EVENT FREQUENCY AND CROSS COMPARISON ANALYSIS OF SEISMIC MONITORING SYSTEM FOR REACTOR TRIGA PUSPATI (RTP)

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ABSTRACT

The Reactor Digital Instrumentation and Control System (ReDICS) is essential for the monitoring and controlling of the Reactor TRIGA PUSPATI (RTP). It includes a seismic monitoring system that records seismic data, such as time history information and peak ground acceleration levels at the reactor building's ground level. This RTP seismic monitoring system can detect and record spike readings that beyond established threshold values, which will be stored as event data. The R Programming open source used to analyze the stored data and it involves process of data preprocessing, event frequency analysis, and cross-comparison with historical seismic event records in peninsular Malaysia. The data analysis indicates that more than 95% of recorded seismic noise is low and uniform throughout reactor operation hours, demonstrating the monitoring system's sensitivity to anthropogenic activities. Two instances of the monitoring system that had power supply failures have been replaced, resulting in data collection gaps over many intervals. The RTP Seismic Monitoring System data were compared with external sources from MET Malaysia, and the three closest monitoring stations were identified. Out of the 14 known seismic activities, only three were deemed acceptable for comparison. The association between RTP events and MET Malaysia data was minimal, due to system deficiencies including power outages and the lack of notable seismic occurrences.

ABSTRAK

Sistem Instrumentasi dan Kawalan Digital Reaktor (ReDICS) adalah penting untuk pemantauan dan kawalan Reaktor TRIGA PUSPATI (RTP). Ia termasuk sistem pemantauan seismik yang merekodkan data seismik, seperti maklumat sejarah masa dan tahap pecutan tanah puncak di aras tanah bangunan reaktor. Sistem pemantauan seismik RTP ini boleh mengesan dan merekodkan bacaan lonjakan yang melebihi nilai ambang yang ditetapkan, yang akan disimpan sebagai data peristiwa. Sumber terbuka Pengaturcaraan R digunakan untuk menganalisis data yang disimpan dan ia melibatkan proses prapemprosesan data, analisis kekerapan kejadian, dan perbandingan silang dengan rekod peristiwa seismik sejarah di semenanjung Malaysia. Analisis data menunjukkan bahawa lebih daripada 95% bunyi seismik yang direkodkan adalah rendah dan seragam sepanjang waktu operasi reaktor, menunjukkan sensitiviti sistem pemantauan terhadap aktiviti antropogenik . Dua contoh sistem pemantauan yang mengalami kegagalan bekalan kuasa telah diganti, mengakibatkan jurang pengumpulan data dalam banyak selang waktu. Data Sistem Pemantauan Seismik RTP telah dibandingkan dengan sumber luar *daripada MET Malaysia, dan tiga stesen pemantauan terdekat telah dikenal pasti. Daripada 14 aktiviti seismik yang diketahui, hanya tiga yang dianggap boleh diterima untuk perbandingan. Perkaitan antara peristiwa RTP dan data MET Malaysia adalah minimum, disebabkan oleh kekurangan sistem termasuk gangguan bekalan elektrik dan kekurangan kejadian seismik yang ketara.*

Keywords: Reactor TRIGA, Seismic Monitoring, Reactor Digital Instrumentation and Control System

INTRODUCTION

Current nuclear facilities use seismic monitoring systems to record critical seismic data, such as time history, peak ground acceleration (PGA), and several seismic activity parameters. This is important to ensure the structural integrity and safe operation of the reactors. Nuclear facilities have benefitted by these advancements, especially in data retrieval and analysis of seismic activity. It leads to improved seismic event detection and decision-making during potential disasters [1,2].

Malaysia located on the southern periphery of the Eurasian plate, often exhibits minimal seismic activity, especially in Peninsular Malaysia. Nonetheless, seismic monitoring is essential, particularly for critical infrastructure such as Reactor TRIGA PUSPATI (RTP). Monitoring seismic occurrences including those of lesser magnitude will facilitate the timely identification of structural vulnerabilities, hence reducing the hazards to the reactor. This study analyses the occurrence rate of seismic data recorded by the RTP seismic monitoring system and compares these occurrences with external data sources to assess the system's efficacy [3,4].

This paper aims to discuss the characteristics and functionality of the Reactor TRIGA PUSPATI (RTP) seismic monitoring system, especially on the acquisition and analysis of time history data and event file recorded from the AK-2000 system. This study seeks to conduct a thorough cross-comparison of the seismic data obtained from the AK-2000 with external sources, including recorded seismic events from the Meteorological Department of Malaysia. This approach aims to verify the precision and dependability of the RTP seismic monitoring system in detecting major seismic occurrences in the Malaysian Peninsula.

METHODOLOGY

AK-2000-12 Seismometer Description

Reactor TRIGA PUSPATI (RTP) has effectively used the Reactor Digital Instrumentation and Control System (ReDICS) since 2013. It includes a seismic monitoring system that records seismic data, such as time history information and peak ground acceleration levels at the reactor building's basement. This system features alarm notification to alerts plant operators following an event to assure continuous system and simplicity of operation and maintenance for Reactor TRIGA PUSPATI (RTP). The seismic monitoring system is used to detect and record spike readings that exceed predetermined threshold levels and the particular spike reading will be saved as event data.

Figure 1: AK-2000-12 Digital Strong-motion Seismometer

The seismic monitoring system at Reactor TRIGA PUSPATI (RTP) utilizes AK-2000-12 sensors to accurately record seismic activity across three orthogonal components (X, Y, Z axes). The system accommodates a maximum of 12 channels from diverse sensors, with data processed at several sampling rates between 200Hz and 5Hz. It includes a touchscreen display, and GPS synchronization for time adjustment, and utilizes many communication protocols, including RS232 and TCP/IP. The system analyses seismic intensity, including both horizontal and vertical components, and initiates recording using logical operations on these components. It guarantees precise event documentation for safety and operational determinations within the reactor setting.

Table 1: Basic Specifications of AK-2000-12

Digital Seismometer	
Category	**Specification**
Model	AK-2000-12
Converter Specification	24bit X:128dB Y:128dB Z:128dB
Display	Touchscreen 12.1” TFT LCD
Number of Channels	3 channel -12 channel (1 sensor – 4 sensor)
Input Signal	10V
Communication Medium	RS232, RS 422, RS485, TCP/IP
Time Correction	GPS Synchronization
Sampling	200Hz, 100Hz, 50Hz, 20Hz, 10Hz 5Hz
Arithmetic Equation	Intensity (JMI, MMI), horizontal component, vertical component, total component, STA/LTA
Boot Conditions (Trigger)	Logical operations (AND/OR) of the specified three components, trigger activation of all X, Y and Z components (Channel Base)
Recording Suspension	Stop automatic recording by entering the stop value.

This seismic monitoring system has been functional since August 2013, after the successful modernization of the RTP reactor console from analog to digital as part of the reactor console digitalization initiative with KAERI. The seismic alarm signal is incorporated into the Reactor Digital Instrumentation and Control System (REDICS) to notify the reactor operator of seismic activity. As of July 2023, the seismic monitoring system has recorded approximately 148 GB of stored data. This research concentrates on the positioning of our sensor, located at the ground level of the Reactor TRIGA PUSPATI. The sensor is a strong-motion device, specifically engineered to detect large seismic events, hence enabling early detection and response to considerable seismic activity.

Research process flow

This research makes use of a decade-long AK-2000 seismic time history data. The first step for this research started with retrieve the PGA and time history from the AK-2000 database. The raw data must first undergo preprocessing to remove noise and convert the dataset to a suitable format before the data analysis process begins. The data must be clean before being analyzed with R. Seismic event frequencies and magnitudes of ground acceleration are revealed through analysis that employs statistical and signal processing approaches to extract seismic features.

The next step is to compare the frequency of recorded earthquakes. For the sake of comparison, a dataset is assembled consisting of actual seismic events reported in the Malaysian Peninsula, sourced from the Meteorological Department of Malaysia (MET Malaysia). This external data is correlated with the seismic events captured by the AK-2000 system, with the occurrences being synchronized concerning time, location, and, if relevant, magnitude.

The flowchart shows the steps involved in this research. It starts with data retrieval and continues through data preprocessing, data quality evaluations, and data analysis. Visualisations summarising both matched and mismatched seismic occurrences are used to display the results once the procedure culminates in cross-comparing with MET Malaysia data.

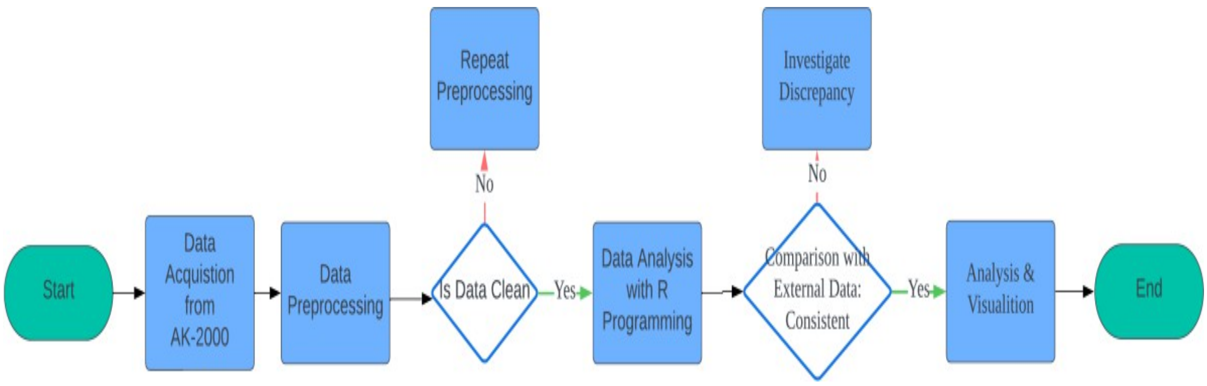

Figure 2: Flow Chart of the research

RESULTS AND DISCUSSIONS

The RTP Seismic Monitoring System features a seismic detector that can deliver seismic data as Comma-Separated Values (CSV) files instead of conventional seismic waveforms. It captures critical data characteristics, which include time history data (known as event file) that encompasses details such as date, time, total ground acceleration (measured in gal, corresponding to 1 cm/s^2), kinetic energy, and intensity according to the Modified Mercalli Intensity (MMI) scale. Moreover, it records Peak Ground Acceleration (PGA) data, encompassing three orthogonal components—East-West (X), North-South (Y), and vertical (Z)—at a sampling rate of 100 Hz, yielding comprehensive datasets. The recordings are routinely stored on an external hard drive, guaranteeing data integrity and availability for subsequent analysis.

The initial dataset provided by AK-2000-12 is shown in Figure 3. This dataset had been pre- processed and segregated into different Excel sheets according to its years and further detailed down to identified specific day, date and time. The purpose of this data detailing is to identify whether the daily operation of RTP and activities around the reactor facilities cause noise that has been captured by the seismic monitoring system.

	A	B	C	D	E	F	G	H	I
1	Sensor	Time	TotalGal(ga	Intensity scale	SI(kine				
2	Sensor1	2023-07-13 15:42:42.103	0.6	0	0.02				
3	Sensor1	2023-07-13 15:37:10.103	0.2	0	0				
4	Sensor1	2023-07-13 15:35:10.103	0.1	0	0				
5	Sensor1	2023-07-13 15:30:00.103	0.2	0	0				
6	Sensor1	2023-07-13 14:56:33.102	28.5	4	1.93				
7	Sensor1	2023-07-13 13:31:14.101	1.1	1	0.07				
8	Sensor1	2023-07-13 13:00:45.101	0.9	0	0.05				
9	Sensor1	2023-07-13 09:41:11.098	3.4	2	0.2				
10	Sensor1	2023-07-13 08:57:52.097	0.1	0	0				
11	Sensor1	2023-07-13 08:55:45.097	0.1	0	0				
12	Sensor1	2023-07-13 08:54:05.097	0.1	0	0				
13	Sensor1	2023-07-13 08:52:12.097	0.1	0	0				
14	Sensor1	2023-07-13 08:50:48.097	0.1	0	0				
15	Sensor1	2023-07-13 08:49:32.097	0.1	0	0				
16	Sensor1	2023-07-13 08:46:42.097	0.1	0	0				
17	Sensor1	2023-07-13 08:45:37.097	0.2	0	0				
18	Sensor1	2023-07-13 08:44:32.097	0.1	0	0				
19	Sensor1	2023-07-13 08:43:16.097	0.1	0	0				
20	Sensor1	2023-07-13 08:41:55.097	0.1	0	0				
21	Sensor1	2023-07-13 08:40:32.097	0.1	0	0				
22	Sensor1	2023-07-13 08:39:05.097	0.1	0	0				
23	Sensor1	2023-07-13 08:37:52.097	0.1	0	0				
24	Sensor1	2023-07-12 16:17:46.083	0.1	0	0				
25	Sensor1	2023-07-12 16:16:30.083	0.1	0	0				
26	Sensor1	2023-07-12 16:15:26.083	0.1	0	0				
27	Sensor1	2023-07-12 16:14:23.083	0.1	0	0				
28	Sensor1	2023-07-12 16:13:19.083	0.1	0	0				
29	Sensor1	2023-07-12 16:12:13.083	0.1	0	0.01				

... | 2023 | 2022 | 2021 | 2020 | 2019 | 2018 | 2017 | 2016 | 2015 | 2014 | 2013 | AK-2000 Data

Figure 3: The raw dataset from the RTP seismic monitoring system

	A	B	C	D	E	F	G	H	I	J	K
1	Date	Day	Month	Year	Veekend Da	Time	TotalGal(ga	ntensity sca	SI(kine)		
2	12/31/2022	31	12	2022	Saturday	17:07:48.167	0.1	0	0		
3	12/31/2022	31	12	2022	Saturday	16:56:44.167	0.2	0	0		
4	12/30/2022	30	12	2022	Friday	15:59:15.146	0.1	0	0		
5	12/30/2022	30	12	2022	Friday	15:57:40.146	0.1	0	0		
6	12/30/2022	30	12	2022	Friday	15:56:31.146	0.1	0	0		
7	12/30/2022	30	12	2022	Friday	15:55:11.146	0.1	0	0		
8	12/30/2022	30	12	2022	Friday	15:53:24.146	0.1	0	0		
9	12/30/2022	30	12	2022	Friday	15:52:11.146	0.1	0	0		
10	12/30/2022	30	12	2022	Friday	15:49:26.146	0.3	0	0.01		
11	12/30/2022	30	12	2022	Friday	15:47:24.146	0.1	0	0		
12	12/30/2022	30	12	2022	Friday	15:46:03.146	0.2	0	0		
13	12/30/2022	30	12	2022	Friday	15:44:42.146	0.1	0	0		
14	12/30/2022	30	12	2022	Friday	15:43:00.146	0.2	0	0		
15	12/30/2022	30	12	2022	Friday	15:41:27.146	0.1	0	0		
16	12/30/2022	30	12	2022	Friday	15:39:34.146	0.1	0	0		
17	12/30/2022	30	12	2022	Friday	15:38:27.146	0.1	0	0		
18	12/30/2022	30	12	2022	Friday	15:37:08.146	0.1	0	0		
19	12/30/2022	30	12	2022	Friday	15:35:54.146	0.2	0	0		
20	12/30/2022	30	12	2022	Friday	15:32:19.146	0.2	0	0		
21	12/30/2022	30	12	2022	Friday	15:30:56.146	0.1	0	0		
22	12/30/2022	30	12	2022	Friday	15:28:48.146	0.2	0	0		
23	12/30/2022	30	12	2022	Friday	15:25:58.146	0.1	0	0		
24	12/30/2022	30	12	2022	Friday	15:24:39.146	0.2	0	0		
25	12/30/2022	30	12	2022	Friday	15:23:08.146	0.1	0	0		
26	12/30/2022	30	12	2022	Friday	15:21:18.146	0.2	0	0		
27	12/30/2022	30	12	2022	Friday	15:20:00.146	0.1	0	0		
28	12/30/2022	30	12	2022	Friday	15:18:07.146	0.1	0	0		
29	12/30/2022	30	12	2022	Friday	15:16:55.146	0.1	0	0		

... | 2023 | 2022 | 2021 | 2020 | 2019 | 2018 | 2017 | 2016 | 2015 | 2014 | 2013 | AK-2000 Data

Figure 4: The dataset after data processing

Table 2: The amount of data collected from the RTP seismic monitoring system by year

Year	No. of data collected (Event File.csv)
2023	6396
2022	17419
2021	62
2020	31
2019	1814
2018	11916
2017	32948
2016	44383
2015	18554
2014	121
2013	34

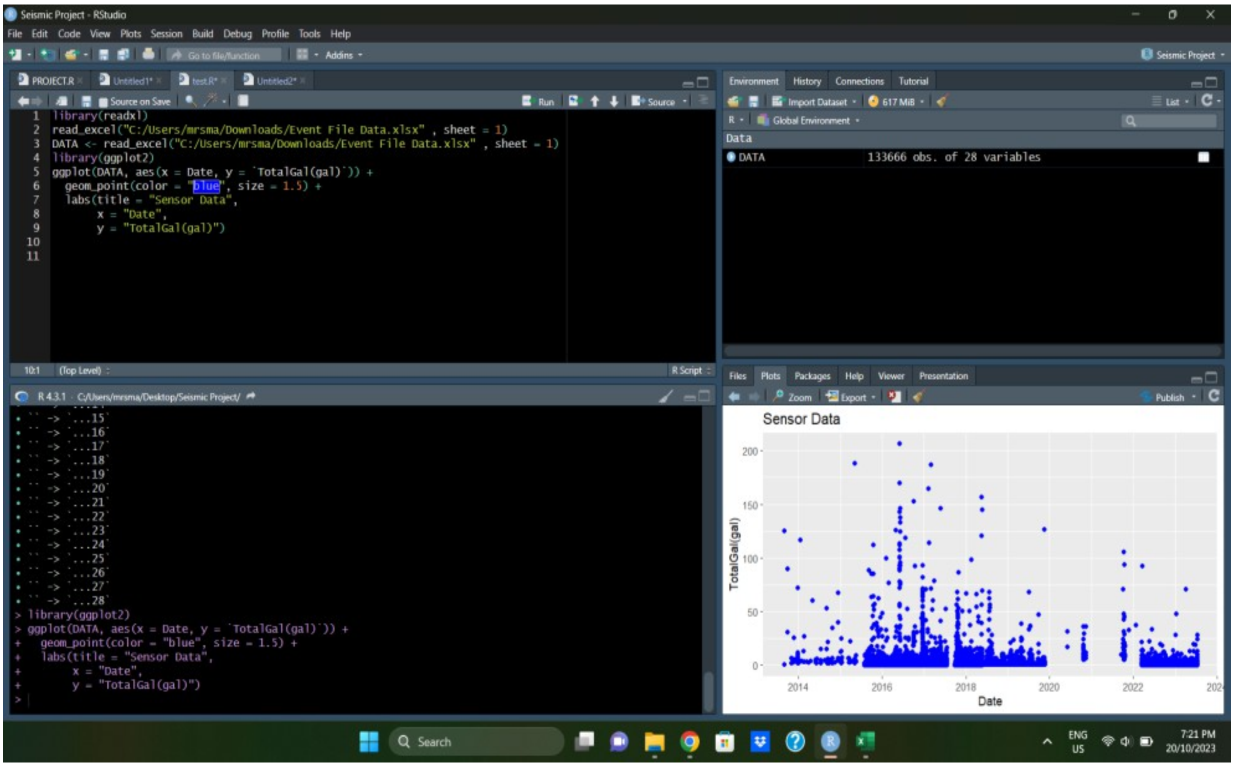

Figure 5: Data Analysis with R Programming

The R programming was used to analyze and tabulate data from August 2013 to July 2023, as shown in Table 2 and Figure 5. Ground motion is usually below 50 gal in most circumstances. This fits the region's low seismic activity, minor tectonic movements, and few significant seismic events [1]. Since strong-motion sensors are designed to detect larger seismic events, low-magnitude events are hard to detect. This seismic monitoring system can only detect earthquakes of adequate magnitude. This feature aligns closely with the monitoring system employed by the Meteorological Department of Malaysia (MET Malaysia), which are nearest to the RTP facilities.

All sensors utilized by MET Malaysia are strong-motion sensors, hence restricting their sensitivity to minor earthquakes.

The recorded seismic activities in the event file are likely caused by the RTP working environment and external vehicular activity. The important observation is most of the detections occur during working hours, particularly from 8 AM to 6 PM. This indicates that anthropogenic activities likely play a major role in the seismic background noise captured by the RTP seismic monitoring system.

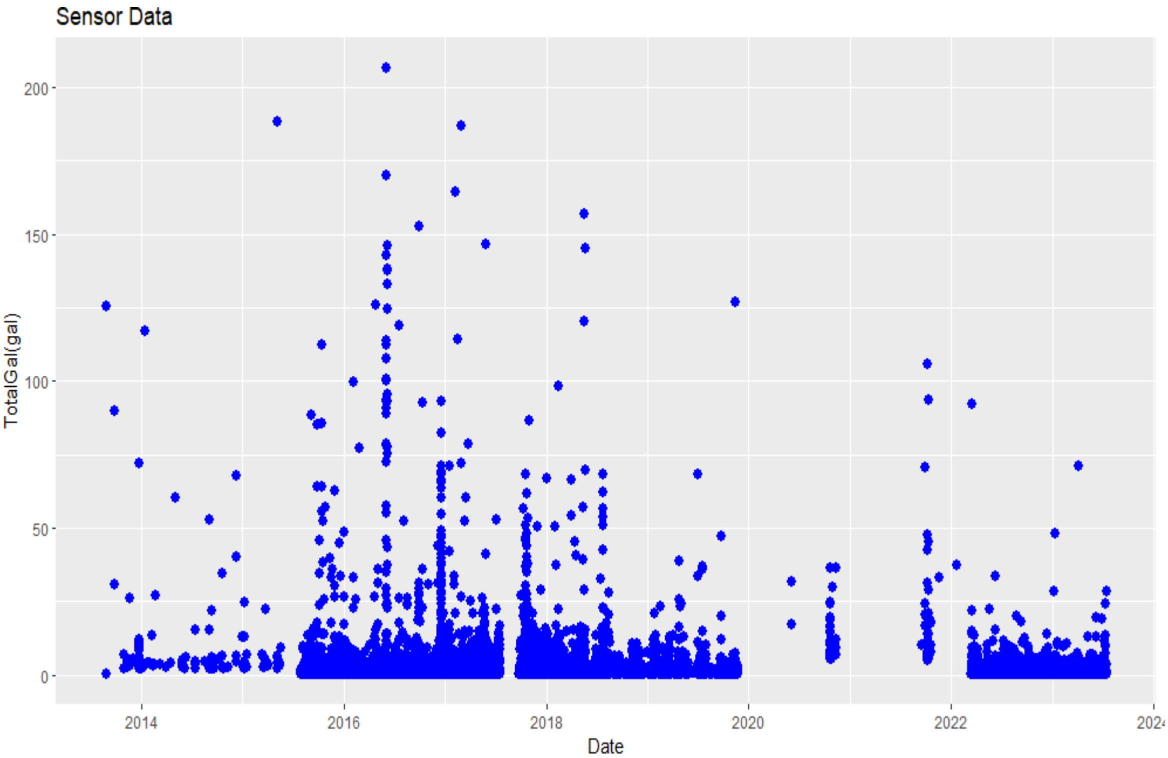

Figure 6: Seismic Activity Trend (2013-2023)

The data analysis revealed that over 95% of recorded seismic noise is low and consistent throughout reactor operation hours, indicating the monitoring system's sensitivity to earthquake magnitude. The signal has a calibration of 1.25 milliamperes, which is equivalent to 100 gal. On the other hand, the seismic monitoring system has not yet been designed to revert to a baseline value to ensure that measurements are consistent. It is vital to create calibration methods that constantly adjust the system to a baseline to establish accurate measurements. This will ensure that the data-gathering process is accurate and reliable. In addition, there were two instances of the monitoring system experiencing a loss of power supply, which have since been replaced. As a consequence, there were gaps in the data that were captured for several different periods. The existence of these gaps draws attention to the necessity of enhancing the processes for system maintenance and backup [2].

The data from the RTP seismic monitoring system had been compared with external sources and were owned by MET Malaysia. Out of an estimated 80 monitoring stations owned by MET Malaysia, this research chose the nearest three monitoring stations which are located at Beranang (Station Code: BRSM), Perbadanan Putrajaya (Station Code: PYSM), and Wetland Putrajaya (Station Code: PJSM). All of these monitoring stations utilize strong motion sensors for their seismic monitoring system and are located approximately 10 kilometers away in different directions from reactor facilities as shown in Figure 7.

Table 3: The criterion for selecting the external MET Malaysia monitoring stations

	LAT (N)	LONG (E)	Heigh t (KM)	Distance (km)
BLOCK 20 REACTOR	2.9123715	101.7714372		0
SELANGOR				
FRIM Kepong	3.237	101.625	97	40
Shah Alam	3.097	101.512	28	35
Ulu Yam	3.272	101.685	84	41
Kundang	3.27	101.515	27	49
Serendah	3.365	101.618	61	53
Dusun Tua	3.131	101.84	67	25
Beranang	**2.902**	**101.863**	**73**	**10**
Bukit Gasing	3.093	101.656	80	24
KUALA LUMPUR				
Perbadanan Putrajaya	**2.918**	**101.684**	**74**	**10**
Wetland, Putrajaya	**2.968**	**101.695**	**45**	**10**
Bukit Kiara	3.147	101.645	66	30
NEGERI SEMBILAN				
Batu Kikir, Kuala Pilah	2.858	102.271	135	56
Kuala Pilah	2.727	102.249	109	57
Jempol	2.899	102.407	62	71

Figure 7: Location of references MET Malaysia monitoring Station used for cross-comparison

The listed number of seismic activities has been narrowed down to only the peninsular Malaysia region and a total of 14 felt earthquake activities had been detected. Of those 14 shortlisted seismic activities, only 3 of those were able to be detected by one or more references MET Malaysia monitoring stations for 10 years. Two of those seismic activities happened in July 2013 and it has been detected by BRSM station. However, during that period, RTP wasn't yet equipped with a seismic monitoring system and the earliest data recorded by RTP seismic monitoring system was on 28th August 2013.

The latter seismic activities were detected by both BRSM and PJSM stations on 25th February 2022. The RTP had been equipped with a seismic monitoring system during this time but unfortunately, the monitoring system experienced a loss of power supply and was unable to detect and record this seismic activity. Hence, there was none of the known activities able to relate the RTP monitoring station with the references MET Malaysia monitoring stations.

REKOD GEMPA BUMI YANG DIRASAI / FELT EARTHQUAKE								
BIL / NO	**LOKASI / LOCATION**	**LATITUT / LATITUDE**	**LONGITUT / LONGITUDE**	**TARIKH / DATE**	**MASA / TIME**	**MAGNITUD / MAGNITUDE**	**KEDALAMAN/ DEPTH**	**STATION**
1	Northern Sumatra, Indonesia	2.28 °N	98.87 °E	10/6/2022	8:31:02	4.6	18	GMM, IPM, KUM, TGM, DVM, KNM, KPM, LAM, MTM, PRM, SBM ,SMM,SYM
2	Northern Sumatra, Indonesia	2.1746 °N	98.8259 °E	9/30/2022	28:43.0	5.7	29	IPM, BKM, KUM,JRM, TGM,GMM,LAM,SBM,NIM,TNM,TPM,KAM,WRM,KPM,SYM, RAM, PRM,MTM,KDM,PTM,TLM,DVM,KNM,KIM,SMM
3	Northern Sumatra, Indonesia	3.72 °N	96.1 °E	9/23/2022	53:02.0	6.1	73	KUM,IPM,TGM,GMM,BKM,JRM,FSM,SBM,NIM,TNM,KKM,TPM,SPM,WRM,KPMSYM,RAM,PRM,MTM,KDM,PTM,TLM,DVM,KIM,KNM,SMM
4	Sumatera Selatan	0.5849 °N	98.6416 °E	3/13/2022	21:09:21	6.2	15.6	SASM,STSM,BTSM,DVM,FSM,KAM,KNM,KPM,MTM,PRM,PTM,RAM,SDM,SPM,SRM,SYM,TLM
5	Sumatera Utara	0.1671 °N	99.9740 °E	2/25/2022	4:02:18	5.1	2.6	DTSM,GRSM,JBSM,JRM,KOM,KTM,UYSM
6	Sumatera Utara	0.1686°N	100.0206 °E	2/25/2022	1:39:33	5.9	5	**BRSM,PJSM**,SASM,BGSM,KNSM,UYSM,BMSM,BPSM,JPSM,JBSM,BTSM,GPSM,STSM,MSSM,TRSM,TKSM,KUM,BUSM,TGM,GRSM,KTM,KUSM,LGSM,CPSM,KAM,KPM,SYM,RM,PRM,MTM,SRM,SDM,PTM,DVM,KNM,SMM,LDM
7	Tasik Kenyir, Terengganu	5.0316 °N	102.8402 °E	2/23/2016	13:25:36	3	2.4	KTM,JRM,IPM,KUM,KRM,TPSM
8	Temenggor, Perak	5.5498°N	101.3538 °E	1/3/2016	21:07:55	3	10.9	KUM,IPM
9	Temenggor, Perak	5.5213°N	101.3686 °E	1/3/2016	16:23:03	3.1	15.3	KUM,IPM
10	Temenggor, Perak	5.5537°N	101.3622 °E	1/3/2016	17:33:15	3.2	12	KUM,IPM
11	Temenggor, Perak	5.416°N	101.360 °E	8/20/2013	0:26:27	4.1	1.6	KUM,KTM,JRM,IPM
12	Sumatera Utara	5.495°N	98.086 °E	7/16/2013	23:41:10	5.4	10	**BRSM**,UYSM,DTSM,SRSM,JRM,KOM,IPM,KUM
13	Sumatera Utara	1.831°N	99.077 °E	7/11/2013	7:16:27	5.2	10	**BRSM**,KUM,IPM,FRM,KOM,JRM,PYSM_B9,JBSM,DTSM,UYSM
14	Sumatera Utara	4.611°N	96.604 °E	7/2/2013	7:37:03	5.9	11.4	KUM,IPM,FRM,KTM,KOM,JRM,BNM, SRSM,UYSM

Figure 8: List of felt earthquakes experienced in Peninsular Malaysia from 2013-2023

There was only a small correlation between the events that were recorded by RTP and the data that was collected from the monitoring stations of MET Malaysia. This discrepancy was not caused by an increased sensitivity to low-amplitude seismic noise in the local area but rather attributable to gaps in the system, which included power failures and the absence of big seismic occurrences throughout the monitoring period. RTP's seismic monitoring system is capable of accurately capturing small ambient noise, but has still yet proven to detect larger seismic events. In order to improve synchronization with external datasets and detect significant seismic occurrences, stability improvements are crucial for this seismic monitoring system.

CONCLUSION

The RTP seismic monitoring system fulfill its role on detecting seismic activity. The sensitivity of the instruments causes the detection of large number of low seismic event which caused by human and working activities in Reaktor TRIGA PUSPATI. It is advisable to collaborate with MET Malaysia and utilize data from reputable international sources such as USGS, IRIS, and CTBTO IMS for comparative analysis. To enhance precision and prepare for future projects, including new reactors like MPR or SMR, future improvements should focus on calibrating and maintaining the detector.

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