QubScout-S1 Formal Orbital Debris Assessment Report (ODAR)

In accordance with NPR 8715.6A, this report is presented as compliance with the required reporting format per NASA-STD-8719.14, APPENDIX A.

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DAS Software Used in This Analysis: DAS v2.0.2

QubScout-S1 Satellite Project

Orbital Debris Assessment Report (ODAR)

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1 Revision History

Rev.	Date	Pages	Description of Change	Author(s)
A	2/18/2013	All	Initial Release	Steven Buczkowski

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3 Self-assessment and OSMA assessment of the ODAR using the format in Appendix A.2 of NASA-STD-8719.14

A self-assessment is provided below in accordance with the assessment format proovided in Appendix A.2 of NASA-STD-8719.14. In the final ODAR document, this assessment will reflect any inputs from the OSMA as well.

Orbital Debris Self-Assessment Report Evaluation: Qubscout-S1

Requirement #	Launch Vehicle				Spacecraft			Comments
	Compliant	Not Compliant	Incomplete	Standard Non Compliant	Compliant	Not Compliant	Incomplete	
4.3-1.a			x		x			No Debris Released in LEO. See note 1.
4.3-1.b			x		x			No Debris Released in LEO. See note 1.
4.3-2			x		x			No Debris Released in GEO. See note 1.
4.4-1			x		x			See note 1.
4.4-2			x		x			See note 1.
4.4-3			x		x			No planned breakups. See Note 1.
4.4-4			x		x			No planned breakups. See Note 1.
4.5-1			x		x			See note 1.
4.5-2					x			
4.6-1(a)			x		x			See note 1.
4.6-1(b)			x		x			See note 1.
4.6-1(c)			x		x			See note 1.
4.6-2			x		x			See note 1.
4.6-3			x		x			See note 1.
4.6-4			x		x			See note 1.
4.6-5			x		x			See note 1.
4.7-1			x		x			See note 1.
4.8-1					x			No tethers used.

Note 1: Qubscout-S1 is part of a parasitic payload of nano-satellites to be launched within an integrated launcher. Qubscout-S1 is not a lead on the primary launch stack, any primary payloads or the MRFOD pocketQub deployer.

4 Mission Description

QubScout-S1 is a 2U pocketQub satellite to be deployed as part of a group of pocketQub class satellites from the Unisat-5 satellite (University of Rome) to be launched from Yasny Russia in May 2013 on a Dnepr rocket

QubScout-S1 will test and validate two technologies in Low Earth Orbit (LEO): a sun position sensor developed at University of Maryland Baltimore County (UMBC) and a deployable de-orbit system for pocketQubs also developed at UMBC.

QubScout-S1 will fly stowed in an MRFOD deployer developed and built by Morehead State University. The MRFOD will be integrated as part of the Unisat-5 payload. Unisat-5 will be inserted into an orbit at 640km apogee and 600km perigee, on an inclination from the equator of 97.79°. Aproximately one month into the primary mission of Unisat-5, the MRFOD deployer will be activated to deploy the stowed pocketQubs, including QubScout-S1, by means of spring-loaded pusher plates. This push will give QubScout-S1 a velocity of ~ 5 cm/s relative to Unisat-5. There are no propellants involved.

Approximately one hour after deployment, QubScout-S1 will deploy a flexible dipole antenna via a nichrome wire cutter and will begin transmitting in the amateur UHF 70cm band. Transmissions will be a beacon containing satellite ID, system status indicators and several data packets from the sun sensor primary payload. Longer (15 minute) data transmissions will be commanded periodically from the ground.

One month after the start of transmission, a second nichrome cutter will be used to deploy the de-orbit panels. Satellite operations will continue until de-orbiting occurs approximately 6.5 years later.

Launch vehicle and launch site Dnepr, Yasny Russia

Proposed launch date May 2013

Mission duration 6.5 years

Launch and deployment profile: operational orbit, parking and transfer

Apogee 640km

Perigee 600km

Inclination 97.79°

QubScout-S1 has no propulsion and, therefore, does not actively change orbits. The only orbital changes expected are those naturally occuring as QubScout-S1 de-orbits from its operational orbit. There are no parking or transfer orbits.

Interaction or potential physical interference with other operational Spacecraft:

The main risks of this satellite are the Lithium-ion battery used by the spacecraft, radio-frequency noise generated when the system power is applied, radio-frequency interference between the QubScout-S1 radio and radios on other nearby spacecraft and the possibility of QubScout-S1 impacting other deploying pocketQubs or the parent vehicle (Unisat-5). Because of the inherently low power levels in both the C&DH circuitry and the UHF transmitter and active frequency coordination with both the parent vehicle and the other pocketQubs, we believe risks due to RFI are minimal. Multiple nano-satellite launches from similar, spring-loaded, multi-object deployers are relatively commonplace and occur with little risk of impact between neighboring devices. We believe the risk of collision between QubScout-S1 and either neighboring pocketQubs or Unisat-5 to be minimal.

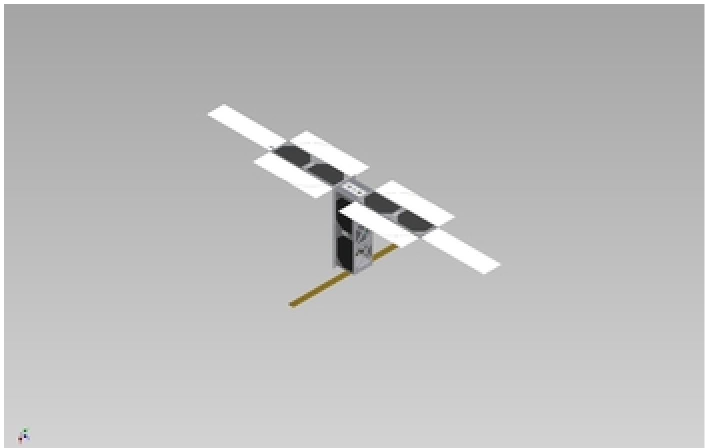

Figure 1: QubScout-S1 with antenna and de-orbit panels deployed

5 Spacecraft Description

Physical description of the spacecraft:

QubScout-S1 is a 2U pocketQub femto-satellite with dimensions 50mm x 50mm x 100mm and a total mass of 0.430kg. QubScout-S1 will contain the following systems: two solar position sensors, Arduino Mini micro-controller, 500mW 400MHz UHF radio, one deployed dipole antenna, one Li-ion battery and four high efficiency solar panels

Arduino Mini C&DH computer. Reads all onboard sensors and controls timing of antenna and de-orbit panel deployment.

Solar Position sensor 2-D photodiode to sense position of sun relative to spacecraft body coordinates (2 mounted on opposing faces of spacecraft to monitor tumble)

Radio 0.5W UHF transceiver operating at 437.525MHz AX.25 packet for command uplink, data downlink and beacon functions. The ham radio community will be invited to participate in collecting beacon data.

Antenna 1/2-wave dipole *tape measure* type spring deployable antenna

Li-ion battery Samsung LGABC11865: Primary power supply

Solar panels Pico-satellite panels form Clyde Space

Total satellite mass at launch, including all propellents and fluids
0.430kg

Dry mass of satellite at launch, excluding solid motor propellents

0.430kg

Description of all propulsion systems
There will be no propulsion systems on QubScout-S1.

Identification, including mass and pressure, of all fluids (liquids and gases) planned to be on board and a description of the fluid loading plan or strategies, excluding fluids in sealed heat pipes:
Not applicable as there will be no fluids or gasses on board.

Fluids in pressurized batteries:
None. QubScout-S1 uses unpressurized standard COTS Lithium-Ion battery cells.

Description of attitude control system and indication of the normal attitude of the spacecraft with respect to the velocity vector:
QubScout-S1 has no active or passive attitude controls and will free tumble. Average surface area when the de-orbit panels are deployed has been modeled as an even weighted average of all exposed surface areas.

Description of any range safety or other pyrotechnic devices:
QubScout-S1 utilizes two NiChrome wire heating elements for use in antenna and de-orbit panel deployment. The NiChrome wire is wound in a coil shape with nylon cord strung through the coil. Each NiChrome wire coil is located on one of the spacecraft distal ends and is physically mounted and electrically connected via a PCB interface. This design is based on cutter designs common among smallsats

Description of the electrical generation and storage system:
Power will be generated by (8) Clyde Space solar panels mounted in pairs on the four rectangular sides of the spacecraft bus. Two of those pairs form the de-orbit panel covers and will retain their power generation function after the panels are deployed. The panels are sized to be able to be able to charge the Li-ion battery and power the radio in beacon operations but not to supply sufficient power for the radio in extended data transmission. The panels will provide current to charge the system Samsung LGABC11685 Li-Ion battery.

Identification of any other sources of stored energy not noted above:
None

Identification of any radioactive materials on board:
None

6 Assessment of Spacecraft Debris Released during Normal Operations

Identification of any object (>1 mm) expected to be released from the spacecraft any time after launch, including object dimensions, mass, and material:
There are no intentional releases.

Rationale/necessity for release of each object:
N/A.

Time of release of each object, relative to launch time:
N/A.

Release velocity of each object with respect to spacecraft:
N/A.

Expected orbital parameters (apogee, perigee, and inclination) of each object after release:
N/A.

Calculated orbital lifetime of each object, including time spent in Low Earth Orbit (LEO):
N/A.

Assessment of spacecraft compliance with Requirements 4.3-1 and 4.3-2 (per DAS v2.0.2)
4.3-1, Mission Related Debris Passing Through LEO:

COMPLIANT

4.3-2, Mission Related Debris Passing Near GEO:
COMPLIANT

7 Assessment of Spacecraft Intentional Breakups and Potential for Explosions.

Potential causes of spacecraft breakup during deployment and mission operations:
There is no credible scenario that would result in spacecraft breakup during normal deployment and operations.

Summary of failure modes and effects analyses of all credible failure modes which may lead to an accidental explosion:
The battery on-board QubScout-S1 is the only part of the spacecraft subsystems which has potential as an explosion hazard. The possibilities of such a failure are discussed in the Requirement 4.4-1 failure mode analysis on page 9.

Detailed plan for any designed spacecraft breakup, including explosions and intentional collisions:
There are no planned breakups.

List of components which shall be passivated at End of Mission (EOM) including method of passivation and amount which cannot be passivated:
None.

Rationale for all items which are required to be passivated, but cannot be due to their design:

QubScout-S1 will be on orbit for 6.5 years based on the DAS analysis shown in this report, and it is planned to operate until deorbit. Therefore, no postmission passivation will be performed, as the satellite will break up on re-entry at the end of the mission.

Assessment of spacecraft compliance with Requirements 4.4-1 through 4.4-4:

Requirement 4.4-1: Limiting the risk to other space systems from accidental explosions during deployment and mission operations while in orbit about Earth or the Moon: For each spacecraft and launch vehicle orbital stage employed for a mission, the program or project shall demonstrate, via failure mode and effects analyses or equivalent analyses, that the integrated probability of explosion for all credible failure modes of each spacecraft and launch vehicle is less than 0.001 (excluding small particle impacts) (Requirement 56449). Compliance statement:

Required Probability: 0.001.

Expected probability: 0.000.

Supporting Rationale and FMEA details:

Payload Pressure Vessel Failure:
The maximum payload pressure is 14.7 PSIa. At this pressure, the payload is considered to be a sealed container and not a pressure vessel. This contained pressure is considered to be insufficient to cause catastrophic failure of the vessel.

Battery explosion:
Failure mode 1: Battery internal short circuit.
Mitigation 1: Pre-flight environmental testing of battery under vacuum, thermal and repeated charge-discharge cycling failed to identify any significant internal short circuit hazard.
Combined faults required for realized failure: Environmental testing **AND** functional charge-discharge testing must both be ineffective in discovery of the failure mode.
Failure Mode 2: Internal thermal rise due to high load discharge rate.
Mitigation 2: Power is drawn from the battery through current limiting diodes rated for 1A. The battery is rated to handle discharge current in excess of 2A under normal use.
Combined faults required for realized failure: Mechanical failure releasing conductive material into the satellite volume **AND** that material must short circuit across the battery within the battery holder such that it bypasses the output diode.
Failure Mode 3: Overcharging and excessive charge rate.
Mitigation 3: The solar panels are sized such that the maximum possible input voltage and current available to the charging circuit are both below the hazard limits for the battery.
Combined faults required for realized failure: No known combination of faults can activate this failure mode.
Failure Mode 4: Excessive discharge rate or short circuit due to external device failure or terminal contact with conductors not at battery voltage levels (due to abrasion or inadequate proximity separation).

Mitigation 4: Any realizable short circuit ultimately draws battery power cross the current limiting diodes in series with the battery. This limits the output current to 1A which is well within the acceptable current draw from the battery. Wiring and circuitboard traces are designed and managed to reduce the possibility of any short circuits downstream of the battery output diode.
Combined faults required for realized failure: Mechanical failure releasing conductive material into the satellite volume **AND** that material must short circuit across the battery within the battery holder such that it bypasses the output diode.
Failure Mode 5: Crushing
Mitigation 5: This mode is negated by spacecraft design. There are no moving parts in the proximity of the battery.
Combined faults required for realized failure: A catastrophic failure must occur in an external system **AND** the failure must cause a collision sufficient to crush the battery leading to an internal short circuit **AND** the satellite must be in a naturally sustained orbit at the time the crushing occurs.
Failure Mode 6: Low level current leakage or short-circuit through battery pack case or due to moisture-based degradation of insulators.
Mitigation 6: These modes are negated by a) battery holder/case design made of non-conductive plastic, and b) operation in vacuum such that no moisture can affect insulators.
Combined faults required for realized failure: Abrasion or piercing failure of circuit board coating or wire insulators **AND** dislocation of battery packs **AND** failure of battery terminal insulators **AND** failure to detect such failures in environmental tests must occur to result in this failure mode.
Failure Mode 7: Excess temperatures due to orbital environment and high discharge combined.
Mitigation 7: The spacecraft thermal design will negate this possibility. Thermal rise has been analyzed in combination with space environment temperatures showing that the battery does not exceed normal allowable operating temperatures which are well below temperatures of concern for explosions.
Combined faults required for realized failure: Thermal analysis **AND** thermal design **AND** mission simulations in thermal-vacuum chamber testing **AND** over-current control must all fail for this failure mode to occur.
Failure Mode 8: Polarity reversal due to over-discharge caused by continuous load during periods of negative power generation vs. consumption.
Mitigation 8: The QubScout-S1 battery is rated for safe discharge down to 2.0V. The C&DH microcontroller and the radio operate at 3.3V and both cease to function between 3.1 and 3.3V. The radio in full data transmit mode is the primary load on the battery. If radio transmission drives the battery voltage below 3.3V, the radio will shut down and terminate the current draw before a deep discharge can occur.
Combined faults required for realized failure:

Short Circuit As discussed in failure modes above.

Continuous Load Radio would need to lock up in full transmit mode **AND** the radio would need to continue transmitting at supply voltages significantly below its rated supply voltage lower limit.

Requirement 4.4-2: Design for passivation after completion of mission operations while in orbit about Earth or the Moon: Design of all spacecraft and launch vehicle orbital stages shall include the ability to deplete all onboard sources of stored energy and disconnect all energy generation sources when they are no longer required for mission operations or post mission disposal or control to a level which can not cause an explosion or deflagration large enough to release orbital debris or break up the spacecraft (Requirement 56450).

Compliance statement: QubScout-S1 will be on orbit for 6.5 years based on the DAS analysis shown in this report, and it is planned to operate until deorbit. Therefore, no postmission passivation will be performed, as the satellite will break up on re-entry at the end of the mission. Therefore, the QubScout-S1 battery will meet the above requirement.

Requirement 4.4-3. Limiting the long-term risk to other space systems from planned breakups:
Compliance statement: This requirement is not applicable. There are no planned breakups.

Requirement 4.4-4: Limiting the short-term risk to other space systems from planned breakups:
Compliance statement: This requirement is not applicable. There are no planned breakups.

8 Assessment of Spacecraft Potential for On-Orbit Collisions

Assessment of spacecraft compliance with Requirements 4.5-1 and 4.5-2 (per DAS v2.0.2, and calculation methods provided in NASA-STD-8719.14, section 4.5.4):

Requirement 4.5-1. Limiting debris generated by collisions with large objects when operating in Earth orbit: For each spacecraft and launch vehicle orbital stage in or passing through LEO, the program or project shall demonstrate that, during the orbital lifetime of each spacecraft and orbital stage, the probability of accidental collision with space objects larger than 10 cm in diameter is less than 0.001 (Requirement 56506).

Large Object Impact and Debris Generation Probability:

0.000000; COMPLIANT.

Requirement 4.5-2. Limiting debris generated by collisions with small objects when operating in Earth or lunar orbit: For each spacecraft, the program or project shall demonstrate that, during the mission of the spacecraft, the probability of accidental collision with orbital debris and meteoroids sufficient to prevent compliance with the applicable postmission disposal requirements is less than 0.01 (Requirement 56507).

Small Object Impact and Debris Generation Probability:
0.000000; COMPLIANT

9 Assessment of Spacecraft Postmission Disposal Plans and Procedures

Description of spacecraft disposal option selected:
The satellite will de-orbit naturally by atmospheric re-entry. There is no propulsion system.

Plan for any spacecraft maneuvers required to accomplish postmission disposal:
None

Calculation of area-to-mass ratio after postmission disposal, if the controlled reentry option is not selected:

Spacecraft Mass: 0.430kg

Average Cross-sectional Area: $0.025784m^2$(de-orbiter deployed) [$0.0066m^2$ stowed]

Area to mass ratio: $0.025784/0.430 = 0.05996m^2/kg$ (de-orbiter deployed)

Note: Cross-sectional area is an evenly weighted average over all faces of the spacecraft. i.e. assumes random tumble for orientation

Assessment of spacecraft compliance with Requirements 4.6-1 through 4.6-5 (per DAS v2.0.2 and NASA-STD-8719.14 section):

Requirement 4.6-1. Disposal for space structures passing through LEO: A spacecraft or orbital stage with a perigee altitude below 2000 km shall be disposed of by one of three methods: (Requirement 56557)

1. Atmospheric reentry option:
   (a) Leave the space structure in an orbit in which natural forces will lead to atmospheric reentry within 25 years after the completion of mission but no more than 30 years after launch; or
   (b) Maneuver the space structure into a controlled de-orbit trajectory as soon as practical after completion of mission.
2. Storage orbit option: Maneuver the space structure into an orbit with perigee altitude greater than 2000 km and apogee less than GEO - 500 km.
3. Direct retrieval: Retrieve the space structure and remove it from orbit within 10 years after completion of mission.

Analysis: The QubScout-S1 satellite reentry is COMPLIANT using Method a. QubScout-S1 will reenter approximately 6.5 years after launch with orbit history as shown in Figure 2 (analysis assumes an approximate random tumbling behavior with deployed de-orbit panels). In the unlikely event that the de-orbit panels do not deploy, DAS v2.0.2 predicts an orbital lifetime of 12.37 years which is still compliant with this requirement.

Requirement 4.6-2. Disposal for space structures near GEO.
Analysis: Not applicable. QubScout-S1 orbit is LEO.

Requirement 4.6-3. Disposal for space structures between LEO and GEO.
Analysis: Not applicable. QubScout-S1 orbit is LEO.

Requirement 4.6-4. Reliability of Postmission Disposal Operations
Analysis: QubScout-S1 deploys two sets of spring–loaded, fold out panels during normal mission operations which increase the average surface area by a factor of 4. These panels are released by a NiChrome wire cutter melting a length of nylon line which holds the panels to the body of the spacecraft. Should this

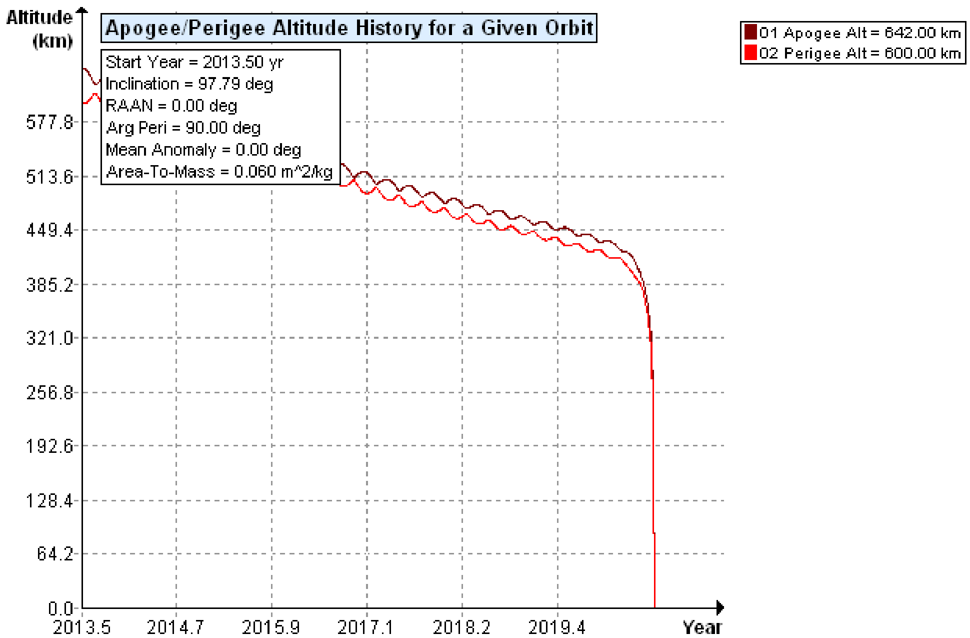

Figure 2: DAS v2.0.2 predicted orbital lifetime for QubScout-S1 with de-orbit panels deployed in random tumble

cutter fail, the nylon wire will degrade in the LEO solar UV environment releasing the panels. There are no recognized failure modes where the de-orbit panels do not eventually deploy. In the extremely unlikely event that such a failure mode does exist, QubScout-S1 has still been shown to de-orbit well within the required 25 year period even with the de-orbit panels stowed.

10 Assessment of Spacecraft Reentry Hazards

Assessment of spacecraft compliance with Requirement 4.7-1:

Requirement 4.7-1. Limit the risk of human casualty: The potential for human casualty is assumed for any object with an impacting kinetic energy in excess of 15 joules:

1. For uncontrolled reentry, the risk of human casualty from surviving debris shall not exceed 0.0001 (1:10,000) (Requirement 56626)

2. For controlled reentry, the selected trajectory shall ensure that no surviving debris impact with a kinetic energy greater than 15 joules is closer than 370 km from foreign landmasses, or is within 50 km from the continental U.S., territories of the U.S., and the permanent ice pack of Antarctica (Requirement 56627).

3. For controlled reentries, the product of the probability of failure of the reentry burn (from Requirement 4.6-4.b) and the risk of human casualty assuming uncontrolled reentry shall not exceed 0.0001 (1:10,000) (Requirement 56628).

Summary analysis results:
DAS v2.0.2 reports the QubScout-S1 is compliant with the requirement 4.7-1a. The reported risk is 1 : 0 but this must be an erroneous value as no pieces are predicted to reach the ground. The DAS results in the reentry survivability table on page 15 show the QubScout-S1 battery surviving deepest into the atmosphere but still with a demise altitude of 67.9km.

Requirements 4.7-1 b and c are **NOT APPLICABLE** for QubScout-S1 as there will be no controlled reentry.

11 Assessment for Tether Missions

Not applicable. There are no tethers in the QubScout-S1 mission.

END of ODAR for QubScout-S1

Appendices

11.1 Reentry survivability

Reentry safety analysis results from DAS v2.0.2

Reentry Data								
Row Num	Name	Material	Body Type	Thermal Mass	Diameter Width	Length	Height	Demise (km)
1	QubScout-S1	Aluminum (generic)	Box	0.43	0.05	0.1	0.05	
2	Solar panel PCB	Fiberglass	Box	0.014	0.05	0.1	0.00157	77.6
3	Solar Panel Glass	Zerodur	Box	0.027	0.05	0.1	0.0022	76.4
4	CPU	Fiberglass	Box	0.002	0.018	0.033	0.002	77.7
5	Radio	Fiberglass	Box	0.0092	0.05	0.05	0.002	77.5
6	Bus	Aluminum (generic)	Box	0.027	0.05	0.1	0.002	76.8
7	Misc (wires,small components)	Fiberglass	Box	0.059	0.05	0.1	0.0065	76.5
8	SunSensor PCB	Fiberglass	Box	0.006	0.04	0.052	0.00157	77.6
9	SunSensor aperture	Aluminum (generic)	Flat Plate	0.004	0.028	0.028		77.1
10	Battery	Iron	Cylinder	0.05	0.018	0.065		67.9

Summary:
COMPLIANT
RISK: 1:0