September 1, 2016

Orbital Debris Assessment for DAVE on the JPSS-1 / ELaNa-XIV Mission per NASA-STD 8719.14A

Sensitive But Unclassified (SBU)

REFERENCES:

A. *NASA Procedural Requirements for Limiting Orbital Debris Generation*, NPR 8715.6A, 5 February 2008
B. *Process for Limiting Orbital Debris*, NASA-STD-8719.14A, 25 May 2012
C. Preliminary Mission Analysis For The Delta II 7920-10 / JPSS-1 Spacecraft Mission, ULA-TP-15-096, July 21, 2015.
D. McKissock, Barbara, Patricia Loyselle, and Elisa Vogel. *Guidelines on Lithium-ion Battery Use in Space Applications*. Tech. no. RP-08-75. NASA Glenn Research Center Cleveland, Ohio
E. *UL Standard for Safety for Lithium Batteries, UL 1642*. UL Standard. 4th ed. Northbrook, IL, Underwriters Laboratories, 2007
F. Kwas, Robert. Thermal Analysis of ELaNa-4 CubeSat Batteries, ELVL-2012-0043254; Nov 2012
G. Range Safety User Requirements Manual Volume 3- Launch Vehicles, Payloads, and Ground Support Systems Requirements, AFSCM 91-710 V3.
H. *UL Standard for Safety for Household and Commercial Batteries, UL 2054*. UL Standard. 2nd ed. Northbrook, IL, Underwriters Laboratories, 2005

The intent of this report is to satisfy the orbital debris requirements listed in ref. (a) for the DAVE CubeSat, part of the ELaNa-XIV auxiliary mission launching in conjunction with the JPSS-1 primary payload. Sections 1 through 8 of ref. (b) are addressed in this document; sections 9 through 14 fall under the requirements levied on the primary mission and are not presented here.

The following table summarizes the compliance status of the DAVE CubeSat, part of the ELaNa-XIV auxiliary payload mission flown on JPSS-1. The CubeSat is fully compliant with all applicable requirements.

Table 1: Orbital Debris Requirement Compliance Matrix

Requirement	Compliance Assessment	Comments
4.3-1a	Not applicable	No planned debris release
4.3-1b	Not applicable	No planned debris release
4.3-2	Not applicable	No planned debris release
4.4-1	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-2	Compliant	Minimal risk to orbital environment, mitigated by orbital lifetime.
4.4-3	Not applicable	No planned breakups
4.4-4	Not applicable	No planned breakups
4.5-1	Compliant	
4.5-2	Not applicable	
4.6-1(a)	Compliant	Worst case lifetime 13.8 yrs
4.6-1(b)	Not applicable	
4.6-1(c)	Not applicable	
4.6-2	Not applicable	
4.6-3	Not applicable	
4.6-4	Not applicable	Passive disposal
4.6-5	Compliant	
4.7-1	Compliant	Non-credible risk of human casualty
4.8-1	Compliant	No planned tether release under DAVE mission

Section 1: Program Management and Mission Overview

The ELaNa-XIV mission is sponsored by the Space Operations Mission Directorate at NASA Headquarters. The Program Executive is Jason Crusan. Responsible program/project manager and senior scientific and management personnel are as follows:

DAVE: Dr. Jordi Puig-Suari <jpuigsua@calpoly.edu>
Dr. John Bellardo <bellardo@calpoly.edu>
Justin Foley <jfoley@calpoly.edu>

Program Milestone Schedule	
Task	**Date**
CubeSat Selection	August 5, 2016
CubeSat Build, Test, and Integration	September 1, 2016
MRR	October 4, 2016
CubeSat Integration into P-PODs	November 7, 2016
CubeSat Delivery to VAFB	January 9, 2017
Launch	January 2017

Figure 1: Program Milestone Schedule

The ELaNa-XIV mission will be launched as an auxiliary payload on the JPSS-1 mission on a Delta II 7920-10 launch vehicle from Space Launch Complex 2 West (SLC-2W) at Vandenberg Air Force Base (VAFB). ELaNa-XIV, will deploy 5 pico-satellites (or CubeSats). The CubeSat slotted position is identified in Table 2: ELaNa-XIV CubeSats. The ELaNa-XIV manifest includes: Buccaneer, EagleSat, DAVE, MiRaTA and, RadFXSat. The current launch date is January 20, 2017. The (5) CubeSats will be ejected from a P-POD carrier attached to the launch vehicle, placing the CubeSats in an orbit approximately 440 km X 811 km at inclination of 97.7 deg (ref. (c)).
The CubeSat standard form ranges in sizes from a 10 cm cube to 10 cm x 10cm x 30 cm, with masses from about 1 kg to 4 kg total. The CubeSats have been designed and universities and government agencies and each have their own mission goals.

Section 2: Spacecraft Description

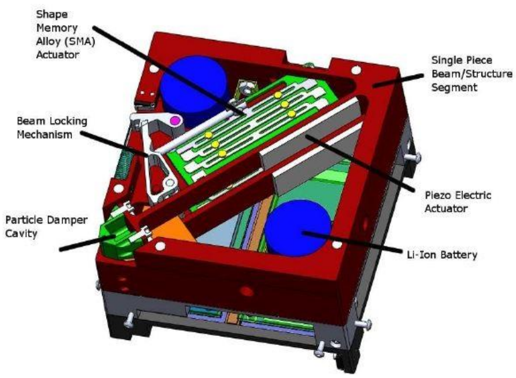
There are five CubeSats flying to comprise ELaNa-XIV. The CubeSats will be deployed out of 3 PPODs, as shown in Table 2: ELaNa-XIV CubeSats below.

Table 2: ELaNa-2 CubeSats

PPOD Slot	CubeSat Quantity	CubeSat size	CubeSat Names	CubeSat Masses (kg)
P-POD #1	3	1U (10 cm X 10 cm X 10 cm) 1U (10 cm X 10 cm X 10 cm) 1U (10 cm X 10 cm X 10 cm)	EagleSat DAVE RadFXSat	1.1 1.40 1.32
P-POD #2	1	3U (10 cm X 10 cm X 32.5 cm)	Buccaneer	3.98
P-POD #3	1	3U (10 cm X 10 cm X 32.5 cm)	MiRaTA	4.19

The following subsections contain description of DAVE.

DAVE CubeSat Description, Cal Poly – 1U



The Damping and Vibration Experiment (DAVE) CubeSat implements a payload to evaluate a mechanical damping technology in microgravity. This technology, called particle damping, exploits the dynamics of multiple constrained particles to dissipate vibration energy. Terrestrial applications demonstrate particle damping performance to be largely unaffected by extreme environments yet simple and cheap to implement. This feature set makes particle damping an attractive technology for applications in spacecraft, where dampers are needed to steady sensitive instrumentation and inhibit destructive structural resonant modes.

In orbit, DAVE provides a low cost and low risk platform to characterize unknown particle damper microgravity behavior and provide flight heritage for particle damper technology. The completion of these objectives overcomes barriers currently inhibiting the employment of particle dampers in space.

DAVE is equipped with one OmniVision imager. The primary purpose of the imager is verifying the rotation rates of the spacecraft prior to performing experiments. The secondary mission is acquiring Earth imagery to support public outreach activities.

After deployment from the P-POD, the satellite will power on. Approximately 15 minutes later, antenna deployment will occur. 115 minutes after antenna deployment, the beacon will be activated and the satellite will be available to acquire with the ground station. A full parameter sweep vibration experiment will begin automatically within a few hours of launch. Results will be downloaded over subsequent passes. Additional experiments can be commanded from the ground as necessary to improve confidence in the results.

The structure is made entirely of 6061-T6 Aluminum. The antenna is made of NiTi and Delrin. The ceramic piezo electric beam actuators are lead zirconate titanate. The tips of the booms contain tungsten particles. The satellite contains mostly standard commercial off the shelf materials, electrical components, PCBs, and solar cells.

There are no pressure vessels, hazardous materials, or exotic materials. The cavities containing the tungsten particles are not freely vented.

There are 2x UL listed 3.7V 2600mAh Lithium-Ion 18650 batteries connected in parallel. The UL listing number is MH48285. There is battery protection circuitry and over-charge protection.

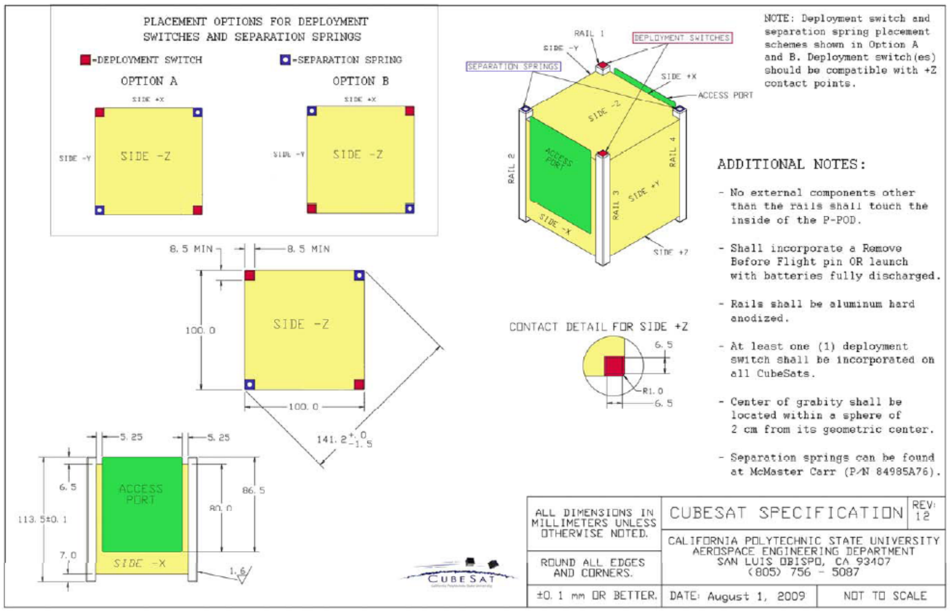


Figure 2: 1U CubeSat Specification

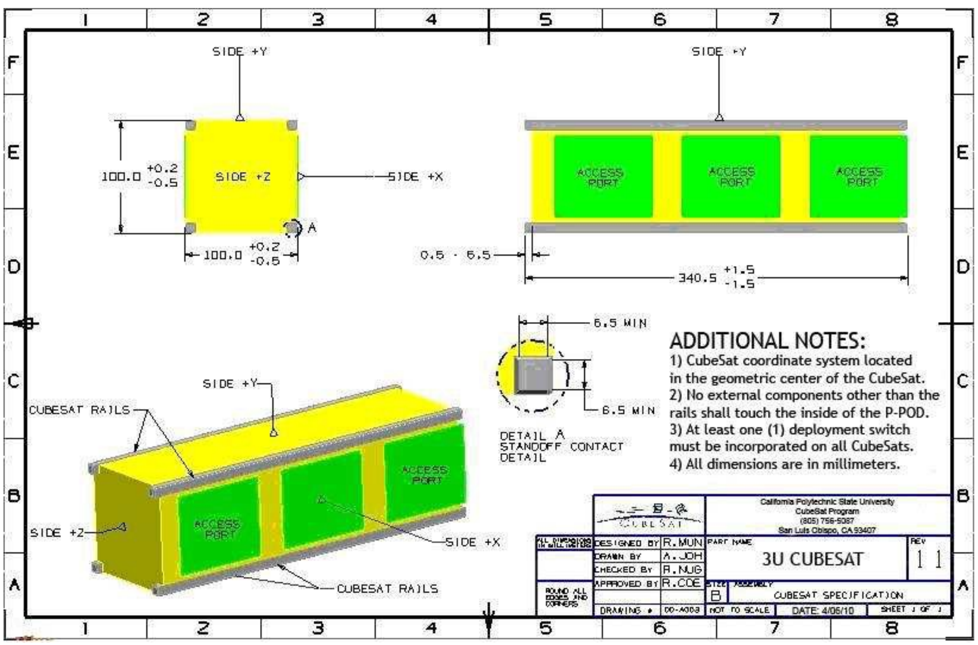


Figure 3: 3U CubeSat Specification

Section 3: Assessment of Spacecraft Debris Released during Normal Operations

The assessment of spacecraft debris requires the identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material.

The section 3 requires rationale/necessity for release of each object, time of release of each object, relative to launch time, release velocity of each object with respect to spacecraft, expected orbital parameters (apogee, perigee, and inclination) of each object after release, calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO), and an assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2.

No releases are planned on the DAVE CubeSat mission therefore this section is not applicable.

Section 4: Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

There are NO plans for designed spacecraft breakups, explosions, or intentional collisions on the DAVE mission.

The probability of battery explosion is very low, and, due to the very small mass of the satellites and their short orbital lifetimes the effect of an explosion on the far-term low earth orbit environment is negligible (ref (h)).

The CubeSat batteries still meet Req. 56450 (4.4-2) by virtue of the HQ OSMA policy regarding CubeSat battery disconnect stating;

> “CubeSats as a satellite class need not disconnect their batteries if flown in LEO with orbital lifetimes less than 25 years.” (ref. (h))

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4 shows that with a maximum lifetime of 8.4 years the DAVE CubeSat is compliant.

Section 5: Assessment of Spacecraft Potential for On-Orbit Collisions

Calculation of spacecraft probability of collision with space objects larger than 10 cm in diameter during the orbital lifetime of the spacecraft takes into account both the mean cross sectional area and orbital lifetime.

The largest mean cross sectional area (CSA) among the five CubeSats, is that of the Buccaneer CubeSat (10 X 10 X 32.5 cm):

$$\boldsymbol{Mean\ CSA} = \frac{\sum \boldsymbol{Surface\ Area}}{\mathbf{4}} = \frac{[\mathbf{2} * (\boldsymbol{w} * \boldsymbol{l}) + \mathbf{4} * (\boldsymbol{w} * \boldsymbol{h})]}{\mathbf{4}}$$

Equation 1: Mean Cross Sectional Area for Convex Objects

$$\boldsymbol{Mean\ CSA} = \frac{(\boldsymbol{A_{max}} + \boldsymbol{A_1} + \boldsymbol{A_1})}{\mathbf{2}}$$

Equation 2: Mean Cross Sectional Area for Complex Objects

All CubeSats evaluated for this ODAR are stowed in a convex configuration, indicating there are no elements of the CubeSats obscuring another element of the same CubeSats from view. Thus, mean CSA for all stowed CubeSats was calculated using Equation 1. This configuration renders the longest orbital life times for all CubeSats.

Once a CubeSat has been ejected from the P-POD and deployables have been extended Equation 2 is utilized to determine the mean CSA. A_{max} is identified as the view that yields the maximum cross-sectional area. A1 and A2 are the two cross-sectional areas orthogonal to A_{max}. Refer to Appendix A for dimensions used in these calculations.

The Buccaneer CubeSat has an orbit at deployment of 440 km perigee altitude by 811 km apogee altitude, with an inclination of 97.7 degrees. With an area to mass (3.98 kg) ratio of 0.046 m2/kg, DAS yields 5.2 years for orbit lifetime for its deployed state. Even with the variation in CubeSat design and orbital lifetime ELaNa-XIV CubeSats see an average of 0.00000 probability of collision. Buccaneer, with the largest cross sectional area will see the highest probability of collision of 0.00000. **Table 3** below provides complete results.

There will be no post-mission disposal operation. As such the identification of all systems and components required to accomplish post-mission disposal operation, including passivation and maneuvering, is not applicable.

Table 3: CubeSat Orbital Lifetime & Collision Probability

	CubeSat	DAVE	Buccaneer	EagleSat	MiRaTA	RadFXSat
	Mass (kg)	1.4	3.98	1.1	4.19	1.32
Stowed	Mean C/S Area (m^2)	0.0155	0.38	0.016	0.0364	0.015
	Area-to Mass (m^2/kg)	0.011	0.009	0.014	0.0089	0.011
	Orbital Lifetime (yrs)	8.4	8.5	7.4	13.8	8.5
	Probability of collision (10^X)	0.00000	0.00000	0.00000	0.00000	0.00000
Deployed	Mean C/S Area (m^2)	0.0155	0.183	0.021	0.0385	0.0153
	Area-to Mass (m^2/kg)	0.011	0.046	0.019	0.0092	0.012
	Orbital Lifetime (yrs)	8.4	5.2	6.6	12.5	8.3
	Probability of collision (10^X)	0.00000	0.00000	0.00000	0.00000	0.00000

The probability of any ELaNa-XIV spacecraft collision with debris and meteoroids greater than 10 cm in diameter and capable of preventing post-mission disposal is less than 0.00000, for any configuration. This satisfies the 0.001 maximum probability requirement 4.5-1.

Since the CubeSats have no capability or plan for end-of-mission disposal, requirement 4.5-2 is not applicable.

Assessment of spacecraft compliance with Requirements 4.5-1 shows ELaNa-XIV to be compliant. Requirement 4.5-2 is not applicable to this mission.

Section 6: Assessment of Spacecraft Postmission Disposal Plans and Procedures

All ELaNa-XIV spacecraft will naturally decay from orbit within 25 years after end of the mission, satisfying requirement 4.6-1a detailing the spacecraft disposal option.

Planning for spacecraft maneuvers to accomplish post-mission disposal is not applicable. Disposal is achieved via passive atmospheric reentry.

Calculating the area-to-mass ratio for the worst-case, longest orbital lifetime (smallest Area-to-Mass) post-mission disposal among the CubeSats finds MiRaTA in its stowed configuration as the longest lived. The area-to-mass is calculated for is as follows:

$$\frac{\boldsymbol{Mean}\ {}^{\boldsymbol{C}}/_{\boldsymbol{S}}\,\boldsymbol{Area}\ (\boldsymbol{m^2})}{\boldsymbol{Mass}\ (\boldsymbol{kg})} = \boldsymbol{Area - to - Mass}\ (\frac{\boldsymbol{m^2}}{\boldsymbol{kg}})$$

Equation 3: Area to Mass

$$\frac{0.0374\ m^2}{4.19\ kg} = 0.0089\frac{m^2}{kg}$$

MiRaTA has the smallest Area-to-Mass ratio and as a result will have the longest orbital lifetime (worst cast time to deorbit). The assessment of the spacecraft illustrates they are compliant with Requirements 4.6-1 through 4.6-5.

<u>DAS 2.0.2 Orbital Lifetime Calculations:</u>

DAS inputs are: 440 km maximum perigee 811 km maximum apogee altitudes with an inclination of 97.7 degrees at deployment in January 20 of 2017. An area to mass ratio of 0.0089 m2/kg for the MiRaTA CubeSat was imputed. DAS 2.0.2 (using a solar flux file dated 10/14/2015) yields a 13.8-year orbit lifetime for MiRaTA in its stowed state.

This meets requirement 4.6-1. For the complete list of CubeSat orbital lifetimes reference Table 3: CubeSat Orbital Lifetime & Collision Probability.

Assessment results show compliance.

Section 7: Assessment of Spacecraft Reentry Hazards

A detailed assessment of the components to be flown on ELaNa-XIV was performed. The assessment used DAS 2.0.2, a conservative tool used by the NASA Orbital Debris Office to verify Requirement 4.7-1. The analysis is intended to provide a bounding analysis for characterizing the survivability of a CubeSat's component during re-entry. For example, when DAS shows a component surviving reentry it is not taking into account the material ablating away or charring due to oxidative heating. Both physical effects are experienced upon reentry and will decrease the mass and size of the real-life components as the reenter the atmosphere, reducing the risk they pose still further.

The following steps are used to identify and evaluate a components potential reentry risk relative to the 4.7-1 requirement of having less than 15 J of kinetic energy and a 1:10,000 probability of a human casualty in the event the survive reentry.

1. Low melting temperature (less than 1000 °C) components are identified as materials that would never survive reentry and pose no risk to human casualty. This is confirmed through DAS analysis that showed materials with melting temperatures equal to or below that of copper (1080 °C) will always demise upon reentry for any size component up to the dimensions of a 1U CubeSat.

2. The remaining high temperature materials are shown to pose negligible risk to human casualty through a bounding DAS analysis of the highest temperature components, stainless steel (1500°C). If a component is of similar dimensions and has a melting temperature between 1000 °C and 1500°C, it can be expected to posses the same negligible risk as stainless steel components. See Table 4.

Table 4: Survivability Analysis

CubeSat	High Temp Component	Material	Mass (g)	Demise Alt (km)	KE (J)
DAVE	PZT Actuator	Ceramic	3.5	0	0
DAVE	Damping powder*	Tungsten	20	0	0

*Tungsten powder, total 20 grams, modeled as 200 x 0.1 gram spheres.

A significant number of the high temperature components demise upon reentry. The components that DAS conservatively identifies as reaching the ground have less than 15 joules of kinetic energy. No high temperature component will pose a risk to human casualty as defined by the Range Commander's Council. In fact, any injury incurred or inflicted by an object with such low energy would be negligible and wouldn't require the individual to seek medical attention.

Components, reported by DAS to have a demise altitude of 0 km and kinetic energy of 0J, can be assumed to have energy less than one joule as DAS does not supply decimal result.

Through the method described above, Table 4, and the full component lists in the Appendix all CubeSats launching under the ELaNa-XIV mission are conservatively shown to be in compliance with Requirement 4.7-1 of NASA- STD-8719.14A.

Section 8: Assessment for Tether Missions

DAVE will not be deploying any tethers.

DAVE satisfies Section 8’s requirement 4.8-1.

Section 9-14

ODAR sections 9 through 14 for the launch vehicle are addressed in ref. (g), and are not covered here.

If you have any questions, please contact the undersigned at 805-756-5074.

/original signed by/

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Appendix Index:

Appendix A. DAVE Component List

Row Number	Name	External/Internal (Major/Minor Components)	Qty	Material	Body Type	Mass (g)	Diameter/ Width (mm)	Length (mm)	Height (mm)	Low Melting	Melting Temp	Comment
1	DAVE		1	Various	Box		100	100	113.5	Y		Demises
2	CubeSat Structure	External - Major	1	Aluminum 6061	Box	535	100	100	113.5	Y		Demises
3	Antenna Route	External - Major	1	Delrin	Square	7	65	65	3.5	Y		Demises
4	Antenna Wire	External - Major	2	Nickel Titanium (NiTi)	Rectangular	2.638	2.2	80	12	Y		Demises
5	Solar Cells	External - Major	10	Eglass	Rectangular	2.2512	0.5	68	40	Y		Demises
6	Side Panels	External - Major	5	FR4 Multilayer PCB	Rectangular	35	1.5	83	72	Y		Demises
7	Z-Panels	External - Major	1	FR4 Multilayer PCB	Square	45	1.5	100	100	Y		Demises
8	Cavity Caps	Internal - Major	3	316 Stainless Steel	Box	10.5	20	13	13	Y		Demises
9	Ceramic Piezoelectric Actuators	Internal - Major	3	Lead Zirconate Titanate	Box	3.5	2.54	44.45	12.7	N	1350 °C	Survives with <1J of energy
10	Tungsten Crystalline Powder	Internal - Major	1	Tungsten	Powder	20	N/A	N/A	N/A	N	3422 °C	Survives with <1J of energy
11	SMA Actuators Boards	Internal - Major	4	Nickel Titanium (NiTi)	Wire	0.5	0.05	100	N/A	Y		Demises
12	SMA Actuators wire	Internal - Major	4	FR4 Multilayer PCB	Rectangular	22	1.524	68.707	24.257	Y		Demises
13	Torque Shaft	Internal - Major	1	Aluminum 6061	Cylindrical	3	4		62	Y		Demises
14	Locking springs	Internal - Major	3	302 Stainless	Cylindrical	3				Y		Demises
15	Sep/Actuating Switches	External - Minor	5	Plastic (PBT)	Rectangular	2	6	8	7	Y		Demises
16	Batteries	Internal - Major	2	Lithium Ion	Cylindrical	90.7	26.3	65.8	N/A	Y		Demises
17	Payload Board	Internal - Major	2	FR4 Multilayer PCB	Board	33	1.5	83	83	Y		Demises
18	Sensor Board	Internal - Major	3	FR4 Multilayer PCB	Board	5	1.5	32	32	Y		Demises
19	Comm Board	Internal - Major	1	FR4 Multilayer PCB	Board	12	1.5	83	36	Y		Demises
20	Breakout Board	Internal - Major	1	FR4 Multilayer PCB	Board	12	1.5	83	36	Y		Demises
21	C&DH Board	Internal - Major	1	FR4 Multilayer PCB	Board	30	1.5	83	83	Y		Demises
22	Fasteners	Internal - Minor	1	18-8 Stainless	Screw	35	2.2	Various	N/A	Y		Demises
23	Staking Compound	Internal/External - Minor	1	3M Scotch Weld 2216	Rectangular	15	N/A	N/A	N/A	Y		Demises
24	Heat Shrink	Internal - Minor	1	RNF-100 Polyolefin Heat Shrink	Tube	0	N/A	N/A	N/A	Y		Demises
25	Kapton Tape	Internal/External - Minor	1	Kapton Tape	Tape	0	Various	Various	0.05	Y		Demises