P) = -1.1470 \ln(r) + 2.1046 \quad \sigma_{ln} = 1.2508 \quad 25 \times 25$ $\ln(P) = -0.9000 \ln(r) + 0.9866 \quad \sigma_{ln} = 1.1470 \quad 50 \times 50$ $\ln(P) = -1.0114 \ln(r) + 2.5572 \quad \sigma_{ln} = 1.0917 \quad 100 \times 100$ $\ln(P) = -1.0934 \ln(r) + 3.5526 \quad \sigma_{ln} = 1.0188 \quad 150 \times 150$ $\ln(P) = -1.1538 \ln(r) + 4.2342 \quad \sigma_{ln} = 1.0177 \quad 200 \times 200$	1.0

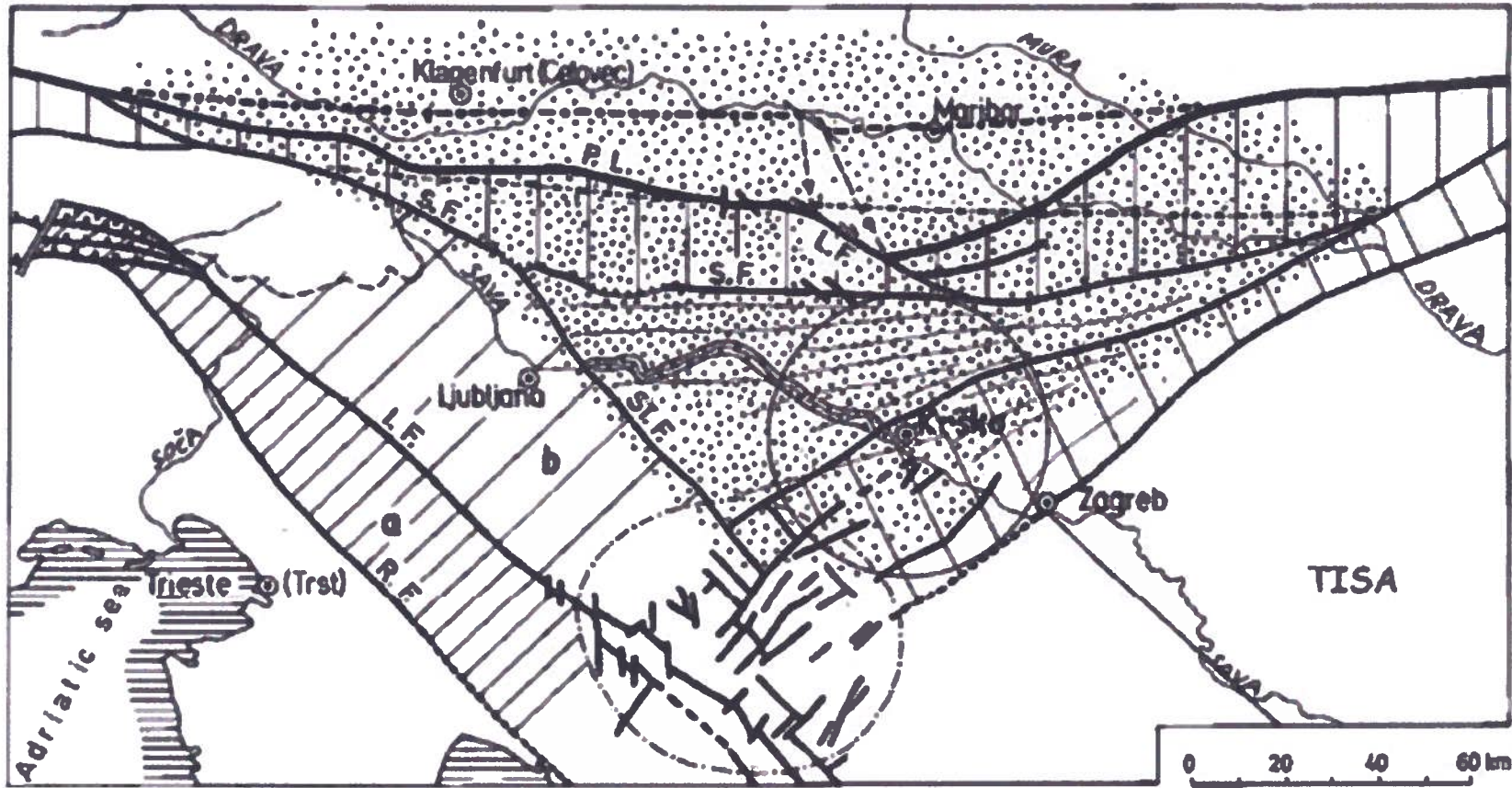
Source: RIZZO, (2013b); Petersen et al., (2011)

TABLE 9
TOTAL SURFACE FAULT DISPLACEMENT HAZARD FOR THE EAST AND WEST SITES BEING CONSIDERED FOR THE KRŠKO 2 NPP

SURFACE DISPLACEMENT (m)	MEAN ANNUAL FREQUENCY OF EXCEEDANCE	
	EAST SITE	WEST SITE
0.001	1.52E-06	1.27E-06
0.002	5.51E-07	4.53E-07
0.004	4.11E-07	3.31E-07
0.006	2.84E-07	2.21E-07
0.009	1.78E-07	1.32E-07
0.014	1.04E-07	7.12E-08
0.021	5.60E-08	3.40E-08
0.033	2.80E-08	1.42E-08
0.051	1.33E-08	5.28E-09
0.079	6.03E-09	1.70E-09
0.122	2.60E-09	4.82E-10
0.188	1.06E-09	1.18E-10
0.292	3.99E-10	2.53E-11
0.451	1.39E-10	4.71E-12
0.698	4.41E-11	7.64E-13
1.080	1.27E-11	1.01E-13
1.670	3.30E-12	1.74E-15
2.590	7.84E-13	1.12E-16
4.000	1.69E-13	2.80E-17

Source: RIZZO, (2013b)

FIGURES



- | | | | |
|--|--|-------|--|
| | Periadriatic tectonic zone | | Primary position of the Periadriatic lineament |
| | Mid-Hungarian tectonic zone | | Primary position of the Sava fault |
| | Idrija tectonic zone, a- outer part, b- inner part | | Sava gorge |
| | Sava compressive wedge | | Primary position of the Labot (Lavant) fault |
| | Idrija-Mid-Hungarian transsection zone | | Generalized direction of the folds |
| | | P.L. | Periadriatic lineament |
| | | S.F. | Sava fault |
| | | ST.F. | Stična fault |
| | | I.F. | Idrija fault |
| | | R.F. | Raša fault |
| | | L.F. | Labot (Lavant) fault |

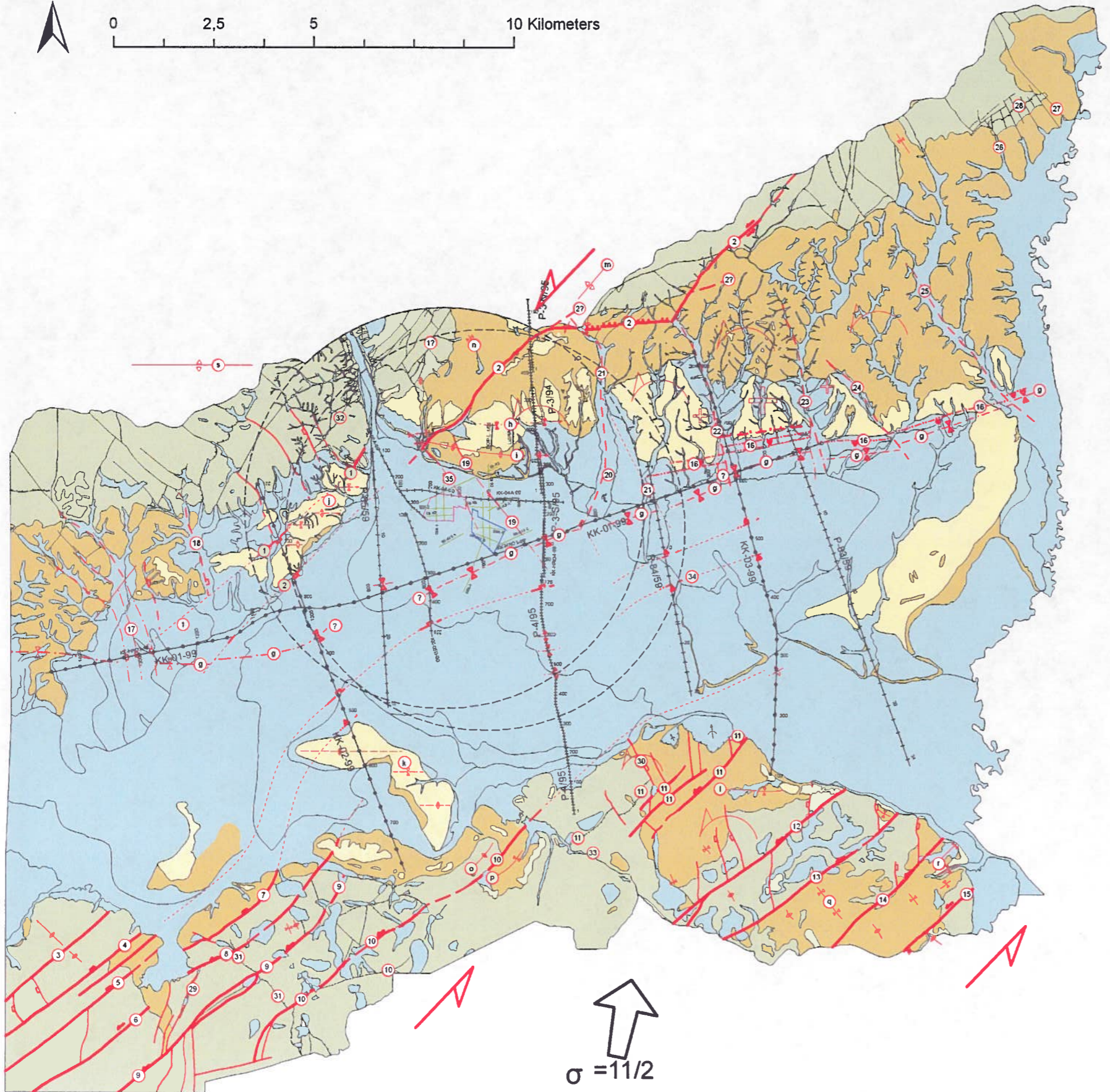
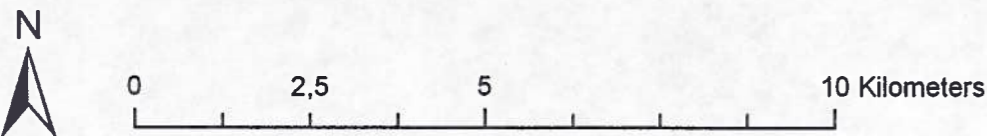
Figure 1

Regional Tectonic and Geologic Setting of the Krško 2 NPP Sites

PREPARED FOR
 GEN Energija
 Krško, Slovenia

Source: Updated Safety Analysis Report Rev. 14 (Figure 2.5-3) Nuclear Power Plant Krško.

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EXPLANATION

STRATIGRAPHIC UNITS

- Quaternary
- Pliocene
- Neogene
- Mesozoic and Paleozoic

STRUCTURAL FEATURES

- Geological boundaries in general
- Fault (by line thickness and colour): principal Neogene fault, secondary Neogene fault, other faults
- Fault (by line type): mapped, inferred on geological data, inferred on geophysical and geological data (covered by the Q deposits), suspected on geophysical data (covered by the Q deposits)
- Fault character: normal, reverse, strike-slip (subvertical)
- Flexure (triangle on the steeper side of inflexion line): based on field and borehole data, based on geophysical data
- Fold axis (mapped) - wavelength < 1 km: syncline, anticline
- Fold with plunging axis (mapped) - wavelength < 1 km: syncline, anticline
- Fold axis based on geophysical data - wavelength < 1 km: syncline, anticline
- Fold axis inferred on field (mapped) data - wavelength < 1 km: syncline, anticline
- Krško syncline axis: based on the seismic reflection and gravity data, based on the gravity data
- Landslide
- Alternative course of a structure
- Prevailing shear orientation
- Rotation of structures
- Recent uplift based on the morphometric analysis: significant, less significant (size of the sign not to scale)
- OTHER**
- Max. stress orientation based on the fault plane solutions in the Krško basin
- Proposed locations for the NPP
- Site vicinity area (5 km radius) of the NEK - 1 (W) and NEK - 1 (E) proposed locations
- Geophysical lines

FAULTS

- | | | |
|---------------------------------|---------------------------|----------------------------------|
| P1 Gric fault | 13 Koritno fault | 25 Dranjiča fault |
| 2 Orlica fault | 14 Ribnica fault | 26 Sušica fault |
| 3 Rakovnik - Dobe fault | 15 Jesenice fault | 27 Bukovje fault |
| 4 Maš Ban fault | 16 Artica fault / flexure | 28 Bizješko fault |
| 5 Kocarija fault | 17 Lokavec fault system | 29 Orehovec - Kostanjevica fault |
| 6 Podšim fault | 18 Senosa fault | 30 Majence fault |
| 7 Zabjaki fault | 19 Libna fault | 31 Ključ - Črna vas fault |
| 8 Studena fault | 20 Mocnik fault 1 | 32 Krško fault |
| 9 Ostrca fault | 21 Mocnik fault 2 | 33 Gornja Ptrosica - Izvir fault |
| 10 Postena vas fault | 22 Sromjica fault | 34 Brezice flexure |
| 11 Catež - Brvi structural zone | 23 Gabrnica fault | 35 Stara vas fault |
| 12 Gol Cimik ta | 24 Trsnjak fault | |

FOLDS

- | | |
|------------------------|--|
| Pg Krško syncline | p Postena vas syncline |
| h Črna mlaka syncline | q Koritno syncline |
| i Libna anticline | r Ribnica folded area |
| j Leskovec folded area | s Krško Hills anticline |
| k Mraševo folded area | t Folds observed in the P-3-4/95 seismic section |
| l Prilipe syncline | |
| m Orlica anticline | |
| n Anovec syncline | |
| o Bešinje anticline | |

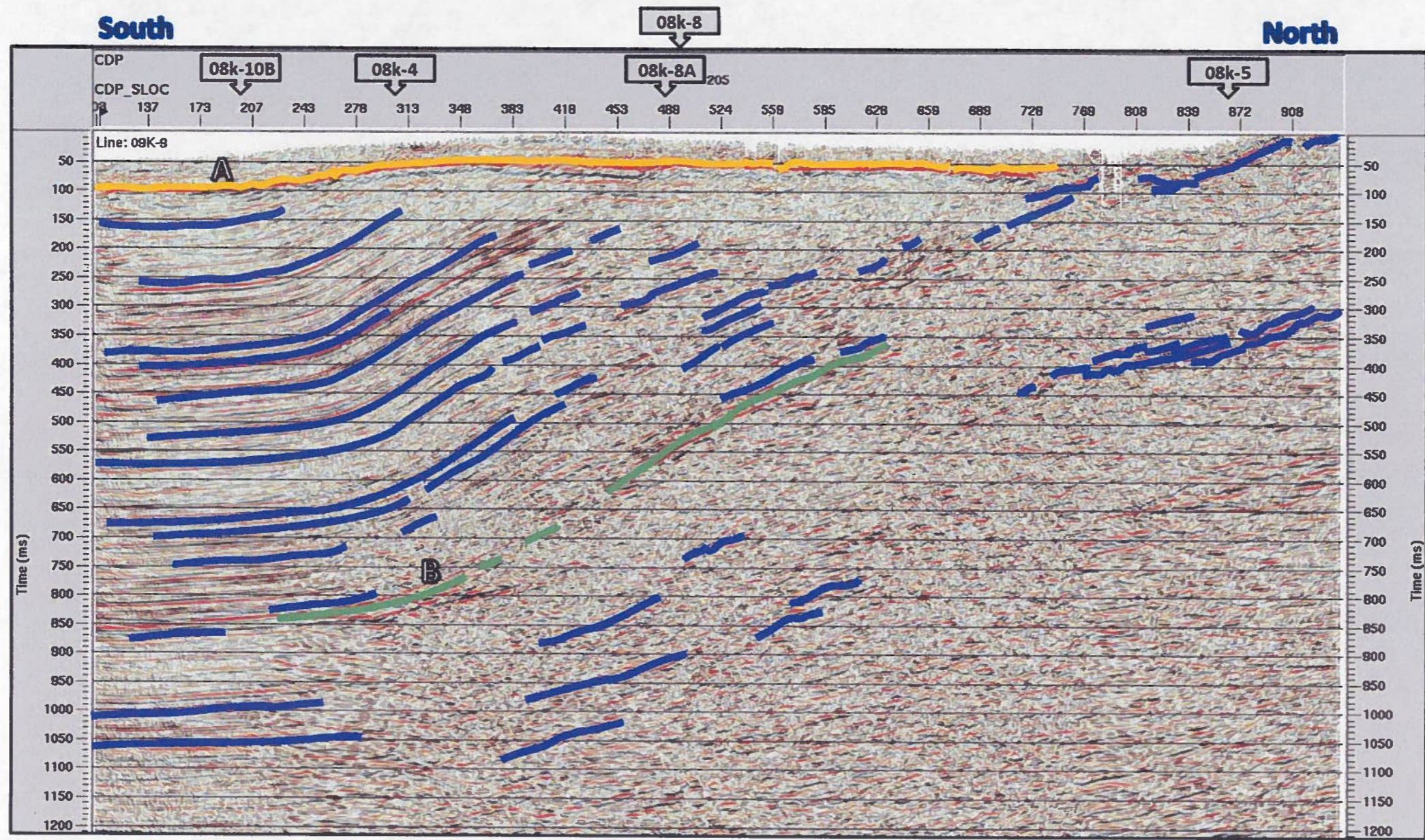
Figure 2

Structural Geologic Map of the Krško Basin and Surrounding Area

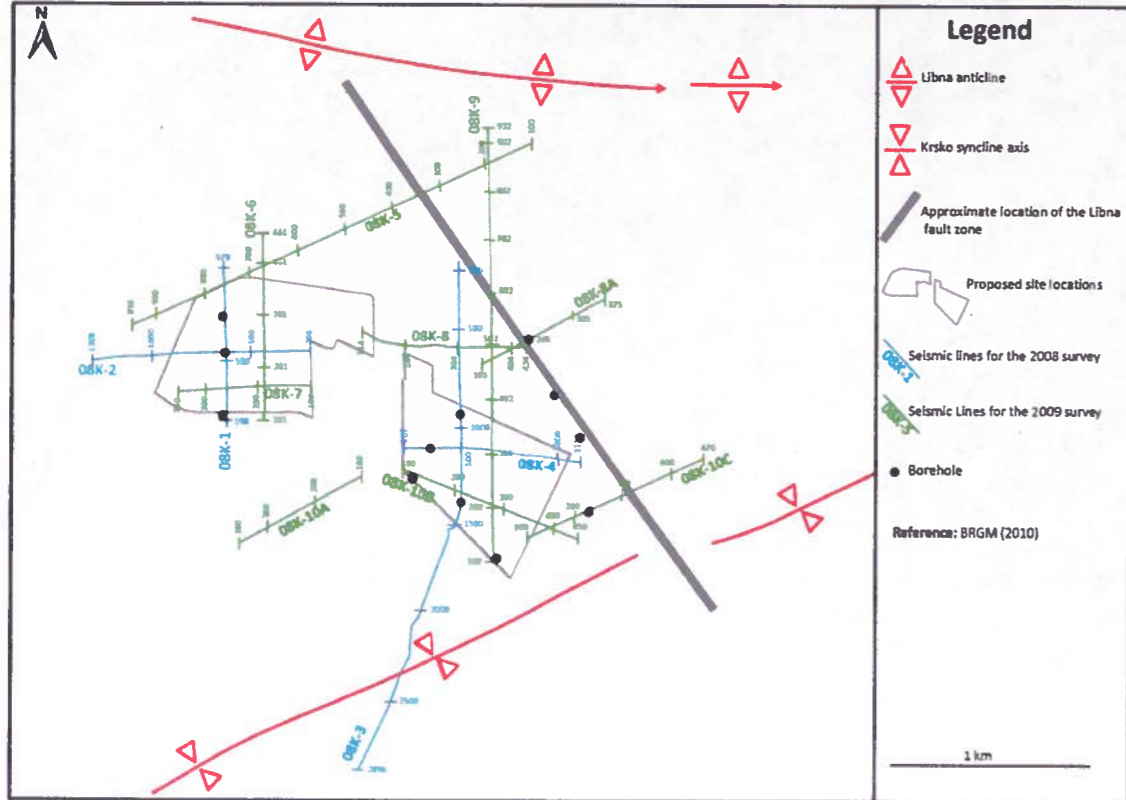
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Source: BRGM (2010), Figure 18.

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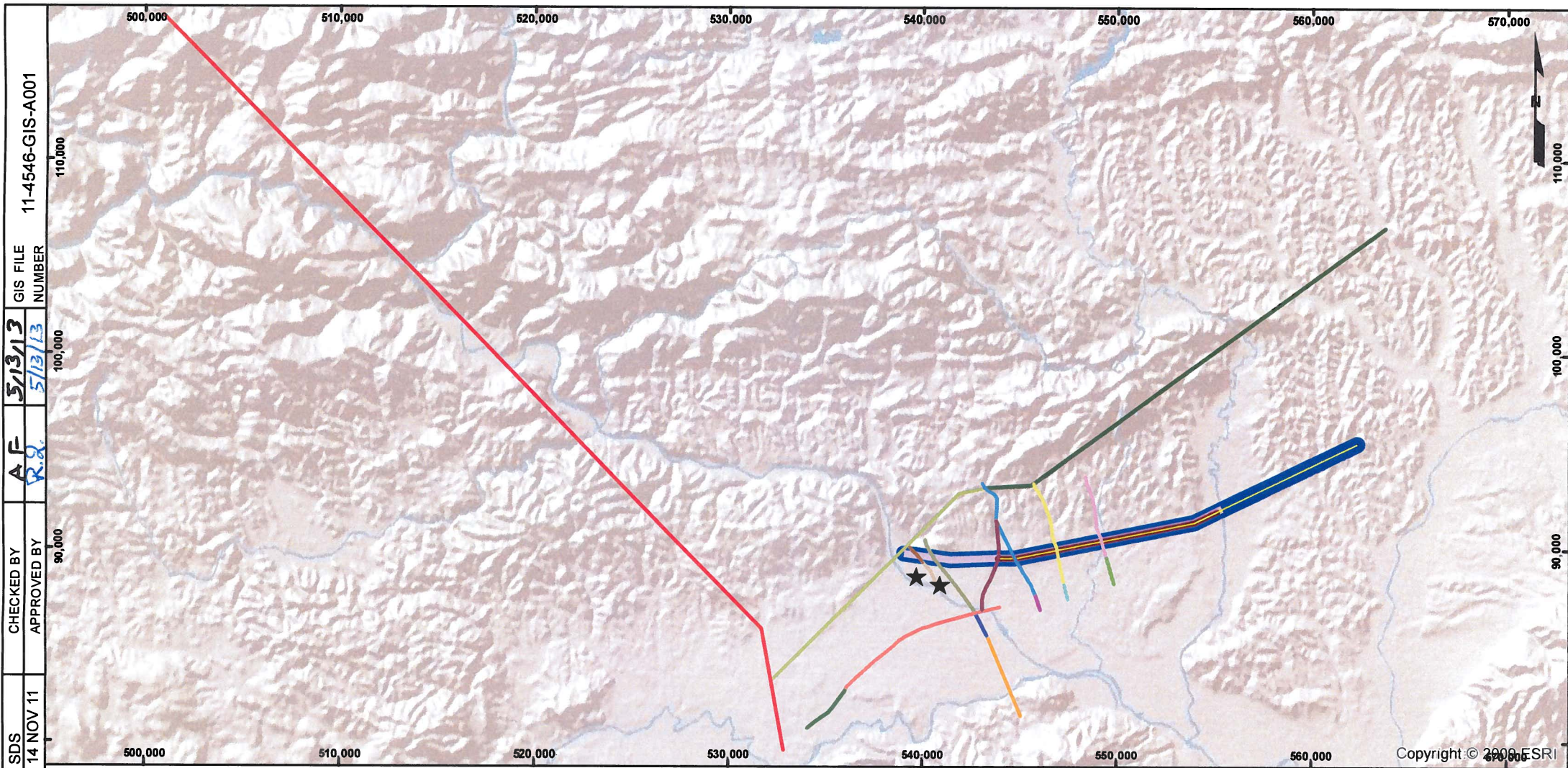


Index Map



Note: Interpreted seismic reflection profile for line 08K-9. The A reflector represents the base of Plio-Quaternary deposits. The B reflector is the top of Badenian limestone deposits.

Figure 3
 Stratigraphy of the Krško Basin
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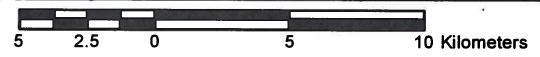


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LEGEND

- ★ Site
- Libna A
- Libna B
- Libna C
- Mocnik 1
- Mocnik 2A
- Mocnik 2B
- Sromljica A
- Sromljica B
- Gabrnica A
- Gabrnica B
- Gorica A
- Gorica B
- Stara Vas A
- Stara Vas B
- Hrastnik
- Orlica North
- Orlica South
- Artiče Extended East
- Artiče Short
- Artiče Extended West
- Artiče Long



DATUM: D48
 PROJECTION: Slovenia TM

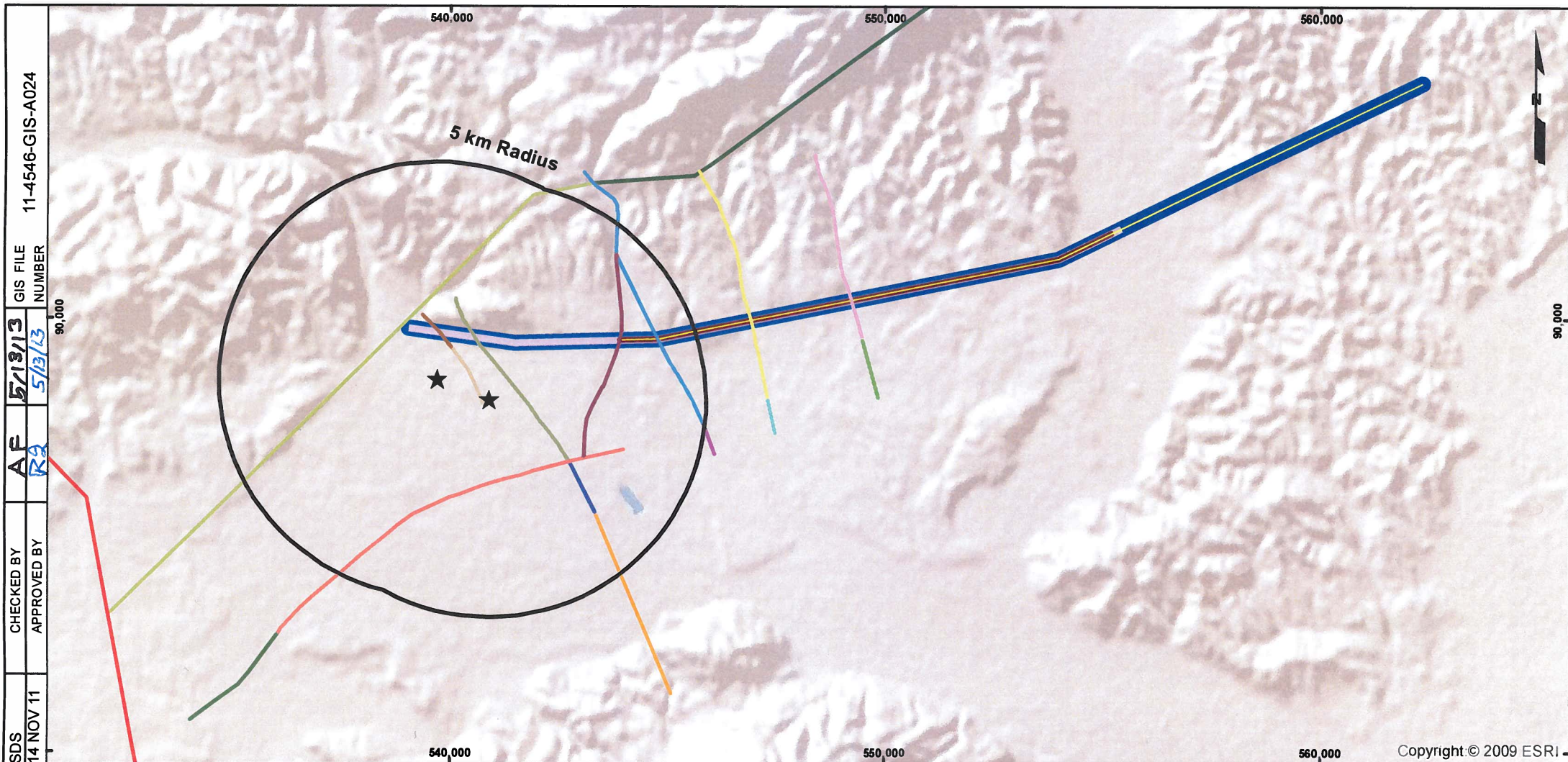
Reference(s):
 1. Rizzo (2013a)

Figure 5

Faults Included in the Probabilistic Fault Displacement Hazard Analysis

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- LEGEND**
- ★ Site
 - 5 km. Radius
 - Libna A
 - Libna B
 - Libna C
 - Mocnik 1
 - Mocnik 2A
 - Mocnik 2B
 - Sromljica A
 - Sromljica B
 - Gabrnica A
 - Gabrnica B
 - Gorica A
 - Gorica B
 - Stara Vas A
 - Stara Vas B
 - Hrastnik
 - Orlica North
 - Orlica South
 - Artice Extended East
 - Artice Short
 - Artice Extended West
 - Artice Long



DATUM: D48
 PROJECTION: Slovenia TM

Reference(s):
 1. Rizzo (2013a)

Figure 6
Faults Closest to the East and West Sites Being Considered for the Krsko 2 NPP
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Krsko, Slovenia

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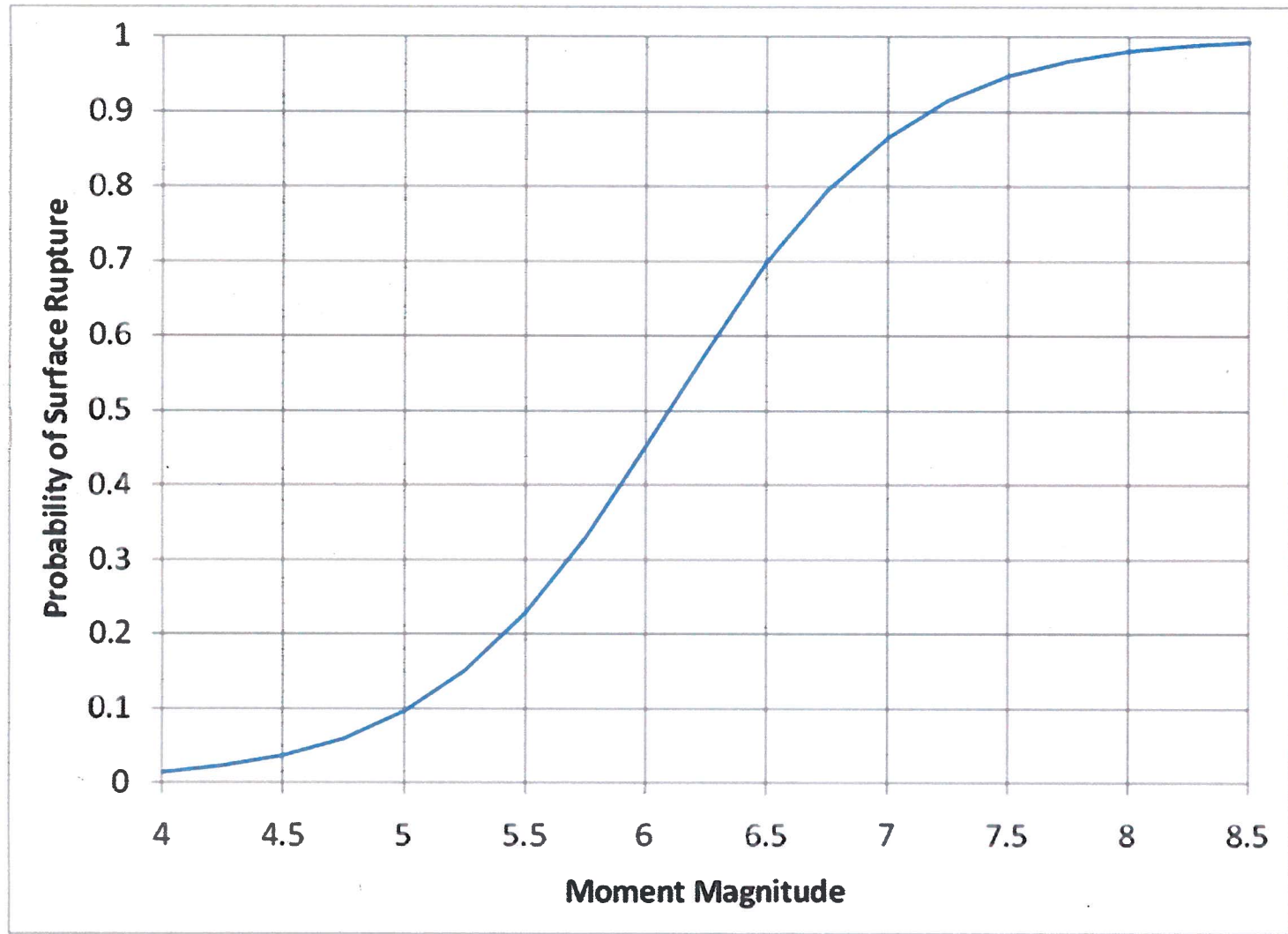
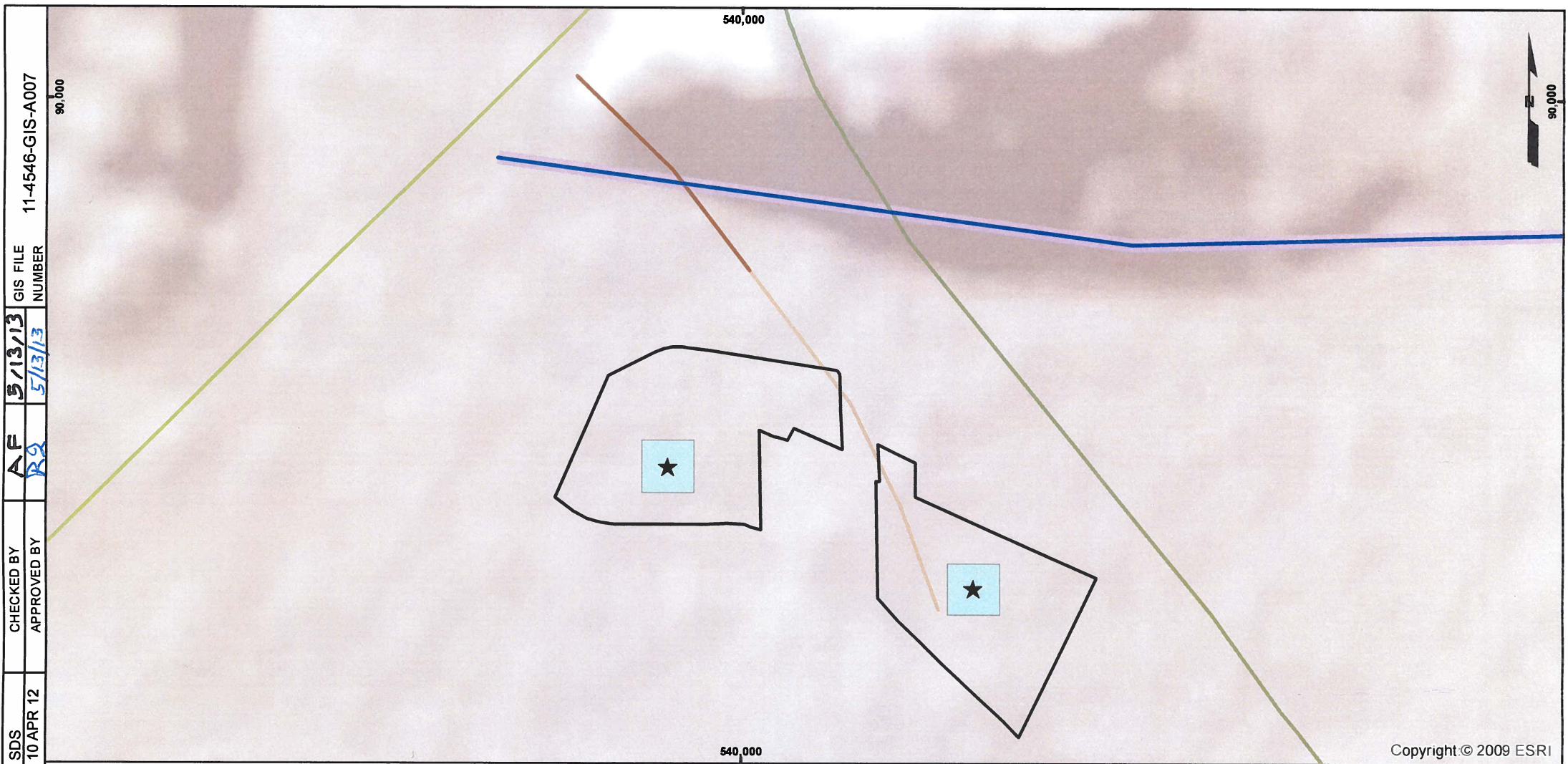


Figure 7

Probability of Surface Rupture as a Function of Moment Magnitude Using Wells and Coppersmith (1993)

PREPARED FOR
GEN Energija
Krško, Slovenia

Source: Wells and Coppersmith (1993)



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 CHECKED BY: _____
 APPROVED BY: _____
 AF: _____
 5/13/13
 5/13/13
 GIS FILE NUMBER: 11-4546-GIS-A007



DATUM: D48
PROJECTION: Slovenia TM

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LEGEND

- ★ Site
- Site Boundary
- Artiče Long
- Artiče Extended West
- Orliča South
- Libna A
- Stara Vas A
- Stara Vas B
- Fault Displacement Hazard Cell

REFERENCE(S):
1. Rizzo, (2013a).

Figure 8
200 x 200 meter Cell Used in Probabilistic Fault Displacement Hazard Analysis for the East and West Sites Being Considered for the Krško 2 NPP
 PREPARED FOR
GEN Energija
Krško, Slovenia

DRAWN BY: [Redacted]
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 GIS FILE NUMBER: 11-4546-GIS-A009
 DATE: 5/13/13

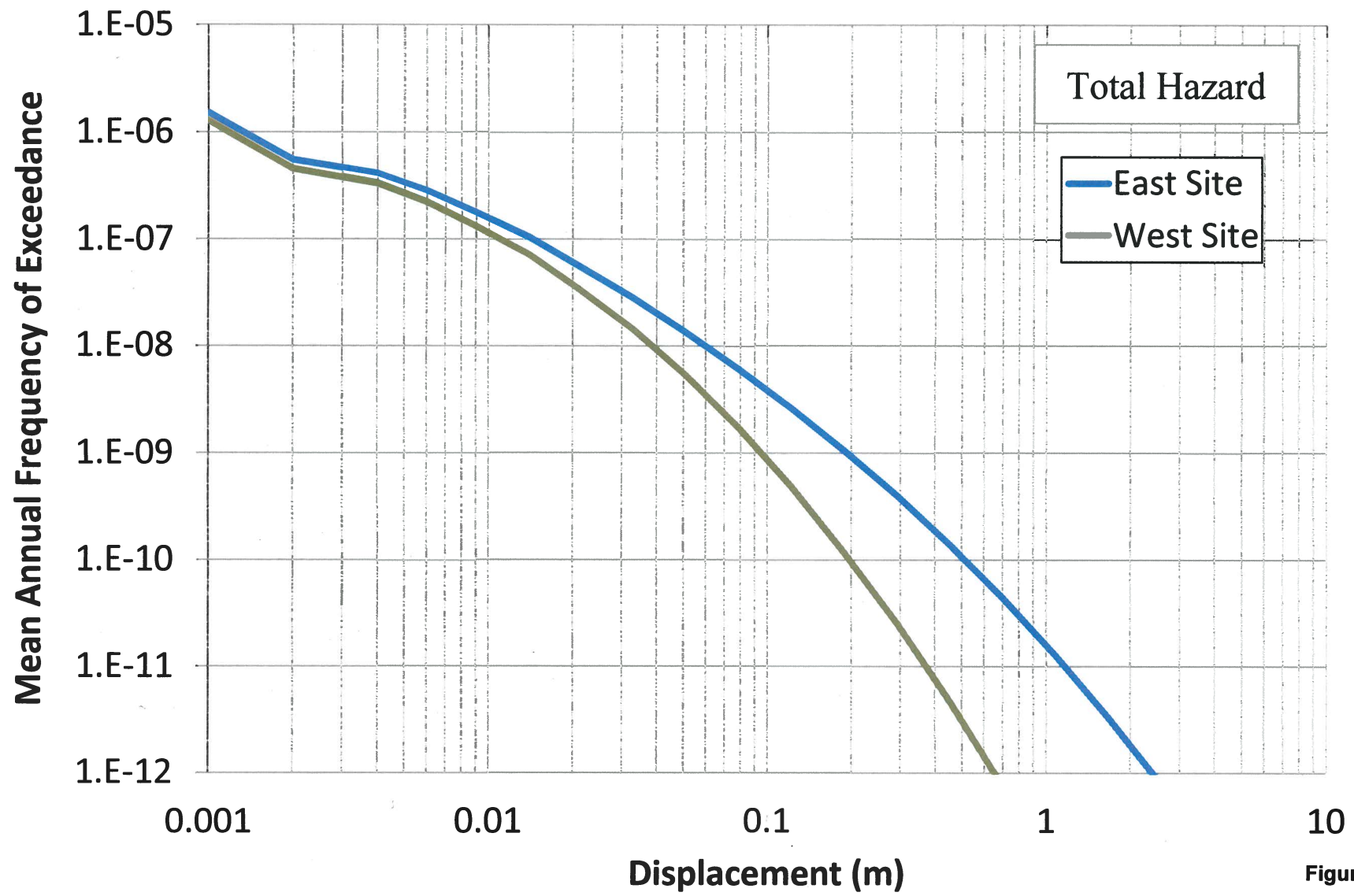


Figure 9

Total Surface Displacement Hazard for the East and West Sites being Considered for the Krško 2 NPP

PREPARED FOR
 GEN Energija
 Krško, Slovenia

Source: RIZZO (2013b, Figure 8)

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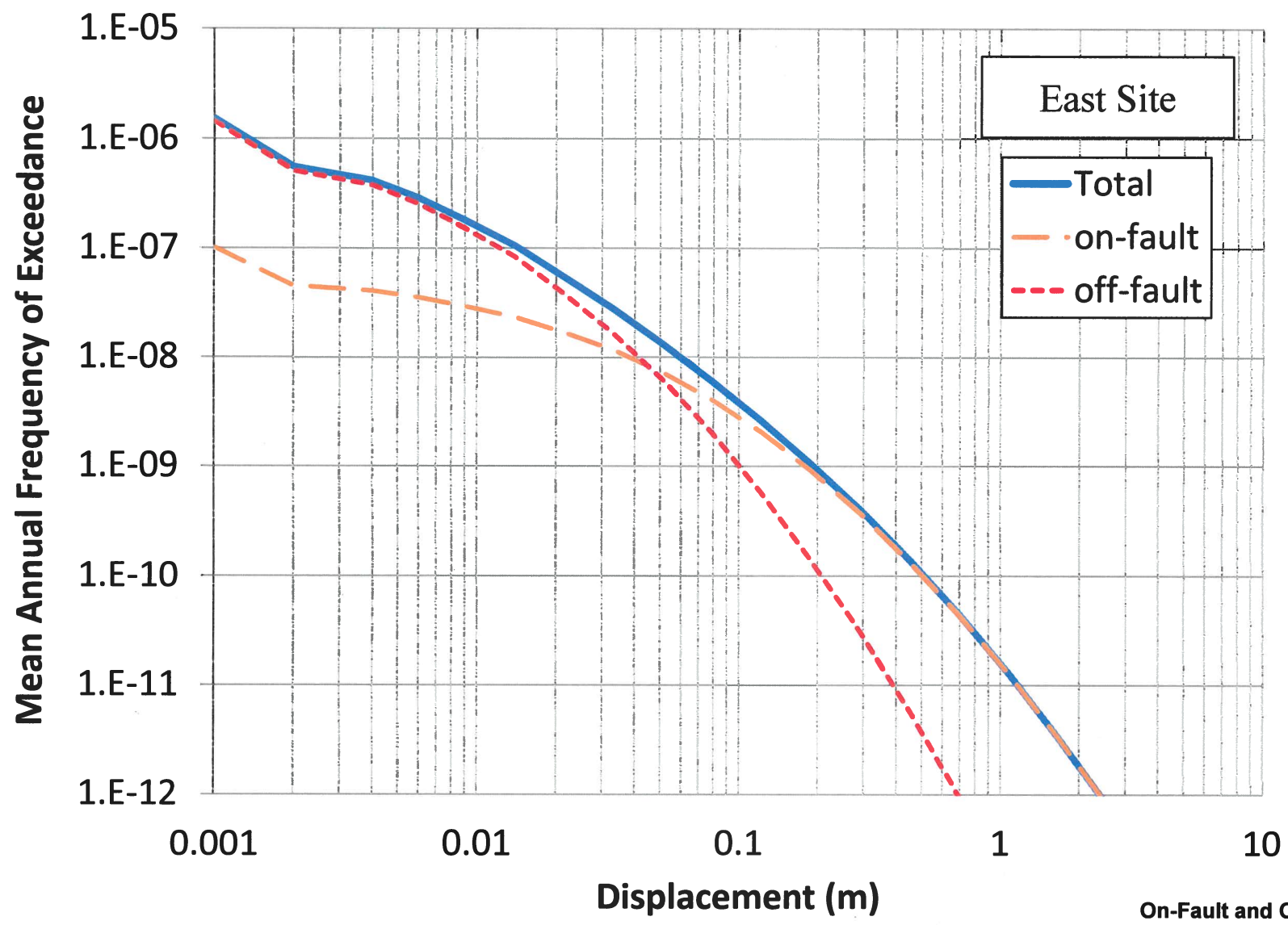


Figure 10
On-Fault and Off-Fault Contributions to Total Hazard for the East Site being Considered for the Krško 2 NPP
 PREPARED FOR
GEN Energija
 Krško, Slovenia

Source: RIZZO (2013b, Figure 9, CD Excel file Hazard-Contribution_Charts.xlsx)

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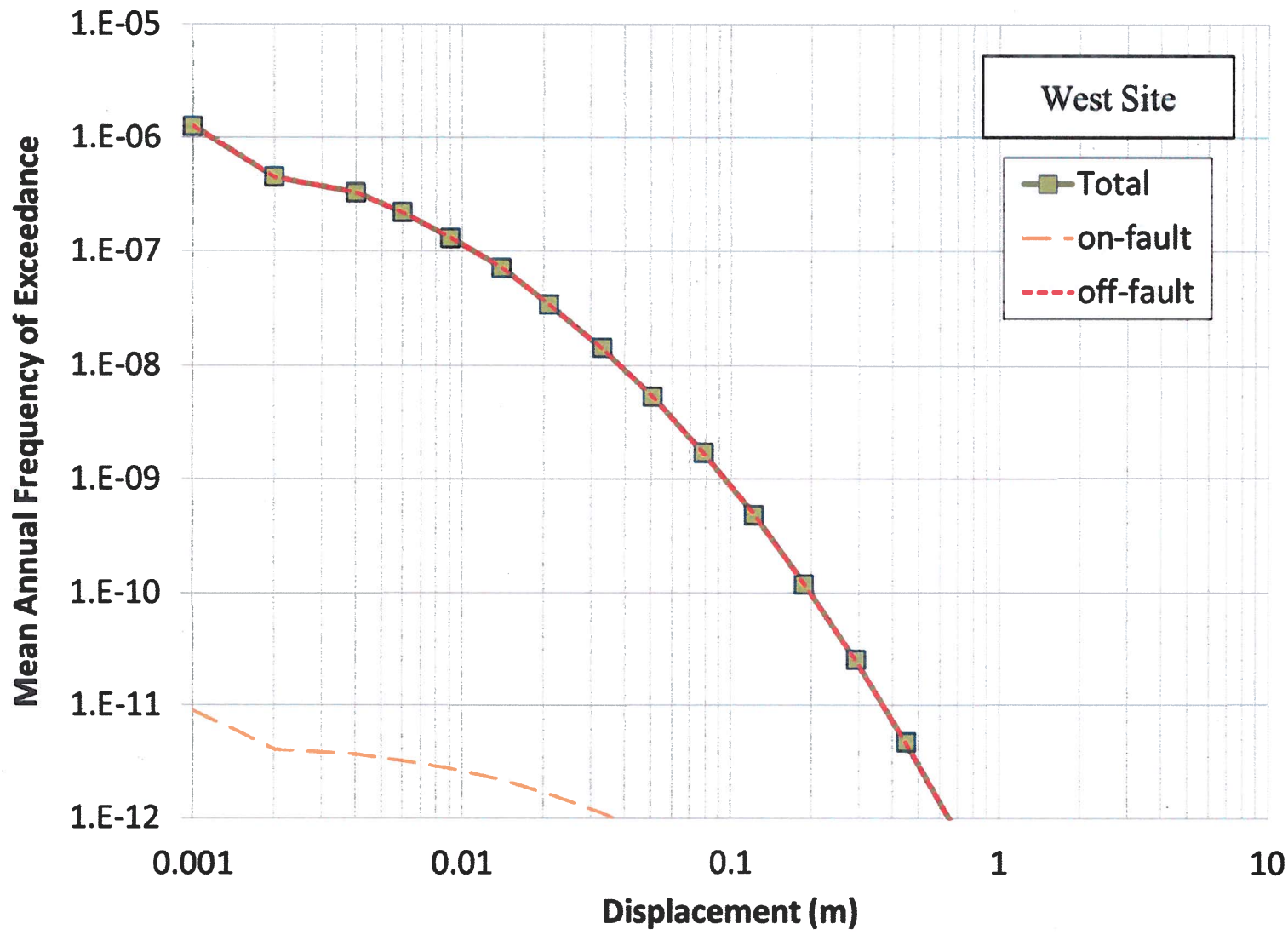


Figure 11

On-Fault and Off-Fault Contributions to Total Hazard for the West Site being Considered for the Krško 2 NPP

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 Krško, Slovenia

Source: RIZZO (2013b, Figure 10, CD Excel file Hazard-Contribution_Charts.xlsx)

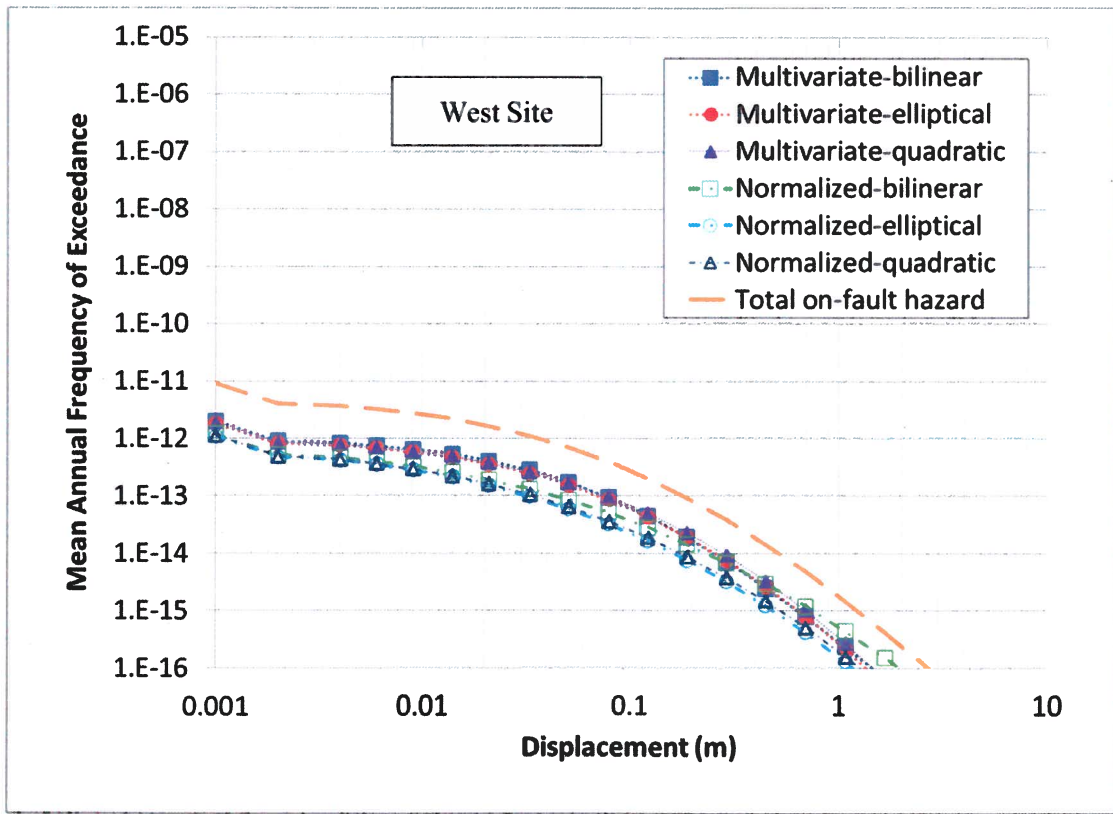
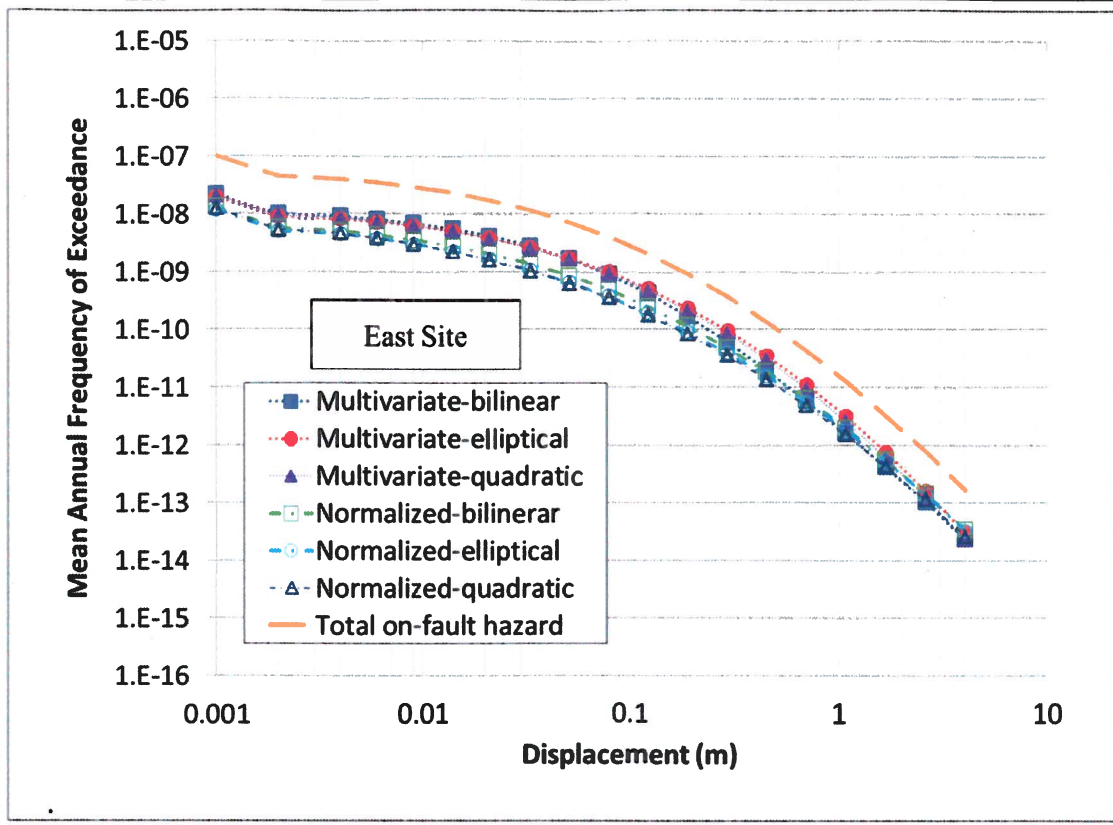


Figure 12
Contributions to On-Fault Displacement Hazard from the Various Surface Displacement Models for the East and West Sites being Considered for the

Krško 2 NPP
PREPARED FOR
GEN Energija
Krško, Slovenia

Source: RIZZO (2013b, Figures 11 and 13, CD Excel file Hazard-Contribution_Charts.xlsx)

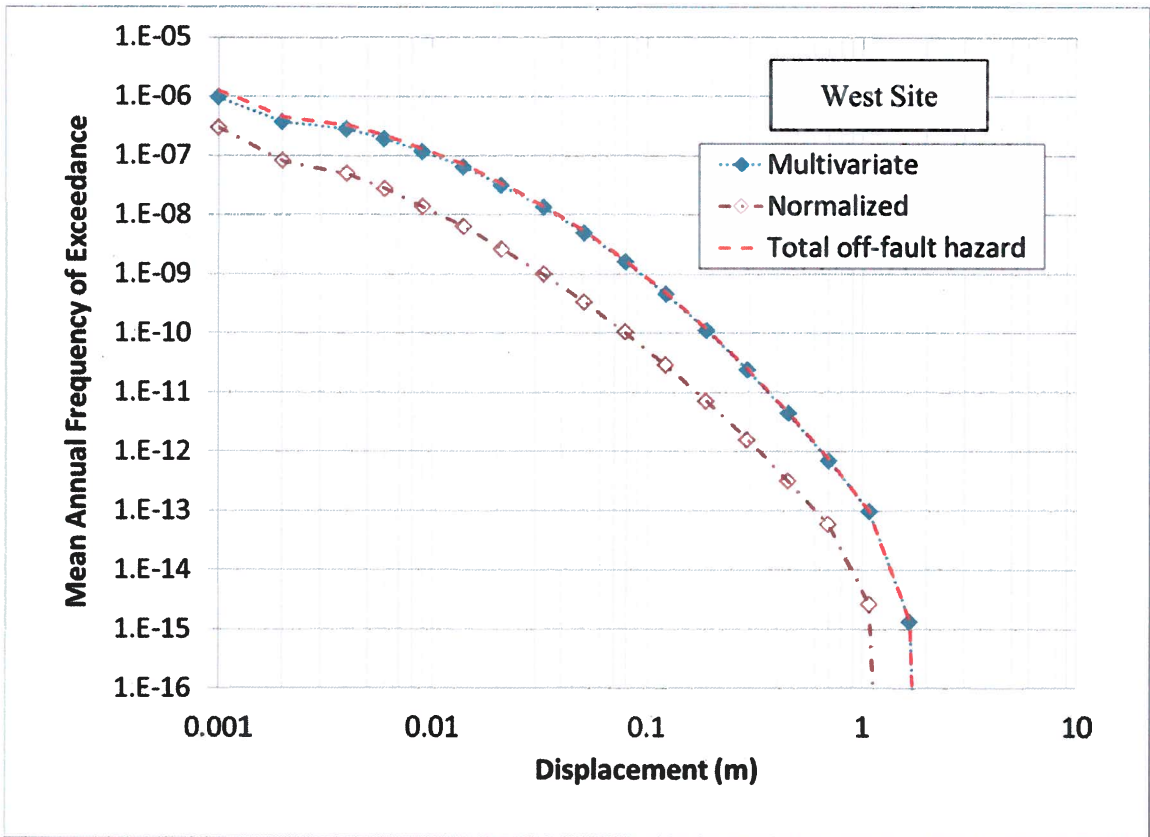
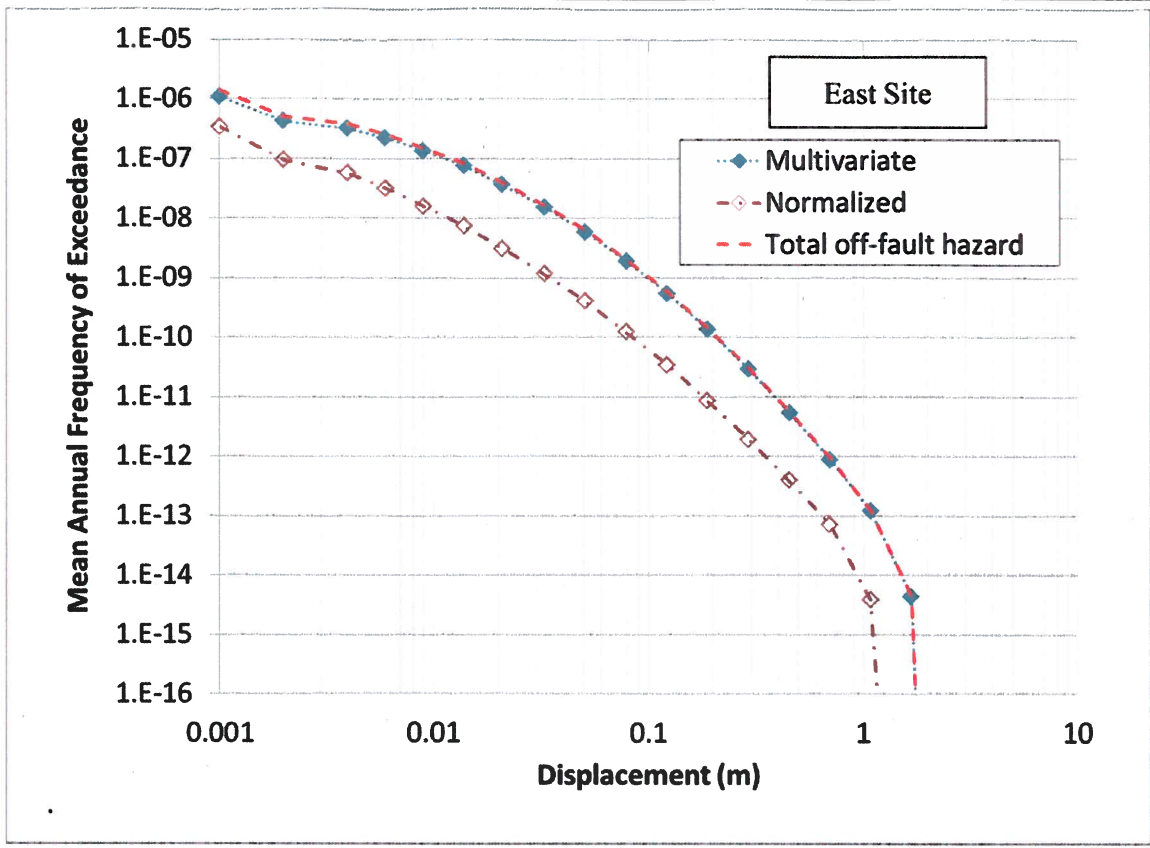


Figure 13
Contributions to Off-Fault Displacement Hazard from the Various Surface Displacement Models for the East and West Sites being Considered for the

Krško 2 NPP
PREPARED FOR
GEN Energija
Krško, Slovenia

Source: RIZZO (2013b, Figures 12 and 14, CD Excel file Hazard-Contribution_Charts.xlsx)

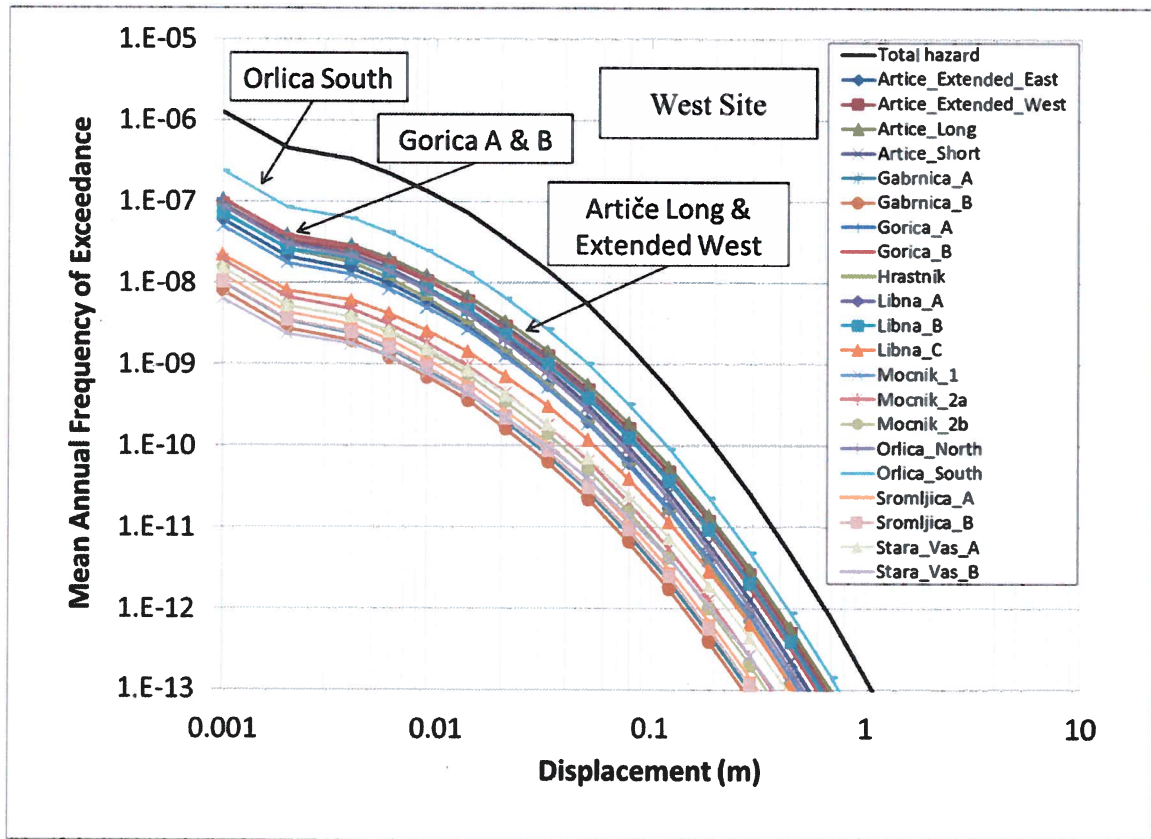
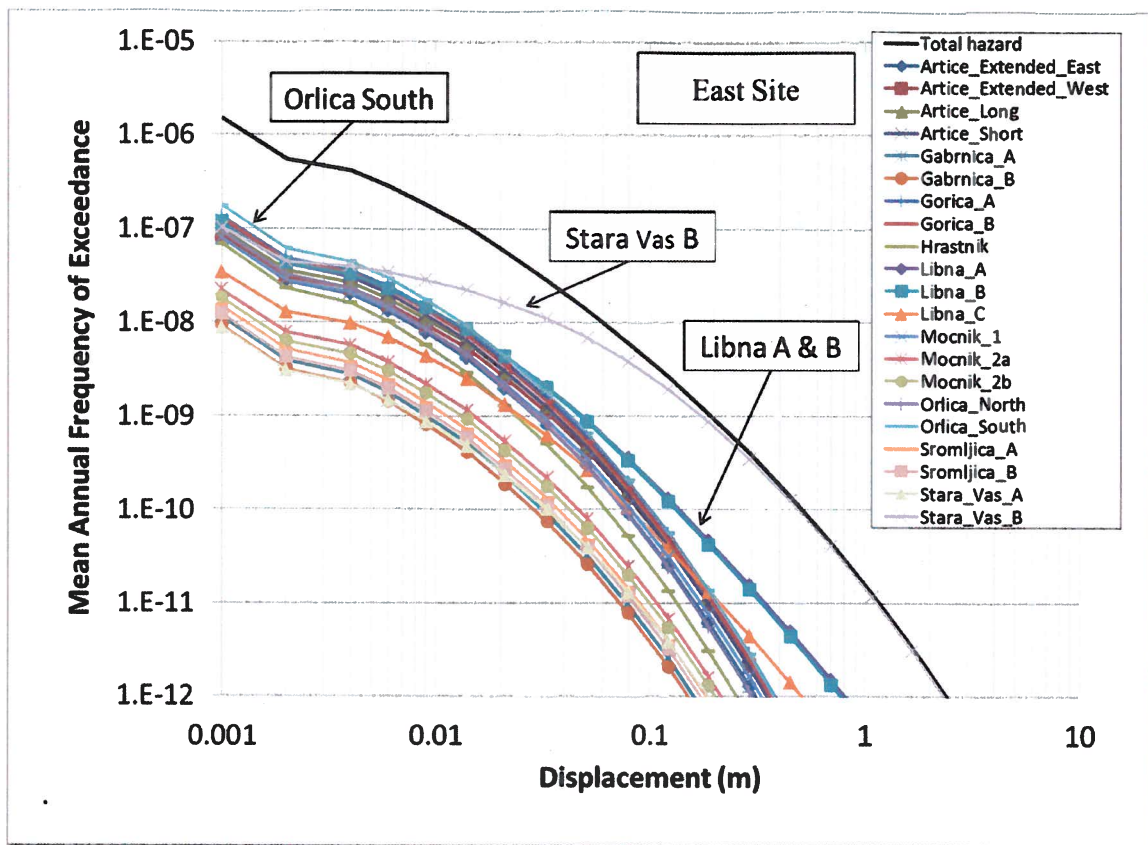


Figure 14

Contributions to Total Displacement Hazard by Source for the East and West Sites being Considered for the Krško 2 NPP

PREPARED FOR

GEN Energija

Krško, Slovenia

APPENDICES

APPENDIX A

PEER REVIEW LETTER REPORT

Leonello Serva

Carl Costantino

Aybars Gürpınar

20 January 2013

Dr. Richard Quittmeyer
Vice President, Seismology
Paul C. Rizzo Associates, Inc.
500 Penn Center Boulevard
Penn Center East, Building 5, Suite 100
Pittsburgh PA, 15235
United States of America

Dear Dr. Quittmeyer,

This letter conveys an assessment of the Peer Review Panel (PRP) on the development of a probabilistic fault displacement hazard analysis (PFDHA) to determine if potential ground surface displacements need to be considered for design of the proposed KRSKO2 nuclear power plant in Slovenia. The PRP was formed in 2012 and consists of three individuals (Drs. Serva, Costantino, and Gürpınar) all of whom participated in a meeting held in Pittsburgh, USA, on 16/17 January 2013.

The PRP reviewed the PFDHA Technical Report (Rev. 0), the Sensitivity Studies Report (Rev. 0), as well as the Geotechnical, Geologic and Seismological Report, Phase 1 (Rev. 1) and attended the presentation at the offices of Rizzo Associates where procedures used during the study and results developed were discussed. This letter report presents a summary of the PRP comments on the study and recommendations for future activities in the following paragraphs.

1. For the new KRSKO NPP Unit, there is no clear, undisputed evidence that would indicate that a fault displacement hazard is present using the criteria of the IAEA Safety Guide SSG-9. It is important to note that all faults in the KRSKO plain are postulated and their presence is questionable. Because the seismic reflection data do not yield unquestionable results, offsets on these faults are not considered significant.
2. Although, the IAEA Safety Guide recommends the use of a probabilistic fault displacement hazard analysis for existing NPPs, the present study is valuable for the following reasons:
 - It constitutes a risk informed approach for the estimation of potential displacements and their engineering significance,
 - It assists in understanding the importance of the various supposed faults in the site vicinity in order to prioritize additional field investigations

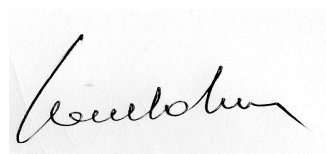
- It provides a qualitative basis for preferring one site over the other (East versus West)
3. The present study constitutes a “first of a kind” application of a PFDHA as recommended in SSG-9. For this reason, RIZZO was very cautious and conservative in selection of parameters used in the calculations. In this regard, the following examples can be cited:
 - the chosen tectonic model with the assumption that each of the considered faults are individually seismogenic (i.e. primary fault) with a specific slip rate;
 - assigning the possibility of a magnitude $M_w = 6.1$ to the Libna fault;
 - use of rather high slip rates (0.25 mm/yr) for the individual faults;
 - selecting a large value for the area of the NPP footprint.

Therefore the base-case analysis results are expected to be overly conservative. In a PFDHA, it would be expected that the base-case would be “best estimate”. It is suggested that some checks be made to ensure that these conservative assumptions have not led to unrealistically conservative results.

4. The faults considered in the PFDHA do not include some faults coming from literature and other type of data. The report should mention these and the reasons for not considering them further in the study should be provided. Fault description reported by Gosar, 1998 and Verbic, 1993 [references shown below] fall into this category.
5. Since the considered faults for the PFDHA indicate a significant normal component, it would be useful to compare this type of faulting with the database used in the Petersen paper.
6. In the M_{max} assessment, the slip-rate versus Magnitude relationship reported in the papers of Slemmons and dePolo (1986) or dePolo and Slemmons (1990) should be taken into consideration and weighted appropriately in the PFDHA.
7. With regard to the fault location sensitivity analysis, it is recommended that the hypothesis that the Artice fault crosses the two chosen study areas be removed from the study. This is due to the fact that the excavation already completed for the existing NPP reportedly does not indicate any evidence of faulting in this area. The results from this postulated case are therefore unrealistic and should not be treated in the same light as the other studies.
8. In order to estimate an appropriate range of slip rate for the PFDHA, it could be useful to calculate the sedimentation and or deformation rate(s) using the thickness and the deformation of the different miocenic period horizons visible in the seismic reflection profile lines. These data can also provide a basis for selection of weights applied to the slip rate values used in the PFDHA.

9. The potential seismic surface displacement of engineering significance needs to be defined for application to the KRSKO NPP site. The magnitude of fault offset that may impact seismic demands on the facility for generic sites is clearly a function of stiffness and strength of the foundation materials immediately adjacent to the facilities. For the KRSKO2 site, soil sediments at some locations extend to depths of meters, while at some locations are relatively shallow. The impact of fault offsets on design seismic demands is expected to be different at these locations. Considering the conservatism that has been included in the displacement predictions, the degree to which the displacements are important will depend on these local site conditions.
10. A PSHA study was recently completed for the KRSKO site and a new study is currently being conducted. There are many common input parameters between the PSHA and PFDHA related to fault characteristics, recurrence values, etc. The consistency of these studies need to be checked and differences (if any) need to be appropriately justified.
11. The cutoff value for the annual probability of exceedance need not be lower than several orders of magnitude below those corresponding to severe accidents involving LERF (Large Early Release Frequency). Therefore, the output tables from the PFDHA should not go to levels below, e.g. 10^{-10} . Screening values of 10^{-7} for exceedance probabilities and 5 – 10 cm for displacements of engineering significance would be appropriate.

The Peer Review Panel agrees that the PFDHA study has shown that the resulting magnitude of offset displacements for the base-case parameters are small and insignificant and need not be considered for further study for the new facility.



Leonello Serva



Carl Costantino



Aybars Gürpınar

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VERBIC T., 1993, Kwartarni Sedimenti v Krski Kotlini, Raziskave za potrebe ugotavljanja potresne nevarnosti na lokaciji NEK, Ljubljana.