DEPARTMENT OF ASTRONOMY
The University of Wisconsin-Madison
475 N Charter Street
Madison Wisconsin 53706-1582
Telephone: (608) 262-3071
FAX: (608) 263-6386
http://www.astro.wisc.edu

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PROJECT:	**SOUTHERN AFRICAN LARGE TELESCOPE ROBERT STOBIE SPECTROGRAPH NEAR INFRARED INSTRUMENT**
DOCUMENT TITLE:	**SYSTEM FMEA**
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APPROVALS:

AUTHOR:

_____ Da_____

Tom D ke
afety M nag

ENGINEE G:

_____ Da_____

Don Thielman
System Engineer

QUALITY:

_____ Date:_____

Tom Demke
Quality Assurance

PROJECT:

_____ Date:_____

Mark Mulligan
Project Manager

REVISION HISTORY:

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1.0 PURPOSE

This FMEA was conducted to review potential hazards and failure mechanisms associated with the SALT Near Infrared Spectrograph; develop a plan to mitigate those hazards and issues; track the mitigations to closure and document those activities.

2.0 SCOPE

The document addresses failures that can result in safety and quality (performance) related issues. Because it discusses safety items, it acts as the hazard analysis for the NIR system.

3.0 REFERENCES

The following documents were used to define the system/subsystem/component operation/use, potential hazards/issues, assess the severity/probability/detectability of the hazards, determine mitigations or justify analysis.

3501AA0001.xls – FMEA Table

3501AA0001.doc – FMEA Summary, Meeting Notes

4.0 DEFINITIONS

4.1 **FMEA** – Failure modes and effects analysis.

4.2 **NIR** – Near Infrared Spectrograph

4.3 **Quality-Related Issues** – Any failure or operational process that results in decreased performance, functionality, reliability, uptime or mean time to failure, or require increased levels of service or maintenance.

4.4 **Safety-Related Issues** – Any failure or operational process that results in potential injury to staff or by-standers, potential injury to indigenous flora/fauna, has a deleterious affect on the environment where the unit is operated or can significantly damage system or nearby equipment.

4.5 **SALT** – Southern African Large Telescope

4.6 **UW-SSEC** – University of Wisconsin-Madison, Space Science & Engineering Center

5.0 RESPONSIBILITIES

5.1 **NIR Management** is responsible for the ensuring an adequate safety assessment of the NIR system is completed and mitigations are implemented appropriately.

5.2 **NIR Engineering or SSEC QA** is responsible for the generation and maintenance of this document.

5.3 **NIR Development Staff** is responsible for ensuring that the system is designed to be tested, installed, used and maintained in safe manner.

5.4 **SALT Facility Staff** is responsible for ensuring the NIR system is operated and maintained in a safe manner.

5.5 **SSEC QA** is responsible for ensuring that this document is created, reviewed, approved, maintained and changed per SSEC processes.

6.0 SUMMARY OF POTENTIAL HAZARDS

6.1 The following potential hazards were reviewed as a part of this analysis:

- Chemical
- Electrical
- Environmental
- Fire
- Mechanical
- Optical
- Pneumatics
- Suspended Masses
- Thermal
- Use

6.2 Statistical Summary Of Risk Mitigation

Risk Reduction	# Of Hazards	# Of Quality Issues
Total Potential Issue/Cause Combinations	77	10
Major Risk Reduced to Moderate:	1	0
Major to Minor:	18	0
Moderate to Moderate:	0	0
Moderate to Minor:	48	10
Minor to Minor:	10	0
# Mitigated to Minor:	64	10
# Justified:	1	0
# Unmitigated (or Minor to Minor):	10	0
# Eliminated:	2	0
Total Issues	87	

6.3 Justifications For Not Reducing The Risk On Moderate Risk Issues

The following issues were assessed as having moderate risk. Review of these issues indicated that no additional mitigation was required as described below. Justifications for not mitigating a potential issue can include:

a) Additional mitigation may introduce additional or more serious risk.

b) It may be cost prohibitive to implement additional mitigation.

c) It may be technologically difficult to implement additional mitigation.

d) Standard work practices should be adequate to identify the issue prior to its manifestation.

Item #	Issue/Cause	Justification
2.10	Accidental contact with HV to etalon	There may be circumstances where the HV needs to be on during servicing. In these cases, interlocks to disable the HV will need to be defeated. The safety of the servicer is then dependent on the safety training the servicer has received and implementation of safe work practices, which may be completed differently by different people.

6.4 Status Of The Hazard Analysis (choose one of the following)

CLOSED – The potential hazards have been assessed, actions determined and all mitigations/rationale have been completed.

***IMPLEMENT* – The potential hazards have been assessed, actions determined, but not all mitigations/rationale have been completed. 66 issues; 91 actions remain open.**

REVIEW – The assessment has been started, but not all hazards or mitigations have been identified, or the scoring has not been completed.

REOPEN – This analysis has been previously closed. However, design change or new information has been made available that necessitates reevaluation of the potential hazards associated with this system, subsystem or component.

6.4.1 The following information needs to be compiled as evidence that the issues described in this FMEA have been appropriately mitigated.

Item	Evidence	Completed/ Attached
1	**Preventive Maintenance (PM):**	
	• Verify NIR, tracker, facility & other equipment are adequately grounded @ PM	• 2.4. 2.5, 2.6
	• No loose cables, cables wire-ties or in cable wrap	• 2.11
	• Inspect optical elements for dust or debris	• 3.7, 3.8
	• No sharp edges from manufacturing or broken equipment	• 5.1, 5.2
	• Verify integrity of pneumatic line & fittings	• 7.1
	• Check all fasteners are securely fastened	• 8.6
	• Check for coolant leaks	• 9.3
2	**Verification Plan:**	
	• Verify heat transfer fluid compatible w/ components it contacts	• 1.1, 1.5
	• Verify index matching fluids compatible w/ lens & other items they	• 1.2

Item	Evidence	Completed/ Attached
	contact	
	• Verify hygroscopic lenses are buffered from atmosphere by dry index matching fluids, other lenses or purged dry air	• 1.3
	• Verify cryotiger gas is compatible w/ instrument materials it contacts	• 1.4
	• Test EMI emissions & susceptibility	• 3.1, 3.2, 3.3, 3.4
	• Verify operation of thermal control system	• 3.5
	• Verify operation of humidity sensors	• 3.6
	• Verify operation of moisture reduction system	• 3.6
	• Verify optical elements are enclosed or purged to prevent dust or debris from settling on them	• 3.7. 3.8
	• Verify operation of overtemperature shutoffs	• 4.10, 4.11
	• Verify load capacity of tracker	• 5.14
	• Verify stray light from LED's on boards cannot affect images	• 6.6
	• Verify articulation bearing is rated for the load	• 8.7
3	**Design Safety Inspection:**	
	• Verify heat transfer fluid is non-toxic or handling procedures are in place	• 1.6
	• Verify index matching fluid is non-toxic or handling procedures are in place	• 1.9
	• Verify cryotiger cooling gas does not present a hazard if a leak occurs	• 1.7
	• Verify cryotiger gas routed away from hot objects	• 4.5
	• Verify purge gas is dry air rather than N_2 or O_2 monitoring is available near purge area	• 1.8
	• Proper termination of all wires	• 2.1
	• Guards present on electrical connections > 36V	• 2.1
	• Verify cables are properly sized for V, A, temp & bend radius	• 2.2, 2.3, 2.13
	• Connectors are keyed or labeled to prevent misconnection	• 2.7, 2.8, 2.14
	• Interlock to disable 1000v to etalon when enclosure opened	• 2.10
	• No loose cables, cables wire-ties or in cable wrap	• 2.11, 2.13, 4.6
	• Electrical equipment protected from chemicals	• 2.12
	• Verify use of UPS on temperature & humidity controls	• 2.15
	• Overcurrent protection of electrical circuits	• 4.7
	• Verify crimps and cable terminations are acceptable	• 4.8
	• Motor selection suitable for applicable	• 4.9
	• Motor protection trip limits are acceptable	• 4.9
	• Verify that coolant is non-flammable or not routed near hot objects	• 4.1, 4.2
	• Verify non-flammable materials or materials not near hot objects	• 4.3, 4.4
	• No sharp edges due to manufacturing	• 5.1
	• No sharp edges due to broken equipment	• 5.2
	• Fan guards present of thermo electric cooler fans	• 5.3
	• Verify mechanical lock of tracker mechanism	• 5.4
	• Verify safety lockout on enclosure	• 5.6
	• Captive screws & panels for normally serviced parts	• 5.8
	• Verify mechanism to lock filters & gratings into magazines	• 5.13
	• Watch-dog timers to prevent unintended motion of NIR during service	• 5.16
	• Hardware safety limits to prevent unintended motion of NIR during service	• 5.16
	• Mechanical lockouts to prevent unintended motion of NIR during service	• 5.16
	• Motion limiters to prevent unintended motion due to motor failure	• 5.17
	• Verify mechanism to lock camera drive during servicing	• 5.18
	• Verify use of eyesafe lasers for aligning instrument	• 6.3
	• Verify presence of guides & pins for installation	• 8.4

Item	Evidence	Completed/ Attached
	• Verify "HOT" labels are affixed near thermoelectric coolers • Verify cryotiger is enclosed in temperature cooled cabinet • Verify pre-dewar chiller is enclosed in temperature cooled cabinet • Verify all cold parts are enclosed to prevent inadvertent contact	• 9.1 • 9.2 • 9.3 • 9.4
4	**Installation Safety Inspection:** • Verify NIR, tracker, facility & other equipment are adequately grounded @ installation • No loose cables, cables wire-ties or in cable wrap • No sharp edges from manufacturing or broken equipment • Create installation inspection checklist • Verify cables & hoses are routed to prevent tripping or running into	 • 2.4, 2.5, 2.6 • 2.11 • 5.1, 5.2 • 5.9, 8.4, 8.5 • 10.1, 10.2
5	**Engineering Evaluations/Analyses:** • Verify crane capacity for lifting RSS w/ margin • Verify rigging capacity for lifting RSS • Verify lift points w/ safety margin • Verify load capacity of installation guides & pins • Verify articulation bearing is rated for load of RSS	 • **DONE 3/12/09** – 8.1 • 8.1 • 8.2 • 8.4 • 8.7
6	**Procedures:** • Installation procedure • Installation procedures for filters, etalons, gratings & masks • Service procedure for etalon • Screen or netting to catch falling objects during service • Tether filters, etalons, gratings, masks during changeout • Use only experienced staff for aligning instrument • Use only experienced staff for cutting masks* • Use only experienced staff to calibrate instrument • Use only experienced riggers for lifting* • Mark supports that cannot be used for tie-offs or harnessing	 • 2.8, 5.9, 8.4, 8.5 • 5.10, 5.11, 5.12 • 2.10 • 5.7, 5.8, 5.10, 5.11, 5.12 • 5.10, 5.11, 5.12 • 6.3 • 6.4 • 6.5 • 8.3 • 10.5
7	**Training:** • Lockout/tagout training • 2 person rule when etalon must be worked on live • Pinchpoints between: • RSS & Tracker • Filters/gratings/etalons & NIR during installation & positioning • NIR hardware during rotation • Vis & NIR when moved separately • Tethering tools during service to prevent tools from falling • No working under a service area • No working under a suspended mass • Outside of thermoelectric coolers hot to touch • Servicers wear harnesses/fall restraints when working off the ground	 • 2.9 • 2.10 • 5.4 • 5.5 • 5.6 • 5.15 • 5.7, 5.8 • 5.7, 5.8, 5.10, 5.11, 5.12 • 8.1, 8.2, 8.3 • 9.1 • 10.4
8	**Personal Protective Equipment:** • O_2 monitor for cleaning optics w/ dry CO_2 or handling N_2 purge gas • Provide protective eyewear for cutting masks* • Servicers wear harnesses/fall restraints when working off the ground	 • 1.8, 1.10 • 6.4 • 10.4

* - This action may be a requirement on the SALT facility staff rather than NIR staff.

6.5 Issues - None

7.0 RECORDS

The following records shall be maintained:

7.1 FMEA spreadsheet.

7.2 Records that close mitigations (where applicable), such as:

7.2.1 Test results.

7.2.2 Analyses.

7.2.3 Training agendas and attendance.

7.2.4 Assembly, installation, operation and service instructions.

FAILURE MODES EFFECTS ANALYSIS

System: Near Infrared Spectrograph

Author: T. Demke

ITEM	POTENTIAL HAZARD	FAILURE CAUSE	INITIAL RISK Sev	Prob	Det	RPN	Failure Class	MITIGATION	RESIDUAL RISK Sev	Prob	Det	RPN	EVIDENCE	REQUIREMENTS	STATUS	COMMENTS
NEAR INFRARED SPECTROGRAPH (NIR)																
1.1	CHEMICAL - Incompatability	Heat transfer fluid used in glycol cooling loop incompatible with instrument	2	6	2	24	S	Verify cooling loop mix and additives are compatible with all materials that they comes in contact with.	1	6	1	6	Verify compatibility of cooling loop fluid		Open - evidence	
1.2		Lenses and index matching fluids	4	6	1	24	Q	Verify that all of the index matching fluids are compatible with the lenses and other materials that they come in contact with.	1	6	1	6	Verify compatibility of index matching fluid		Open - evidence	
1.3		Hygroscopic Lens materials	3	6	1	18	Q	Verify that all hygroscopic lenses are buffered from the atmosphere by dry index matching fluids, other lenses or purged dry air.	1	6	1	6	Verify hygroscopic lenses are protected		Open - evidence	
1.4		Cryotiger gas is incompatible with optics or other NIR materials	3	6	1	18	Q	Verify the cryotiger gas is compatible with the instrument materials it will contact	1	6	1	6	Verify compatibility of cryotiger gas		Open - evidence	How complicated & costly is this to implement?
1.5		Heat transfer fluid in pre-dewar cooling loop is compatible with instrument	3	6	1	18	Q	Verify the heat transfer fluid is compatible with the instrument materials it will contact	1	6	1	6	Verify compatibility of heat transfer fluid		Open - evidence	
1.6	CHEMICAL - Toxicity	Heat transfer fluid used in cooling loops toxic to users	3	3	2	18	S	Verify the material is non-toxic or handling procedures are in place	3	2	2	12	Verify heat transfer fluid is non-toxic		Open - evidence	If the material is non-toxic the residual risk is 1, 3, 2. If handling procedures are used, then the residual risk is 3, 2, 2.
1.7		Cryotiger cooling gas leak	3	3	2	18	S	Verify the cryotiger cooling gas does not present a hazard in case of a leak.	1	3	2	6	Verify handling procedures for cryotiger gas		Open - evidence	
1.8		Purge gas asphyxiation	4	4	2	32	S	Verify the purge gas is dry air, and not N2. If any N2 is used, O2 monitoring must be used when working in the enclosure.	1	4	2	8	Add O2 monitoring for N2 purge gas		Open - evidence	If air is used the residual risk is 1, 4, 2. If N2 is used with an oxygen monitor, then the residual risk is 4, 2, 1.
1.9		Index matching fluid leaks from bladder	3	3	2	18	S	Verify the material is non-toxic or handling procedures are in place	3	2	2	12	Verify index matching fluid id non-toxic		Open - evidence	If the material is non-toxic the residual risk is 1, 3, 2. If handling procedures are used, then the residual risk is 3, 2, 2.
1.10		Dry CO_2 cleaning of optics	4	4	2	32	S	O2 monitoring must be used when cleaning the optics w/ dry CO2.	4	2	1	8	See 1.8	See 1.8	CLOSED	Probably would need to be completed every 2 years.
1.11		Lens coupling fluid potentially toxic	3	3	2	18	S	The proposed lens coupling fluid is nonflammable	0	0	0	0	Eliminated		ELIMINATED	Cargille Laser Liquid (cat # 20109) is proposed.
2.1	ELECTRICAL - Shock	Exposed connections / terminals	4	4	2	32	S	Proper termination of all wires, and guards where there are live connections >36 VAC or VDC.	4	1	2	8	Inspect for guards on connections > 36 V		Open - evidence	
2.2		Cable failure	4	2	3	24	S	Proper cable selection with respect to voltage, current, temperature, and bend radius.	4	1	3	12	Verify cables rated for use and load		Open - evidence	
2.3		Underrated cables	4	2	3	24	S	See 2.2	4	1	3	12	See 2.2	See 2.2	CLOSED	
2.4		Inadequate ground	4	3	3	36	S	Design, installation verification	4	2	1	8	Verify the NIR, tracker, facility & other equipment are adequately grounded together at installation & PM		Open - evidence	Detectable through electrical measurements
2.5		Ground for tracker & NIR at different potentials	4	3	3	36	S	Verify the NIR, tracker, facility & other equipment are adequately grounded together at installation & PM	4	2	1	8	See 2.4	See 2.4	CLOSED	Detectable through electrical measurements

FAILURE MODES EFFECTS ANALYSIS

System: Near Infrared Spectrograph

Author: T. Demke

ITEM	POTENTIAL HAZARD	FAILURE CAUSE	INITIAL RISK				Failure Class	MITIGATION	RESIDUAL RISK				EVIDENCE	REQUIREMENTS	STATUS	COMMENTS
			Sev	Prob	Det	RPN			Sev	Prob	Det	RPN				
2.6		Ground for NIR & facility at different potentials	4	3	3	36	S	Verify the NIR, tracker, facility & other equipment are adequately grounded together at installation & PM	4	2	1	8	See 2.4	See 2.4	CLOSED	Detectable through electrical measurements
2.7		Misconnected connectors	4	2	3	24	S	Connector selection, Labeling and Keying of connectors.	1	2	1	2	Verify connections are keyed or labeled		Open - evidence	
2.8		Cables connected to incorrect input power	4	2	3	24	S	Connector selection, Labeling and Keying of connectors. Installation procedures.	4	2	1	8	See 2.7		CLOSED	
2.9		Power left on during maintenance	4	5	2	40	S	Lockout/tagout procedure	4	3	1	12	Safety training		Open - evidence	
2.10		Accidental contact with HV (1000-2000 V) to etalon	4	4	3	48	S	Interlocks to disable power when enclosure opened. Special procedures and 2 person rule when etalon must be worked on live.	4	2	2	16	1) Verify interlock to disable etalon power when enclosure opened 2) Safety training		Open - evidence	We may need to construct a table showing the power that each electrical component receives & what needs to be interlocked to prevent accidental contact with hazardous voltages
2.11	ELECTRICAL - Short	Loose cable	4	2	2	16	S	Design, PM	4	2	1	8	1) Installation inspection 2) Preventive maintenance plan		Open - evidence	
2.12		Contact with fluids / chemicals	4	2	2	16	S	Design - location (cables located above hoses) or protected	4	2	1	8	Verify electrical cables are protected from fluid handling hoses		Open - evidence	
2.13		Cable failure	4	2	2	16	S	See 2.2, proper stress relief and termination of all cables.	4	1	2	8	Verify cables are properly terminated & have adequate stress relief		Open - evidence	
2.14		Misconnected connectors	4	2	2	16	S	See 2.7	1	2	1	2	See 2.7	See 2.7	CLOSED	
2.15	ELECTRICAL - Major Power Failure	Temperature and humidity become uncontrolled.	2	6	2	24	Q	UPS	2	3	2	12	Verify UPS used on temperature & humidty controls		Open - evidence	
3.1	ENVIRONMENTAL - EMI/C	Emissions from NIR affects other equipment	1	2	4	8	S	EMI filters as needed, Test during build-up, installation, and comissioning.	1	2	3	6	See 3.4	See 3.4	CLOSED	
3.2		Emissions from NIR affects itself	1	2	4	8	S	EMI filters as needed, Test during build-up, installation, and comissioning.	1	2	3	6	See 3.4	See 3.4	CLOSED	
3.3		NIR susceptible to emissions from other equipment	1	2	4	8	S	EMI filters as needed, Test during build-up, installation, and comissioning.	1	2	3	6	See 3.4	See 3.4	CLOSED	
3.4		Uncontrolled motor motion due to EMI	3	3	4	36	S	EMI filters as needed, Test during build-up, installation, and commissioning.	2	2	3	12	1) Verification testing 2) EMI filters as needed		Open - evidence	
3.5	ENVIRONMENTAL - Temperature	Excessive heat or cold	2	4	2	16	Q	No safety issues expected as a result of heat or cold. System design & thermal system conditions instrument.	2	1	2	4	Verify operation of thermal system	Don	Open - evidence	System design & thermal system conditions instrument, and will prevent critical components from operating when they are outside of their operating ranges.
3.6	ENVIRONMENTAL - Humidity	High dew point conditions	3	3	3	27	Q	Humidity sensors in the system monitor dew point conditions. Moisture reduction system for make-up & purge air.	3	1	2	6	Verify operation of humidity sensors & moisture reduction system	Don	Open - evidence	
3.7	ENVIRONMENTAL - Particulates	Dust settles on optical elements	3	4	2	24	Q	Optical elements enclosed, air around elements purged or PM	3	2	2	12	Preventive maintenance plan		Open - evidence	

FAILURE MODES EFFECTS ANALYSIS

System: Near Infrared Spectrograph **Author: T. Demke**

ITEM	POTENTIAL HAZARD	FAILURE CAUSE	INITIAL RISK				Failure	MITIGATION	RESIDUAL RISK				EVIDENCE	REQUIREMENTS	STATUS	COMMENTS
			Sev	Prob	Det	RPN	Class		Sev	Prob	Det	RPN				
3.8		Particulates from motors, bearings & gears settle on optical elements	3	4	2	24	Q	Air around elements purged or PM	3	2	2	12	See 3.7		CLOSED	
4.1	FIRE - Flammable chemicals	Coolant exposed to hot components due to leaking connector for tubing	3	3	2	18	S	Coolant non-flammable or not routed near hot objects	3	1	2	6	Installation inspection to verify coolant is not routed near hot objects		Open - evidence	If non-flammable then residual risk is 0, 0, 0. If addressed by spacing the residual risk is 3, 1, 2.
4.2		Coolant exposed to hot components due to failed tubing	3	3	2	18	S	Coolant non-flammable or not routed near hot objects	3	1	2	6	See 4.1	See 4.1	CLOSED	If non-flammable then residual risk is 0, 0, 0. If addressed by routing the residual risk is 3, 1, 2.
4.3	FIRE - Flammable materials	Materials exposed to hot components	3	3	2	18	S	NIR constructed out of non-flammable materials or materials not near hot objects	3	1	2	6	Verify components are non-flammable or not routed near hot objects		Open - evidence	If non-flammable then residual risk is 0, 0, 0. If addressed by spacing the residual risk is 3, 1, 2.
4.4		Device constructed with flammable or combustible materials	3	3	3	27	S	NIR constructed out of non-flammable materials or materials not near hot objects	3	1	2	6	See 4.3	See 4.3	CLOSED	If non-flammable then residual risk is 0, 0, 0. If addressed by spacing the residual risk is 3, 1, 2.
4.5		Cryotiger gas potentially flammable	3	3	3	27	S	Route away from hot objects	3	1	2	6	Installation inspection to verify cryotiger gas is not routed near hot objects		Open - evidence	Per the MSDS, the PT-13, -14, -16, -30 refrigerant used in the CryoTiger contains a high % of methane, ethane & propane
4.6		Lens coupling fluid potentially flammable	2	3	3	18	S	The proposed lens coupling fluid is nonflammable	0	0	0	0	Eliminated		ELIMINATED	Cargille Laser Liquid (cat # 20109) is proposed.
4.7	FIRE - Electrical	Short	3	3	3	27	S	See 2.13	3	2	2	12	See 2.13	See 2.13	CLOSED	
4.8		Electrical equipment failure due to overcurrent	3	3	3	27	S	Proper circuit protection elements.	3	1	1	3	Verify proper circuit protection on system		Open - evidence	
4.9		Poor crimp or electrical cable terminations	3	3	3	27	S	Workmanship, selection of cables & terminations	3	1	2	6	1) Assembly inspection 2) Verification testing		Open - evidence	
4.10		Motor failure	3	3	3	27	S	Proper selection of motor size and protection trip limits.	3	1	2	6	1) Motors sized for use 2) Motors have torque or current limits		Open - evidence	
4.11		Cooling system fails	3	3	2	18	S	Over temperature cut-outs.	3	1	2	6	Verify operation of overtemp cut-outs		Open - evidence	
4.12		Thermal runaway	3	3	2	18	S	Over temperature cut-outs.	3	1	2	6	See 4.10	See 4.10	CLOSED	
5.1	MECHANICAL - Cuts	Sharp edges due to manufacturing	3	3	3	27	S	Workmanship & inspection	3	1	2	6	Assembly inspection		Open - evidence	
5.2		Sharp edges due to equipment breaking	3	4	2	24	S	Design & PM	3	2	2	12	Preventive maintenance plan		Open - evidence	
5.3		Contact w/ thermoelectric cooler fans	3	3	2	18	S	Fan guards present	3	1	1	3	Assembly inspection		Open - evidence	
5.4	MECHANICAL - Pinch / entrapment	Between RSS & base/track during installation & service	3	4	1	12	S	Mechanical lock-up of mechanism during servicing.	3	1	1	3	Verify mechanical lock of tracker mechanism		Open - evidence	
5.5		Between filters/gratings/etalons & NIR structure during positioning/use	3	3	1	9	S	None; should be an obvious pinch point	3	3	1	9	None	None	CLOSED	

FAILURE MODES EFFECTS ANALYSIS

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ITEM	POTENTIAL HAZARD	FAILURE CAUSE	INITIAL RISK				Failure Class	MITIGATION	RESIDUAL RISK				EVIDENCE	REQUIREMENTS	STATUS	COMMENTS
			Sev	Prob	Det	RPN			Sev	Prob	Det	RPN				
5.6		Between NIR hardware during rotation	3	3	1	9	S	Safety lock-out switches on enclosure.	3	2	1	6	Verify safety lockout on enclosure		Open - evidence	
5.7	MECHANICAL - Falling objects	Tools dropped during installation or maintenance	4	3	2	24	S	Tether tools; screen or netting; no working under service area	4	2	1	8	1) Tether tools 2) Safety training		Open - evidence	
5.8		Components/NIR dropped during installation or maintenance due to improper handling	4	3	2	24	S	Captive screws and panels on normally serviced components; see 5.7	4	2	1	8	1) Verify captive screws and panels on normally serviced components; 2) See 5.7		Open - evidence	
5.9		Components/NIR dropped during installation or maintenance due to improper installation	4	3	2	24	S	Proper installation procedures & installation inspection	4	1	2	8	Installation inspection		Open - evidence	
5.10		Filters, etalons, gratings dropped during change out	4	3	2	24	S	Proper installation procedures. Cassette for filters and gratings; See 5.7	4	2	1	8	1) Proper installation procedures. 2) Cassette for filters and gratings; 3) Tether units during change out. 4) See 5.7		Open - evidence	
5.11		Filter or grating cassette dropped during change out	4	3	2	24	S	Proper installation procedures; See 5.7	4	2	1	8	See 5.10	See 5.10	CLOSED	
5.12		Masks dropped during change out	4	3	2	24	S	Proper installation procedures; See 5.7	4	2	1	8	See 5.10	See 5.10	CLOSED	
5.13		Fliters or gratings slip out of magazine during change out	4	3	2	24	S	Mechanicals locks on filters & gratings in magazines	4	1	2	8	1) Verify mechanism to lock filters & gratings into magazines		Open - evidence	
5.14		Too much weight on tracker during installation results in staff or equipment falling due to tracker failure	4	6	3	72	S	Verify load capacity of tracker	4	1	3	12	Verify load capacity of tracker		Open - evidence	
5.15	MECHANICAL - Trauma	Articulation of Vis & NIR separately caused pinch/entrapment point	3	3	3	27	S	Safety training	3	2	2	12	Safety training		Open - evidence	
5.16		Unintended motion of NIR during service/installation/use due to software failure	3	3	4	36	S	Watch-dog timers, Mechanical lock-outs, Current or torque limits on motors	4	1	2	8	1) Verify mechanical lockouts available on NIR 2) Verify current or torque limits on motors		Open - evidence	Motion does not move as commanded such as it (1) moves faster than expected, (2) moves in the wrong direction, (3) does not stop when commanded, or (4) starts moving when not commanded to do so
5.17		Unintended motion of NIR during service/installation/use due to motor failure	3	3	3	27	S	Design, motion rate limiters	4	1	2	8	By design		Open - evidence	
5.18		Camera drive mechanism fails during service/installation/use causing runaway motion	3	3	4	36	S	Locking mechanism for camera drive	3	1	4	12	1) Verify mechanism to lock camera drive during servicing		Open - evidence	
6.1	OPTICAL - Exposure to fibreoptic light (communication cables from computers to instrument)	Direct view of light from cable during installation / calibration / service / maintenance	2	2	2	8	S	Unlikely to cause severe eye damage	2	2	2	8	Unlikely to cause severe eye damage based upon article from The Fiber Optic Association.		CLOSED	
6.2		Fibreoptic cable breaks allowing light to be viewed directly by by-stander	2	2	2	8	S	Unlikely to cause severe eye damage	2	2	2	8	See 6.1	See 6.1	CLOSED	
6.3	OPTICAL - Exposure to laser light	Exposure to lasers used to align instrument in lab	4	6	2	48	S	Experienced personnel; eye safe lasers	4	1	2	8	1) Experienced staff used for aligning instrument 2) Verify use of eyesafe lasers		Open - evidence	Probably a Class 1 or 2 laser.
6.4		Exposure to laser cutter operations w/ gold plated masks	4	6	2	48	S	Experienced personnel; protective eyewear	4	1	2	8	1) Experienced staff for cutting masks 2) PPE		Open - evidence	

FAILURE MODES EFFECTS ANALYSIS

System: Near Infrared Spectrograph

Author: T. Demke

ITEM	POTENTIAL HAZARD	FAILURE CAUSE	INITIAL RISK Sev	Prob	Det	RPN	Failure Class	MITIGATION	RESIDUAL RISK Sev	Prob	Det	RPN	EVIDENCE	REQUIREMENTS	STATUS	COMMENTS
6.5	OPTICAL - Exposure to UV radiation	Exposure to UV radiation source used to calibration the instrument	4	4	2	32	S	Experienced personnel	4	1	2	8	Experienced staff to calibrate instrument		Open - evidence	
6.6	OPTICAL - Stray light	LED's on boards produc stray light that can affect images	2	6	2	24	Q	Boards containing LED's are enclosed to prevent stray light from being emitted	2	1	2	4	Verify stray light from boards cannot affect images		Open - evidence	
7.1	PNEUMATICS	Pneumatic line fails	2	3	3	18	S	PM	2	1	2	4	Preventive maintenance schedule		Open - evidence	This line runs from the basement to the RSS & may be used to drive air cylinders to move filters, gratings, etalon & maybe open latches. Probably 70-80 psi. Issue is not likely to result in direct serious injury, although injury due to surprise or recoil is possible
8.1	SUSPENDED MASSES - NIR or RSS dropped in handling	Crane or rigging failure	4	3	3	36	S	Verify crane capacity is capable of lifting the NIR w/ a margin of safety; do not work under suspended masses; verify rigging capacity	4	1	2	8	1) **DONE 3/12/09** - Verify crane capacity 2) Verify rigging capacity 3) Safety training		Open - evidence	Per e-mail dated 3/12/09, Ockert stated the lifting capacity of the dome crane is 1000 kg.
8.2		Improper attachment or lifting - inadequate lift points	4	3	3	36	S	Determine lift points through analysis with a margin of safety; do not work under suspended masses	4	1	2	8	1) Load analysis on lift points 2) Safety Training		Open - evidence	
8.3		Improper attachment or lifting - lifting procedure not followed	4	3	3	36	S	Use only persons experienced in lifting; do not work under suspended masses	4	1	2	8	1) Only use persons experienced in lifting 2) See 8.2		Open - evidence	
8.4	SUSPENDED MASSES - RSS falls into telescope	RSS attached incorrectly (installation procedure not followed)	4	3	3	36	S	Installation guides & pins	4	1	2	8	1) Verify presence of guides to position & pins to secure RSS during installation 2) Verify load capacity of guides & pins		Open - evidence	
8.5		Mounting loosens due to fasteners not torqued adequately	4	3	3	36	S	Installation procedure & inspection	4	1	2	8	1) Installation procedure 2) Installation inspection		Open - evidence	
8.6		Mounting loosens due to vibration	4	3	3	36	S	PM	4	1	2	8	Preventive maintenance plan		Open - evidence	
8.7		Articulation bearing not rated for load	4	3	3	36	S	Verify that articulation bearing is rated for load	4	1	1	4	Verify articulation bearing is rated for the load		Open - evidence	
9.1	THERMAL - Contact burn	Outside of thermoelectric coolers hot to touch	2	6	2	24	S	Safety training; labels	2	2	2	8	1) Apply labels near hot surfaces 2) Safety training		Open - evidence	
9.2		Cryotiger hot	2	6	2	24	S	Enclosed in temperature controlled cabinet	2	2	2	8	Verify unit installed in temperature controlled cabinet		Open - evidence	
9.3		Pre-dewar chiller hot	2	6	2	24	S	Enclosed in temperature controlled cabinet	2	2	2	8	Verify unit installed in temperature controlled cabinet		Open - evidence	
9.4	THERMAL - Cold to touch	Contact with cold components	2	6	2	24	S	All cold parts enclosed; only worked on warm	2	1	2	4	Verify all cold components are enclosed		Open - evidence	Exception: The mask is the only component that could be cold; however, it should be cold at non-injurious temperatures.
10.1	USE - Contact	Tripping on cables or hoses	2	6	1	12	S	Routing: (1) away from walking paths, (2) suspended above head height	2	1	2	4	Installation inspection		Open - evidence	
10.2		Running into cables or hoses	2	6	1	12	S	Routing: (1) away from walking paths, (2) suspended above head height	2	1	2	4	See 10.1	See 10.1	CLOSED	

FAILURE MODES EFFECTS ANALYSIS

System: Near Infrared Spectrograph

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ITEM	POTENTIAL HAZARD	FAILURE CAUSE	INITIAL RISK				Failure	MITIGATION	RESIDUAL RISK				EVIDENCE	REQUIREMENTS	STATUS	COMMENTS
			Sev	Prob	Det	RPN	Class		Sev	Prob	Det	RPN				
10.3	USE - Slipping	Coolant leaks from equipment onto floor	3	3	3	27	S	PM to check for leaks	3	2	2	12	Preventive maintenance plan		Open - evidence	
10.4	USE - Falling	Falling from system during servicing (such as climbing over unit)	4	6	1	24	S	Servicers wear harnesses	4	1	1	4	Personal protective equipment		Open - evidence	
10.5		Equipment can't support person during installation or servicing	4	6	2	48	S	Mark supports that are no to be used for tie-offs or harnessing	4	1	2	8	Mark supports that are no to be used for tie-offs or harnessing		Open - evidence	Typically, this issue would be given a 3 for detectability. However, the servicer would be working suspended above of the ground. Therefore, they should be aware that they need to be secure at all times to prevent a fall.