B17

模擬 SRM スラグ飛翔体を用いた超高速衝突実験計画

Experimental Plan of Hypervelocity Impact Using Simulated SRM Slag

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Yasuhiro Akahoshi (Kyutech), Masumi Higashide (JAXA), Shogo Tagami,
Masaya Ikeda, Toui Yoshida, Takafumi Hanakusa, Sota Koga
and Takao Koura (Kyutech)

アルミニウム粉を含む固体ロケットエンジンではノズル手前の淀み点近傍において、燃焼後アルミナが凝集される傾向があり、固体ロケットエンジン停止前後においてこの凝集されたアルミナの塊（SRM スラグ）が放出される可能性がある。一段目の固体ロケットエンジンは軌道速度に到達しないので大きな問題とはならないが、二段目以降で地球に対する周回軌道に入る場合、この SRM スラグも軌道速度を獲得し、スペースデブリとして周回する可能性がある。ISO24113の改定作業過程において、ヨーロッパを中心にSRMスラグに対する規制を強める方向で議論が進んだ。そこで、本研究では SRM スラグが仮にスペースデブリとして周回軌道に入ってしまったとして、どの程度の危険性を有するのか、地上試験でSRMスラグを模擬した飛翔体を用意し、同じ大きさのアルミ球との比較を行う超高速衝突実験を立案することとした。本講演では、この実験計画ならびに予備実験について講演を行う予定である。

Alumina particles trend to gather one another after combustion near stagnation point upper than nozzle of a solid rocket motor containing aluminum powder. Although there is no serious problem because the first solid rocket motor will not reach the earth orbit, SRM slag will reach the earth orbit and will go around the earth as space debris. In the process of revision of ISO24113, European P-members insisted to add regulation for SRM slag. So then in this we will study potential danger of SRM slag on space structures such as artificial satellites and so on if SRM slag goes around the earth orbit as space debris. Namely we will consider a plan of hypervelocity impact tests using a projectile which imitates SRM slag as well as aluminum sphere. In this presentation, we will address its experimental plan and some results of preliminary experiments.

8th Space Debris Workshop

Experimental Plan of Hypervelocity Impact Using Simulated SRM Slag

December 4th, 2018

〇Yasuhiro Akahoshi(Kyutech), Masumi HIGASHIDE(JAXA), Shogo TAGAMI(Kyutech), Masaya IKEDA, Toui YOSHIDA, Takafumi HANAKUSA, Sota KOGA, Takao KOURA

Outline of Today’s Presentation

1．Introduction
2．Experimental Facilities
3．Preliminary Experiment Using Imitated Projectile
4．Future Experimental Plan
5．Closure

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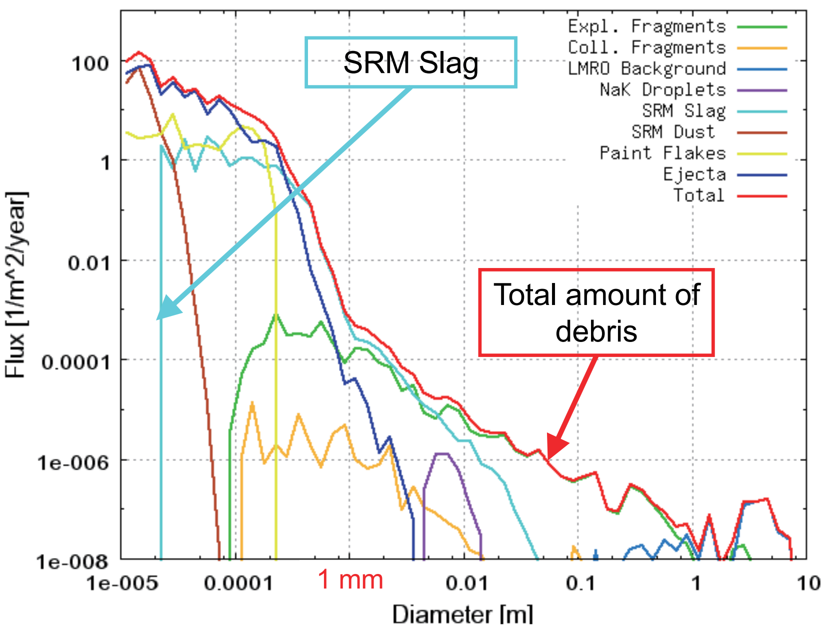
SRM Slag



Generation causes of debris calculated by MASTER 2005

(ref.: Sinya FUKUSHIGE, Yasuhiro AKAHOSHI, Yukihito KITAZAWA, Takeo GOKA, "Comparison of Debris Environment Models; ORDEM2000, MASTER2001 and MASTER2005", IHI Engineering Review Vol. 40 No. 1 February (2007), p.31-41.)

SRM Slag could be the second dominant between 0.1-1mm

DRAFT INTERNATIONAL STANDARD
ISO/DIS 24113

ISO/TC **20**/SC **14** Secretariat: **ANSI**

Voting begins on: **2018-09-20** Voting terminates on: **2018-12-13**

Space systems — Space debris mitigation requirements

Systèmes spatiaux — Exigences de mitigation des débris spatiaux

ICS: 49.140

第8回スペースデブリワークショップ@JAXA(2018. 12. 04)

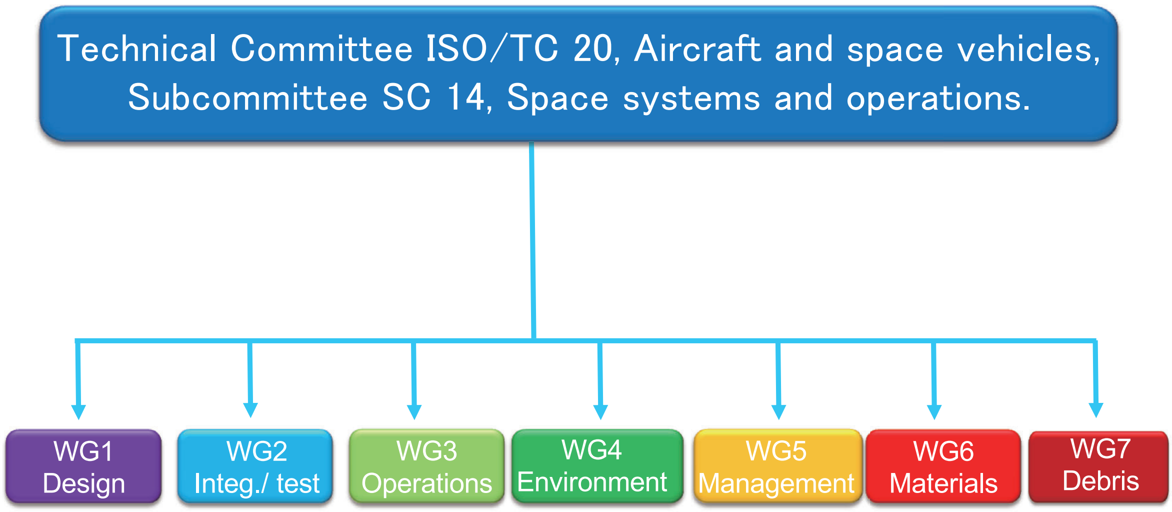
6 Technical requirements

6.1 Avoiding the intentional release of space debris into Earth orbit during normal operations

6.1.2 Space debris from pyrotechnics and solid rocket motors

6.1.2.2 Solid rocket motors shall be designed and operated so as not to release space debris larger than 1 mm in their largest dimension into Earth orbit.

NOTE The main aim of this requirement is to limit the generation of slag debris ejected into Earth orbit during the final phase of combustion. Slag debris is potentially hazardous to current and future space operations due to its size, number and orbital lifetime. This is particularly the case when slag debris is ejected into a high orbital region where it can pose an impact risk for a long period of time.



ISO24113 is discussed in joint session between WG3 and WG7.

Crater Depth

$$D_c = 5.52 \times d^{19/18} \times H^{-1/4} \times \boxed{\left(\frac{\rho_p}{\rho_t}\right)^{1/2}} \times \left(\frac{V_p}{c}\right)^{2/3}$$

d_p : *the projectile diameter*

H : *Brinell hardness*

ρ_p : *the density of the projectile*

ρ_t : *the density of the target*

c : *the sound velocity of the target*

6 Technical requirements

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There is no description on density of SRM Slag in 6.1.2.2.

Literature Survey of Density of SRM Slag

(Summarized by Dr.Kitazawa)

No.	出典	値	根拠	備考
1	ORDEM 3.0 （Krisko et al.,2015)	「中密度」（2.8g /cm ^{3} ）のカテゴリー中に含む	STS の窓の衝突痕のうち、Al2O3 と同定できたものは、全体の2%のみで数が少ないものとして中密度に	

Density of SRM Slag is distributed between 1.6 and $2.6\ g/cm^3$.

No.	出典	値	根拠	備考
	al.,1997 (MASTERマニュアルの参考文献39)			
6	CHAUVOUT et al.,1995 (AIAA-95-2729)	p=5632-1.127xT p：アルミナ･ドロップレット密度(kg/m^3) T：チャンバ内温度（K）	過去研究で、スラグ重量が液滴密度にほぼ比例。地上試験での結果をもとに実燃焼時の液滴密度を外挿	ﾁｬﾝﾊﾞ温度 密度 (K) (g/cm^3) 2700 2.59 2800 2.48 地上試験 3500 1.69 実燃焼（外挿）

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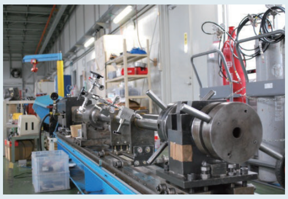
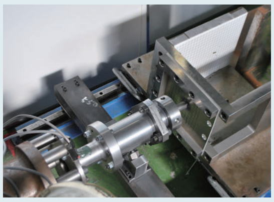
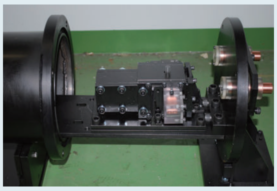
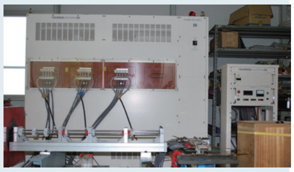
Guns in KIT (1/2)

	Large LGG	Small LGG	Air gun
Pictures			
Length [m]	7	3	3
Bore[mm]	5, 14, 30	5	25
Pump tube[mm]	60	20	-
Velocity [km/sec]	~ 5	~ 5	~ 0.3
Velocity measurement	Wire-cut	Laser-cut	Laser-cut Highspeed camera
Research topics	Deflection of asteroid	Eject test based on International standardization Discharge test of solar array	Development fan case of jet engine

Guns in KIT (2/2)

	Single stage gun	Plasma drug gun	Rail gun
Pictures			
Length [m]	0.1	1	1
Bore[mm]	10, 20	5	5x20
Velocity [m/sec]	20 - 100	2000	200
Velocity measurement	Highspeed camera	Photo-detector	laser-cut
Research topics	Harpoon for ADR	No experiment	No experiment

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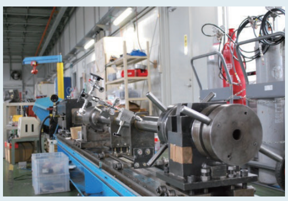
Guns in KIT (1/2)

	Large LGG	Small LGG	Air gun
Pictures			
Length [m]	7	3	3
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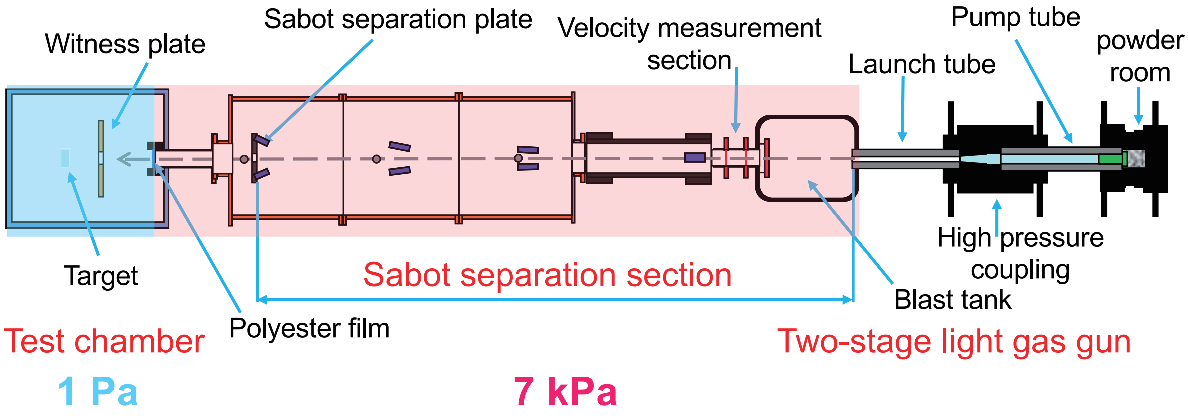
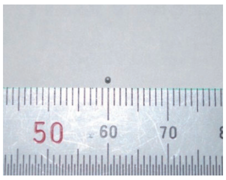
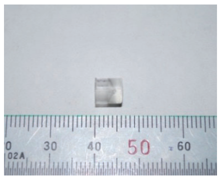
Test Facility





Material : A2017
Diameter : ϕ1.0±0.1mm
Mass : 1.5 mg

Projectile



Material : PC
Diameter : ϕ6.0mm
Mass : 120 mg

Sabot

INTERNATIONAL STANDARD

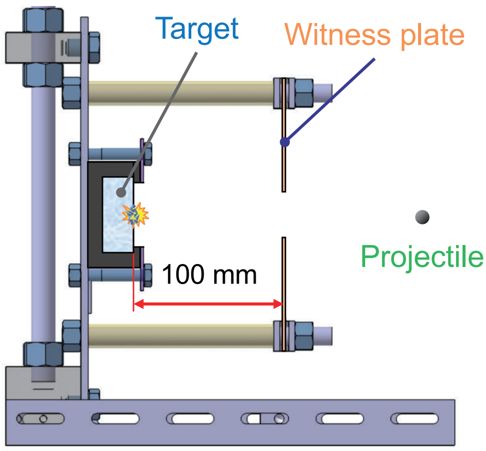
ISO 11227

First edition
2012-09-15

Space systems — Test procedure to evaluate spacecraft material ejecta upon hypervelocity impact

Systèmes spatiaux — Mode opératoire d'essai pour l'évaluation des éjectats de matériaux des véhicules spatiaux résultant d'impacts à hypervitesse

Experimental condition



Configuration diagram of target

Projectile

Material : aluminum (Al2017)
Shape : sphere
Size : diameter of 1mm
Impact velocity: around 5km/sec

Target

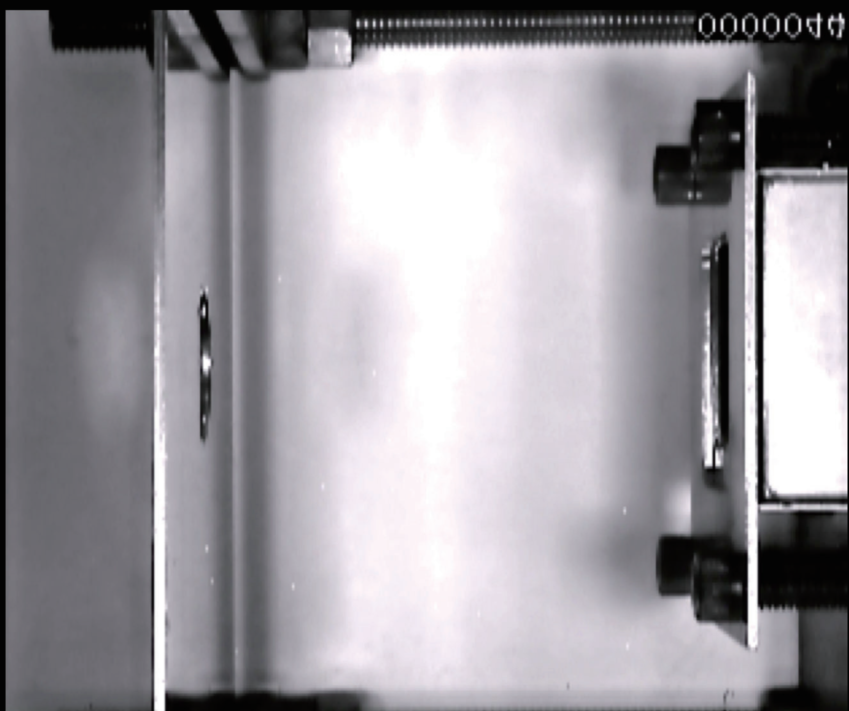
Material : synthetic fused silica
Size : 50 x 50 x 20mm
Supporter : sponge rubber

Witness Plate

Material : Copper
(JIS H3100 C1100-1/4H)
Hole diameter : 30 mm at its center
Surface : machined finish

Witness plate is in 100 mm front of target

High-speed Video 09-101



Experimental results Shot No. 09-101
V= 4.03 km/sec, Witness plate – Target: 100 mm
Recoding rate: 250 kfps, Pixels: 312 x 260 pixels

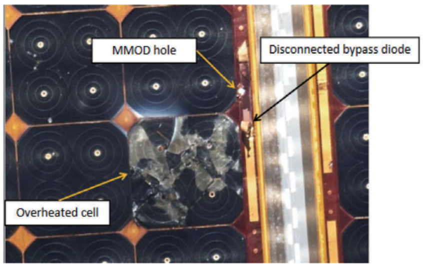
✓ Discharge by debris impact

High density plasma is created by debris impact

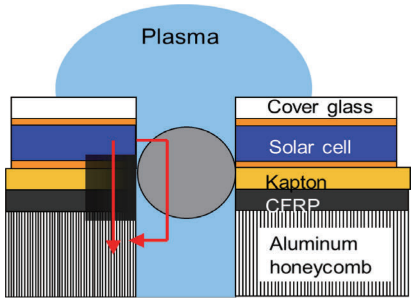
Discharge occurs through the plasma : Primary Arc (PA)

Permanent Sustained Arc (PSA)

Electricity does not flow to the payload and the power generation capacity is reduced



NASA The Orbital Debris Quarterly News Vol.18-4 (2014, Oct)



IADC-00-00
Month Year

Inter-Agency Space Debris Coordination Committee

Spacecraft Component Vulnerability for Space Debris Impact

Issued by IADC Working Group 3

Action Item 31.3

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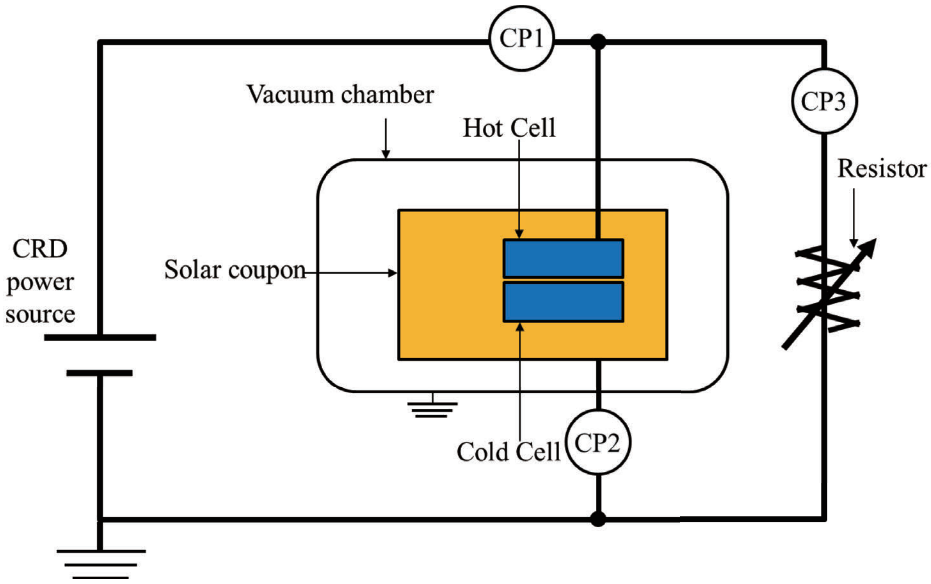
2 Solar Array

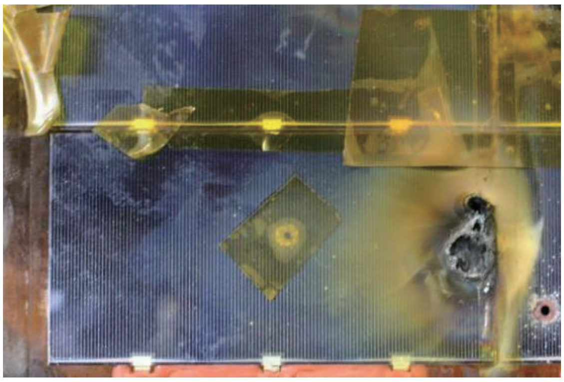
2.1 Damage Mode

In recent years, a solar array of a spacecraft has become larger with the voltage higher because a spacecraft needs a large amount of power in requests from an advanced mission. Therefore the risk of a space debris impact and discharge on the solar array is increasing because the number of small space debris such as ejecta is increasing [2-1]. Space debris impact to the solar array causes not only mechanical damage such as destruction of a solar cell and insulation layer but also electrical damage due to local high density plasma induced by impact energy [2-2]. This plasma can lead to arcing between solar cells or cell and substrate on the solar array [2-3]. In the worst case, Joule heating of arcing can carbonize insulation layer and create permanent short-circuit path [2-4]. This phenomena is called “Permanent Sustained Arc“ (PSA).

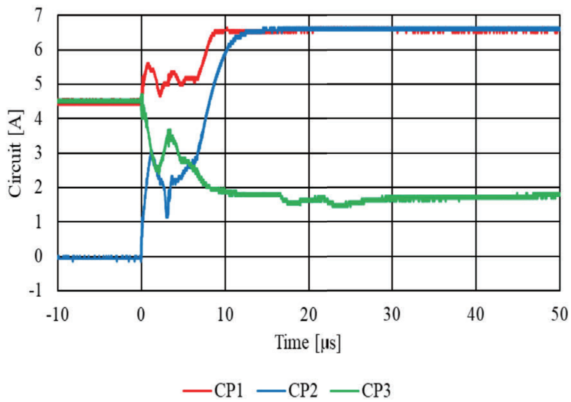
Measurement Positions of Current Probes in Electric Circuit used at Discharge Test due to Hypervelocity Impact



Test No.	Voltage [V]	Current [A]	Discharge		
			Type	Resistance [Ω]	Time [μs]
18-018	192	4.8	PSA	10	∞



Impact point



Waveform of discharge

PSA generation condition (192V)

- Discharge time needs more than 2 μs
- Maximum discharge current needs about 3 A

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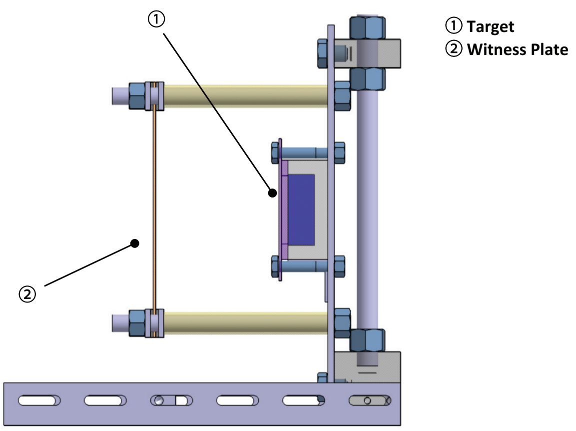

Figure C.1 — Sketch of target and witness plate assembly

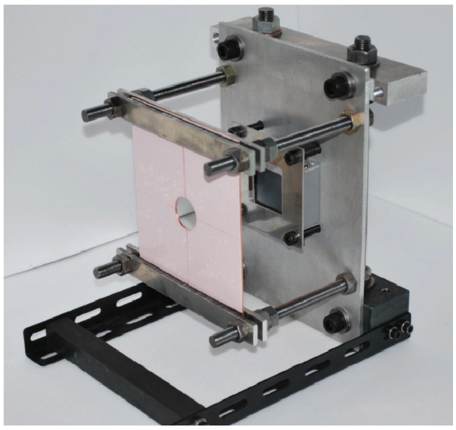

Figure C.2 — Picture of target and witness plate set-up

Test impact configuration is based on Annex C of ISO11227.

Experimental Conditions Using Imitated Projectile

Projectile : A2017, ϕ1mm with/without 0.3mm perforation hole

Target : A2024-T3 plate, 80 x 100 x 6 mm

Impact Velocity : 5km/s

Experimental Results

Shot No.	KIT-18-006	KIT-18-010	KIT-18-020
Diameter of Projectile [mm]	0.998	0.976	1.014
Mass of Projectile [mg]	1.5	1.2	1.1
0.3 mm perforation hole	No	Yes	Yes
Impact Velocity [km/s]	5.34	5.05	4.43
Diameter of Crater [mm]	3.036	2.860	2.176
Depth of Crater [mm]	1.629	1.471	1.039
Volume of Crater [mm^3]	1.340	0.769	0.578
Mass of Ejecta [mg]	5.0	3.2	0.8

Experimental Results

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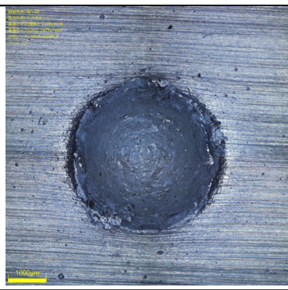
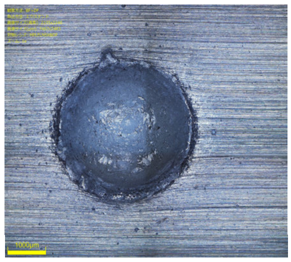
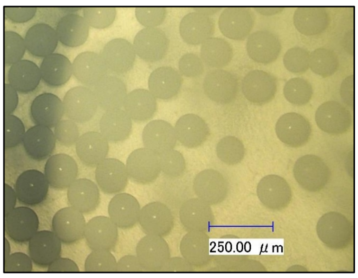
			

Current status of conventional impact tests using simulated SRM slag projectiles

12 porous alumina balls were given to Kyutech by JAXA and conventional impact tests will be done next month in Kyutech.



	Diameter(mm)	Mass(mg)
No.1	1.874	8.65
No.2	1.817	7.50
No.3	1.820	7.73
No.4	1.653	5.86
No.5	1.753	7.03
No.6	1.850	8.09
No.7	1.876	8.60
No.8	1.770	7.01
No.9	1.840	8.17
No.10	1.754	7.36
No.11	1.813	7.50
No.12	1.801	7.85

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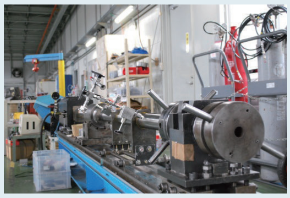
Porosity of SRM Slag could be 30% and it could be very fragile. So then it could be broken during acceleration (>10^4G) in a two-stage light gas gun.

Reverse Impact should be introduced.

Guns in KIT (1/2)

	Large LGG	Small LGG	Air gun
Pictures			
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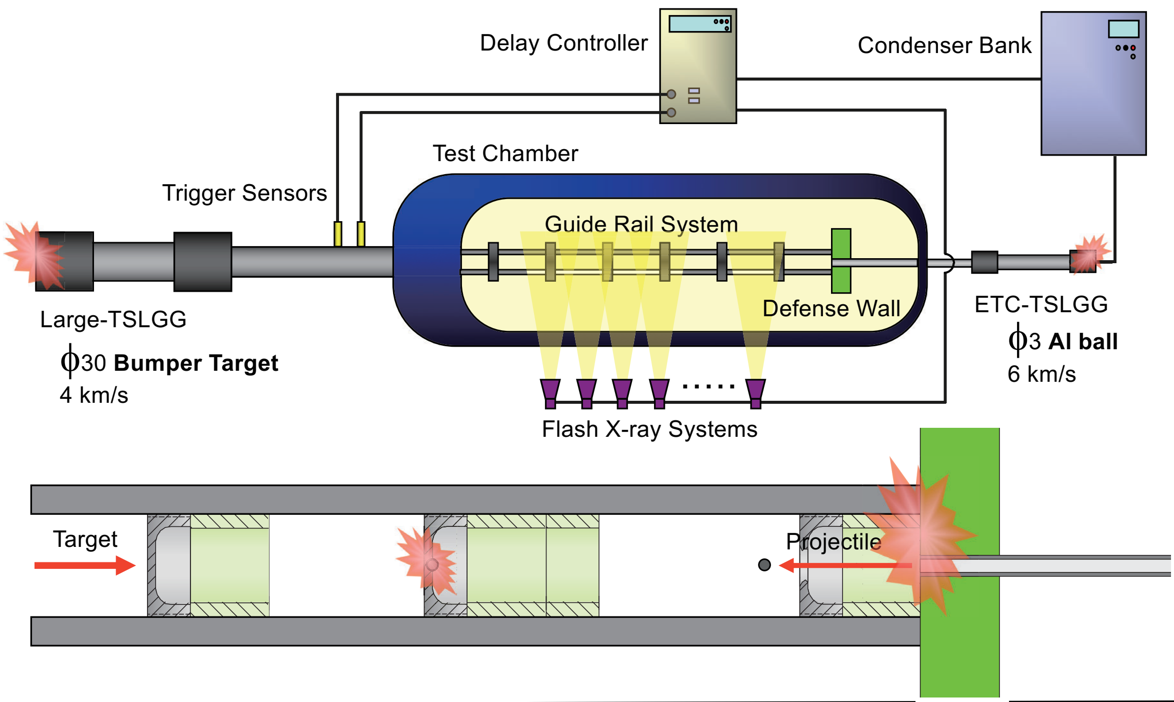
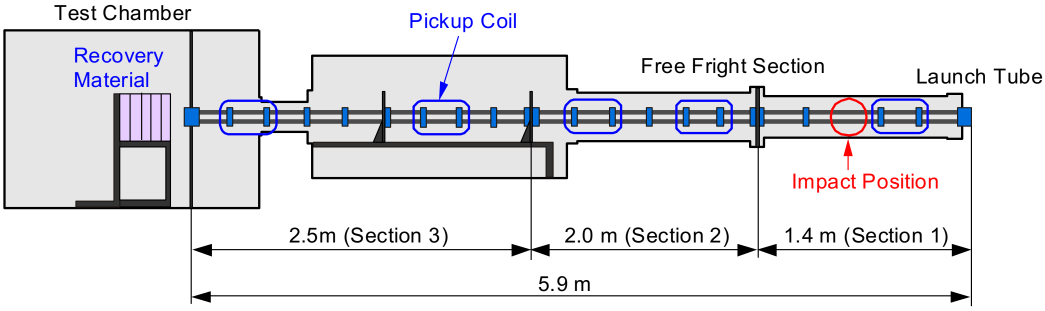
Concept of Counter-Impact (FY2006)

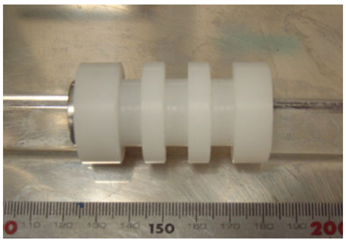


Reverse Impact Test

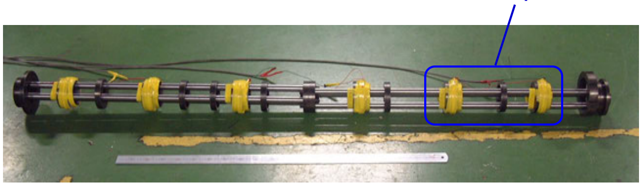
Soft recover system



Target projectile



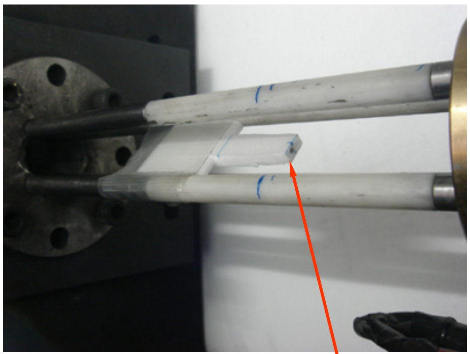
Guide rail for target projectile



Example of recovered target projectile

Successfully recover of target projectile

Flash X-ray image of secondary debris cloud in reverse impact test



Aluminum ball

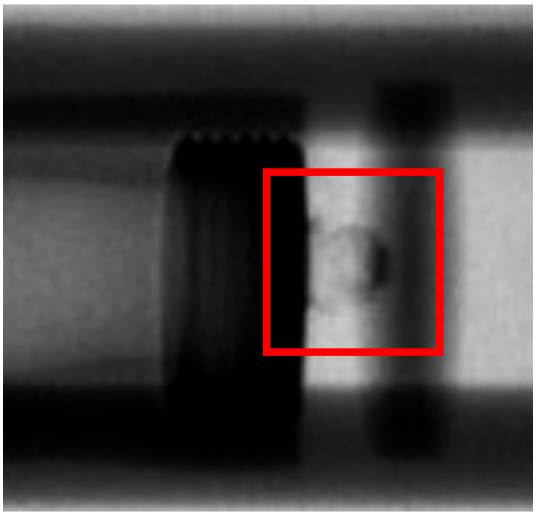


Fig. V = 2.27 km/s (LTS06-60)

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Another Reverse Impact Test (FY2013)

Sample return from surface of asteroid

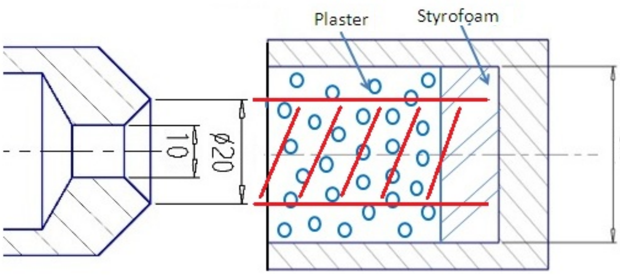
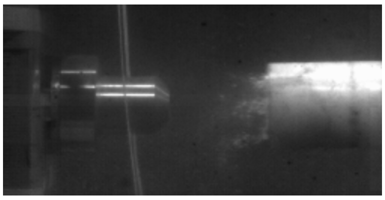
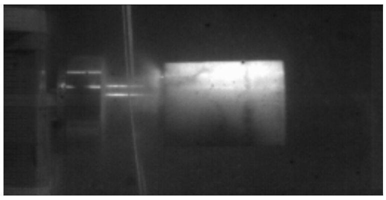
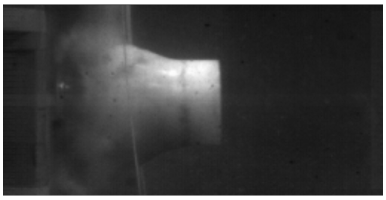
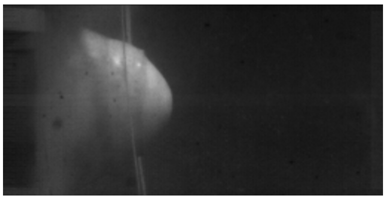


Fig. Sampler fixed in impact axis.

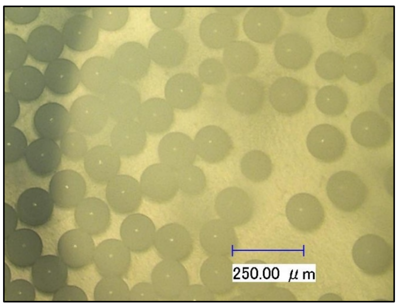
Experimental Result of Reverse Impact

	
(a) t – 83μs	(b) t + 13μs
	
(c) t + 59μs	(d) t + 103μs
Fig. Snapshots of Reverse Impact (V=0.969 km/s)	

Current status of reverse impact tests using imitated and simulated SRM slag projectiles

(1) Porous alumina balls were given by JAXA and reverse impact tests are under preparation in Kyutech.

(2) Manufacturer of porous alumina ball (same size, same mass (same density), and spherical shape are ideal) is looked for by JAXA.



Outline of Today’s Presentation

Closure

- In Draft IS24113 it is written that solid rocket motors shall be designed and operated so as not release space debris larger then 1mm in their largest dimension into Earth orbit. Draft IS24113 is now under DIS voting.
- Preliminary experiments using imitated projectile were successfully done in the manner of conventional impact.
- Reverse impact test is under consideration instead of acceleration of a fragile projectile which is made of 30% porous alumina. Density of SRM slag was reviewed based on published papers, and it is distributed between 1.6 and 2.6 [g/cm^3].

Thank you for your attention.