Part 21 (PAR) Event # 51907

Rep Org: ROTORK CONTROLS, INC.	**Notification Date / Time:** 05/04/2016 14:56	(EDT)
Supplier: JOHNSON ELECTRIC	**Event Date / Time:** 01/25/2016	(EDT)
	Last Modification: 05/04/2016	
Region: 1	**Docket #:**	
City: ROCHESTER	**Agreement State:** Yes	
County:	**License #:**	
State: NY		

NRC Notified by:	PATRICK SHAW	**Notifications:** FRED BOWER	R1DO
HQ Ops Officer:	DONG HWA PARK	MIKE ERNSTES	R2DO
Emergency Class:	NON EMERGENCY	NICK VALOS	R3DO
10 CFR Section:		JOHN KRAMER	R4DO
21.21(d)(3)(i)	DEFECTS AND NONCOMPLIANCE	PART 21/50.55 REACTORS	EMAIL

PART 21 - ANOMALY RELATED TO MICRO SWITCHES

The following report was received via email:

"Based on test data, Rotork believes an unsafe condition may exist as defined under 10CFR21. The adhesive formulation used for the construction of V12 and K5 safety related micro switches was altered by the switch maker's sub-supplier. K5 switches have no reported failures, but are affected because of construction. The altered adhesive formulation outgases an insulating material at elevated temperatures, which coats the switch contacts as it cools, and can prevent the conduction of electricity."

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To: NRC Operations Center **From:**

Fax: (301) 815- **Pages:** (Including Cover Page)

Phone: (585) 770-1019 **Date:** 05/04/2016

Re: **CC:**

☐ Urgent ☐ For Review ☐ Please Comment ☐ Please Reply ☐ Please Recycle

Dear Sir/Madame,

Please find attached a Part 21 notification from Rotork Controls Inc. concerning safety related micro-switches

Part Nos and description:

N69-921 , U12/3252
N69-926 , K5/3252
N69-838 , K5/3252-A2

Also included is Rotork engineering report ER857.

Sincerely
Patrick A Shaw
Quality Assurance Manager.

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U.S. Nuclear Regulatory Commission,
Washington, DC 20555-0001

From: Patrick A. Shaw, P.E
To: NRC Operations Center
Date: May 4th 2016

Subject: Rotork Controls Inc. Part 21 Notification, concerning V12 [Pt No N69-921] and K5 [N69-838 & N69-926] safety related micro switches

Dear Sir/Madame,

On January 25th 2016 Rotork Controls Inc. opened a formal Part 21 investigation into an anomaly reported by Duke Energy from testing conducted at Kinectrics in Canada. The anomaly related to Basic micro switches incorporated within Rotork safety related NA1E range electric actuators; also referred to as electric Valve Operators. The anomaly description was "switches failed to change state [Pt No N69-921]" and was observed after ten (10) days of thermal aging at 125 Centigrade (257 Fahrenheit).

On March 18th 2016 Rotork wrote to the U.S. NRC requesting a 40 day extension to the 60 day investigation period permitted under 10CFR21 (Ref. Event No ML16088A087).

Based on test data, Rotork believes an unsafe condition may exist as defined under 10CFR21. The adhesive formulation used for the construction of V12 and K5 safety related micro switches was altered by the switch maker's sub-supplier. K5 switches have no reported failures, but are affected because of construction. The altered adhesive formulation outgases an insulating material at elevated temperatures, which coats the switch contacts as it cools, and can prevent the conduction of electricity.

The anomaly onset is a function of temperature and time. The anomaly may occur when a switch is maintained above 90°C (194°F) for an extended period of time, and then subsequently cooled below 65°C (150)°F (see Rotork Engineering Report ER857 for details). Based on Rotork's NCR data this anomaly has not been reported by any U.S. NRC licensed operator. The anomaly is not observed at normal operating temperatures. Furthermore, all switches are expected to function normally while at elevated temperatures (i.e. above 65°C (150°F)). The concern is limited to accident design based events that include heating above 90°C (194°F) and subsequent cooling below 65°C (150°F). Tests described within report ER857 suggests the anomaly has a lower limit of 90°C (194°F) (i.e. the switch is expected to function normally if the temperature is maintained below 90°C (194°F)). To assist the industry with risk assessment, the report includes tests performed using temperature time accident

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profiles provided by the industry. The extent of condition affects switches manufactured from 2007 to 2015, inclusive. Product supplied prior to this date was tested and did not exhibit the anomaly.

Below is a summary in accordance with 10CFR Part 21.21(d)(4), which includes a list of all supplied actuators and spare components containing V12 and K5 switches affected by this notification.

Sincerely

Patrick A. Shaw, P.E
Quality Assurance Manager
Tel (585) 770-1019
Patrick.Shaw@rotork.com

Robert Arnold, P.E
President

Required information as per 10CFR Part 21.21(d)(4) follows:

(i) *Name and address of the individual or individuals informing the Commission.*

Patrick A. Shaw, P.E.
Rotork Controls Inc,
675 Mile Crossing Blvd,
Rochester, New York
14624

(ii) *Identification of the facility, the activity, or the basic component supplied for such facility or such activity within the United States which fails to comply or contains a defect.*

Rotork part number N69-921 Micro-Switch V12/3252 (RS104) and N69-926 Micro-Switch K5/3252 (RS378) and N69-838 Micro-Switch K5/3252-A2 (RS366) manufactured by Johnson Electric (Formerly Burgess) from 2007 to 2015.

(iii) *Identification of the firm constructing the facility or supplying the basic component which fails to comply or contains a defect.*

Rotork Controls Ltd
Brassmill Lane
Bath, England
BA1 3JQ

(iv) *Nature of the defect or failure to comply and the safety hazard which is created or could be created by such defect or failure to comply.*

The supplier (Johnson Electric) incorporates a small amount of adhesive in each switch's construction to secure the two halves of the switch housing together. The specified adhesive & hardener are AY103 & HY951, respectively. Both are provided to Johnson Electric by Huntsman. To comply with legislation concerning toxicity, Huntsman altered the formulation and renamed the adhesive AY103-1; the HY951 is unaltered. This change was not formally communicated by Huntsman and the modified adhesive name was not noticed by Johnson Electric.

The altered adhesive formulation outgases at elevated temperatures and deposits an insulating material layer onto the switch internal electrical contacts as it cools (see Rotork Engineering Report ER857 for specifics). The deposit of insulation material results in contact resistances exceeding the supplier acceptance criteria of 25mΩ max, the industry 500mΩ max acceptance criteria and in some cases causes an open circuit.

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(v) *The date on which the information of such defect or failure to comply was obtained.*

January 25th 2016

(vi) *In the case of a basic component which contains a defect or fails to comply, the number and location of these components in use at, supplied for, being supplied for, or may be supplied for, manufactured, or being manufactured for one or more facilities or activities subject to the regulations in this part.*

V12 switch list

Order	Part	Qty	Description	Customer_PO	Project
3S5818 formally B40993010301	NA/3S581801	1	14NA 1EFA14A N WTU 2021VNO	RSP35818 (RCI SERVICE) / 00108308 (DUKE)	CATAWBA
B38669	NA/B3866901	1	16NA 1 FA14A N WTU 2023VNO	00051126	MCGUIRE
B38773	NA/B3877301	3	30NAX 1 FA16A N WTU 2023VNO	00078626	CATAWBA
B38786	NA/B3878601	1	16NA 1 FA14A N WTU 2023VNO	00079069	MCGUIRE
B38854	NA/B3885401	1	90NA 1 FA30A N WTU 2021VNO	00080357	MCGUIRE
B38854	NA/B3885402	1	7 NA 1 FA10A N WTU 2023VNO	00080357	MCGUIRE
B38945	NA/B3894501	3	16NA 1 FA14A N WTU 2023VNO	00081992	MCGUIRE
B38945	NA/B3894502	5	7 NA 1 FA10A N WTU 2023VNO	00081992	MCGUIRE
B38963	NA/B3896301	6	11NA 1 FA10A N WTU 2023VNO	00082321	MCGUIRE
B39003	NA/B3900301	2	90NA 1 FA30A N WTU 2021VNO	00083027	CATAWBA
B39315	NA/B3931501	1	70NAX 1 FA25A N WTU 2021VNO	00087663	CATAWBA
B39400	NA/B3940001	1	40NA 1 FA25A N WTU 2023VNO	00088722	MCGUIRE
B39435	NA/B3943501	1	14NA 1 FA14A N WTU 2021VNO	00089037	CATAWBA
B39475	NA/B3947501	1	30NA 1 FA16A N WTU 2023VNO	00089808	MCGUIRE
B39693	NA/B3969301	6	16NA 1EFA14A N WTU 2023VNO	00092438	MCGUIRE
B39725	NA/B3972501	4	30NAX 1EFA16A N WTU 2023VNO	40726 (CRANE)	MCGUIRE
B39765	NA/B3976501	1	14NA 1 FA14A N WTU 2021VNO	00093385	CATAWBA
B39836	NA/B3983601	2	11NA 1 FA10A N WTU 2021VNO	00094314	CATAWBA
B39970	NA/B3997001	1	30NAX 1EFA16A N WTU 2023VNO	00096162	CATAWBA
B39974	NA/B3997401	1	11NA 1EFA10A N WTU 2021VNO	00096233	MCGUIRE
B39974	NA/B3997402	1	30NAX 1EFA16A N WTU 2023VNO	00096233	MCGUIRE
B39975	NA/B3997501	2	11NA 1EFA10A N WTU 2021VNO	00096222	CATAWBA
B39977	NA/B3997701	2	14NA 1EFA14A N WTU 2021VNO	00096249	CATAWBA
B40076	NA/B4007601	2	40NAX 1 FA25A N WTU 2021VNO	00097864	CATAWBA
B40243	NA/B4024301	2	11NA 1 FA10A N WTU 2023VNO	00099808	MCGUIRE
B40243	NA/B4024302	1	70NA 1 FA25A N WTU 2023VNO	00099808	MCGUIRE
B40312	NA/B4031201	1	30NA 1EFA16A N WTU 2023VNO	00099864	MCGUIRE

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Order	Part	Qty	Description	Customer_PO	Project
B40313	NA/B4031301	2	14NA 1EFA14A N WTU 2023VNO	00099865	MCGUIRE
B40451	NA/B4045101	2	16NA 1EFA14A N WTU 2023VNO	00102329	MCGUIRE
B40877	NA/B4087701	2	11NA 1EFA10A N WTU 2021VNO	00106558	CATAWBA
B40877	NA/B4087702	1	16NAX 1EFA14A N WTU 2021VNO	00106558	CATAWBA
B40993	NA/B4099301	4	14NA 1EFA14A N WTU 2021VNO	00108308	CATAWBA
B41029	NA/B4102901	1	30NAX 1EFA16A N WTU 2023VNO	43604 (CRANE)	MCGUIRE
B41560	NA/B4156001	3	16NA 1EFA14A N WTU 2023VNO	00115319	MCGUIRE
B41573	NA/B4157301	2	11NA 1EFA10A N WTU 2023VNO	00115417	MCGUIRE
B41573	NA/B4157302	2	40NA 1EFA25A N WTU 2023VNO	00115417	MCGUIRE
B41609	NA/B4160901	1	11NA 1 FA10A N WTU 2023VNO	00115991	MCGUIRE
B41617	NA/B4161701	1	14NA 1EFA14A N WTU 2023VNO	00116103	MCGUIRE
B41785	NA/B4178501	1	11NA 1 FA10A N WTU 2023VNO	00118959	MCGUIRE
B41910	NA/B4191001	2	16NA 1EFA14A N WTU 2023VNO	00120513	MCGUIRE
B41981	NA/B4198101	1	14NA 1EFA14A N WTU 2023VNO	00121598	MCGUIRE
B41981	NA/B4198102	1	40NA 1EFA25A N WTU 2023VNO	00121598	MCGUIRE
B42068	NA/B4206801	1	14NA 1EFA14A N WTU 2021VNO	00123289	CATAWBA
B42078	NA/B4207801	1	90NA 1 FA30A N WTU 2021VNO	00123469	MCGUIRE
B42234	NA/B4223401	2	16NA 1EFA14A N WTU 2023VNO	00126085	MCGUIRE
B42279	NA/B4227901	2	70NA 1EFA25A N WTU 2023VNO	00127067	MCGUIRE
B42279	NA/B4227902	2	11NA 1EFA10A N WTU 2023VNO	00127067	MCGUIRE
B42353	NA/B4235301	2	14NA 1EFA14A N WTU 2021VNO	00128249	CATAWBA
B42373	NA/B4237301	1	90NA 1 FA30A N WTU 2023VNO	00128425	MCGUIRE
B42457	NA/B4245701	1	40NA 1EFA25A N WTU 2023VNO	00130114	MCGUIRE
B42525	NA/B4252501	1	16NAX 1EFA14A N WTU 2021VNO	00131141	CATAWBA
B42525	NA/B4252502	1	30NAX 1EFA16A N WTU 2021VNO	00131141	CATAWBA
B42525	NA/B4252503	1	11NA 1EFA10A N WTU 2021VNO	00131141	CATAWBA
B42585	NA/B4258501	1	40NA 1EFA25A N WTU 2023VNO	00132277	MCGUIRE
B42696	NA/B4269601	1	11NA 1EFA10A N WTU 2023VNO	00133938	MCGUIRE
B42831	NA/B4283101	2	14NA 1EFA14A N WTU 2021VNO	00135938	CATAWBA
B42855	NA/B4285501	6	40NA 1EFA25A N WTU 2029VNO	97567 (FLOWSERVE)	LUNGMEN
B42868	NA/B4286801	2	11NA 1EFA10A N WTU 2023VNO	00136550	MCGUIRE
B42871	NA/B4287101	1	40NA 1EFA25A N WTU 2023VNO	00136593	MCGUIRE
B42918	NA/B4291801	1	70NA 1EFA25A N WTU 2023VNO	00137202	CATAWBA
B42918	NA/B4291802	1	40NAX 1EFA25A N WTU 2023VNO	00137202	CATAWBA
B42922	NA/B4292201	1	16NAX 1EFA14A N WTU 2021VNO	00137242	CATAWBA
B42922	NA/B4292202	1	30NAX 1EFA16A N WTU 2021VNO	00137242	CATAWBA
B42953	NA/B4295301	1	14NA 1EFA14A N WTU 2023VNO	00137763	MCGUIRE
B43608	NA/B4360801	1	11NA 1EFA10A N WTU 2023VNO	00142102	MCGUIRE

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Order	Part	Qty	Description	Customer_PO	Project
B43661	WN82398	3	NA1/5E 12SW V12 AOP1	00142224	MCGUIRE
B43946	WN82398	12	NA1/5E 12SW V12 AOP1	RSP38104	DUKE MCGUIRE
B44151	NA/B4415101	2	14NA 1EFA14A N WTU 2021VNO	00143556	DUKE CATAWBA
B44269	NA/B4426901	1	16NA 1EFA14A N WTU 2023 VNO	00143880	MCGUIRE
B45067	NA/B4506705	2	MOD3A 40NA1 C-WISE SW.MECH ASSY.	104962	OPG
B45067	NA/B4506706	2	MOD8A 12 SW WTU 2029VNO AOP1 ASSY.	104962	OPG
B45074	NA/B4507401	2	11NA 1EFA10A N WTU 2023VNO	00145881	MCGUIRE
B46016	NA/B4601601	1	14NA 1EFA14A N WTU 2023VNO	00147120	MCGUIRE
B46022	NA/B4602201	1	11NA 1EFA10A N WTU 2023VNO	00147790	MCGUIRE
B46028	WN82395	5	NA1/5E 6SW V12 AOP1	00147787	CATAWBA
B46724	NA/B4672401	1	90NA 1EFA30A N WTU 2023VNO	00148800	MCGUIRE
B46724	NA/B4672402	2	16NA 1EFA14A N WTU 2023VNO	00148800	MCGUIRE
B47288	WN82398	9	NA1/5E 12SW V12 AOP1	RSP39208 (RCI SERVICE) / 00147756 (DUKE)	MCGUIRE
B47352	NA/B4735201	1	11NA 1EFA10A N WTU 2023VNO	00150030	MCGUIRE
B47745	NA-03-102	5	NA1/5 SWITCH MECH	O11208N (RCC) / 00208959 (OPG)	OPG
B48378	NA/B4837801	8	11NA 5EF10 B4 1WN3 WTU 2021VNO	04284SR ECU CORPORATION	NOT KNOWN
B48687	NA/B4868701	1	11NA 1EFA10A N WTU 2023VNO	00152920	MCGUIRE
B48811	NA/B4881101	1	16NA 1EFA14A N WTU 2023VNO	00153320	MCGUIRE
B48925	NA/B4892501	2	11NA 1EFA10A N WTU 2021VNO	00153564	CATAWBA
B49264	NA/B4926401	1	14NA 1EFA14A N WTU 2021VNO	00154397	CATAWBA
B49369	NA/B4936901	2	11NA 1EFA10A N WTU 2021VNO	00155275	DUKE CATAWBA
B49459	NA/B4945901	1	14NA 1EFA14A N WTU 2021VNO	00155653	CATAWBA
B49620	NA/B4962001	1	MOD8A 6 SW WTU 2021VNO AOP1 ASSY.	205435	AK NUCLEAR 1
B49770	NA/B4977001	1	14NA 1EFA14A N WTU 2023VNO	00156719	MCGUIRE
B49774	WN80262	4	MOD11A 7/11NA1/4 COMP KIT POST 78	RSP41188 (RCI SERVICE) 0230945 (SEABROOK)	SEABROOK
B49774	NA-03-102	1	NA1/5 SWITCH MECH	RSP41188 (RCI SERVICE) 0230945 (SEABROOK)	SEABROOK
B49777	WN82398	6	NA1/5E 12SW V12 AOP1	RSP41660 (RCI SERVICE) / 00155079 (DUKE)	MCGUIRE
B49779	WN80262	2	MOD11A 7/11NA1/4 COMP KIT POST 78	RSP41189 (RCI SERVICE) / 02302948 (SEABROOK)	SEABROOK
B49779	NA/B4977911	1	7 NA 1 FA10A N WTU 2021VNO	RSP41189 (RCI SERVICE) / 02302948 (SEABROOK)	SEABROOK

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Order	Part	Qty	Description	Customer_PO	Project
B49779	NA/B4977912	1	7 NA 1 FA10A N WTU 2021VNO	RSP41189 (RCI SERVICE) / 02302948 (SEABROOK)	SEABROOK
B49781	NA/B4978101	1	14NA 1EFA14A N WTU 2021VNO	RSE39823 (RCI SERVICE) / 00155773 (DUKE)	CATAWBA
B49783	NA/B4978301	1	14NA 1EFA14A N WTU 2023VNO	RSE39410 (RCI SERVICE) / 00155086 (DUKE)	MCGUIRE
B49842	NA/B4984201	1	90NA 1EFA30A N WTU 2023VNO	00156967	MCGUIRE
B49890	WN80334	1	MODID 14/16NA5 G/CASE MAINT KIT POST 78	O12171N (RCC) / 00214820 (OPG)	OPG
B50131	NA-03-102	2	NA1/5 SWITCH MECH	00158579	MCGUIRE
B50641	NA/B5064101	1	11NA 1EFA10A N WTU 2023VNO	00159726	MCGUIRE
B50665	WN82398	8	NA1/5E 12SW V12 AOP1	NCR114367 (RCI) / 00157511 (DUKE)	MCGUIRE
B50775	WN81509	5	MOD3B V12 NA'E' S/M	00160864	MCGUIRE
B51199	NA/B5119901	1	14NA 1EFA14A N WTU 2023VNO	00162285	MCGUIRE
B51201	NA/B5120101	1	11NA 1EFA10A N WTU 2023VNO	00162286	MCGUIRE
B51470	NA/B5147001	1	90NA 1 FA30A N WTU 2023VNO	00163632	MCGUIRE
B51625	NA-03-102	4	NA1/5 SWITCH MECH	NU02SR748437	VC SUMMER ST
B51684	NA/B5168401	1	16NA 1EFA14A N WTU 2023VNO	00164715	MCGUIRE
B51902	NA/B5190201	2	30NAX 1EFA16A N WTU 2023VNO	00165981	MCGUIRE
B52307	NA/B5230701	1	14NA 1EFA14A N WTU 2021VNO	RSE41495 (RCI SERVICE) / 00164457 (DUKE)	CATAWBA
B52439	NA/B5243901	1	90NA 1EFA30A N WTU 2023VNO	00168826	MCGUIRE
B52790	NA/B5279001	1	16NA 1EFA14A N WTU 2023VNO	00170740	MCGUIRE
B52801	NA/B5280101	2	30NAX 1EFA16A N WTU 2023VNO	57081 CRANE NUKE	DUKE
B53470	NA/B5347001	3	7 NA 1EFA10B4 1WN3 WTU 2023VNO	890706ON	DUKE MCGUIRE
B53613	NA/B5361301	1	14NA 1EFA14A N WTU 2021VNO	00172853 (DUKE)	CATAWBA
B54087	NA/B5408701	2	30NAX 1EFA16A N WTU 2023VNO	58666	CRANE NUKE
B54177	NA/B5417701	1	14NA 1EFA14A N WTU 2021VNO	RSP46290 (RCI SERVICE) B441510101	DUKE CATAWBA
B54177	NA/B5417704	1	14NA 1EFA14A N WTU 2021VNO	RSP46290 (RCI SERVICE) / 00174477 (DUKE)	CATAWBA
B54330	NA/B5433001	1	14NA 1EFA14A N WTU 2021VNO	00177225	DUKE CATAWBA
B54444	WN82395	1	NA1/5E 6SW V12 AOP1	NCR136918 (RCI) / 00176305 (DUKE)	MCGUIRE

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Order	Part	Qty	Description	Customer_PO	Project
B54444	WN82398	10	NA1/5E 12SW V12 AOP1	NCR136918 (RCI) / 00176305 (DUKE)	MCGUIRE
B54727	NA/B5472701	2	14NA 1EFA14A N WTU 2021VNO	00179165	DUKE CATAWBA
B54727	NA/B5472702	2	14NA 1EFA14A N WTU 2021VNO	00179165	DUKE CATAWBA
B54842	NA-03-102	6	NA1/5 SWITCH MECH	00179639	CATAWBA
B56398	NA/B5639801	2	14NA 1EFA14A N WTU 2021VNO	00186461	CATAWBA
B56437	NA/B5643706	1	11NA 1EFA10A N WTU 2023VNO	RSP48672	DUKE MCGURIE
B56515	NA/B5651501	1	11NA 1EFA10A N WTU 2023VNO	00186989	DUKE MCGUIRE
B57235	NA/B5723501	1	90NA 1EFA30A N WTU 2023VNO	00189572	DUKE-MCGUIRE
B57239	NA/B5723901	3	16NA 1EFA14A N WTU 2023VNO	00189629	DUKE-MCGUIRE
B57239	NA/B5723902	1	90NA 1EFA30A N WTU 2023VNO	00189629	DUKE-MCGUIRE
B57239	NA/B5723903	1	90NA 1EFA30A N WTU 2023VNO	00189629	DUKE-MCGUIRE
B57443	NA/B5744301	3	7 NA 5EFA10B4 1WN3 WTU 2220VNO	1193547	OPG ESW STRA
B57603	NA/B5760301	1	70NAX 1 FA25A N WTU 2021VNO	00191051	CATAWBA
B57687	WN80334	1	MODID 14/16NA5 G/CASE MAINT KIT POST 78	P002240-4 (RCC) / 00286201 (OPG)	OPG
B57722	NA/B5772201	1	40NA 1EFA25A N WTU 2023VNO	00191584	MCGUIRE
B58332	NA/B5833201	2	14NA 1EFA14A N WTU 2023VNO	00193561	DUKE-MCGUIRE
B58901	NA/B5890101	1	11NA 1EFA10A N WTU 2023VNO	00195572	DUKE MCGUIRE
B59205	NA/B5920501	4	16NA 1EFA14A N WTU 2023VNO	00196629	DUKE-OCONEE
B59205	NA/B5920502	1	16NA 1EFA14A N WTU 2023VNO	00196629	DUKE-OCONEE
B59319	NA/B5931901	1	16NA 1EFA14A N WTU 2021VNO	00197087	CATAWBA
B59392	NA/B5939201	1	70NA 1EFA25A N WTU 2023VNO	00197274	DUKE MCGUIRE
B59392	NA/B5939202	1	11NA 1EFA10A N WTU 2023VNO	00197274	DUKE MCGUIRE
B59879	NA/B5987901	1	11NA 1EFA10A N WTU 2021VNO	00199184	DUKE CATAWBA
B60213	NA/B6021301	1	7 NA 5EFA10A N WTC 2021VNO	P006139 (RCI) / P1500268 (NEWMAN HATTERSLEY)	OPG
B60896	NA/B6089601	2	11NA 1EFA10A N WTU 2023VNO	03003170	MCGUIRE
B61560	WN81509	2	MOD3B V12 NA'E' S/M	03007832	CATAWBA
B61721	N69-921	6	SWITCH-M V12/3252	RSP54951 / NCR164927 (RCI SERVICE	O13962010301) OPG
B61721	NA/B6172101	1	7 NA 5EFA10A N WTC 2021VNO	RSP54951 / NCR164927 (RCI SERVICE)	O13962010301 - OPG

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Order	Part	Qty	Description	Customer_PO	Project
B61721	WN81509	1	MOD3B V12 NA'E' S/M	RSP54951 / NCR164927 (RCI SERVICE)	O13962010301 - NEWMAN HATTERSLEY - OPG
D12989	NA/D1298901	2	30NA 1 FA16A N WTC WD18016	00153869	OPG
D13140	NA/D1314001	2	30NA 1 FA16A N WTC WD18016	00159480	OPG
D13151	NA/D1315101	1	40NA 1 FA25Z N WTC WD03142	00155590	OPG
O10979	NA/O1097901	1	16NA 1EFA14A N WTC 2029VNO	P1100211 NEWMAN HATTERSLEY -	CERNAVODA
O13359	NA/O1335901	1	7 NA 1EFA10B4 1WN3 WTC 2024VNO	P1200360 (NEWMAN HATTERSLEY)	EMBALSE NPP
O13359	NA/O1335902	1	7 NA 1EFA10B4 1WN3 WTC 2024VNO	P1200360 (NEWMAN HATTERSLEY)	EMBALSE NPP
O13385	NA/O1338501	1	7 NA 5EFA10B4 1WN3 WTC 2020VNO	12-12079 (RITEPRO)	EMBALSE NPP
O13962	NA/O1396201	3	7 NA 5EFA10A N WTC 2021VNO	P1300202 (NEWMAN HATTERSLEY)	OPG
SD9393	NA/SD939302	1	MOD3A 90NA1 C-WISE SM.MECH ASSY.	216341, REPLACMENT FOR 10156515 (ENTERGY)	ENTERGY
WE2984	NA-03-102	3	NA1/5 SWITCH MECH	114800 CURTIS WRIGHT - ENERTECH,	PALO VERDE
WE3110	NA-03-102	5	NA1/5 SWITCH MECH	ESD8468N (RCC) / 00151524 (OPG)	OPG
WE3167	NA-03-102	1	NA1/5 SWITCH MECH	ESD8630N (RCC) / 00154615 (OPG)	OPG
WE3267	NA/WE326701	1	N00-03-020 NA1 SWITCH MECH	4500362690	PSEG
WE3747	NA-03-102	3	NA1/5 SWITCH MECH	ESD9023N (RCC) / 0016228 (OPG)	OPG
WE3873	NA-03-102	1	NA1/5 SWITCH MECH	ESD9070N (RCC) / 00163571 (OPG)	OPG
WE3907	NA-03-102	2	NA1/5 SWITCH MECH	4500428140	PSEG
WE3910	NA-03-102	2	NA1/5 SWITCH MECH	ED13239R (RCC)	OPG TRAINING PURPOSES PER PO,
WE4022	NA-03-102	1	NA1/5 SWITCH MECH	ESD9135N (RCC) / 00158829 (OPG)	OPG
WE4037	NA-03-102	2	NA1/5 SWITCH MECH	00098888	MCGUIRE
WE4246	NA-03-102	1	NA1/5 SWITCH MECH	SJ15871	ENTERGY

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Order	Part	Qty	Description	Customer_PO	Project
WE4396	NA-03-102	1	NA1/5 SWITCH MECH	ESD9278N (RCC) / 00168401 (OPG)	OPG
WE4869	NA-03-102	2	NA1/5 SWITCH MECH	ESD9491N (RCC) / 00173259 (OPG)	OPG
WE5621	NA-03-102	8	NA1/5 SWITCH MECH	ESD9801N (RCC) / 00181008 (OPG)	OPG
WE6060	NA-03-102	6	NA1/5 SWITCH MECH	ESD0028N/REV2 (RCC) / 00186517 (OPG)	OPG
WE6152	NA-03-102	2	NA1/5 SWITCH MECH	ESD0092N (RCC) / 00188202 (OPG)	OPG
WE6660	NA-03-102	1	NA1/5 SWITCH MECH	500546062	APS - PALO VERDE
WE6822	NA-08-706	1	NA1 6SW V12 AOPI ASS	RSP35818 (RCI SERVICE) / 00132331 (DUKE)	RCI SERVICE / CATAWBA
WE6904	WN82395	4	NA1/5E 6SW V12 AOPI	00136411	CATAWBA
WE7023	WN82395	5	NA1/5E 6SW V12 AOPI	00137764	CATAWBA
WE7085	WN82398	15	NA1/5E 12SW V12 AOPI	00138769	MCGUIRE
WE7139	WN80262	1	MOD11A 7/11NA1/4 COMP KIT POST 78	02263579	SEABROOK
WE7247	WN82398	3	NA1/5E 12SW V12 AOPI	00140435	MCGUIRE

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K5 switch list

Order	Part	Qty	Description	Customer PO	Project
B4641102	N56484	2	NA1 SWITCH MECH SPEC	O10634N (RCC) / 4503054188 (Hydro Quebec)	HYDRO QUBEC / CENTRALE GENTILLY II
B49458	WN80653	11	NA1 SW MECH K5-3252-A2	O11965N (RCC) / 00171079 (BRUCE POWER)	BRUCE POWER
B49779	NAS03B-0004	2	NA1/5 SWITCH MECH K5	RSP41189 (RCI SERVICE) / 02302948 (SEABROOK)	SEABROOK
B49524	N56484	3	NA1 SWITCH MECH SPEC	O11998N (RCC) / 1065218 (MOBILE VALVE) / 4500370878 (NEW BRUNSWICK POWER)	MOBIL VALVE / NEW BRUNSWICK POWER
B50333	WN80653	6	NA1 SW MECH K5-3252-A2	O12410N (RCC) / 00216597 (OPG)	OPG
B51532	WN80653	8	NA1 SW MECH K5-3252-A2	O12969N (RCC) / 00177514 (BRUCE POWER)	BRUCE POWER
B52075	N56484	3	NA1 SWITCH MECH SPEC	O13329N (RCC) / 00179606 (BRUCE POWER)	BRUCE POWER
B53208	NAS03B-0005	1	SWITCH MECH NA1 K5 DAP. ANNEALED RYTON	O13968N (RCC) / 00226962 (OPG)	OPG
B53575	N56484	1	NA1 SWITCH MECH SPEC	O13877N (RCC) / 00183812 (BRUCE POWER)	BRUCE POWER
B54843	N56484	3	NA1 SWITCH MECH SPEC	O14684N (RCC) / 1177461 (MOBILE VALVE) / 4500398343 (NEW BRUNSWICK POWER)	BRUNSWICK POWER
B55380	N56483	1	NA1 SWITCH BANK SPEC	P000623-1 (RCC) / 00232427 (OPG)	OPG
B56689	N56484	1	NA1 SWITCH MECH SPEC	NCR148775	NCR SPARES
B56643	NA/B5664301	5	MOD3A 90NA1 C-WISE SW.MECH ASSY.	P002330-1 (RCC) / 00235579 (OPG)	OPG
B55572	NAS03B-0005	1	SWITCH MECH NA1 K5 DAP. ANNEALED RYTON	P000918-1 (RCC) / 00233354 (OPG)	OPG
O12090	NA/O1209001	3	7 NA 5EFA10B4 1WN3 WTC 2040-NO	202546 (BRAY)	BRAY, BRUCE POWER
O14002	NA/O1400201	1	14NA 1 FA14A N WTC 2024-NO	00183784 (BRUCE POWER)	BRUCE POWER

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(vii) *The corrective action which has been, is being, or will be taken; the name of the individual or organization responsible for the action; and the length of time that has been or will be taken to complete the action.*

By this notification Rotork is informing all Utilities and listing affected customer orders. Utilities may contact their local Rotork office or the undersigned for support relating to their specific units. Rotork recommends the replacement of switches in the affected orders.

Rotork is currently evaluating options regarding replacement switches with the supply chain. The switch assembly's design will be changed by Johnson Electric so that the adhesive AY103-1 is no longer used.

(viii) *Any advice related to the defect or failure to comply about the facility, activity, or basic component that has been, is being, or will be given to purchasers or licensees.*

U.S. Licensees with installed or in storage actuators, switch mechanisms or Add-On-Pak (AOP) spares modules containing V12 and K5 switches identified in section *(vi)* should evaluate the impact of a high contact resistance or open circuit condition on safety related systems.

(ix) *In the case of an early site permit, the entities to whom an early site permit was transferred*

Not Applicable

Rotork Controls Limited

Approved by Engineering

Nuclear Engineering Report No. **ER857 Issue 1**

Date: 3rd May 2016

REVISION SHEET

ORIGIN Priyang Jadav & Patrick Shaw

DATE OF ISSUE 03/05/2016

TITLE Part 21 Investigation. Anomaly of V12 Micro-Switch N69-921.

Prepared	Checked	Approved
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Issue No	Date	Revision	By
1	03/05/16	Original	PUJ

CONTENTS

1. Summary

This report documents work performed to support a Part 21 investigation opened by Rotork Controls Inc. ref. tracking number NCR173472. Measurements and tests were performed to establish the operational reliability of Rotork safety related micro-switches. Non-compliant switches were identified from a batch manufactured in 2015 against Rotork purchase order PO128459. The investigation has confirmed that the defect is only attributed to batches received in 2007 and later.

The switch supplier (Johnson Electric) incorporates a small amount of adhesive in each switch's construction to secure the two halves of the switch housing together. The adhesive formulation was altered in 2003 by the adhesive supplier (Huntsman). Tests detailed in this report show that the altered formulation outgases at elevated temperatures and deposits an insulating material layer onto the switch internal electrical contacts as it cools.

2. Deviation description

On January 25, 2016 Rotork Controls Inc. opened a formal Part 21 investigation into an anomaly relating to a Basic micro-switch - Part No. N69-921 (RS104), description "V12". The anomaly is high resistance or loss of electrical continuity and was first observed following a customer thermal aging test of Rotork Safety Related NA Range electric Actuators; also referred to as an electric Valve Operator. Following 10 days at 125°C (257°F) a significant percentage of micro-switches in the test actuators exhibited open circuit.

Subsequent in-house testing has revealed that the anomaly also relates to Basic micro-switches with the following Part Nos. as they are constructed using the same adhesive.
N69-838 (RS366), description "K5" (screw terminals)
N69-926 (RS378), description "K5" (fast-on terminals)

Drawings of the three switches can be found in Appendix A.

3. Micro-switch function

The micro-switch has four functions:

- Rotork actuators can be set to operate to a maximum torque level of opening or closing a valve. When the torque sensing mechanism in the actuator registers this maximum torque, the micro-switch will be tripped to turn off the motor.

- Rotork actuators can also be set to operate to a maximum travel limit. The mechanism inside the actuator will register when the maximum travel in the open or close direction is reached and the micro-switch will be tripped to turn off the motor.

- In the Add-on-Pak (AOP) the switch is intended for indication purposes but can also be used for interlocks and permissives to start other equipment such as pumps and valves. AOP switches can be set to trip at any point during valve travel. The AOP can also be used for torque switch bypass. If the circuit is "open" then the MOV could stop before achieving "end of travel".

- Switches must be "closed" to initiate travel.

4. Review of orders affected

The following are details of the affected switches.

- 11000 V12 switches N69-921 supplied to Rotork against the following purchase orders.

Purchase order no.	Quantity	Rotork Lot reference	Manufacture Year
PO081139	700	LC006383	2007
	1050	LC006391	
	1500	LC006398	
	725	LC006399	
	2025	LC006402	
PO128459	183	LC010448	2015
	500	LC010464	
	700	LC010483	
	483	LC010509	
	612	LC010539	
	1	LC010540	
	639	LC010547	
	640	LC010566	
	640	LC010570	
	448	LC010576	
	154	LC010638	
	11000		

- 1900 K5 switches N69-838 supplied to Rotork against the following purchase orders.

Purchase order no.	Quantity	Rotork Lot reference	Manufacture Year
PO084220	200	LC006390	2007
PO086172	100	LC006539	
PO087057	100	LC006603	2008
PO089251	200	LC007024	
PO090778	100	LC007135	
PO092646	20	LC007254	2009
	80	LC007255	
PO095664	100	LC007450	
PO100333	100	LC007682	2010
	200	LC007693	
	240	LC008194	2011
	183	LC008250	2012
	277	LC008271	
	1900		

- 1503 K5 switches N69-926 supplied to Rotork against the following purchase order.

Purchase order no.	Quantity	Rotork Lot reference	Manufacture Year
PO106615	175	LC008192	2011
	325	LC008193	2012
	476	LC008203	
	149	LC008207	
	253	LC008233	
	125	LC008253	
	1503		

- Suspect V12 and K5 switches have date code ending with 07K to 15K stamped at the location shown below. The code refers to week (43) and year (2015).

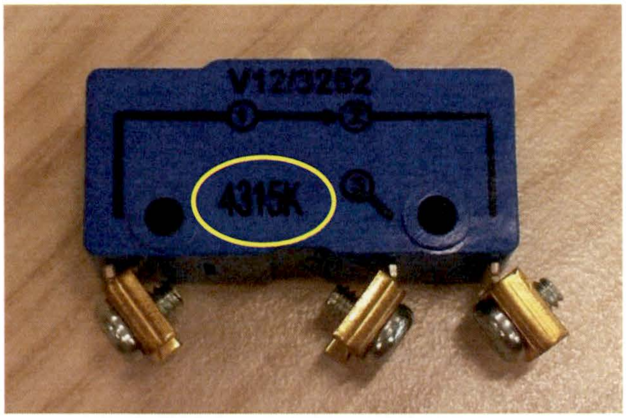


Figure 1: Location of date code on V12 switch

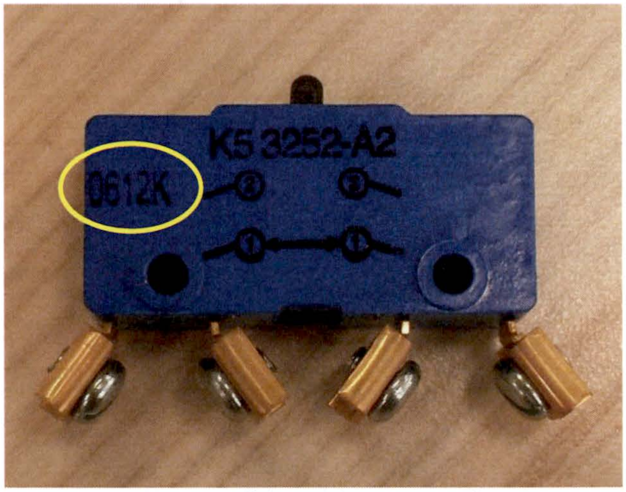


Figure 2: Location of date code on K5 switch N69-838

5. Summary of tests performed

A range of tests were conducted as part of the investigation in order to:

a. Replicate the anomaly
b. Identify root cause
c. Evaluate switches from previously supplied batches
d. Attempt salvaging defect switches
e. Experiment with alternative adhesives
f. Evaluate the effect of the anomaly on switch operation

Table 1 provides a summary of tests performed to cover points a to e above. Further details on each test are provided in subsequent sections which are referenced within the table itself. The experiments were performed using two programmable test ovens. Test switches were placed in metallic enclosures and heated to a fixed temperature for a defined time (thermal aging). The testing was destructive, and new switches and metallic enclosures were used for every test. Prior to use, the metallic enclosures were thermally cleaned to remove any volatile materials remaining from their manufacture. The metallic enclosure construction does not incorporate any non-metallic seals or non-metallic coatings.

Part f is a study of the 1) factors causing the anomaly, 2) estimated anomaly onset, and 3) switch performance under accident profiles. This work is detailed in section 9.

Test no.	Test description	No. of switches tested	Test parameters	Concentration factor (Cf)	Result	Full test details
1	Thermal aging of V12 switches manufactured in 2015.	5 switches, date code 3715K, in a metal container of volume $1680cm^3$.	5.75 days at 125°C (257°F).	$1680cm^3$ test container. $336cm^3$ per switch. Cf = 1.78	Switch anomaly occurs even when the switch is aged in isolation, therefore cause lies within the switch itself. Contamination is present on NO and NC contact rivets. UV images suggest it may be coming from adhesive.	See Section 6.2
2	Volt ramp on aged switches from Test 1.	2 aged switches taken from Test 1.	Volt ramp up to 60VDC across the NO contact with 4.3kΩ fixed resistor in series (14mA max across contacts).	N/A	Volt ramp up to 60VDC, 14mA does not reliably clean the contacts.	See Section 6.3

Test no.	Test description	No. of switches tested	Test parameters	Concentration factor (Cf)	Result	Full test details
3	Thermal aging of V12 switches manufactured in 2007.	4 switches, date code 2807K.	3.93 days at 125°C (257°F).	1680cm^3 test container. 420cm^3 per switch. Cf = 1.42	The 2007 manufactured switches exhibit the same anomaly as the 2015 switches.	See Section 6.4
4	Thermal aging of V12 contacts only.	3 switches, date code 3613K, had their NO, NC and moving contacts removed to be aged.	6 days at 125°C (257°F).	2552cm^3 test container. 851cm^3 per switch. Cf =0.70	There is no issue with the silver plating process of the rivets.	See Section 6.5
5	Post-curing of V12 switches manufactured in 2015.	6 switches, date code 4315K.	Post-cured at 125°C (257°F) for up to 8 days. Then aged inside container for 3.77 days.	245cm^3 test container. 1 switch per container. Cf =2.44	After 8 days of post-curing, outgassing still occurs causing the switch to exhibit the anomaly.	See Section 7.2
6	Thermal aging of K5 switches N69-838 manufactured in 2012.	2 switches, date code 0612K.	6 days at 125°C (257°F).	1680cm^3 test container. 840cm^3 per switch. Cf = 0.71	The K5 switch N69-838 exhibits the same anomaly as the V12. K5 N69-926 is constructed of the same glue thus is also affected.	See Section 7.3
7	Thermal aging of a switch without adhesive.	1 switch, assembled without adhesive applied.	7 days at 125°C (257°F).	245cm^3 test container. 1 switch per container. Cf =2.44	Switch performance is acceptable if no adhesive is present.	See Section 8.1
8	Thermal aging of switch assembled with Duralco 4525.	1 switch	10 days at 125°C (257°F).	245cm^3 test container. 1 switch per container. Cf =2.44	Duralco 4525 outgasses to an extent that the switch will exhibit the anomaly.	See Section 8.2

Test no.	Test description	No. of switches tested	Test parameters	Concentra-tion factor (Cf)	Result	Full test details
9	Thermal aging of switches assembled with AY105-1/HY991.	3 switches	Up to 14.2 days at 125°C (257°F).	245cm^3 test container. 1 switch per container. Cf =2.44	Switch performance is acceptable if assembled using a small quantity of AY105-1/HY991.	See Section 8.3
10	Thermal aging of switch assembled with Raychem S1264.	1 switch	10 days at 125°C (257°F).	245cm^3 test container. 1 switch per container. Cf =2.44	Switch performance is acceptable if assembled using a small quantity of Raychem S1264.	See Section 8.4
11	Thermal aging of switches assembled with X60.	1 switch	10 days at 125°C (257°F).	245cm^3 test container. 1 switch per container. Cf =2.44	X60 outgasses to an extent that the switch will exhibit the anomaly.	See Section 8.5

Table 1: Summary of tests performed

5.1. Air volume of actuator electrical enclosure

During the investigation it was observed that the air volume per switch is an important factor which needs to be considered in aging tests since it can influence the length of aging time before onset of the anomaly. Experimental data demonstrated, for a given temperature, the anomaly would manifest itself in a shorter time period when switches were placed in a smaller enclosure. This is further discussed in section 9. It is necessary to know the air volume in the actuator electrical enclosure in order to relate the test results to the application. To be conservative a small size actuator was used for the calculation, giving a worse switch to air volume ratio. Using CAD the air volume in an empty electrical enclosure was estimated to be 11960cm^3 (Figure 3).

Similarly, the volume of the switch mechanism and AOP were estimated 594cm^3 from CAD (5% of enclosure volume). It is assumed another 5% of enclosure volume is consumed by the heater, looms and other components within the enclosure. The air volume to which a small actuator fitted with a switch mechanism and 12 switch AOP would outgas to is:

$$11960 - 594 - 594 = 10772\text{cm}^3$$

The maximum number of switches available in an actuator are 18. Therefore the estimated volume of air per switch is:

$$10772/18 = 598\text{cm}^3$$

Different sizes of enclosures were utilised. Most of the tests listed in Table 1 were performed using 245ml (=245cm^3) enclosures (Figure 4). The term concentration factor (Cf) is introduced to relate the actuator air volume per switch to the test enclosure volume per switch:

$$Cf = \frac{actuator\ air\ volume\ per\ switch}{test\ enclosure\ volume\ per\ switch} = \frac{598\text{cm}^3}{245\text{cm}^3} = 2.44$$

The concentration factor for each test is also specified in Table 1.

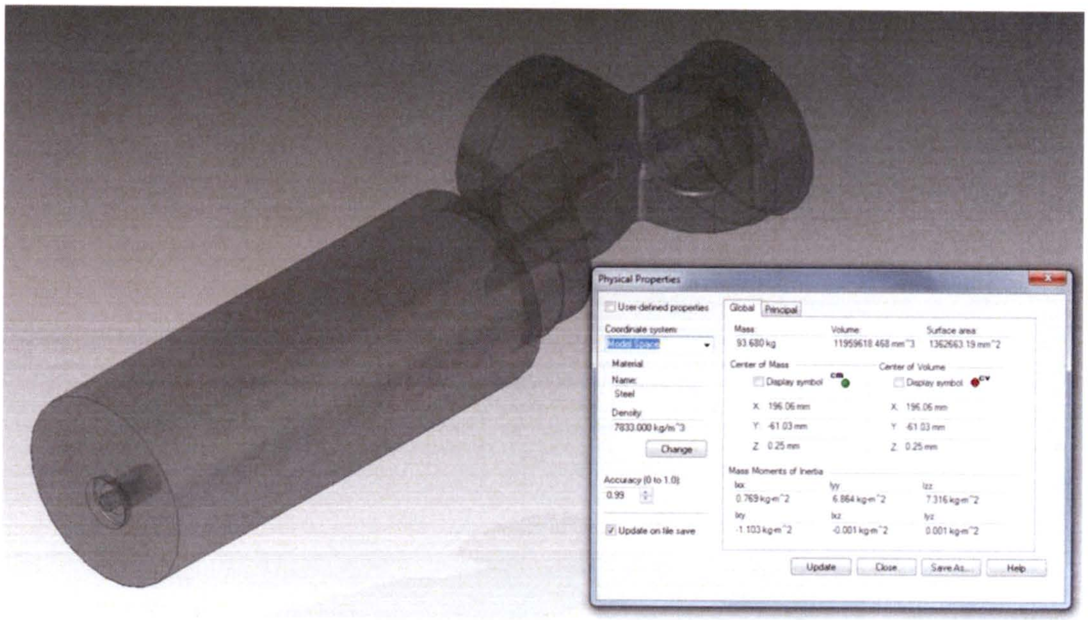


Figure 3: Air volume inside actuator electrical enclosure

Figure 4: 245ml enclosure

6. Tests replicating the anomaly

6.1. Procedure for thermal aging switches inside an enclosure

In-house thermal aging tests were performed to replicate the anomaly. The tests were performed according to the following procedure.

a) Remove screw terminals.
b) Using milliohm meter, record resistance across NC contacts. (Meter used applied 9V, 5mA max. Figure 5). Manufacturer's end-of-line acceptance level is 25mΩ max.

Figure 5: Milliohm meter

c) Operate and hold switch plunger.
d) Record resistance across NO contacts.
e) Release plunger.
f) Repeat steps b – e until 3 NC and 3 NO measurements are obtained for each switch.
g) Fasten screw terminals
h) Place switches inside a metallic container.
i) Thermally age the container at 125°C (257°F). (Total aging time varied for each test and is stated in subsequent sections of the report)
j) Once thermal aging complete, remove container from oven and allow to cool. It is important that the container remains closed until cooled so that any outgassing can condense.
k) Remove switches and repeat resistance check following steps a – g

6.2. Test 1 – 125°C (257°F) aging of V12 switches manufactured in 2015

5 switches, Rotork part no. N69-921, date code 3715K, labelled F – J, were tested following the procedure in section 6.1. A drawing of switch N69-921 is shown in Appendix A. Thermal aging time was 138 hrs (5.75 days).

Results are shown in Appendix B. Before aging, the switches were within the manufacturer's 25mΩ acceptance. After aging, the NO contacts exhibited open circuit, indicated by a dash in the result field. Switch H recovered on the second operation post-aging. A * in the result field indicates that the resistance value was fluctuating between several ohms, to hundreds of ohms, to open circuit.

Green cells identify readings below the 25mΩ manufacturer's end-of-line acceptance.
Yellow cells identify readings below the 500mΩ industry acceptance.
Red cells identify unacceptable reading.

Switch F was opened for examination of the contacts (Figure 6 - Figure 9). Blue plastic particles were formed only as a result of breaking the switch apart. A pale yellow layer appears to have formed on the surface of the NC and NO contact rivets, Figure 6 and Figure 8. At the very centre of the NC and NO rivet, i.e. the point of contact, the layer has broken away and the normal silver appearance of the rivet is visible. The white powder on the moving contact, Figure 7 and Figure 9, indicates that there was transfer of the broken layer from the stationary contacts to the moving contact.

Contacts from aged switches were observed under UV light. Figure 10 indicates the contamination is formed only on the NC and NO stationary contacts. Under UV light the contamination is a similar colour to the residue in the area where adhesive is applied, Figure 11. The conjecture for this is that the NC and NO contact tabs extend outside of the switch housing where the surrounding temperature is lower than the temperature inside the switch. Thus through loss of heat by conduction, the NO and NC contacts would cool quicker than other components enclosed within the switch housing. This would mean that the NO and NC contacts act as heat sinks causing vapours released from the adhesive to condense onto the contacts. The NC and NO stationary contacts are made from Silver-Cadmium-Oxide (AgCdO) which provides the best known performance for switching off electrical current quickly and cleanly (Ref 1).

An independent investigation was performed by an external laboratory Exova in an effort to identify the source of contamination (Section 10). However, due to differences in chemical composition between the non-metallics and the contaminant, the source could not be confirmed by analysis. Nevertheless, literature (section 7), test results of an unglued switch (section 8.1) and UV images identify the adhesive being the root cause.

<u>Summary</u>

- The V12 switch anomaly occurs even when the switch is aged in isolation, therefore the cause lies within the switch itself.
- Contamination is present on the NO and NC contact rivets, and UV images suggest it may be coming from the adhesive.

Figure 6: Switch F, NC contact rivet

Figure 7: Switch F, NC side of moving contact

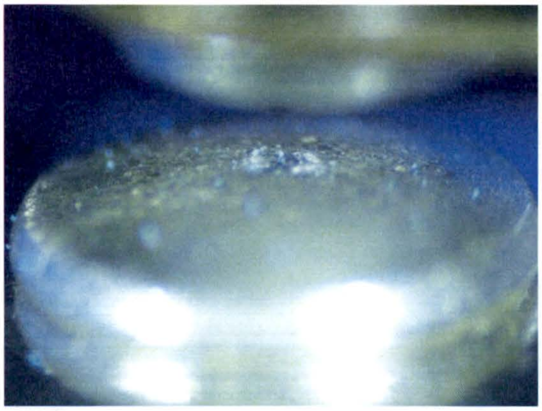


Figure 8: Switch F, NO contact rivet

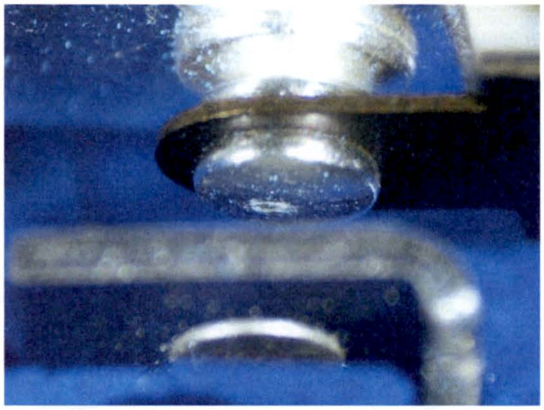


Figure 9: Switch F, NO side of moving contact

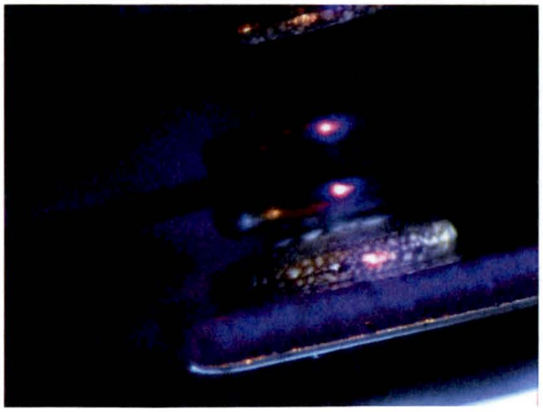


Figure 10: Contact rivets under UV light

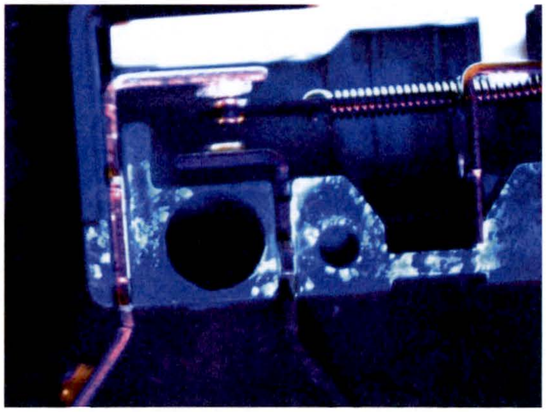


Figure 11: Separated switch housing under UV light

6.3. Test 2 – Volt ramp on aged switches from Test 1

A volt ramp up to 60VDC was performed across the NO contact of switch G, using a 4.3kΩ fixed resistor in series. Switch G maintained open circuit.

$\frac{60V}{4300\Omega} = 14mA$ max across contacts.

The volt ramp was repeated across the NO contact of switch I. At 60VDC the switch started to conduct. The plunger was released for 5 mins before repeating the test. During the second volt ramp switch I began to conduct at 27VDC.

Summary

- Volt ramp up to 60VDC, 14mA does not reliably clean the contacts.

6.4. Test 3 – 125°C (257°F) aging of V12 switches manufactured in 2007

4 switches N69-921, date code 2807K, labelled P, Q, S and T, were tested following the procedure in section 6.1. Thermal aging time was 94.25 hrs (3.93 days).

Results are shown in Appendix B. Before aging, the switches were within the manufacturer's 25mΩ acceptance. After aging, the NO contacts exhibited high resistance or open circuit. Resistance readings up to 500mΩ are generally acceptable in the industry.

Summary

- The 2007 manufactured switches exhibit the same anomaly as the 2015 switches.

6.5. Test 4 – 125°C (257°F) aging of V12 contacts only

UV images of switch internals post-aging (Figure 10) showed that the contamination is deposited only on the NO and NC contact rivets. It was thus thought that the contamination may be related to the silver plating process of the rivets.

3 switches N69-921, date code 3613K, had their NO, NC and moving contacts removed to be aged in isolation inside a metal container. The contacts were resistance checked (Figure 12) pre and post-aging. Thermal aging time was 144 hrs (6 days).

Figure 12: Resistance checks of contacts removed from switches

Thermal aging the contacts in isolation did not influence their ability to conduct current. Pre and post-aging contact resistances were 3 to 4mΩ.

The contacts were also observed under an optical microscope but there were no signs of contamination. The rivets were similar in appearance pre-aging (Figure 13) and post-aging (Figure 14).

Figure 13: Contact rivet pre-aging

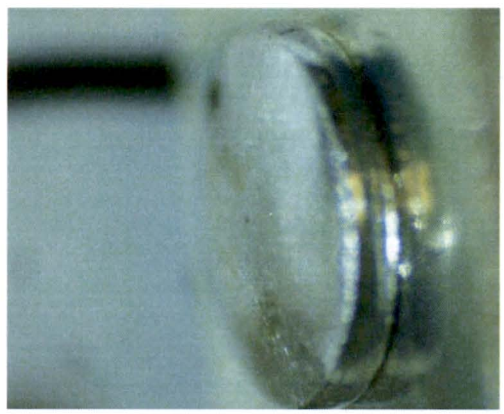


Figure 14: Contact rivet post-aging

Summary

- The results indicate there is no issue with the silver plating process of the rivets.

7. Supporting information and post-curing

A technical report on an adhesive related issue (Ref 2) in the Large Hadron Collider (LHC) provides information supporting this Part 21 investigation. Araldite AY103-1 was used in the construction of a LHC component. The component shows an outgassing effect which has been tracked back to the adhesive. Different adhesives were investigated using a setup for measuring the amount of outgassing after 24hrs aging at 125°C (257°F). The two part epoxy AY103-1 with its hardener HY951 is also used in construction of the V12 switch.

In summary the technical report states the following:

- AY103-1 is a replacement of AY103 which is no longer manufactured.
- Adhesive AY103 did not outgas but AY103-1 does.
- Higher ambient temperatures accelerate the outgassing.
- 68% of the outgas is water but the remainder isn't identified.
- Curing at 40°C (104°F) for two weeks and extracting the condensate reduces the effect.

The adhesive manufacturer, Huntsman, confirmed that AY103 was indeed withdrawn in February 2003 and replaced by AY103-1. In accordance with the 28th adaptation of the EU Dangerous Substances Directive (Directive 2001/59/EC), all products containing >0.5% DBP (Dibutyl phthalate) are to be classed toxic. AY103 would have fallen into this category therefore its formulation was changed. AY103-1 is free of DBP and phthalate esters.

Another technical paper (Ref 3) identifies the plastifiers present in the chemical makeup of the two epoxies. The report states:

- AY103 contained the plastifier dibutyl-phthalate (DBP) which is toxic.
- In the AY103-1 formulation, DBP was replaced with plastifier di-isopropyl-naphthalene (DIPN)
- The plastifier DIPN does not take part in the curing process with the hardener and is expected to remain volatile close to the surface of the hardened epoxy.
- AY105-1 is another epoxy but without any plastifier. See section 8.3 for thermal aging test results with this adhesive.

Based on technical literature, the following conjecture was formed to explain the mechanism which leads to the anomaly. The adhesive is thought to outgas at temperature releasing water vapour, and with it the gaseous plastifier. The water vapour is the carrier of the contaminating material. After thermal aging the NO and NC contacts are thought to cool first (as explained in section 6.2). The contacts thus act as a heat sink enabling water vapour to condense onto them and deposit the contaminating material.

7.1. Procedure for post-curing tests

It has been confirmed from literature that the adhesive AY103-1 used in the construction of the V12 switch outgasses. The literature also indicates that a post-curing process where the condensate is extracted during thermal aging may solve the issue. The following test procedures describes the tests performed to investigate post-curing.

a) Remove screw terminals.
b) Using milliohm meter, record resistance across NC contacts. (Meter used applied 9V, 5mA max. Figure 5). Manufacturer's end-of-line acceptance level is 25mΩ max.
c) Operate and hold switch plunger.
d) Record resistance across NO contacts.
e) Release plunger.
f) Repeat steps b – e until 3 NC and 3 NO measurements are obtained for each switch.
g) Fasten screw terminals
h) Place all switches freely in a fan assisted oven and thermally cure at 125°C (257°F). Post-curing time for each switch is different as shown in Table 2.
i) Remove each switch when its post-curing time is complete and allow to cool.
j) Repeat resistance check following steps a – g.
k) Place each switch in its own aluminium container and perform subsequent aging at 125°C (257°F) as shown in Table 2.

Switch Identification	Date code	Post-curing time at 125°C (257°F)	Subsequent aging inside container at 125°C (257°F)
1	4315K	1 day	90.5 hrs (3.77 days)
2		4 days	
3		5 days	
4		6 days	
5		7 days	
6		8 days	

Table 2: Post-curing time

l) Repeat resistance check following steps a – g.

7.2. Test 5 – Post-curing

6 switches N69-921, date code 4315K, labelled 1 to 6, were tested following the procedure in section 7.1. As detailed in the procedure and in Table 2 the switches were post-cured for different number of days up to 8 days in a fan assisted oven. Following post-curing each switch was removed, resistance checked, then placed in a separate container. The containers were further aged to see if after being post-cured each switch would still outgas and exhibit the anomaly in a closed volume of air.

Results are shown in Appendix C. Before any aging the switches were all within the manufacturer's 25mΩ acceptance. After post-curing, the NO contacts showed resistance values above 25mΩ in most operations, however, this would not affect switch performance in the field. All switches remained functional after the post-curing process. However, after further aging in containers the switches exhibited open circuit / unacceptable high resistance across the NO contacts.

Summary

- After 8 days of post-curing, outgassing still occurs causing the switch to exhibit the anomaly.

7.3. Test 6 - 125°C (257°F) aging of K5 switches manufactured in 2012

2 switches N69-838, date code 0612K, labelled 16 and 17, were tested following the procedure in section 6.1. A drawing of switch N69-921 is shown in Appendix A. Thermal aging time was 6 days.

Results are shown in Appendix D. Before aging, the switches were within the 500mΩ industry acceptance. After aging, the NO contacts exhibited high resistance or open circuit. Resistance readings above the 500mΩ acceptance level are highlighted red.

Summary

- K5 switches N69-838 exhibit the same anomaly as the V12.
- The only difference between the two types of K5 switches N69-838 and N69-926 are the contact terminals. Therefore, switches N69-926 also fall within the scope of this Part 21.

8. Tests of unglued and glued switches using different adhesives

8.1. Test 7 – 125°C (257°F) aging of a switch without adhesive

1 switch N69-921, assembled in 2016 without adhesive applied, and labelled 18, was tested following the procedure in section 6.1. Results are shown in Appendix E. After aging for 2 days at 125°C (257°F) in a container the resistance readings were still below manufacturer's acceptance. The switch was placed back into the container and aged for a further 4.96 days. This made the NO resistance higher but still acceptable for in-field use. The switch was again placed back into the container and aged for a further 3.98 days. Contact resistances remained acceptable for in-field use.

Total aging of unglued switch = 2 days + 4.96 days + 3.98 days = 10.94 days

Summary

- The switch performance is acceptable if no adhesive is present.

8.2. Test 8 – 125°C (257°F) aging of switch assembled with Duralco 4525

A switch labelled 21 was assembled using Duralco 4525 (Figure 15) and cured in a fan assisted oven for 1 hour at 121°C (250°F), as per the adhesive's datasheet. The switch was then left for 15 hours before being tested to the procedure in section 6.1.

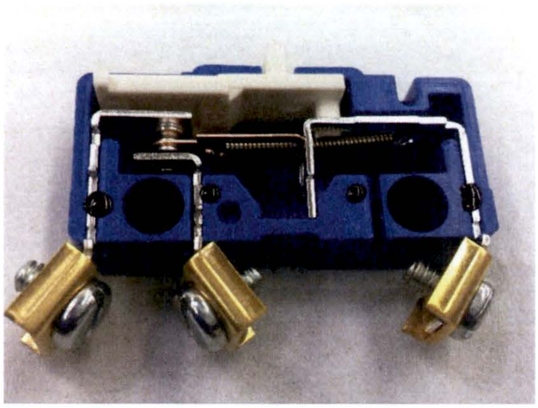


Figure 15: Switch 21, 4 drops of Duralco 4525

Results are shown in Appendix F. After being aged for 10 days at 125°C (257°F) the switch exhibited open circuit mode across the NO contacts.

Summary

- Duralco 4525 outgasses to an extent that the switch will exhibit the anomaly after 10 days aging at 125°C (257°F).

8.3. Test 9 – 125°C (257°F) aging of switches assembled with AY105-1/HY991

The Araldite manufacturer Huntsman suggested an alternative adhesive/hardener system.

Used by switch manufacturer: AY103-1/HY951
Suggested alternative: AY105-1/HY991

AY105-1/HY991 has been found to be low outgassing in NASA tests. 2 switches labelled 19 and 20 were assembled using AY105-1/HY991 and cured in a fan assisted oven for 35 mins at 60°C (140°F), as per the adhesive's datasheet. The switches were then left for 3 hours before being tested to the procedure in section 6.1.

Results are shown in Appendix G.
Switch 19 was aged for 2 days at 125°C (257°F) and remained functional.
Switch 20 was aged for 6 days at 125°C (257°F) and remained functional.

The switches were placed back into the containers and aged further.
Switch 19 was aged for a total of 14.2 days, following which the NO contact exhibited open circuit.
Switch 20 was aged for a total of 10.1 days, following which the NO contact exhibited open circuit.

It was believed that using less adhesive would reduce the effect of outgassing. Therefore, the test was repeated with switch 50, which was assembled with just 3 small droplets of AY105-1/HY991. Figure 16 and Figure 17 compare the quantity of adhesive applied to Switch 20 vs. Switch 50. With reduced amount of adhesive the switch passed the 125°C (257°F) 10 day aging test (results in Appendix G).

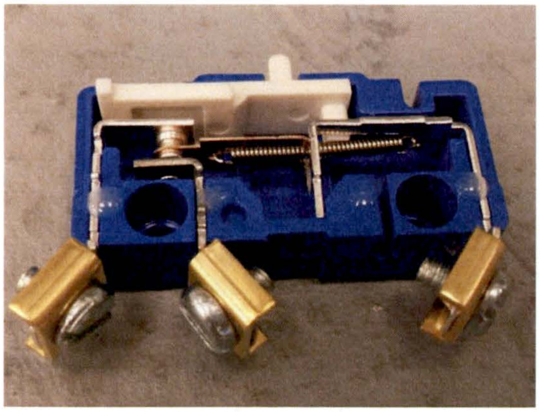


Figure 16: Switch 20, 4 drops of AY105-1/HY991

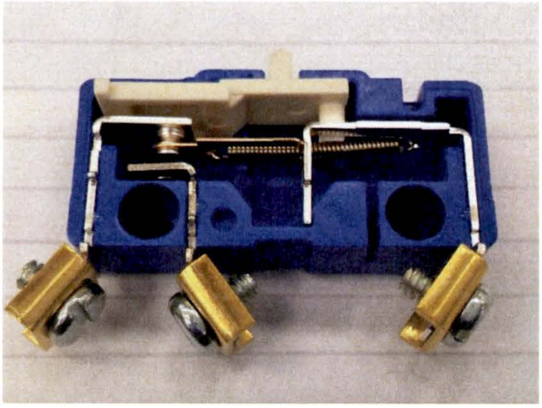


Figure 17: Switch 50, 3 small drops of AY105-1/HY991

Summary

- The extent of the anomaly is reduced by reducing the amount of adhesive used.
- AY105-1/HY991 in reduced quantity passed the 10 days aging at 125°C (257°F).

8.4. Test 10 – 125°C (257°F) aging of switch assembled with Raychem S1264

A switch labelled 49 was assembled using 3 small droplets of Raychem S1264 (Figure 18) and cured in a fan assisted oven for 1 hour at 85°C (185°F), as per the adhesive's datasheet. The switch was then left for 3 hours before being tested to the procedure in section 6.1.

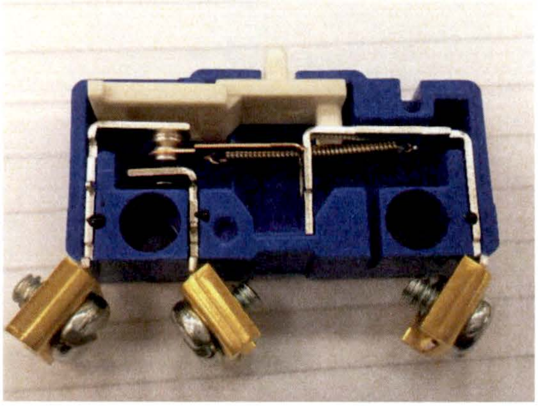


Figure 18: Switch 49, 3 small drops of Raychem S1264

The switch passed the 125°C (257°F) 10 day aging test. Results are shown in Appendix H.

Summary

- Raychem S1264 used in small quantity passed 10 days aging at 125°C (257°F).

8.5. Test 11 – 125°C (257°F) aging of switch assembled with X60

A switch labelled 59 was assembled using 3 small droplets of X60. The adhesive has a very quick cure time of 2 mins at room temperature. The assembled switch was left for 2 hours 40 mins before being tested to the procedure in section 6.1.

The switch did not pass 10 days aging test at 125°C (257°F). NO contacts exhibited open circuit. Results are shown in Appendix H.

Summary

- X60 outgasses to an extent that the switch will exhibit the anomaly after 10 days aging at 125°C (257°F).

9. Anomaly effect upon switch operation

This element of the Part 21 investigation assesses 1) factors causing the anomaly, 2) estimated anomaly onset, and 3) switch performance under accident profiles.

9.1. Factors Causing Anomaly

The anomaly is attributed to outgassing from the adhesive AY103-1/HY951 used in the switch construction, specifically meaning the migration of the plasticizer within the adhesive's phenol base material to the air volume contained within the actuator's electrical enclosure.

By review of published literature a number of papers were found on the subject of modelling outgassing expressed as mass flow rate. Most of the models have exponential forms that are functions of temperature and time with constant bases on material properties e.g. activation energy, gas constant, molecular mass etc. The reviewed papers all appeared to model outgassing to an infinite volume. In actuality the actuator electrical enclosure volume is finite and thus the partial pressure of outgassed material may influence the rate of outgassing. Experimental data demonstrated, for a given temperature, the anomaly would manifest itself in a shorter time period when switches were placed in a smaller enclosure. Based on the aforementioned it is determined the anomaly is a function of temperature, time, and electrical enclosure volume. A series of experiments were thus performed to assess these three factors.

The experiments were performed using three programmable test ovens and sealed metallic enclosures. Test switches were placed in sealed metallic enclosure and heated to a fixed temperature for a defined time (thermal aging). The testing was destructive, and new switches and metallic enclosures were used for every test. Prior to use, the metallic enclosures were thermally cleaned to remove any volatile materials remaining from their manufacture. The metallic enclosure construction does not incorporate any non-metallic seals or non-metallic coatings. Switch contact operation was measured using a EXTECH 380560 milliohm meter [calibrated 6/18/2015, Due 6/18/2016] which provided discrimination from 1mΩ to 20,000Ω (open circuit); alternative methods of assessing circuit continuity were assessed but dismissed. Switch contact resistance was measured prior to and post each thermal aging test (temperature x time). All resistance measurements were performed at room temperature. The switch was considered to exhibit the anomaly when the milliohm meter registered a resistance exceeding 20,000Ω. The switch maker's acceptance criteria is <25mΩ. The industry acceptance criteria is 500mΩ or less.

The relationship between the three factors was assessed by varying their levels in experiments, recording the point of anomaly onset, and plotting scatter diagrams. Using regression analysis and correlation coefficient, the relation between temperature, time, enclosure volume, and anomaly onset was progressively established.

9.2. Estimated Anomaly Onset

The test data reveal two forms of switch anomaly: 1) the normally open (NO) contact failed to change state, 2) the normally closed (NC) contact failed to change state. Failure to change state means the electrical contacts become sufficiently coated with outgassed material to prevent conduction of electricity. As thermal aging progresses, at any fixed temperature, the anomaly is first observed in the NO contact and then later in the NC contact when measured at room temperature. An open contact is more susceptible to the anomaly because the two contact working surfaces are fully exposed. A closed contact partly masks each working surface and requires a higher outgas concentration to become fully coated. Given the switch contacts have identical contact geometry, it is more accurate to state the anomaly occurs first in the contact that is open and later in the contact that is closed during thermal aging. Thus no distinction should be made between NO and NC contacts.

The best fit of data was obtained by plotting temperature (T) against time (t) with a correction factor applied to time (t) that represented the difference between the actuator "switch to air volume" ratio and the metallic test enclosure "switch to air volume" ratio. Smaller than actuator enclosure test volumes were used to increase the "switch to air volume" ratio and accelerate the onset of the anomaly. The term concentration factor (Cf) was thus developed and multiplied the experiment duration time, measured in seconds (T versus $t * Cf$). The electrical enclosure volume in the Rotork NA actuator is slightly different for each model size. To be conservative the smallest NA actuator enclosure volume was used to develop the best fit equation. The line displayed in Figure 19 is the estimated boundary at which the anomaly onset would be observed. Above the line both open and closed contact anomalies were observed. Below the line anomalies were not observed.

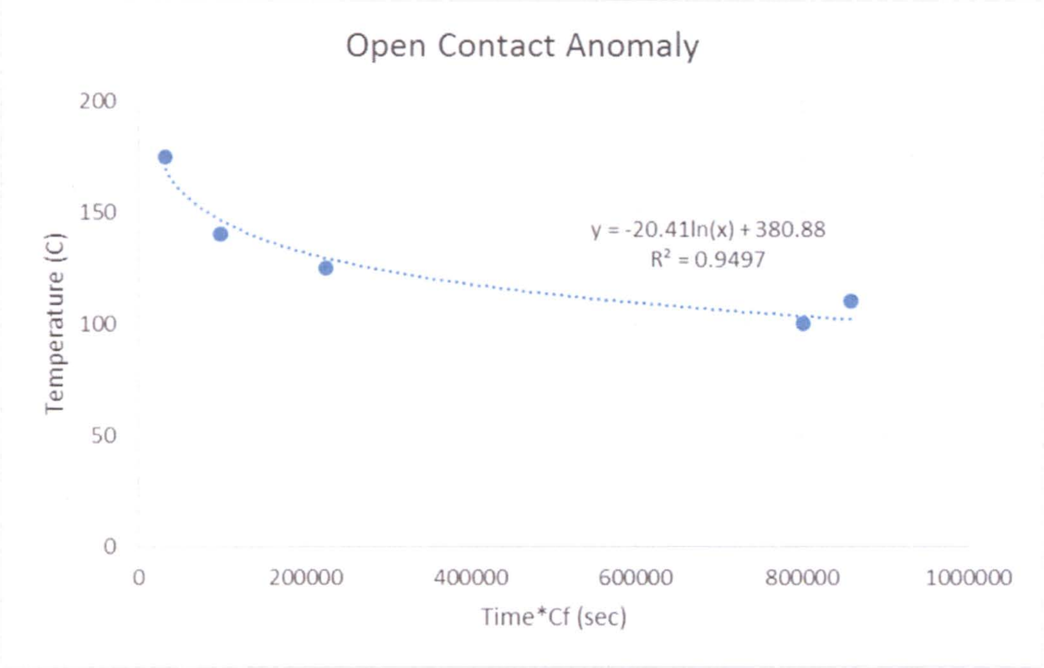


Figure 19

The boundary was found by performing a series of experiments at fixed temperatures. The duration of each experiment was progressively reduced until only the NO contacts started to exhibit the anomaly. The activity was repeated for different temperatures to develop the graph in Figure 19.

Figure 20 displays the accumulated test data from which the following can be concluded:

1. At time t=0 all the switches functioned correctly.
2. Switches function correctly from t=0 (sec) to any green triangles on a constant temperature line.
3. Switches function correctly from temperature T=0°C (32°F) to any green triangles on a constant time line.
4. Switches function correctly where constant temperature and constant time lines intersect and green triangles straddle the intersection points; two blue extension lines showing one intersection example.
5. Based on Rotork NCR data no utility has reported unreliable switch operation, thus at 49°C (120°F) and below the switches function correctly.
6. The effect of temperature is non-linear upon anomaly onset.
7. At 175°C (347°F) the onset of open contact and closed contact anomaly is less distinguishable.
8. At lower temperatures the Log anomaly onset boundary overstates the anomaly onset.
9. At 90°C (194°F) the anomaly was not observed. However, the test for 3,300,000 seconds at 90°C (194°F) exhibited elevated contact resistance in 50% of the open contacts. The measured resistances exceeded the supplier acceptance criteria of <25mΩ but did not exceeded the industry 500mΩ acceptance criteria.

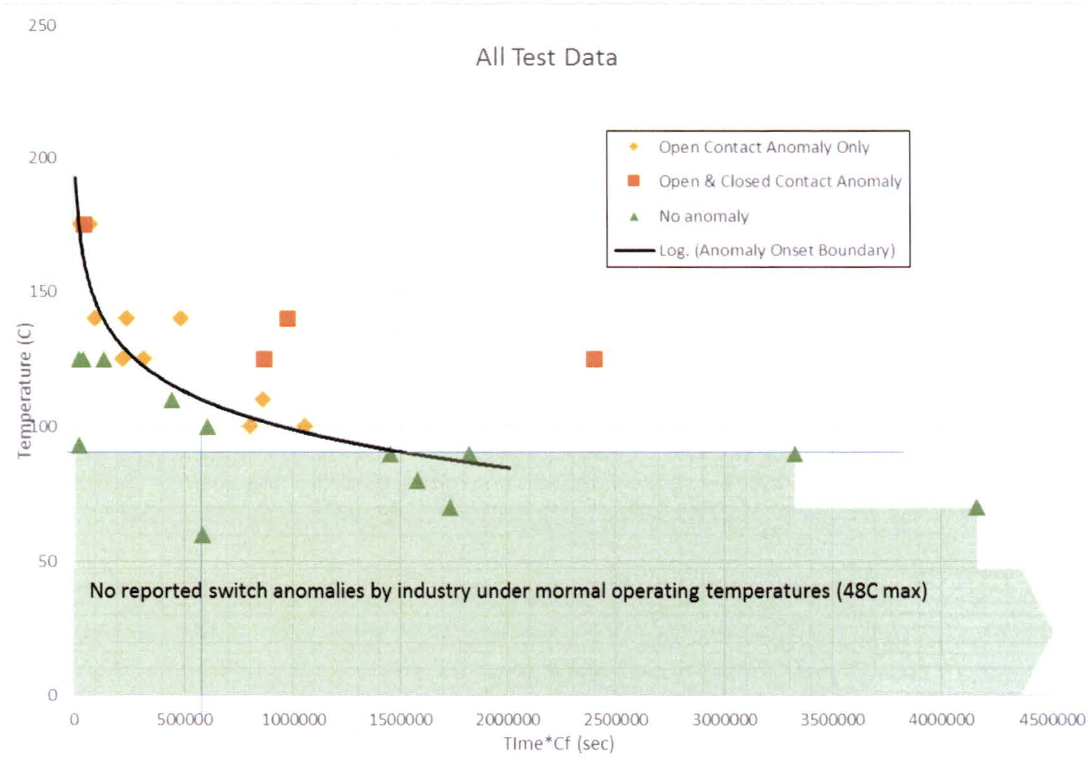


Figure 20

9.3. Switch performance under accident profiles

The figures in the following pages show a number of temperature time profiles applicable to nuclear power plants that use Rotork NA actuators that use Rotork NA actuators. Each test was performed using eight new test switches placed in a new metallic enclosure having a volume of one US gallon. The enclosure volume and number of switches provided a concentration factor of 1.125 thus assuring margin in the testing. In all cases the switches operated after the test and met the industry acceptance criteria of 500mΩ or less. A large proportion of the switches met the supplier acceptance criteria of <25mΩ. Switch resistances were measured before and after test at room temperature. All test instruments were calibrated under the Rotork Appendix B quality program. The data below demonstrates the test switch temperatures either exceeded the computed actuator switch temperature or equaled the oven air temperature.

Three temperature lines are displayed in each graph:

- T_{aopint} is the computed temperature time profile of the switches in an actuator switch mechanism and add-on-pack, based on the environmental air temperature time profile.
- T_{air} is the measured environmental (oven) air temperature for the provided profile.
- $T(8\ test\ switches)$ is the measured temperature profile of 8 test switches, within the closed metallic enclosure, exposed to the T_{air} temperature time profile.

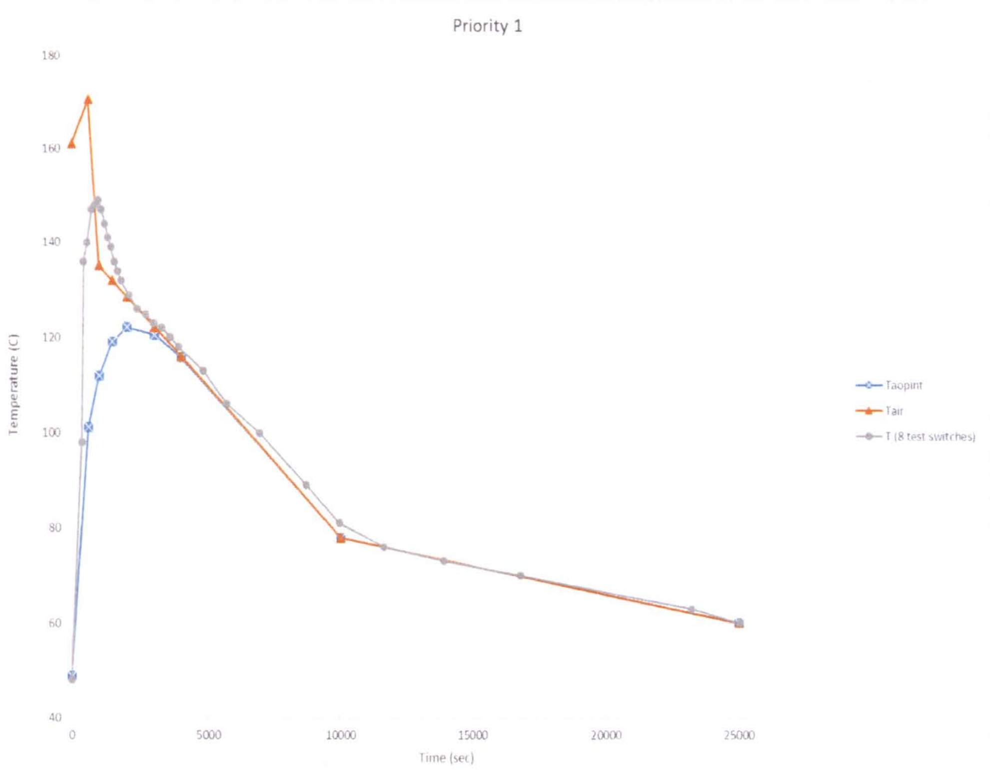


Figure 21a

Measured at 20C 4/15/16 — Priority1 test data

As provided resistance data mili ohms

Sample No ->	4/15-1		4/15-2		4/15-3		4/15-4		4/15-5		4/15-6		4/15-7		4/15-8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	5.8	4.2	4.0	3.3	3.3	4.0	2.4	5.2	3.4	3.6	4.8	3.4	3.2	4.2	3.0	3.0
	5.1	3.4	4.7	2.8	4.0	3.5	2.8	3.6	3.7	3.5	3.5	3.2	3.8	3.9	2.9	3.0
	4.4	2.9	4.4	3.0	3.9	3.3	2.9	3.2	3.1	3.0	3.9	3.2	3.6	3.6	2.9	2.8
	4.1	2.8	4.0	2.9	3.6	3.4	2.9	3.4	3.0	3.2	4.7	3.1	3.9	3.9	2.9	2.8
	4.2	2.8	4.0	2.8	3.6	3.3	3.0	3.2	3.3	3.5	4.1	3.1	3.8	4.0	3.0	2.8
	4.2	2.8	4.0	2.6	3.1	2.8	3.0	3.1	3.4	3.0	4.1	3.0	4.1	3.7	3.0	2.7
	3.9	2.7	4.3	2.5	3.5	3.0	3.0	3.0	3.4	2.9	4.6	2.9	4.4	3.3	3.2	2.7
Ave	**4.5**	**3.1**	**4.2**	**2.8**	**3.6**	**3.3**	**2.9**	**3.5**	**3.3**	**3.2**	**4.2**	**3.1**	**3.8**	**3.8**	**3.0**	**2.8**
Std	**0.7**	**0.5**	**0.3**	**0.3**	**0.3**	**0.4**	**0.2**	**0.8**	**0.2**	**0.3**	**0.5**	**0.2**	**0.4**	**0.3**	**0.1**	**0.1**

Measured at 60C (140F) 4/18/16

Post thermal aging using Priority 1 temp time profile

Sample No ->	4/15-1		4/15-2		4/15-3		4/15-4		4/15-5		4/15-6		4/15-7		4/15-8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	2.2	3.9	2.3	4.2	2.6	3.9	2.6	4.1	2.4	72.0	2.3	3.3	2.3	4.7	2.2	7.2

Measured at 20C 4/19/16

Post thermal aging using Priority 1 temp time profile

Sample No ->	4/15-1		4/15-2		4/15-3		4/15-4		4/15-5		4/15-6		4/15-7		4/15-8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	2.6	30.0	3.0	14.0	3.4	6.2	3.3	5.0	2.8	30.0	3.3	3.8	3.4	5.3	2.8	6.0
	2.9	12.0	3.0	5.5	3.8	6.0	3.0	5.2	3.1	75.0	3.2	3.9	3.6	4.0	3.1	4.3
	3.0	6.0	3.0	4.8	4.1	7.3	3.6	5.9	3.0	80.0	3.2	3.2	3.6	4.1	3.2	3.6
	2.9	3.3	3.0	5.2	4.2	7.6	4.1	4.0	3.1	55.0	3.6	3.0	3.6	4.0	3.3	4.0
	3.0	3.4	2.9	3.9	4.4	7.0	4.9	3.5	3.0	50.0	3.0	2.9	3.7	4.1	3.3	3.4
	3.1	3.0	2.8	3.7	4.2	10.2	4.1	3.2	3.3	30.0	3.0	2.7	3.8	3.9	3.2	3.2
	3.1	3.1	2.9	3.1	5.0	6.6	4.0	3.1	2.9	55.0	3.1	2.8	3.8	4.1	3.3	3.1
Ave	**2.9**	**8.7**	**2.9**	**5.7**	**4.2**	**7.3**	**3.9**	**4.3**	**3.0**	**53.6**	**3.2**	**3.2**	**3.6**	**4.2**	**3.2**	**3.9**
Std	**0.2**	**9.9**	**0.1**	**3.7**	**0.5**	**1.4**	**0.6**	**1.1**	**0.2**	**19.5**	**0.2**	**0.5**	**0.1**	**0.5**	**0.2**	**1.0**

memo: the contact resistance meets the industry acceptance criteria of 500 mili ohms

memo: the contact resistance meets the supplier acceptance criteria of <25 mili ohms

Figure 21b

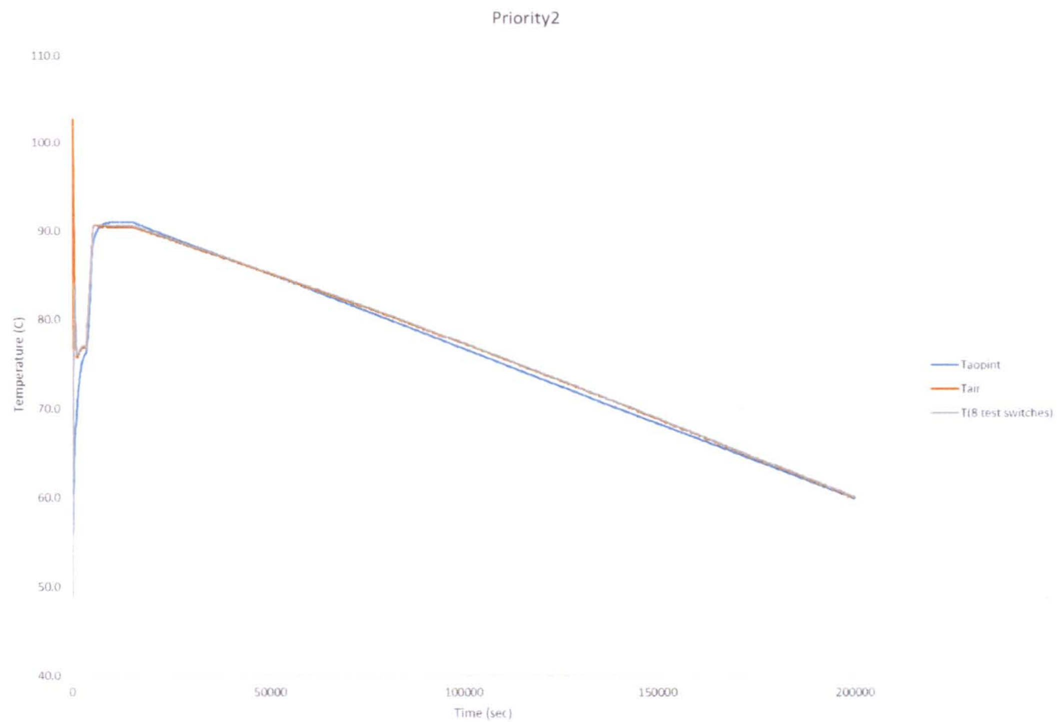


Figure 22a

Measured at 20C 4/19/2016 — Priority2 test data
As provided resistance data mili ohms

Sample No ->	4/19-1		4/19 -2		4/19 -3		4/19 -4		4/19 -5		4/19 -6		4/19 -7		4/19 -8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	2.5	2.8	3.6	3.8	3.3	3.7	4.4	3.3	2.5	3.2	3.4	5.3	2.5	2.7	4.3	4.9
	3.6	2.7	3.7	3.4	3.3	3.7	4.2	3.4	3.3	2.8	3.1	4.4	2.8	2.7	3.9	5.9
	3.4	2.6	3.8	3.4	3.4	3.1	4.2	3.4	4.6	2.8	3.9	4.2	2.9	2.6	3.6	7.0
	3.2	2.6	4.0	3.1	3.4	3.1	3.9	3.4	4.6	2.7	3.3	3.9	2.9	2.5	3.4	7.5
	3.2	2.5	3.6	3.3	3.2	2.8	3.3	3.1	4.0	2.9	3.1	3.6	3.0	2.5	3.0	3.6
	3.3	2.5	3.4	2.9	3.0	2.9	4.0	3.1	4.2	2.7	2.9	3.3	3.1	2.5	3.3	3.1
	3.1	2.6	3.5	2.9	2.9	2.8	4.0	2.9	3.9	2.7	3.1	3.3	2.8	2.5	3.1	3.3
Ave	**3.2**	**2.6**	**3.7**	**3.3**	**3.2**	**3.2**	**4.0**	**3.2**	**3.9**	**2.8**	**3.3**	**4.0**	**2.9**	**2.6**	**3.5**	**5.0**
Std	**0.34**	**0.11**	**0.20**	**0.32**	**0.20**	**0.39**	**0.35**	**0.20**	**0.75**	**0.18**	**0.33**	**0.71**	**0.19**	**0.10**	**0.46**	**1.80**

Measured at 60C (140F) 4/23/2016
Post thermal aging using Priority 2 temp time profile

Sample No ->	4/19-1		4/19 -2		4/19 -3		4/19 -4		4/19 -5		4/19 -6		4/19 -7		4/19 -8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	2.3	12.0	2.5	10.0	2.3	5.3	2.6	6.8	2.4	5.2	2.4	5.0	2.9	3.8	2.4	6.0

Measured at 20C 4/25/2016
Post thermal aging using Priority 2 temp time profile

Sample No ->	4/19-1		4/19 -2		4/19 -3		4/19 -4		4/19 -5		4/19 -6		4/19 -7		4/19 -8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	3	8.3	4.7	5.6	4.1	4.4	5.6	13	2.4	5	3	5.3	3.3	4.6	3.1	7.9
	3.6	7.1	3.3	4	3.9	3.7	5.2	12	2.8	4.8	3.2	4.9	3.6	3.5	4	7.7
	3.9	6.2	3.9	3.7	3.3	3.7	6.3	5.6	3.2	6.3	3.5	4.6	3.8	4.5	3.8	5.9
	3.8	4.9	6	4.2	5	2.7	6.5	4.4	3.1	4	3.4	4.3	3.7	4	4.6	4.5
	4.1	4.9	3.6	3.3	5.5	3.7	6.5	5.1	3.2	4	3.4	3.8	4.2	2.9	4.1	4.5
	3.5	3.9	5.5	3.5	4.2	3.5	6.8	5.9	3.5	4.2	3.5	3.9	3.7	2.8	5.2	5.1
	4.2	4	6.6	3.6	4.7	3	6.7	6	4	3.3	3.5	3.6	3.9	2.7	4.4	5.3
Ave	**3.9**	**5.2**	**4.8**	**3.7**	**4.4**	**3.4**	**6.3**	**6.5**	**3.3**	**4.4**	**3.4**	**4.2**	**3.8**	**3.4**	**4.4**	**5.5**
Std	**0.27**	**1.26**	**1.39**	**0.33**	**0.79**	**0.43**	**0.58**	**2.76**	**0.41**	**1.03**	**0.12**	**0.50**	**0.21**	**0.73**	**0.50**	**1.20**

memo: the contact resistance meets the industry acceptance criteria of 500 mili ohms
memo: the contact resistance meets the supplier acceptance criteria of <25 mili ohms

Figure 22b

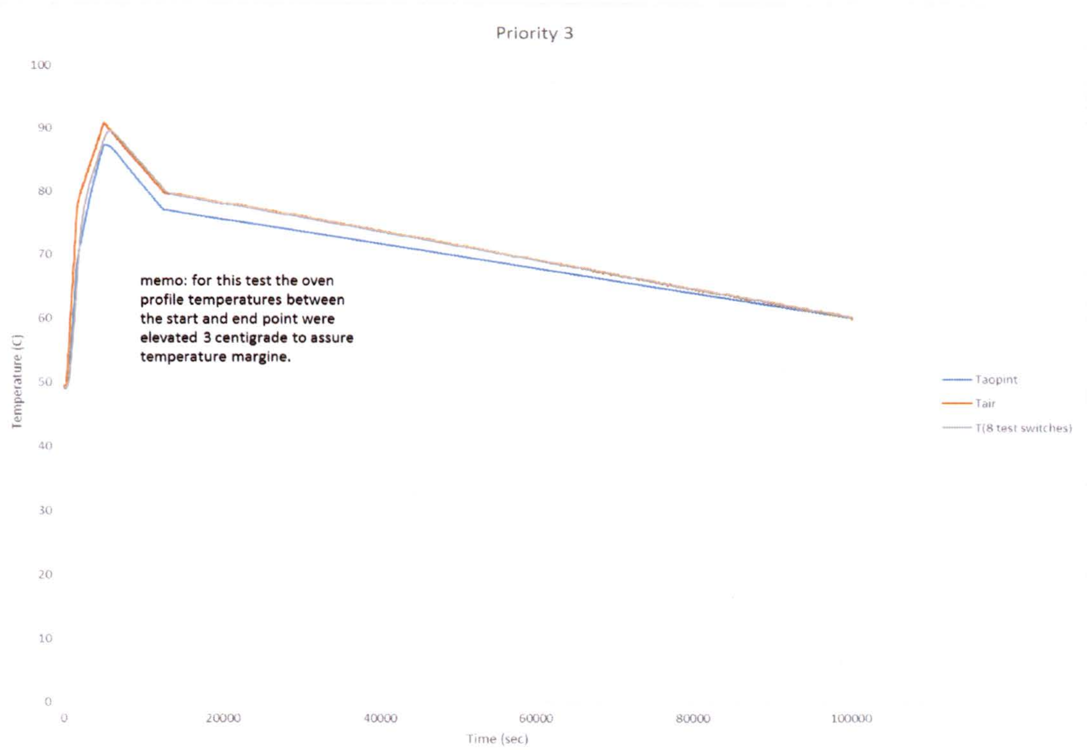


Figure 23a

Measured at 20C 4/25/2016 Priority3 test data

As provided resistance data mili ohms

Sample No ->	4/25-1		4/25-2		4/25-3		4/25-4		4/25-5		4/25-6		4/25-7		4/25-8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	5.0	9.4	3.5	3.2	3.5	4.1	3.2	8.0	4.5	3.2	2.6	3.6	4.8	3.4	4.0	6.4
	4.2	5.8	4.7	3.0	4.6	3.9	6.1	5.1	5.4	3.2	3.6	3.6	4.2	3.3	6.6	5.2
	3.8	4.4	3.2	2.9	4.6	3.8	4.0	3.5	5.1	2.8	4.2	3.3	3.7	3.1	4.0	3.2
	4.6	3.7	3.4	2.9	3.9	3.8	4.7	3.4	5.0	2.8	3.7	3.2	3.9	3.0	6.1	3.6
	4.1	3.3	3.0	3.1	4.6	3.7	4.7	3.5	4.0	2.5	4.2	3.1	3.9	3.0	3.4	3.0
	3.5	3.1	3.1	2.8	4.4	3.7	4.5	3.4	4.6	4.6	3.6	3.2	4.4	2.8	3.2	3.1
	4.0	3.2	3.0	2.8	4.2	3.5	5.5	3.3	4.3	2.6	3.8	3.1	4.0	2.9	3.2	3.2
Ave	**4.2**	**4.7**	**3.4**	**3.0**	**4.3**	**3.8**	**4.7**	**4.3**	**4.7**	**3.1**	**3.7**	**3.3**	**4.1**	**3.1**	**4.4**	**4.0**
Std	**0.50**	**2.28**	**0.60**	**0.15**	**0.42**	**0.19**	**0.95**	**1.74**	**0.49**	**0.71**	**0.54**	**0.22**	**0.37**	**0.21**	**1.41**	**1.32**

Measured at 60C (140F) 4/26/2016

Post thermal aging using Priority 3 temp time profile

Sample No ->	4/25-1		4/25-2		4/25-3		4/25-4		4/25-5		4/25-6		4/25-7		4/25-8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	2.4	5.1	2.4	3.8	2.4	5.0	2.3	3.8	2.3	4.0	2.4	3.8	2.5	4.0	2.4	11.0

Measured at 20C 4/27/2016

Post thermal aging using Priority 3 temp time profile

Sample No ->	4/25-1		4/25-2		4/25-3		4/25-4		4/25-5		4/25-6		4/25-7		4/25-8	
	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO	NC	NO
	4.3	5.3	2.8	3.2	3.2	4.8	2.6	5.2	3.7	4.8	3.1	3.6	3.5	3.6	5.2	12.9
	3.0	4.2	3.0	3.1	3.4	4.3	3.2	3.9	4.0	3.1	4.0	4.0	3.9	3.6	4.4	9.1
	3.7	3.1	3.0	3.5	3.6	4.7	3.3	3.7	4.0	3.4	3.9	3.5	3.9	3.4	5.6	3.8
	2.9	3.1	3.1	3.4	2.4	4.1	3.1	3.9	4.6	3.7	3.9	3.6	4.1	3.3	5.9	3.4
	2.7	2.4	3.1	3.0	3.1	3.9	2.9	4.3	4.4	3.1	4.0	4.4	4.4	3.2	6.3	3.3
	4.0	3.0	3.2	3.0	3.1	4.0	3.6	3.8	4.8	2.8	3.6	3.6	4.2	3.1	7.4	3.3
	4.0	3.1	3.2	3.0	3.2	3.9	4.0	4.2	4.4	2.7	4.1	3.4	4.1	3.4	6.3	3.5
Ave	**3.4**	**3.2**	**3.1**	**3.2**	**3.1**	**4.2**	**3.4**	**4.0**	**4.4**	**3.1**	**3.9**	**3.8**	**4.1**	**3.3**	**6.0**	**4.4**
Std	**0.58**	**0.58**	**0.09**	**0.23**	**0.41**	**0.31**	**0.39**	**0.23**	**0.32**	**0.37**	**0.17**	**0.38**	**0.19**	**0.18**	**0.99**	**2.31**

memo: the contact resistance meets the industry acceptance criteria of 500 mili ohms

memo: the contact resistance meets the supplier acceptance criteria of <25 mili ohms

Figure 23b

Summary

Three factors cause the anomaly onset namely temperature, time, and enclosure volume (concentration factor). An equation relating the three factors to anomaly onset has been developed and is provided for information purposes only – not for prediction. The equation accuracy has not been verified against an adequate sample of design based temperature time accident profiles. The equation is not linear. Testing demonstrated anomalies were not observed at 90°C and below. Published literature suggest that some level of outgassing always occurs.

When temperature varies with time, estimating anomaly onset is far more complicated and requires the integration of the outgassed material mass. Furthermore, it would be necessary to established if an elevated temperature for a brief period of time would then permit the outgassing of material at lower temperatures for an extended period. Given the available time, the latter could not be accomplished and verified by experimentation. Switch performance was thus evaluated by experimentation. Switches within closed metallic enclosures having an actuator representative volume were thermally aged using accident condition temperature time profiles. The test results indicate the switches, though degraded, would operate correctly after completing the thermal aging profiles displayed in Figure 21 through Figure 23.

10. Results from independent test lab

An independent test laboratory, Exova, was requested to investigate the contamination on contact rivets of micro-switches that had exhibited the anomaly after being thermally aged in-house at 125°C (257°F). Contacts were analysed by FTIR (Fourier-Transform Infra-Red) spectroscopy and by SEM-EDX (Scanning Electron Microscope/Energy Dispersive Using X-Ray) analysis.

FTIR spectroscopy is a valuable tool to study the molecular structure of organic materials. SEM-EDX enables an elemental analysis of the contamination.

Figure 24 compares the infrared spectra of the residue collected from the NO contact of an aged switch manufactured in 2015 vs. an aged switch manufactured in 2007. Both infrared fingerprints virtually mirror each other which suggest that they appear to be the same type of contaminant. The following infrared bands were observed:

- 2915, 2850, 1415 cm^{-1} which are likely to relate to alkyl groups (CH2, CH3)
- 1535 cm^{-1} which could relate to alkyl groups (CH2, CH3) or amide (NH-C=O) groups
- 1650 cm^{-1} which could relate to alkene (C=C), aromatic groups (), amide (NH-C=O) or amine groups (R-NH-)
- 1310 cm^{-1} which could relate to amine groups (R-NH-) or alcohol groups (-OH)
- 1030 cm^{-1} which could relate to carbonyl groups (C=O) or alcohol groups (-OH)
- 720 cm^{-1} which could relate to aromatic groups (), chlorinated compounds or methylene groups (CH2)

The infrared spectrum of the residue collected from the NO contact rivet of the 2007 switch was compared to the infrared fingerprints of the Araldite adhesive (Figure 25), the DAP case (Figure 26) and the nylon 66 operating plunger (Figure 27) as they are the only organic components and therefore the only possible direct or indirect sources of contamination. The infrared spectrum of the residue did not match any of the organic materials.

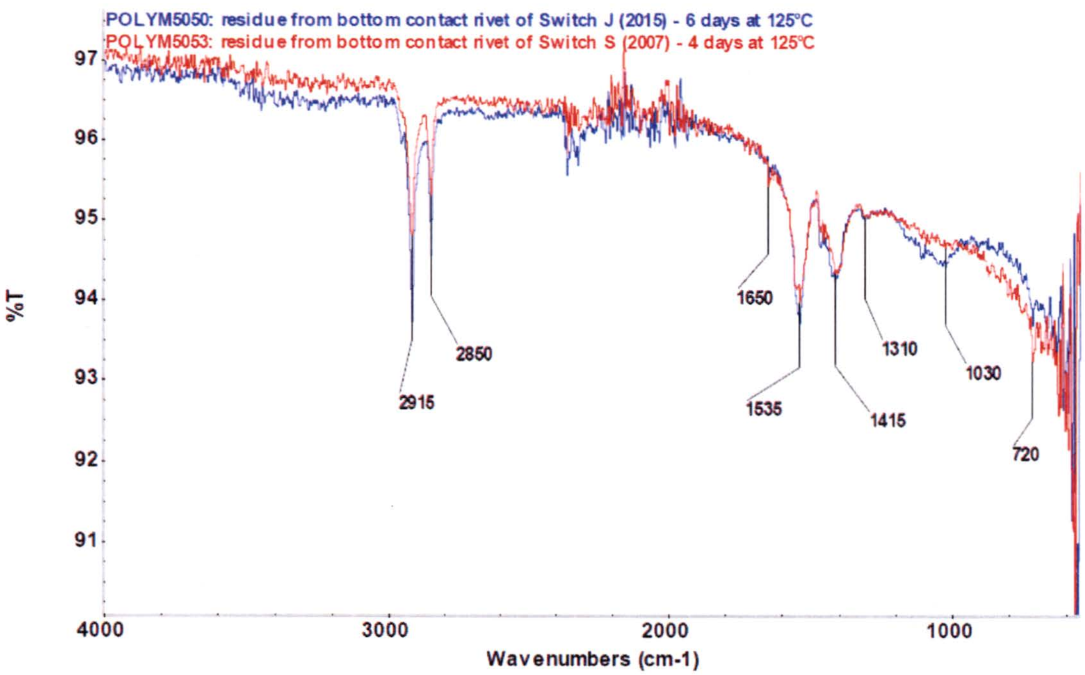


Figure 24: Infrared spectra of residue on NO contact rivets

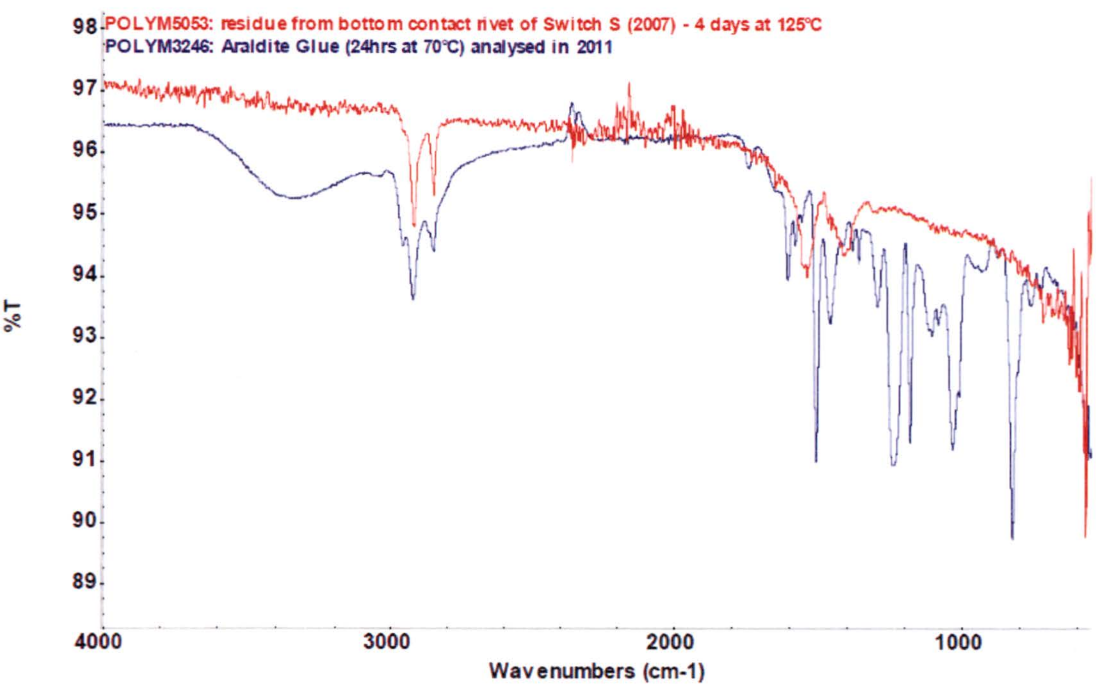


Figure 25: Infrared spectra of residue from NO contact rivet and Araldite adhesive

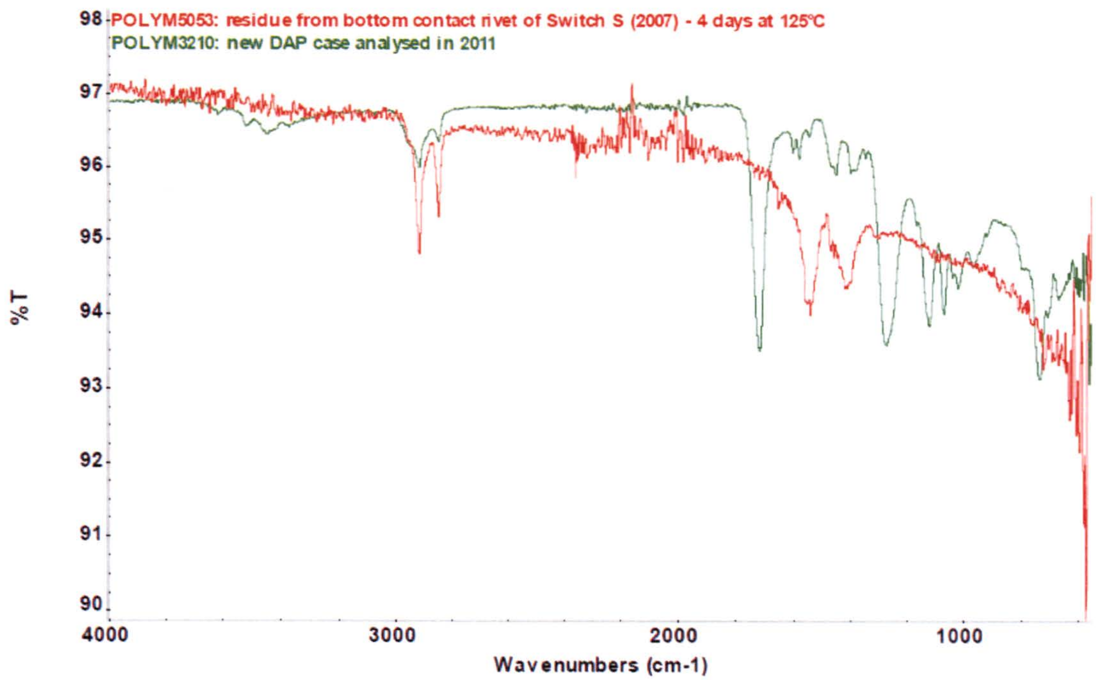


Figure 26: Infrared spectra of residue from NO contact rivet and DAP case

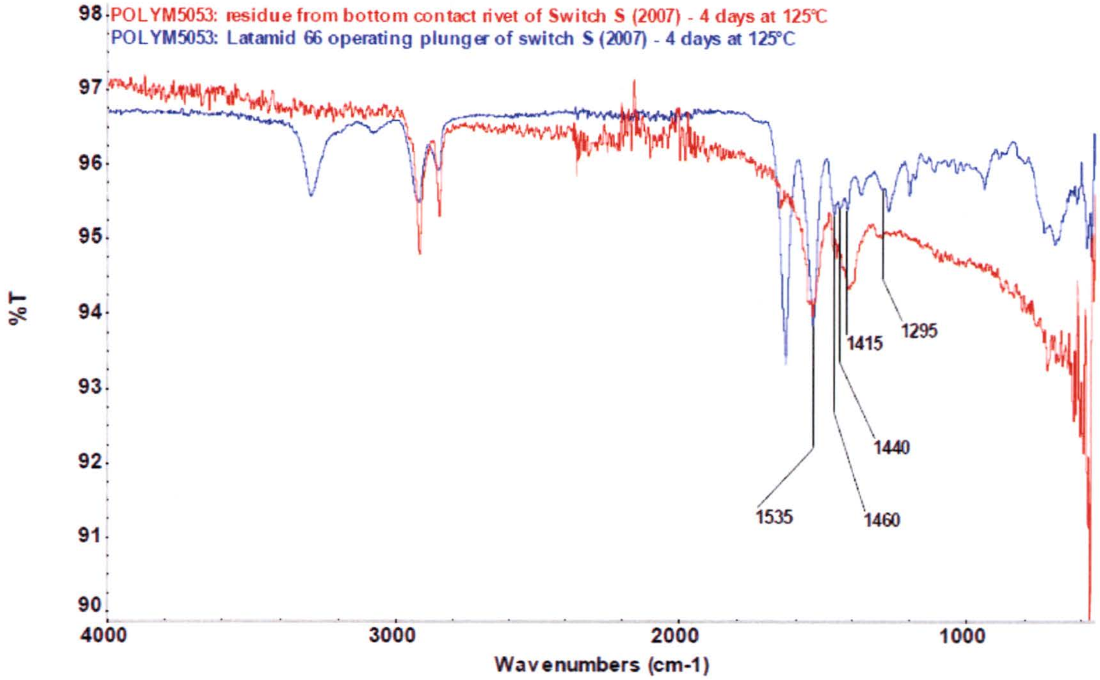


Figure 27: Infrared spectra of residue from NO contact rivet and nylon 66 operating plunger

SEM photographs of the NO and moving contact rivets of an unaged 2015 switch, an aged 2015 switch and an aged 2007 switch are shown in Table 3. The SEM photographs show clear contamination on both the NO and moving contact rivets of aged switches. The pattern was consistently different between the NO and moving rivets and suggests the contamination deposited on the NO contact is then transferred to the moving contact during operation. This observation is in line with the results observed from in-house tests (Figure 6 to Figure 9).

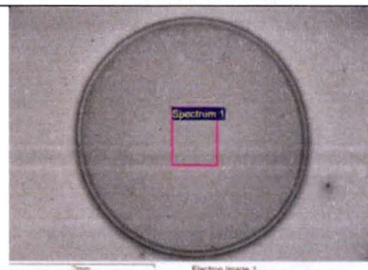
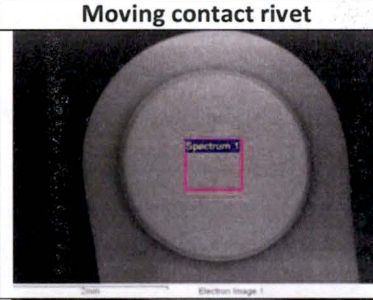
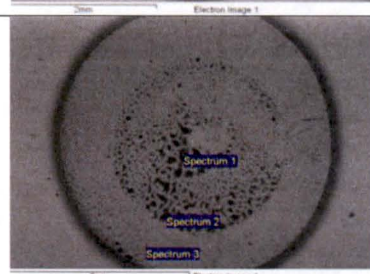
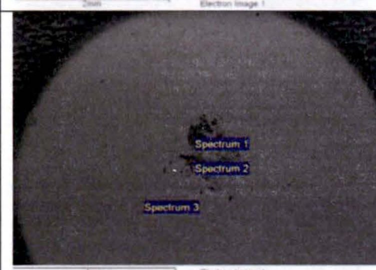
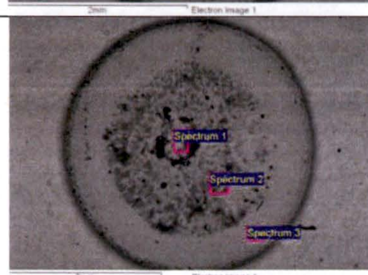
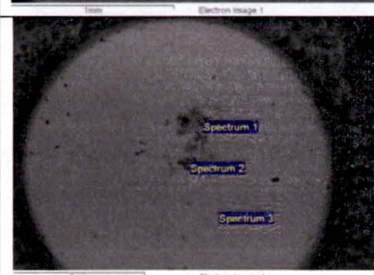
Switch	NO contact rivet	Moving contact rivet
Unaged, manufactured in 2015		
Aged, manufactured in 2015		
Aged, manufactured in 2007		

Table 3: SEM photographs

Elemental analysis results are compiled in Table 4. Results show the presence of a significantly higher level of carbon (C) on the aged contacts relative to the unaged contacts. This suggests that the contaminant appears to be mainly organic, which is in line with FTIR results. A significantly higher level of oxygen (O) was observed on the aged contact rivets, especially the sample from 2007, which could suggest the presence of oxidative products.

Switch	Contact	Location	C	O	Mg	Ag	Cd	Si	Ca	Cr	Fe	Ni	Cu	Br
Unaged, manufactured in 2015	NO	1	2.9	3.5	0.5	83.1	9.3	-	-	-	-	-	-	-
	Moving	1	2.2	1.0	0.4	94.5	1.9	-	-	-	-	-	-	-
Aged, manufactured in 2015	NO	1	54.1	5.4	-	28.8	11.7	-	-	-	-	-	-	-
		2	53.0	4.7	-	31.4	11.0	-	-	-	-	-	-	-
		3(*)	7.5	2.4	-	84.2	5.9	-	-	-	-	-	-	-
	Moving	1	45.2	6.5	-	42.3	6.0	-	-	-	-	-	-	-
		2	42.8	6.9	-	44.8	5.6	-	-	-	-	-	-	-
		3(*)	4.5	-	0.5	93.3	1.8	-	-	-	-	-	-	-
Aged, manufactured in 2007	NO	1	19.9	13.0	-	62.0	5.1	-	-	-	-	-	-	-
		2	31.3	10.5	0.2	52.1	5.9	-	-	-	-	-	-	-
		3(*)	2.8	2.9	0.5	89.9	3.8	-	-	-	-	-	-	-
	Moving	1	29.2	17.0	0.3	47.8	-	0.6	0.3	-	-	-	-	4.9
		2	32.6	12.2	0.3	47.7	-	-	-	1.2	4.3	0.5	-	1.3
		3(*)	12.1	11.1	0.3	73.2	2.9	-	-	-	-	-	0.3	-

(*) away from main contaminated area

Table 4: EDX elemental analysis results indicating % of each element at spectrum location

Summary

- The contaminant appears to be mainly organic. This is in agreement with literature (section 7), test results of an unglued switch (section 8.1) and UV images (Figure 10 and Figure 11) which all identify the adhesive being the root cause.
- The contaminating residue is not formed on the moving contact rivet but is transferred from the NO contact during operation.

11. Conclusion

The altered adhesive formulation outgases at elevated temperatures and deposits an insulating material layer onto the switch internal electrical contacts as it cools. The deposit of insulation material results in contact resistances exceeding the supplier acceptance criteria of 25mΩ max, the industry 500mΩ max acceptance criteria and in some cases causes an open circuit.

It should be noted that tests were performed at constant temperatures. The effect of varying temperature with time has not been investigated in the available time and the possibility exists that an initial high temperature for a short period could subsequently cause outgassing to continue at lower temperatures. Rotork thus recommend that the risk be assessed by testing switches under representative temperature time profiles.

In tests performed by Rotork the anomaly was not observed at temperatures 90°C (194°F) and below. The maximum service temperature for A range and NA5/5E actuators is 70°C (158°F) thus they can be excluded from the scope of this Part 21.

Nuclear power plants that use Rotork NA actuators provided temperature profiles which also were tested. Anomalies were not observed using these profiles.

Rotork are recommending the replacement of the switches in the affected orders which are identified in the Part 21 notification letter.

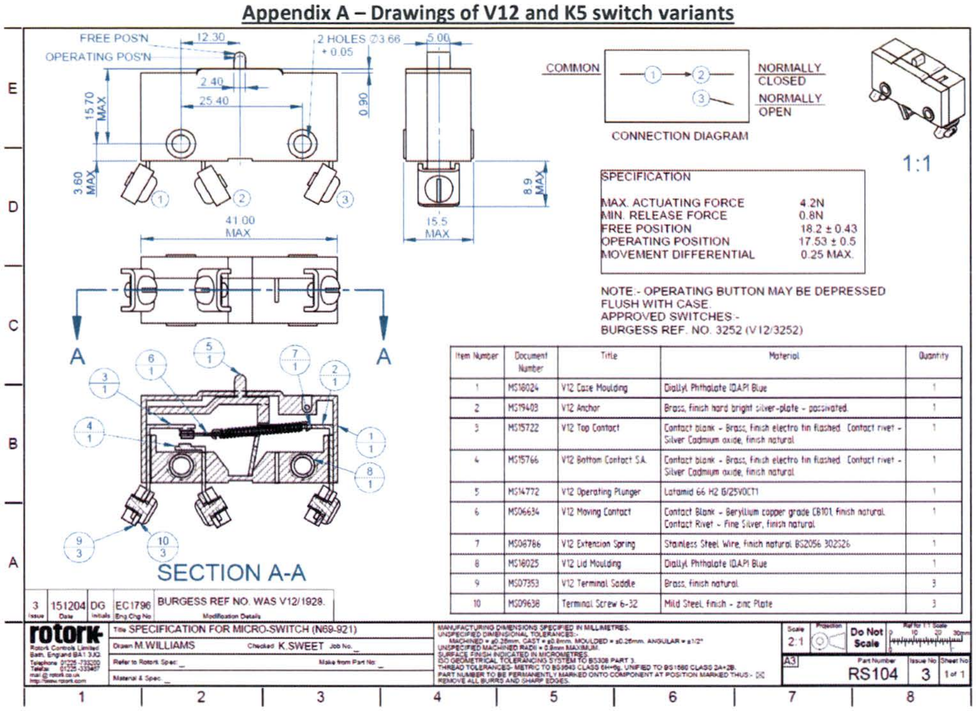
12. References

1) Czarnecki, N. (2012) *Nema White Paper. Cadmium in Electrical Contacts* [online]. Rosslyn, VA. Available from: https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjK5dCdt7PMAhWjBsAKHbPtBbcQFggtMAA&url=https%3A%2F%2Fwww.nema.org%2FProducts%2FDocuments%2Fnema%2Bwhitepaper%2Bon%2Bcadmium%2Bin%2Belectrical%2Bcontacts.pdf&usg=AFQjCNFevJ949rWGVG65Oefdbr4ejjT6kw&sig2=s1UgMfElFnKDWWhowkA4lg [Accessed 29 April 2016]

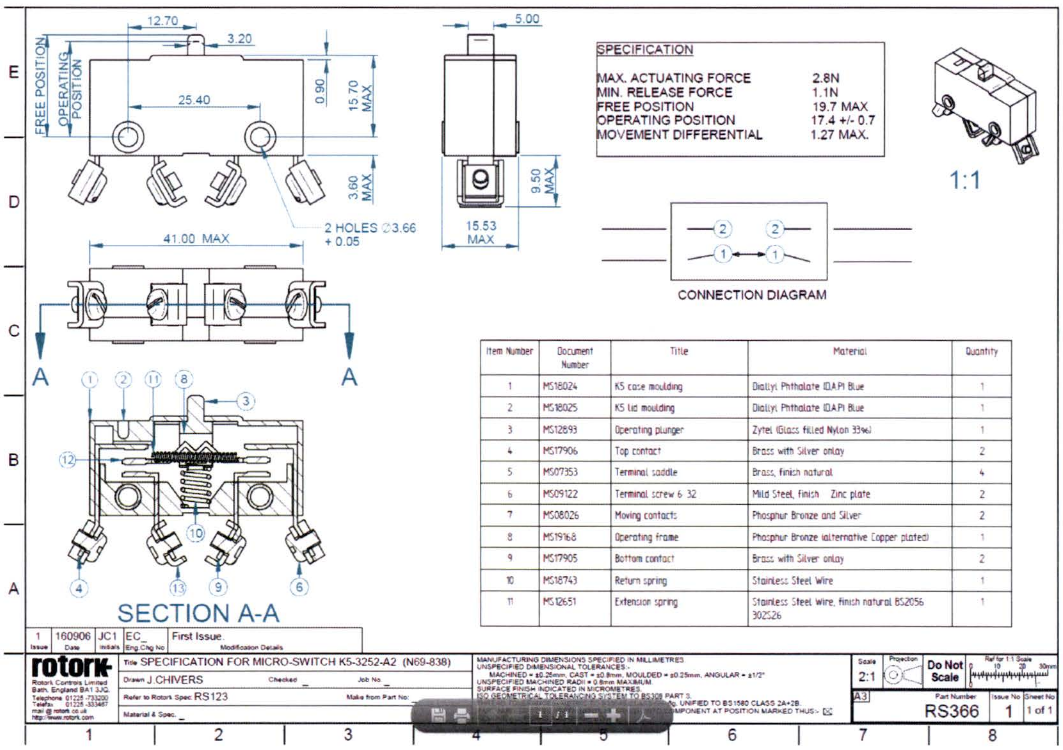
2) Buffing, M. (2009) *Outgassing of glue in the Outer Tracker of LHCb; measurements with a quadrupole mass spectrometer* [online]. BSc, Vrije Universiteit Amsterdam. Available from: http://www.nikhef.nl/pub/experiments/bfys/lhcb/Theses/bachelor/2009_MaartenBuffing.pdf [Accessed 29 April 2016]

3) Tuning, N., et al. (2011) Ageing in the LHCb outertracker: Aromatic hydrocarbons and wire cleaning. *Nuclear Instruments and Methods in Physics Research A*. 656, pp. 45-50

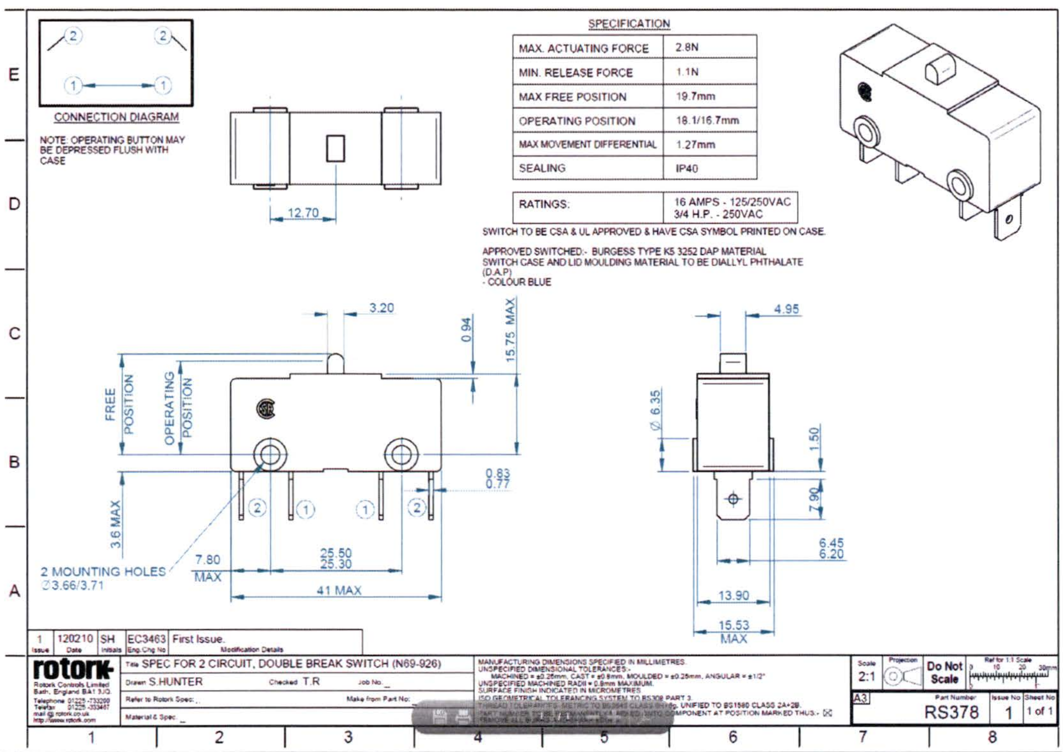
Appendix A – Drawings of V12 and K5 switch variants



Item Number	Document Number	Title	Material	Quantity
1	MS18024	V12 Case Moulding	Diallyl Phthalate (DAP) Blue	1
2	MS19403	V12 Anchor	Brass, finish hard bright silver-plate - passivated.	1
3	MS15722	V12 Top Contact	Contact blank - Brass, finish electro tin flashed. Contact rivet - Silver Cadmium oxide, finish natural	1
4	MS15766	V12 Bottom Contact S.A.	Contact blank - Brass, finish electro tin flashed. Contact rivet - Silver Cadmium oxide, finish natural	1
5	MS14772	V12 Operating Plunger	Latamid 66 H2 G/25V0CT1	1
6	MS06634	V12 Moving Contact	Contact Blank - Beryllium copper grade CB101, finish natural. Contact Rivet - Fine Silver, finish natural	1
7	MS08786	V12 Extension Spring	Stainless Steel Wire, finish natural BS2056 302S26	1
8	MS18025	V12 Lid Moulding	Diallyl Phthalate (DAP) Blue	1
9	MS07353	V12 Terminal Saddle	Brass, finish natural	3
10	MS09638	Terminal Screw 6-32	Mild Steel, finish - zinc Plate	3



Item Number	Document Number	Title	Material	Quantity
1	MS18024	K5 case moulding	Diallyl Phthalate (D.A.P.) Blue	1
2	MS18025	K5 lid moulding	Diallyl Phthalate (D.A.P.) Blue	1
3	MS12893	Operating plunger	Zytel (Glass filled Nylon 33%)	1
4	MS17906	Top contact	Brass with Silver onlay	2
5	MS07353	Terminal saddle	Brass, finish natural	4
6	MS09122	Terminal screw 6-32	Mild Steel, finish Zinc plate	2
7	MS08026	Moving contacts	Phosphur Bronze and Silver	2
8	MS19168	Operating frame	Phosphur Bronze (alternative Copper plated)	1
9	MS17905	Bottom contact	Brass with Silver onlay	2
10	MS18743	Return spring	Stainless Steel Wire	1
11	MS12651	Extension spring	Stainless Steel Wire, finish natural BS2056 302S26	1


CONNECTION DIAGRAM
NOTE: OPERATING BUTTON MAY BE DEPRESSED FLUSH WITH CASE
SPECIFICATION
MAX. ACTUATING FORCE 2.8N
MIN. RELEASE FORCE 1.1N
MAX FREE POSITION 19.7mm
OPERATING POSITION 18.1/16.7mm
MAX MOVEMENT DIFFERENTIAL 1.27mm
SEALING IP40
RATINGS: 16 AMPS - 125/250VAC 3/4 H.P. - 250VAC
SWITCH TO BE CSA & UL APPROVED & HAVE CSA SYMBOL PRINTED ON CASE.
APPROVED SWITCHED:- BURGESS TYPE K5 3252 DAP MATERIAL
SWITCH CASE AND LID MOULDING MATERIAL TO BE DIALLYL PHTHALATE (D.A.P)
- COLOUR BLUE
12.70
3.20
0.94
15.75 MAX
FREE POSITION
OPERATING POSITION
0.83
0.77
3.6 MAX
2 MOUNTING HOLES
Ø3.66/3.71
7.80 MAX
25.50
25.30
41 MAX
4.95
Ø 6.35
1.50
7.90
6.45
6.20
13.90
15.53 MAX
1 120210 SH EC3463 First Issue.
Issue Date Initials Eng.Chg No Modification Details
rotork
Rotork Controls Limited Bath, England BA1 3JQ
Title SPEC FOR 2 CIRCUIT, DOUBLE BREAK SWITCH (N69-926)
Drawn S.HUNTER Checked T.R Job No. _
Refer to Rotork Spec: _ Make from Part No: _
Material & Spec _
MANUFACTURING DIMENSIONS SPECIFIED IN MILLIMETRES.
UNSPECIFIED DIMENSIONAL TOLERANCES:-
MACHINED = ±0.25mm, CAST = ±0.8mm, MOULDED = ±0.25mm, ANGULAR = ±1/2°
UNSPECIFIED MACHINED RADII = 0.8mm MAXIMUM.
SURFACE FINISH INDICATED IN MICROMETRES.
ISO GEOMETRICAL TOLERANCING SYSTEM TO BS308 PART 3.
Scale 2:1
Projection
Do Not Scale
A3
Part Number RS378
Issue No 1
Sheet No 1 of 1

Appendix B – Pre and post-aging resistance results, Test 1 and 3

All results in Ohms.

Test 1 – 125°C (257°F) aging of V12 switches manufactured in 2015

		Results before ageing						Into oven	Out of oven	Total aging	Results after ageing					
		Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6	
	Date Code	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O
F	3715K	0.003	0.003	0.004	0.005	0.004	0.005				0.004	-	0.003	-	0.005	-
G	3715K	0.004	0.005	0.004	0.003	0.005	0.003	14:00	08:00		0.005	-	0.005	-	0.005	-
H	3715K	0.004	0.005	0.004	0.004	0.004	0.004	Tue	Mon	138 hrs	0.006	-	0.006	0.010	0.006	0.007
I	3715K	0.004	0.004	0.006	0.003	0.005	0.004	26/01/16	01/02/16	(5.75 days)	0.004	-	0.005	-	0.005	-
J	3715K	0.004	0.004	0.004	0.004	0.004	0.003				0.005	*	0.006	-	0.008	*

Test 3 – 125°C (257°F) aging of V12 switches manufactured in 2007

		Results before ageing						Into oven	Out of oven	Total aging	Results after ageing					
		Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6	
	Date Code	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O
P	2807K	0.004	0.008	0.008	0.007	0.008	0.007	15:45	14:00		0.004	0.279	0.004	184	0.004	0.124
Q	2807K	0.005	0.008	0.006	0.007	0.006	0.007	Mon	Fri	94.25 hrs	0.004	-	0.009	-	0.005	-
S	2807K	0.014	0.014	0.012	0.007	0.009	0.012	01/02/16	05/02/16	(3.93 days)	0.004	-	0.004	-	0.004	-
T	2807K	0.005	0.009	0.006	0.007	0.006	0.007				0.004	0.642	0.004	0.030	0.007	0.049

- indicates open circuit

* indicates that the resistance value was fluctuating between several ohms, to hundreds of ohms, to open circuit

Appendix C – Resistance results post-curing and subsequent aging, Test 5

All results in Ohms.

Post-curing of each switch in a fan assisted oven

		Results before post-curing						Into oven	Out of oven	Total aging	Results after post-curing					
		Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6	
	Date Code	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O
1	4315K	0.004	0.007	0.005	0.006	0.007	0.006	11:30 Thur 11/02/16	11:55 Fri 12/02/16	1.02 days	0.003	0.023	0.004	0.018	0.002	0.077
2	4315K	0.007	0.010	0.006	0.008	0.006	0.006		11:50 Mon 15/02/16	4.01 days	0.007	0.040	0.007	0.012	0.008	0.014
3	4315K	0.005	0.005	0.004	0.005	0.005	0.005		15:00 Tue 16/02/16	5.15 days	0.004	0.086	0.005	0.047	0.005	0.068
4	4315K	0.002	0.009	0.004	0.006	0.004	0.006		11:30 Wed 17/02/16	6 days	0.005	0.066	0.005	0.006	0.006	0.008
5	4315K	0.004	0.007	0.005	0.008	0.005	0.006		11:30 Thu 18/02/16	7 days	0.006	0.077	0.006	0.176	0.006	0.088
6	4315K	0.004	0.005	0.004	0.005	0.004	0.005		11:30 Fri 19/02/16	8 days	0.005	0.150	0.007	0.159	0.006	0.096

Further aging of post-cured switches in metal containers

		Results before ageing						Into oven	Out of oven	Total aging	Results after ageing					
		Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6	
	Date Code	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O
1	4315K	Above post-cured switches were taken and each switch was placed in its own enclosure.						14:30 Fri 19/02/16	09:00 Tue 23/02/16	90.5 hrs (3.77 days)	0.010	-	0.024	-	0.011	-
2	4315K										0.006	4.800	0.016	0.319	0.018	0.243
3	4315K										0.007	-	0.010	-	0.048	-
4	4315K										0.004	49.700	0.008	3.450	0.006	1.200
5	4315K										0.004	0.059	0.005	0.250	0.005	0.164
6	4315K										0.009	-	0.028	-	0.040	-

- indicates open circuit

* indicates that the resistance value was fluctuating between several ohms, to hundreds of ohms, to open circuit

Appendix D – Resistance results of K5 switches, Test 6

All results in Ohms.

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
16	0.011	0.077	0.024	0.018	0.012	0.080	15:30 Tue 16/02/16	15:30 Mon 22/02/16	6 days	0.005	0.507	0.018	0.492	0.011	0.369	0.008	0.236
17	0.007	0.054	0.020	0.038	0.017	0.020				0.036	1.423	0.054	3.230	0.022	0.720	0.016	2.170

Appendix E – Resistance results of switch aged without adhesive, Test 7

All results in Ohms.

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
18	0.006	0.004	0.005	0.004	0.007	0.005	13:55 Mon 29/02/16	13:55 Wed 02/03/16	2 days	0.004	0.020	0.004	0.012	0.004	0.018	0.004	0.005

Further aging of above switch to complete total 7 days aging

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
18	Above switch was aged further						14:55 Wed 02/03/16	13:55 Mon 07/03/16	4.96 days	0.012	0.004	0.006	0.138	0.014	0.227	0.068	0.077

Further aging of above switch to complete total 10 days aging

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
18	Above switch was aged further						08:30 Fri 01/04/16	08:00 Mon 04/04/16	3.98 days	0.007	0.117	0.082	0.006	0.174	0.015	0.006	0.017

Total aging time for switch 18 = 2 + 4.96 + 3.98 = 10.94 days

Appendix F – Resistance results of switch aged with Duralco 4525, Test 8

All results in Ohms.

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
21	0.004	0.004	0.005	0.004	0.007	0.004	08:30 Fri 01/04/16	08:30 Mon 11/04/16	10 days	0.027	-	0.178	-	0.250	-	0.186	-

- indicates open circuit

* indicates that the resistance value was fluctuating between several ohms, to hundreds of ohms, to open circuit

Appendix G – Resistance results of switches aged with AY105-1/HY991, Test 9

All results in Ohms.

Thermal aging of switches assembled with AY105-1/HY991

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
19	0.004	0.004	0.005	0.004	0.006	0.004	13:10 Tue 08/03/16	13:10 Thu 08/03/16	2 days	0.003	0.005	0.003	0.004	0.003	0.004	0.003	0.004
20	0.003	0.003	0.004	0.003	0.004	0.003	13:10 Tue 08/03/16	13:10 Mon 14/03/16	6 days	0.004	0.013	0.004	0.011	0.004	0.010	0.004	0.007

Further thermal aging of above switches

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
19	Above switches were aged further in their enclosures.						10:30 Thu 17/03/16	15:30 Tue 29/03/16	12days 5hrs	0.004	-	0.008	-	0.014	-	0.017	-
20								14:00 Mon 21/03/16	4days 3hrs 30mins	0.004	-	0.181	-	0.096	-	-	0.010*

Total aging time for switch 19 = 14 days, 5 hrs
Total aging time for switch 20 = 10 days, 3 hrs, 30 mins

- indicates open circuit

* denotes a value that was inconsistent, i.e. the ohm value moved around the value recorded, it did not settle.

Thermal aging of switch assembled with reduced quantity of AY105-1/HY991

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
50	0.006	0.004	0.018	0.004	0.012	0.004	13:00 Thu 14/04/16	08:00 Mon 25/04/16	10days 19hrs	0.030	0.078	0.035	0.008	0.005	0.007	0.170	0.005

Appendix H – Resistance results of switch aged with Raychem S1264, Test 10

All results in Ohms.

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
49	0.004	0.003	0.004	0.003	0.004	0.004	13:00 Thu 14/04/16	08:00 Mon 25/04/16	10days 19hrs	0.010	0.024	0.007	0.021	0.008	0.023	0.012	0.009

Appendix I – Resistance results of switch aged with X60, Test 11

All results in Ohms.

	Results before ageing						Into oven	Out of oven	Total aging	Results after ageing							
	Operation 1		Operation 2		Operation 3					Operation 4		Operation 5		Operation 6		Operation 7	
	N/C	N/O	N/C	N/O	N/C	N/O				N/C	N/O	N/C	N/O	N/C	N/O	N/C	N/O
53	0.006	0.002	0.005	0.002	0.006	0.003	14:20 Mon 18/04/16	14:20 Thu 28/04/16	10 days	0.008	-	0.040	-	0.016	-	0.042	-

\- indicates open circuit

* indicates that the resistance value was fluctuating between several ohms, to hundreds of ohms, to open circuit