Lithium-ion Technology for a Submarine Main Battery

Kokam

UDT
Undersea Defence Technology
26–28 June 2018
SEC, Glasgow

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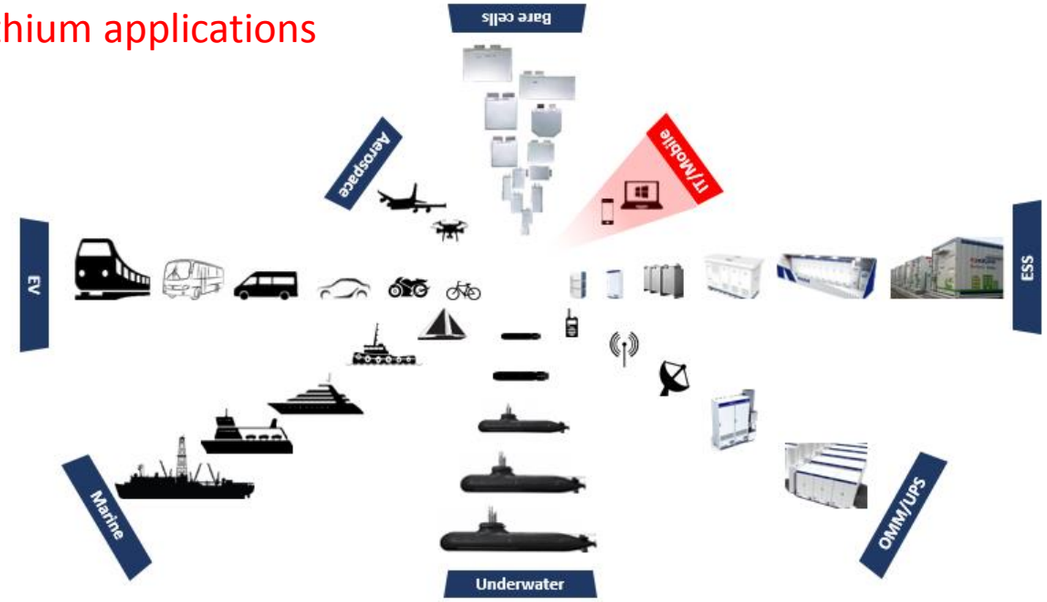
Lithium-ion for energy and power for submarines

Type	Lead Acid	AIP	Lithium-ion
Energy	○	●	●
Power	○	○	●

Lithium applications



Defense sector

7 hours at maximum speed by refit ?

II Lithium-ion Cells

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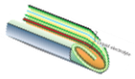
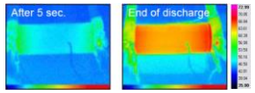
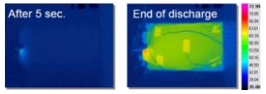
NAVSEA
NAVAL SEA SYSTEMS COMMAND

Cell types

Description	Cylindrical Can	Prismatic Can	Prismatic Pouch
Outer view	30Ah total 	60Ah 	240h 
Inner view	  winding		 Stacking
Heat@1C			
Heat@3C			
Remarks	Lithium-ion		Lithium-ion Polymer

Cell vs Battery

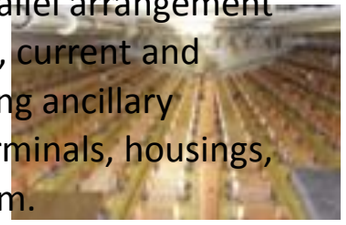
NAVSEA S9310-AQ-SAF-010 Navy Lithium Battery Safety Program

Cell

Is interpreted as an individual unit of a LIB consisting of a container, cathode, anode, separator, electrolyte, and tabs.

Battery

Is interpreted as an assembly of electrochemical cells connected in an appropriate series or parallel arrangement to provide the required operating voltage, current and energy, which is packaged for use, including ancillary components, cables, cases, harnesses, terminals, housings, markings, and battery management system.



Why Pouch for submarines ?

- Maintenance free – less heat no cooling
- Customizing
- Safety

Does a pouch burn ?

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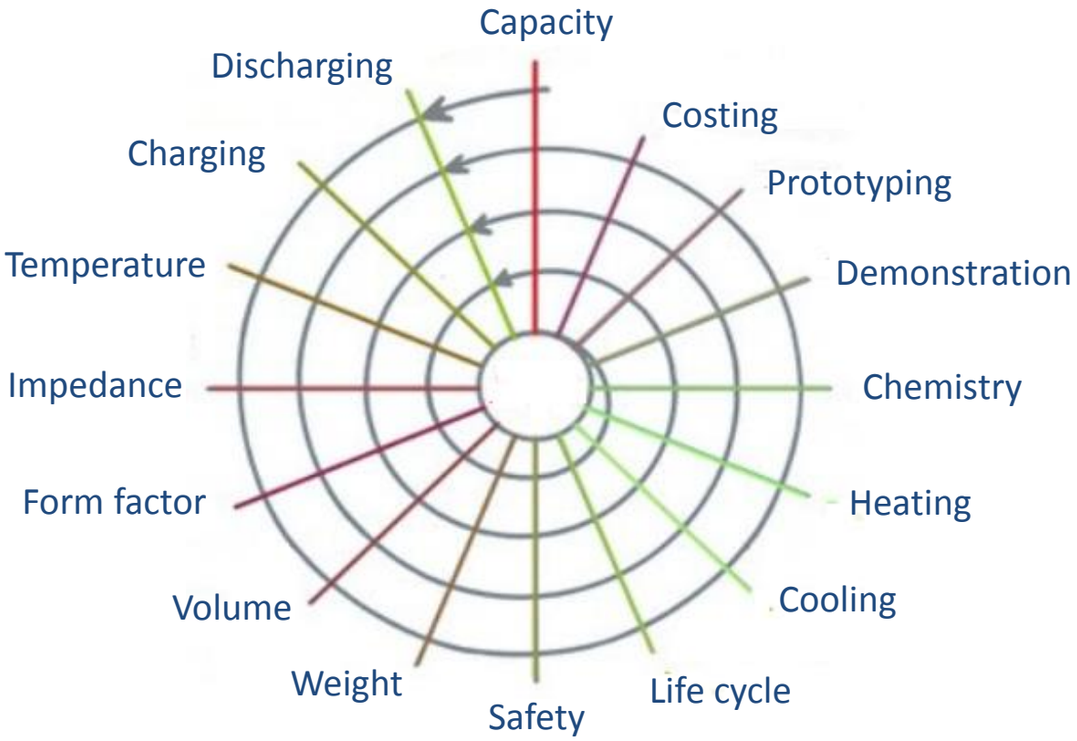
Customizing

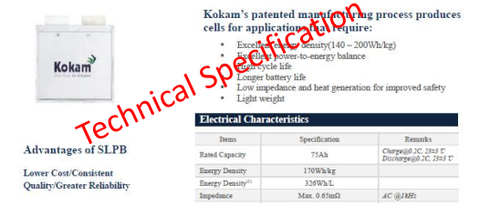
Choice of strategy;
- Design a submarine with readily available cells?
- Design a cell to meet submarine use?

Customizing design spiral ?

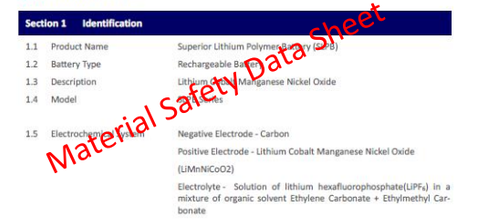


Form factors

Technical Specification



Certificate of compliance



Material Safety Data Sheet

UN 38.3 Certificate

APPARATUS	Lithium Secondary Battery
DESIGNATION	SLPB140460330
RATINGS	3.7 V 200.0Ah
STANDARD	UN Manual (ST/SG/AC. 10/11/Rev.5/Amend.1)
MANUFACTURER	Kokam Co., Ltd. 19 GAYAGONGDAN-GIL, GAYAGOK-MYEON NONSAN-SI, CHUNGCHEONGNAM-DO, KOREA 320-844
DATE OF TESTS	2013. 01. 11. ~ 2013. 03. 08.
DATE OF ISSUE	2013. 03. 08.

The following tests have been carried out in accordance with the specification of the manufacturer, based on UN Manual (ST/SG/AC. 10/11/Rev.5/Amend.1)
(Altitude Simulation, Thermal test, Vibration, Shock, External Short Circuit, Crush, Forced Discharge)

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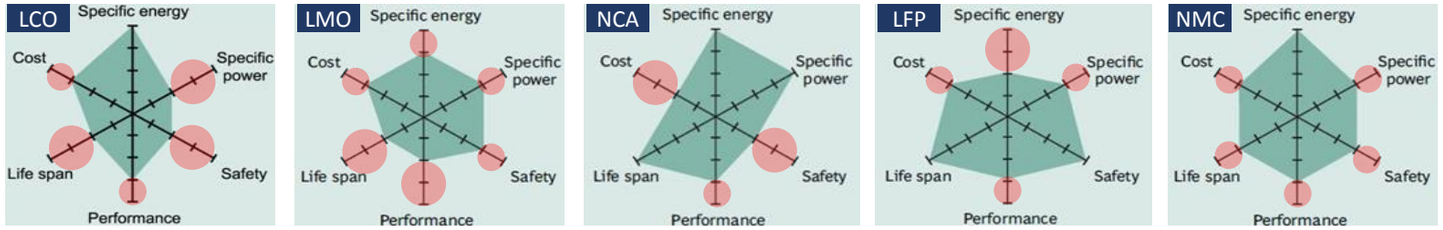
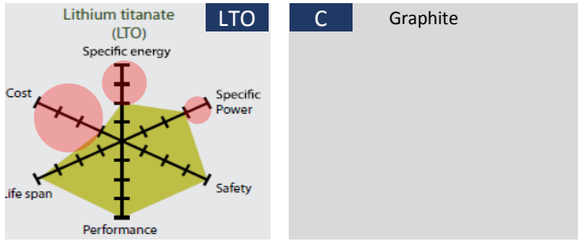
Cell chemistry – Energy and Safety

Choice of Cathode





Choice of Anode

Which one in the light of energy ?

Type	Cathode	Anode	$V_{average}$	%
LFP	LFP	Graphite	3.2 V	86.5%
NMC	NMC	Graphite	3.7 V	100.0%
LTO	*	LTO	2.2 V	59.5%

A way to secure intrinsic safety ?

- LTO
- Solid Electrolyte
- ?

Which chemistry did they use ?

Date	IT/Mobile		Date	Mobility	
21.06.06	• Not known model • Japan • On use In the con-ference		03.09.10	• Boeing 747-400 • Dubai • Crashed after explo-sion on air	
15.07.06	• Not known model • U.S.A. • On use • In the office		11.11.11	• Volt • U.S.A. • After collision test to side chassis	
31.07.07	• Latitude D410 • Singapore • On use • At home		26.05.12	• E6 • China • On collision	
22.02.08	• X-Z1-note -A2007 • Korea • On use • At home		16.01.13	• Boeing 787 • Japan. • Emergency landing upon fire	
24.02.08	• Sens P10 • Korea • On use • At home		12.07.13	• Boeing 787 • U.K. • Fire before take-off	
28.11.11	• I-phone 4 • Australia, • Autonomously In the airplane		01.10.13	• Model S • U.S.A. • On collision with metal object	
14.12.13	• I-Phone 5S • China • after turn on In the office		06.11.13	• Model S • U.S.A. • On penetration of chassis by a metal bar	
30.06.14	• Galaxy S5 • Israel • on charging, the place not known				
08.16	• Galaxy note 7 • World-wide				
10.16	• I-phone 7 • World-wide				

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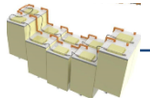
	Elements	Definition	Example
1	Cell	A physical unit that contains a certain amount of electro-chemical energy which cannot be disassembled.	
2	Unit-cell	An electrical configuration consists of two or more Cells connected in parallel (P).	
3	Sub-module	A physical unit that contains a certain number of Unit-cells connected in series (S).	
4	Module *LAB Cell equivalent* 	A physical unit that contains a certain number of Sub-modules in parallel (P). It operates with a Module BMS.	
5	String	An electrical configuration consists of a certain number of Modules connected in series to provide the required operating voltage (S) It operates with a String BMS.	
6	Bank	An electrical configuration that contains a number of Strings connected in parallel to provide the required load current (P). It operates with the Bank BMS.	
7	System	An electrical configuration that contains a number of Banks connected in parallel to provide the required endurance energy (P). It works with System BMS.	

Way to describe a configuration ?

2P 13S 2P 10S 10P 2P

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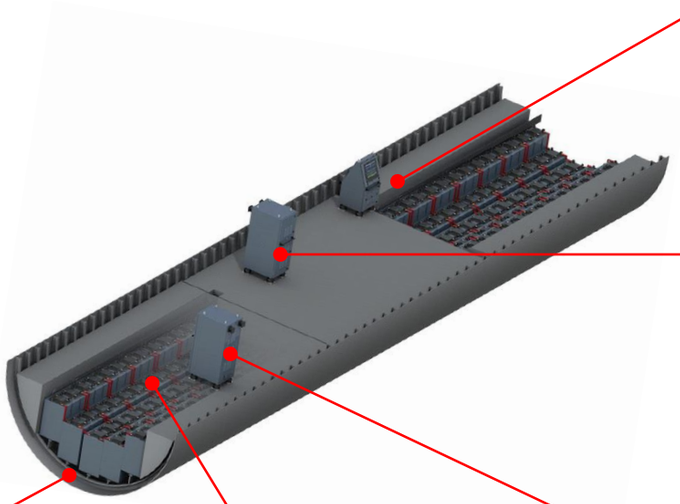
Typical layout onboard

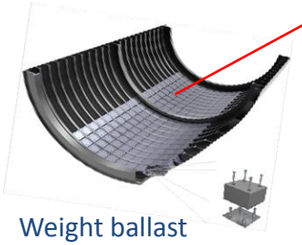
Ship's main switchboard



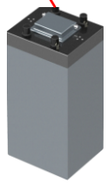
Central Control Console

Local Control Unit

Local Control Unit



Weight ballast



Module

How it looks like onboard ?

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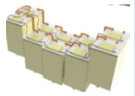
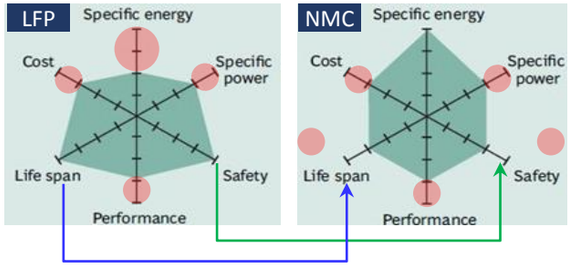
Key Safety Features - Chemistry

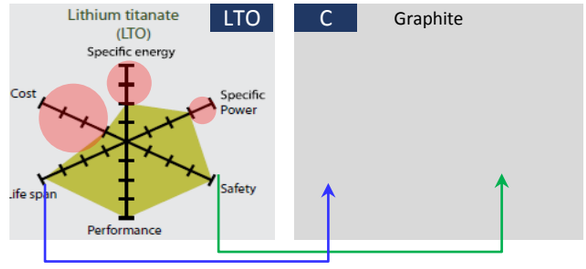
	Elements	Safety measures
1	Cell 	Ignition Resistive Chemistry
2	Unit-cell 	Cross balancing
3	Sub-module 	Tab fusing
4	Module 	BMS
5	String 	BMS Battery Protection Unit (Fuse, Contactor, Circuit Breaker) Current limiter, BMS
6	Bank 	BMS DC Control Panel (ACB)
7	System 	BMS

Composite material packaging

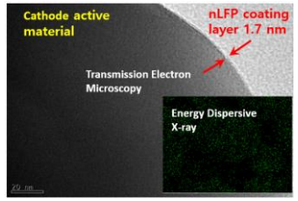
Flexible bus bar

Ignition resistive chemistry – Transplanting ?

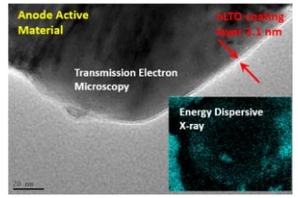




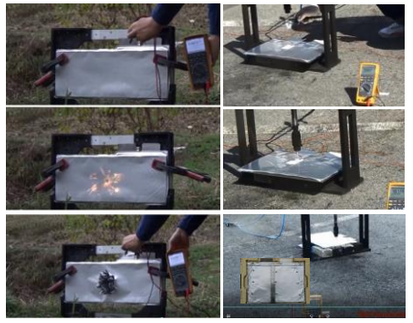
Cathode



Anode



Abuse capability – Ballistic, Nail Penetration



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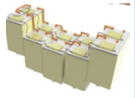
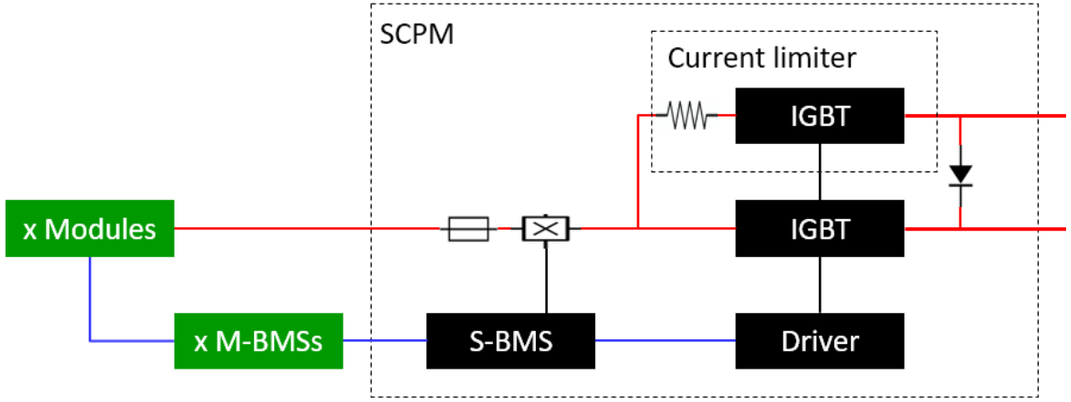
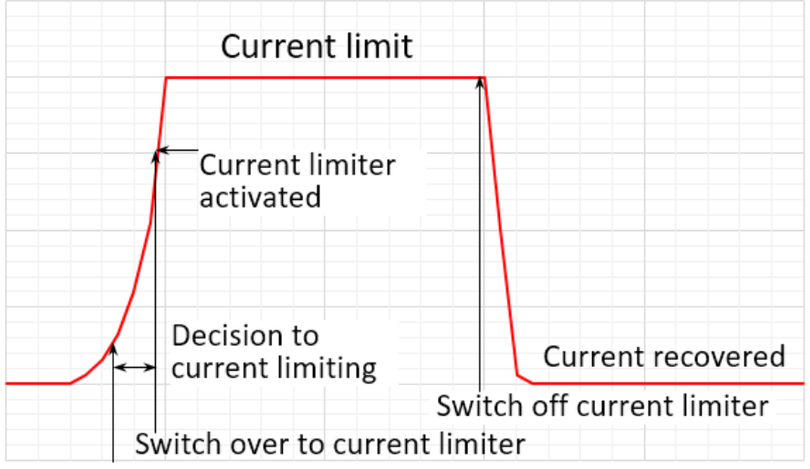
Key Safety Features – Proactively operating string controller

	Elements	Remarks
1	Cell 	Ignition Resistive Chemistry
2	Unit-cell 	Cross balancing
3	Sub-module 	Tab fusing
4	Module 	BMS
5	String 	BMS Battery Protection Unit (Fuse, Contactor, Circuit Breaker) String Control Power Module
6	Bank 	BMS DC Control Panel (ACB)
7	System 	BMS

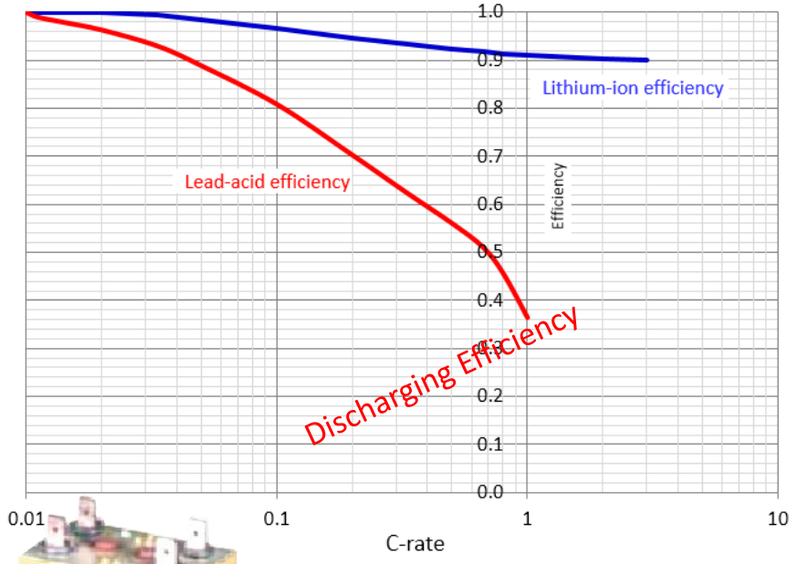
Composite material packaging

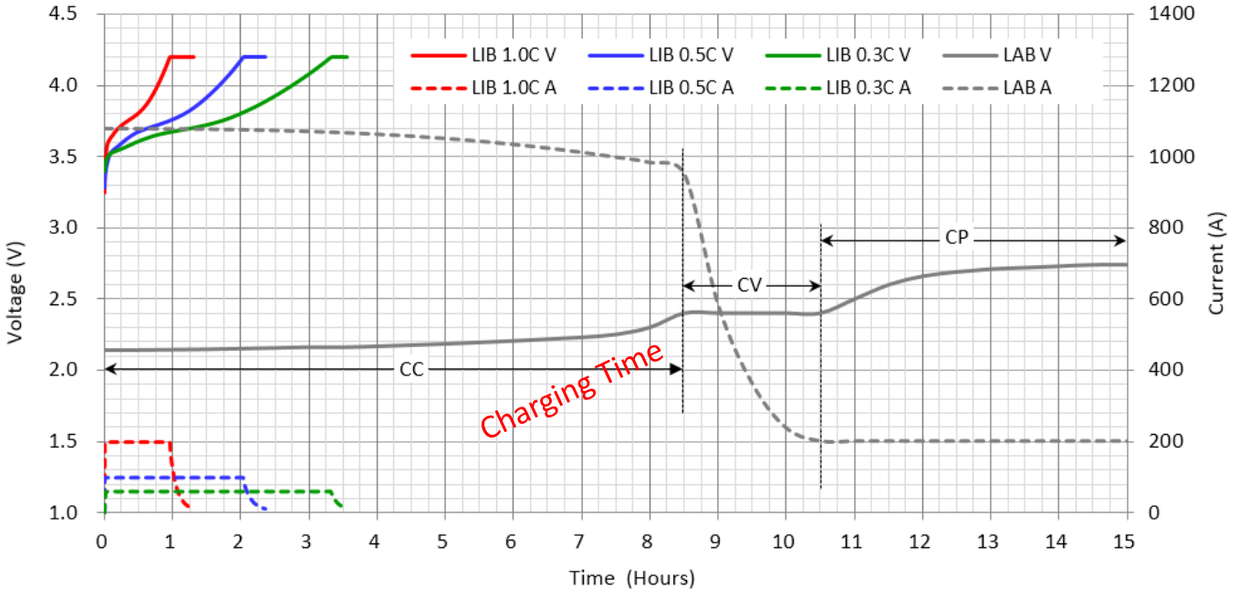
Flexible bus bar





LBTS - The capability to provide an “at-sea” simulated environment





Energy	LAB	LIB
Volume density	1	≈ 2.9
Weight density	1	≈ 4.9
Capacity	1	≈ 2.7

≈ 80 Wh/L ≈ 233 Wh/L
≈ 27 Wh/Kg` ≈ 132 Wh/Kg
≈ 13.9 kWh ≈ 38.4 kWh

Energy Density

What will be the advantage if the same space we use for LIB ?

- Max speed submerged endurance over **X7**
- Cruising speed submarined endurance over **X5**
- Max indiscretion ratio over **X0.1** (if charging power is enough)

VI Type Testing at Land Based Test Site

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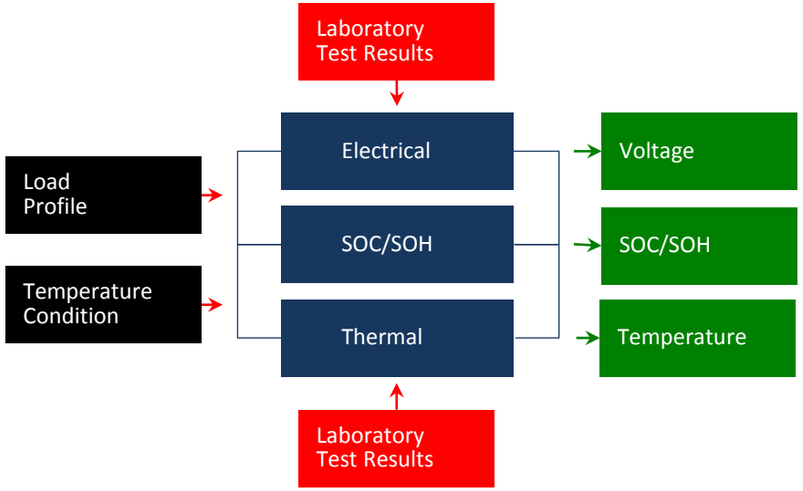
LBTS, the capability to provide an “at-sea” simulated environment

- Testing according to operating profile at sea with replicated actual shipborne electrical plant according to the actual installation design
- Safe controlling testing of all emergency and contingency tests which cannot be tried at sea
- Testing of cells according to international regulatory standards and tailored made in-house abuse testing regime
- Matlab simulation of cells and batteries

Reference	Compliance (eg)
International Battery Standards	UN, UL, CE
International Class Standards	Lloyd's Register, DNV·GL, KR
US Military Standards	901D, 810G, 740-1/2
US NAVSEA Technical Manual	S9310-AQ-SAF-010



VII Summary

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- LIB technology for oceangoing submarines is now **readily available**
- This technology promises **quantum leaps** in endurance and indiscretion ratio

  with the same installation foot print of the existing LAB technology;
  - X5 - X7 longer spurt
  - X2 - X5 longer cruise
  - - X0.1 shorter indiscretion ratio (depending on charging plant capacity)
- The **intrinsic safety** additionally supported by the unique “ignition resistive” **NANO coating technology**
- Demonstrated state of the art of **abuse capability**

Thank you

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