DOI: 10.17199/NOBUGS2016.14

Safety systems at the SAFARI-1 neutron diffraction facility

J.C. Raaths, P.R. van Heerden, D. Marais, A.M. Venter

Research and Development Division, Necsa SOC Limited, PO Box 582, Pretoria, 0001, South Africa

E-mail: deon.marais@necsa.co.za

Abstract. Key safety features of the neutron diffraction facility located at the SAFARI-1 research reactor of the South African Nuclear Energy Corporation (Necsa) SOC Limited are described. This includes the interlock software systems integrated with the primary and secondary beam shutters, the verification of inadvertent entry to radiation risk areas, as well as controls of instrument movements.

1. Introduction

Personnel safety at beam line facilities at nuclear research installations are of primary importance, in conjunction with the establishment of a safe working environment and minimizing of the risk to exposure to ionizing radiation [1]. This can is achieved through robust engineering design of independent safety systems and work-safe procedures.

2. The SAFARI-1 neutron diffraction facility

The SAFARI-1 neutron diffraction facility (NDIFF) presented in Figure 1, accommodates two instruments on one reactor beam line. These instruments are the materials probe for internal strain investigations (MPISI) [2] and the powder instrument for transition in structure investigations (PITSI) [3]. All features along the primary radiation line are shared which include the in-pile collimator with its beam shaper, filtering system and the primary beam shutter (PS). From the monochromator stages on each instrument functions independently with its own instrument control system and secondary beam shutter (SS). The latter comprises two linked sections comprising respectively an *internal* part located within the monochromator chamber, and an *external* part attached to the chamber wall.

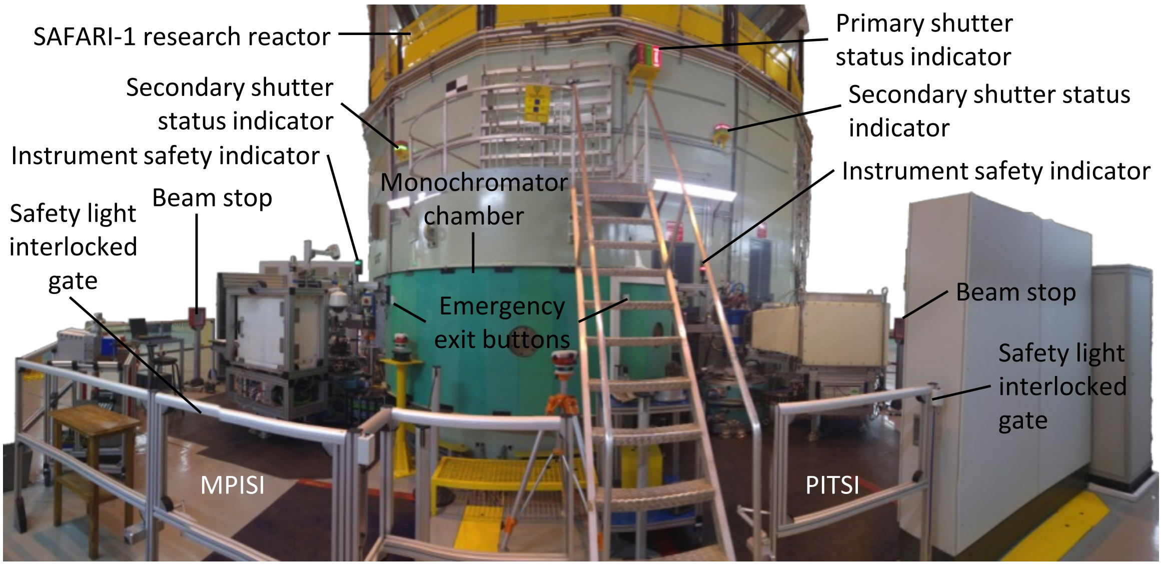


Figure 1. Photograph of the NDIFF with a number of safety systems and indicators identified.

3. Beam shutters

3.1. Shutter description

A functional safety shutter system is the primary protection against accidental exposure to ionizing radiation at beam line facilities. The material configuration of the NDIFF shutters were optimized to ensure that virtually all radiation is attenuated when the shutters are in the closed positions. The PS and internal part of the SS is a layered structure of borated polyethylene, borated aluminium and low carbon mild steel. The external part of the SS contains a 1 mm layer of cadmium and a 50 mm layer of lead.

The PS is located in the core box cavity where the biological reactor wall interfaces with the in-pile collimator. It comprises a large rotatable drum equipped with designated *closed*, *high-intensity* (100 x 60 mm^2 beam) or *high-resolution* (60 x 60 mm^2 beam) positions. It is driven by a chain linked electric motor in conjunction with a resolver that serves as status verification. The drum and chain are visible in Figure 2. The *internal* (Figure 2) and *external* (Figure 3) parts of the SS are operated through a linked pneumatic system. In the event of a power failure, air pressure to the pneumatic pistons is released and the shutters move into their closed positions under gravity, rendering this a passive safety system.

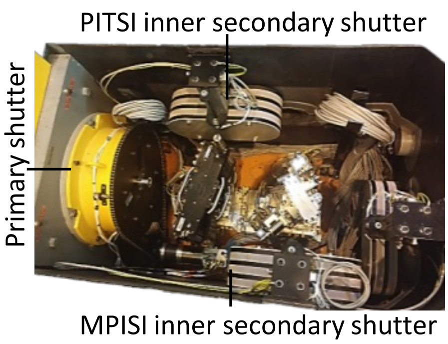


Figure 2. Photograph of the NDIFF monochromator chamber showing the *primary* and *internal* secondary shutters.

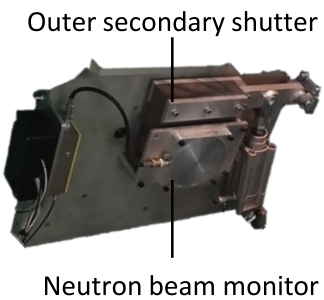


Figure 3. Photograph of an *external* secondary shutter and neutron beam monitor.

Figure 4. Photograph of the shutter control console.

3.2. Shutter control

All shutters are operated from a shared console (shown in Figure 4) located on a pedestal in the NDIFF computer room. The top row of buttons pertains to the PS, the middle to the SS of MPISI and the bottom to the SS of PITSI. Shutters can only be opened if the lockout key is in place. This minimizes the risk that the PS is accidentally opened during maintenance activities inside the chamber.

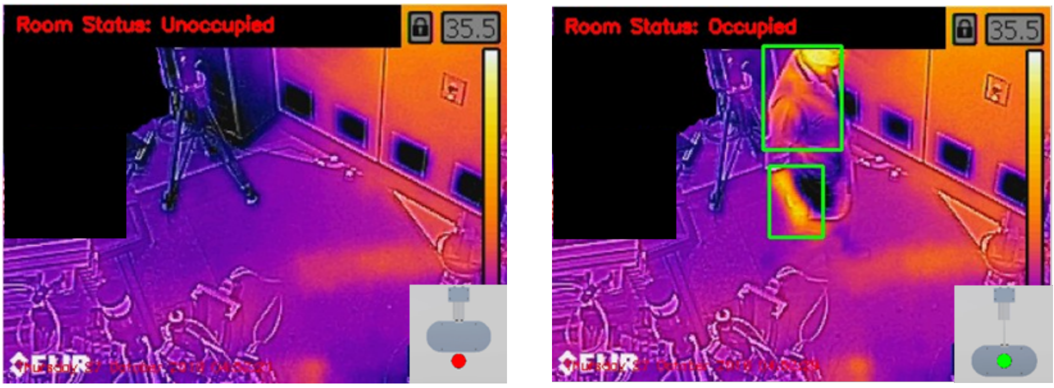
The safety system logic trees and control routines were implemented on a GALIL DMC 2280 motor controller using the GALIL command language [4]. In addition to using the shutter control console, the SS can be closed by executing a command from the instrument control software, enabling the automated closure of the shutter after completion of investigations.

An emergency button located on the motion control cabinet door is within reach from the instrument area. All motor motions are stopped and the SS is closed when this button is depressed.

3.3. Continuous monitoring system prototype

Amongst others, beam line facilities enforce *search procedure* that necessitates that strategically placed *search buttons* to verify that no person accidentally remains within the instrument area when the beam is turned on. At NDIFF, a continuous monitoring approach is employed that utilises a video camera to detect undue movement, or the use of thermal imaging, of personnel within the instrument area. In the event that a person is detected, the SS cannot be opened. In addition, upon unlawful entry into the experimental area, the SS will be closed automatically. This eliminates the need for a search procedure.

The implementation has been performed using a USB camera and a low-cost Raspberry Pi 3 microcomputer with the motion detection aspects done with Python scripts [5] utilizing the OpenCV library [6]. Functionality is also provided to mask out areas on the video frame which should be excluded the monitoring process. To reduce false positives, a thermal USB camera which is insensitive to lightning level changes can be used. Figure 5 shows selected video frames where a person entering the MPISI instrument area is detected. A flow chart of the implementation of the continuous monitoring system is given in Figure 6.



(a) (b)

Figure 5. Video frames retrieved from the continuous monitoring system showing: (a) the unoccupied instrument area; (b) the detection of a person in the area. The secondary shutter status is indicated on the bottom right section of each photograph.

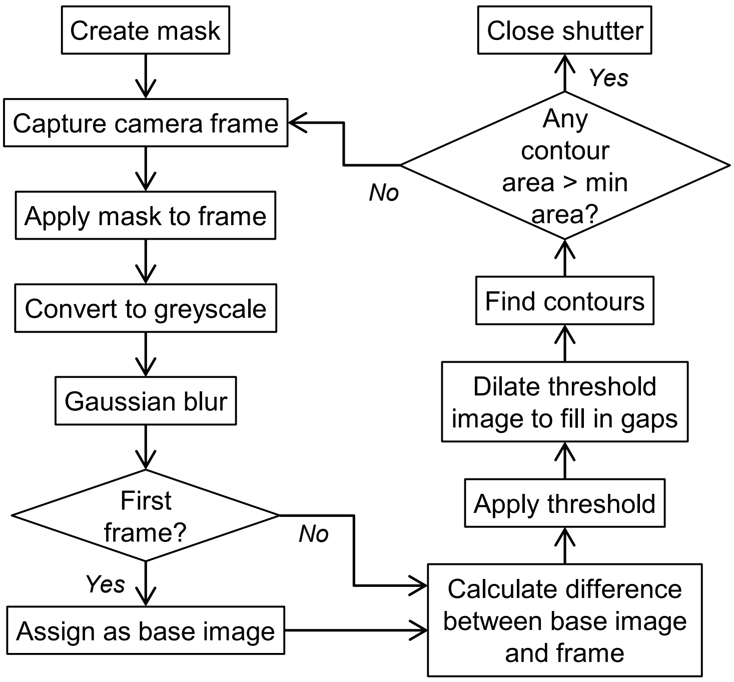


Figure 6. Flow chart of the implementation of the continuous monitoring system at the NDIFF instruments.

4. Visual displays

4.1. Facility and instrument shutter indicators

On all indicator lights, green signifies a safe condition and red an at-risk condition. The PS status indicator (Figure 7) is prominently mounted to the reactor wall and is visible from the SAFARI-1 and NDIFF control rooms. SS indicators (Figure 8) are mounted against the reactor wall above each instrument and are visible from the NDIFF computer room and the respective instrument beam stop locations. These indicators rely solely on the shutter positions and are switched through the GALIL controller.

Figure 7. Photograph of the primary shutter status indicator.

Figure 8. Photograph of a secondary shutter status indicator.

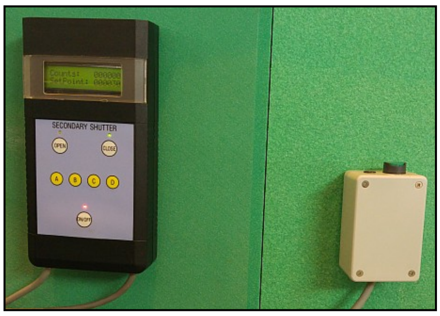
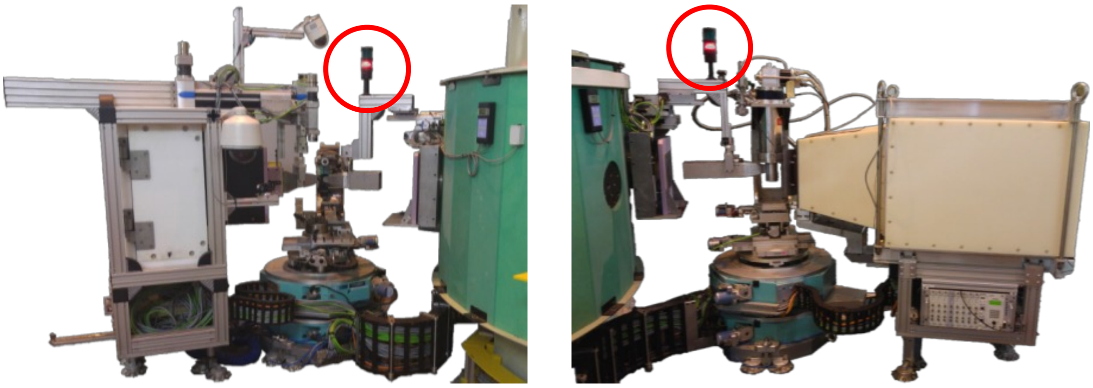


Figure 9. Interlock box and emergency exit button.

4.2. Instrument safety indicators

Each instrument also has a beam status indicator mounted at eye level at the respective beam exit ports as shown in Figure 10. The indicator status is controlled by an interlock box (Figure 9) containing a C programmed dsPIC30F6012 microcontroller using the neutron beam monitor counts directly and will only switch the safety indicator to a safe condition if the neutron count rate is below a pre-determined threshold and the SS is in the closed position.



(a) (b)

Figure 10. Photographs of (a) MPISI and (b) PITSI, highlighting the safety indicators.

5. Gate interlock system

To restrict unauthorized access to the instrument areas during operation, each instrument is enclosed with a fence and interlocked gate. The gate is controlled by the interlock boxes and magnetically locked when the SS are opened and the neutron count subsequently exceeds a threshold value.

In the inadvertent situation that a person enters the monitor area, the gate can be unlocked using an emergency exit button located on the chamber wall. This unlocks the gate for 5 seconds after which the lock is reactivated. Maintenance entry is possible by depressing a button located on the gate for 25 seconds that unlocks the gate for 5 seconds where after the lock is reactivated.

6. Motion interruption

6.1. Motor limit switches

Numerous motorized motion stages exist on both instruments to enable the positioning of the detectors at a specific diffraction angle, as well as the translation of beam apertures and the sample on the goniometer table. All motions pose a risk of damaging the instrument during collisions, or cause injury to inattentive users. Limit switches, which stops all motion once activated, constrain movements within the envisaged work envelope. In addition, beam apertures are mounted on knuckles equipped with contact breakers which stop all motions in the event that the aperture is accidentally crashed into during sample translations.

6.2. Emergency stop buttons

Each instrument is equipped with an emergency motion stop button that is attached to the sample table. This intervention proved to be convenient for sample setup since it enables suspension of motion when a desired sample position has been reached. Emergency stop buttons are also present on the shutter control console inside the NDIFF computer room as well as on the instrument control software graphical user interface, Gumtree [7].

7. Beam stops

Due to the open workspace in the reactor hall, it is of utmost importance to ensure that the neutron beam is contained to the instrument area. Since the primary beam is well collimated and the beam size restricted, a relatively small beam stop shown in Figure 11 is adequate to ensure capture of the transmitted beam. The beam stop is constructed from a 25 mm thick borated polyethylene (5wt% boron) sheet sandwiched between two 5 mm thick sheets of 95% ^{10}B enriched borated aluminium 1100 Alloy (4.5wt% boron) on the beam side and a 16 mm mild steel sheet on the back side.

The effectiveness of the beam stops are summarized in Table 1.

Figure 11. Photograph of an NDIFF instrument beam stop

Table 1. Effective neutron and gamma dose rates in the beam path measured when scattering from the Si (331) monochromator plane

	Dose rate [μSv/h]	
Position	Neutrons	Gammas
Beam port	*470*	*318*
Front of beam stop	*333*	*277*
Behind beam stop	*2.3*	*10.9*

8. Conclusion

Every effort has been made to ensure that the neutron diffraction facility adheres to best practices to ensure the safety of personnel. Reliable software at neutron facilities is not only important for data acquisition, control, analysis and visualisation, but also for safety systems.

References

[1] South Africa 2006 National nuclear regulator act (Act no 47 of 1999): on safety standards and regulatory practices (Government notice no. R388) *Government gazette* 28755, 28 April

[2] Necsa SOC Limited, MPISI - Materials Probe for Internal Strain Investigations, http://www.necsa.co.za/Products-and-Services/Research/Facility-and-Instrument-characteristics/MPISI, Date of access: 27 September 2016

[3] Necsa SOC Limited, PITSI - Powder Instrument for Transition in Structure Investigations, http://www.necsa.co.za/Products-and-Services/Research/Facility-and-Instrument-characteristics/PITSI, Date of access: 27 September 2016

[4] Galil Motion Control Inc. 2011 DMC-2x00 User Manual Rev 2.1 California

[5] Rosebrock A 2015 Home surveillance and motion detection with the Raspberry Pi, Python, OpenCV, and Dropbox, http://www.pyimagesearch.com/2015/06/01/home-surveillance-and-motion-detection-with-the-raspberry-pi-python-and-opencv/, Date of access: 27 September 2016

[6] Itseez Open Source Computer Vision Library, https://github.com/opencv/opencv, Date of access: 27 September 2016

[7] Hugh Rayner H, Hathaway P, Hauser N, Fei Y, Franceschini F and Lam T 2006 *Physica* B **385-386** 1333-1335