Induced Seismicity Management Guideline 2022

21 December 2022

Version 0.1

NORTHERN TERRITORY GOVERNMENT

Document title	Induced Seismicity Management Guideline 2022
Contact details	Petroleum Operations (08) 8999 5388
Approved by	Senior Executive Director, Energy Development, Department of Industry, Tourism and Trade
Date approved	21 December 2022
Document review	Annually

Version	Date	Author	Changes made
0.1	21 December 2022	Petroleum Operations and Onshore Gas Development	Initial Guideline

Acronyms	Full form
DITT	Department of Industry, Tourism and Trade
ISMP	Induced Seismicity Management Plan
PGA	Peak Ground Acceleration
SEED	Standard for the Exchange of Earthquake Data
TLS	Traffic Light System

Unit	Definition
G or g	Gravity - Unit of peak horizontal or vertical ground acceleration % may be used
Hz	The frequency of a sound wave or a radio wave is the number of times it vibrates within a specified period of time. It is measured in hertz (Hz), an international unit of measure where 1 hertz is equal to 1 cycle per second.
PGA	Peak ground acceleration is equal to the maximum ground acceleration that occurred during earthquake shaking at a location.
MMI	Modified Mercalli Intensity. A scale, composed of increasing levels of intensity that range from imperceptible shaking to catastrophic destruction. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects.

Contents

1. Purpose

The Induced Seismicity Management Guideline (Guideline) establishes the criteria for induced seismicity management monitoring, planning and mitigation for all exploration permit, retention licence and production licence holders or their representatives, in relation to hydraulic fracturing in the Northern Territory (NT).

The Guideline applies to on-site seismicity monitoring requirements and a traffic light monitoring system (red, amber, green) during and after a hydraulic fracturing event to monitor and mitigate against the likelihood of an induced significant 'felt' seismic event and any associated damage occurring. The data collected will also contribute to seismic risk data sets covering shale gas operations and allow for forecasts of any potential hazards or risk.

In 2022 a Ministerial Direction was issued in accordance with section 71 of the Petroleum Act 1984 (Act) to ensure that all hydraulic fracturing operations in the NT are conducted in accordance with this Guideline. The direction establishes that all relevant Well Operations Management Plans (WOMP) required by the Schedule for Onshore Petroleum Exploration and Production Requirements (Schedule) must also have an approved Induced Seismicity Management Plan (ISMP) that meets the requirements of this Guideline.

1.1 Induced seismicity

Induced seismicity refers to typically minor earthquakes and tremors that are caused by human activity that alters the stress conditions within the Earth's crust. Most induced earthquakes are of low magnitude.

Low magnitude earthquakes or tremors may occur during hydraulic fracturing. There is potential for induced seismicity to result from the uncontrolled propagation of fractures produced during hydraulic fracturing that may extend for up to several hundred metres in varying directions in the adjacent geological strata. However, the seismicity caused by hydraulic fracturing mostly has very low magnitudes and is unlikely to be felt or cause infrastructure damage, including damage to any petroleum wells, which are specifically designed to withstand the stress of hydraulic fracturing.

Induced seismicity can also be caused by geothermal energy operations, carbon capture and storage, large scale groundwater extraction, loading of artificial water reservoirs, waste water disposal wells and mining activity.

1.2 Traffic Light System

A Traffic Light System is a site-specific, real-time, risk management system with three distinct response levels. Each Traffic Light level is determined using observable criteria and triggers specific actions designed to mitigate the associated risk.

2. Induced Seismicity Management Plan (ISMP)

A petroleum interest holder must submit an ISMP to the Senior Executive Director, Energy Development Branch, Department of Industry, Tourism and Trade (DITT) for assessment at least 30 days prior to commencing hydraulic fracturing operations. An ISMP may be submitted for assessment as part of a WOMP or, where a WOMP has already been approved, as an addendum to a WOMP.

An ISMP must be approved by the Minister for Mining and Industry, or their Delegate, before hydraulic fracturing operations can commence. It is an offence not to comply with a Direction issued under section 71 of the Act. This includes failure to comply with this Guideline, or an ISMP approved in accordance with this Guideline.

An ISMP must include the following components

- Fault assessment and avoidance
  - Details and location of all known faults and geohazards.
- Monitoring and reporting
  - Details of equipment to be used;
  - Proposed location and installation of equipment relative to operations; and
  - Proposed commencement and duration of monitoring.
  - A detailed description of data collection and reporting processes
- Traffic Light System and inclusion of the trigger points included in this Guideline.
- Reporting and notification required by trigger points

2.1 Fault assessment and avoidance

The degree of faulting in an area of interest can increase the potential risk of induced seismicity. Therefore induced seismicity risk can be effectively mitigated by characterization of pre-existing geological fault structures, avoiding them during implementation of drilling and wellbore placement, and using experiences from previous operations in the region.

Petroleum interest holders are required to map the distribution and geometry of geological faults and avoid drilling and hydraulic fracturing activity in proximity of stressed faults.

If a critically stressed fault or faults are known to exist within 3 kilometres of hydraulic fracturing operations and a seismic event exceeding 0.027g PGA occurs, additional assessment requirements will be triggered.

2.2 Monitoring

2.2.1 Equipment requirements

Petroleum interest holders are required to install seismic instrumentation to monitor and record potential earthquake ground motion.

An accelerometer is a vibration sensor that measures acceleration (the rate of change of velocity) of ground motion. Data recorders are required to capture the data obtained from the accelerometer over extended periods of time.

Strong motion accelerometers and data recorders must meet the following criteria:

- Three orthogonal components
- Dynamic range: ± 2g
- Minimum detectability of 0.005 g
- Accurate Global Navigation Satellite System (GNSS) timing
- High-resolution 24-bit recording
- Sampling rate of at least 200 Hz
- Capable of continuous data recording
- Local data storage in Standard for the Exchange of Earthquake Data (SEED) format

- Capable of real-time data transmission via SeedLink protocol

It is the responsibility of the petroleum interest holder to ensure continuous seismicity monitoring during and after fracturing operations as specified in this guideline. Failure to monitor or provide required reports constitutes an offence.

2.2.2 Location and installation of accelerometers

Petroleum interest holders are required to use at least two ground motion accelerometers per common drilling well pad location area.

To reduce the potential for the noise of the operations and any other industrial activities interfering with the data gathered the accelerometers must be located at least 500 m from the common drilling well pad.

To ensure accurate detection of vibrations, the accelerometers must not be located further than 2 km from a common drilling well pad.

Site selection should take all reasonable actions to limit proximity to mechanical noise sources that may reduce the ability of the instrument to monitor induced seismicity at low levels.

Accelerometers must be installed to manufacturers' specifications at depths that allow coupling to competent rock where possible. If not using a posthole instrument, the accelerometer must be anchored to a concrete slab.

2.2.3 Monitoring requirements (duration and timing)

Localised ground motion monitoring must have commenced two days prior to starting the hydraulic fracturing operation, be maintained for the entire duration of those operations including flowback, and continue for a period of one month after completion of hydraulic fracturing operations.

If any seismic events of 0.006g or greater (g is the unit of peak horizontal or vertical ground acceleration) are detected during these periods, they must be included in the Ground Motion Monitoring Report provided to the, Energy Development Branch, DITT (see Section 2.2.4 below).

2.2.4 Data submission and reporting requirements

The titleholder must submit a Ground Motion Monitoring Report within 30 days of completing induced seismicity monitoring. The report shall include:

- Location of active wells
- A chronology of hydraulic fracturing operations
- Instrument metadata, including location of the strong-motion sensor and instrument response information
- A separate list of PGA values for seismic events exceeding 0.006g on any component
- Segmented time-series data in miniSEED format for events with PGA exceeding 0.006g. Segmented data should include at least 2 minutes of pre-event data and 5 minutes of data from the *P*-wave arrival. Continuous data for the full monitoring period may also be contributed.
- Digital time-series data of injection volumes and wellhead pressure.

The Energy Development Branch, DITT may request ground motion monitoring data at any time

2.3 Traffic Light System

2.3.1 Real time assessment of Peak Ground Acceleration (PGA) and Gravity

Building and infrastructure damage from earthquakes can generally be attributed to ground motion. Peak Ground Acceleration (PGA)[1] is a unit used in earthquake engineering and seismic hazard maps, including building codes. Unlike the Richter and moment magnitude scales, it is not a measure of the total energy of an earthquake, but rather of how hard the earth shakes at a given geographic point.

This Guideline requires continuous monitoring and real time assessment of PGA as an indicator of seismicity. Three trigger points have been identified to inform implementation of the required Traffic Light System as they relate to perceived shaking, and therefore potential for damage.

Table 1 below shows how these trigger points correlate to perceived shaking using the Modified Mercalli Intensity Scale. Table 2 describes the actions and required timeframes for implementation that must be undertaken when a seismic event exceeding 0.006g PGA is detected (perceived shaking is greater than 'light').

Table 1: Indicative PGA conversion equation to Modified Mercalli Intensity top illustrate likely perceived shaking

MMI*	Perceived Shaking	g PGA**	TLS Trigger Point
I	Not felt	0.0003	No trigger <0.006g
II	Weak	0.0014	
III	Weak	0.006	Amber trigger 0.006g – 0.027g PGA
IV	Light	0.027	
V	**Moderate**	**0.062**	**Red trigger >0.027g PGA**
VI	**Strong**	**0.12**	
VII	**Very Strong**	**0.22**	
VIII	**Severe**	**0.40**	
IX	**Violent**	**0.75**	

*MMI - Modified Mercalli Intensity
** PGA estimates are based on the PGA-MMI conversion equations of Worden et al (2012)

[1] PGAs are typically measured in units of 'g', or gravity, where g is the acceleration due to gravity of the earth.

Table 2: Required actions associated with trigger points in g PGA

Traffic light	Trigger	Required action	Notification and Reporting to Energy Development Branch
	Seismic event of > 0.027g PGA	**Immediately cease operations** Assess and, if necessary, address damage and immediate impacts If a critically stressed fault has been identified within 3 km of hydraulic fracturing operations then damage must also be assessed at the location of that fault. Do not recommence operations without DITT approval.	**Notify of the event within 2 hours.** o Report on immediate impacts and consequences **Specific Event Report within 6 hours** o Initial assessment of extent of damage o Estimated geographical extent of damage o Identify any ongoing risks related to the seismic event **Ground Motion Monitoring Report within 48 hours, including:** o Provide segmented time-series data for the event or events exceeding 0.027g PGA. o Updated assessment and geographical extent of damage and response o Updated impact assessment o Updated risk assessment o Analysis of time series data **Seismicity Mitigation Plan** o Required for assessment before continuing operations
	Seismic event of 0.006 - 0.027g PGA	**Immediately monitor for any damage to petroleum infrastructure at the site.** If damage is identified that is or may compromise integrity immediately cease operations.	If resultant damage requires cessation of operations and follow notification protocol from red category (above)**; or** **Specific Event Report within 24 hours** o Provide segmented time-series data for the event or events. o Assessment carried out on damage to petroleum infrastructure. **Ground Motion Monitoring Report as normal** o Within 30 days of completing monitoring. o Analysis of time series data
	Seismic event of < 0.006g PGA	Operations, including monitoring, continue as normal	Ground Motion Monitoring Report within 30 days of completing monitoring.

2.3.2 Red Light – Cease operations

In the event that seismic event of greater than 0.027g PGA is detected, the petroleum interest holder must immediately cease operations.

Immediately following cessation of operations, the site and surrounds must be assessed for damage and immediate impacts.

Within 2 hours of the event/events, the petroleum interest holder must notify the Energy Development Branch, DITT of the seismic event/events and provide Report on immediate impacts and consequences.

Within 6 hours of the event/events the petroleum interest holder must submit a Specific Event Report to the Energy Development Branch, DITT. This report should provide preliminary advice on the assessments that have taken place and the extent of damage that has been documented. The Report must describe any ongoing risks related to the seismic event that have been identified and what mitigative action, if any, has been undertaken.

Within 48 hours more comprehensive reporting is required in the form a Ground Motion Monitoring Report (see section 2.2.4). In addition to standard content, the Ground Motion Monitoring Report should provide updated information on assessments and findings pertaining to damage and risks. The Report must include an analysis of all time-series data relevant to the event or events.

Operations cannot be resumed until a **Seismicity Mitigation Plan** has been submitted to and approved by the Senior Executive Director, Energy Development Branch, DITT (see Section 2.3.6).

2.3.3 Amber Light – Report and monitor

In the event of seismic event between 0.006 - 0.027g PGA is detected, or a critically stressed fault is identified within 3 km of hydraulic fracturing operations, a petroleum interest holder must immediately identify any ongoing risk or damage.

If damage to petroleum infrastructure that has or could impact integrity is identified, operations must immediately cease and the protocol for a 'red light' event must be followed (refer above).

Where an amber event has not resulted in increased risk or significant damage, the petroleum interest holder must submit a Specific Event Report to the Energy Development Branch, DITT within 12 hours of the seismic event.

The Specific Event Report must include segmented time-series data for the event or events and details of the assessment that was carried out to ensure there was no ongoing risk.

A Ground Motion Monitoring Report will be required within standard timeframes, but should include an analysis of time series data.

2.3.4 Green Light – Continue operations

If seismic events are continuously less than 0.006g of PGA during an operation the petroleum interest holder can continue operations and monitoring without specific action.

2.3.5 Specific Event Reporting

In the event that an amber or red event is triggered, the petroleum interest holder is required to submit a Specific Event Report.

Specific Event Report for **an amber seismic event** that did not cause damage or increase risk must include:

- Time series data relevant to the seismic event or events that registered 0.006 - 0.027g PGA
- Details of the assessment that was carried out to ensure there was no ongoing risk.

Specific Event Report for **a red seismic event** must include:

- Time series data
- Immediate consequences
- Detail of any damage that has resulted from the seismic event, including:
  - Well integrity;
  - Nearby facilities, including petroleum surface infrastructure;
  - Building and infrastructure

In the event that revised risk levels or significant damage resulting from any seismic activity is identified in a Specific Event Report, the following may need to be reviewed and/or revised:

- Well Operation Management Plan (WOMP)
- Petroleum Surface Infrastructure Plan (PSIP)
- Well Barrier Integrity Validation Report (WBIV)
- Induced Seismicity Management Plan (ISMP)

2.3.6 Seismicity Mitigation Plan

In situations which have resulted in the requirement to cease operations, a Seismicity Mitigation Plan will need to be developed.

A Seismicity Mitigation Plan must include strategies to reduce or eliminate the initiation of additional induced seismic events and demonstrate that no aspect of the operation, including well integrity has been compromised. Where applicable, all known critically stressed faults within 3km of the hydraulic fracturing operations must be incorporated into the Seismicity Mitigation Plan.

Seismicity Mitigations Plans must be submitted to the Energy Development Branch, DITT for assessment. Operations cannot recommence until a Seismicity Mitigation Plan has been approved by the Senior Executive Director, Energy Development Branch, DITT.

2.3.7 Submission of reports and notifications

Reports and notifications must be submitted to the Energy Development Branch, DITT at:

Email: dittpetroleumoperations@nt.gov.au

Emergency telephone, including afterhours 1300 935 250

3. Publication of data

Ground Motion Monitoring Reports will be made publicly available on the DITT website.