von KARMAN INSTITUTE FOR FLUID DYNAMICS INPA
INSTITUT von KARMAN DE DYNAMIQUE DES FLUIDES AISBL
von KARMAN INSTITUUT VOOR STROMINGSDYNAMICA IVZW

REF. SPR1310/HD/dl/949
12 Januari 2017

AANGETEKEND SCHRIJVEN

Mevrouw Elke Sleurs
Staatssecretaris voor Wetenschapsbeleid
Koning Albert II-Laan 33 bus 1
1030 Brussel

Geachte mevrouw de Staatssecretaris,

Het von Karman instituut voor stromingsdynamica (VKI) werd in 2011 door de Europese Commissie geselecteerd als coördinator van een project gericht op het lanceren van 50 nanosatellieten in een baan om de aarde. Het project, dat de naam QB50 kreeg, verenigt onderzoeksinstellingen en universiteiten over de hele wereld in een onderzoek naar de samenstelling van de thermosfeer en de terugkeer in de atmosfeer van kleine satellieten ("CubeSats").

Voor het VKI is het QB50 project uitermate belangrijk op wetenschappelijk en strategisch vlak. Niet alleen betekent dit voor het instituut een nieuwe activiteit in het domein van de nanosatellieten, maar opent het project eveneens toekomstige opportuniteiten van samenwerking met andere onderzoeks- en onderwijsinstellingen. Daarenboven verhoogt het de zichtbaarheid en de bekendheid van het VKI op nationaal en internationaal vlak. Tot slot is de (prestigieuze) rol van coördinator een erkenning van de jarenlange expertise van het instituut.

Na de succesvolle lancering van de twee precursor satellieten in juni 2014 (machtiging 2014/01), worden nu twee verschillende lanceringen van in totaal 44 satellieten voorzien. Elke lancering vormt het voorwerp van een machtigingsaanvraag. Dit schrijven heeft betrekking op de tweede van de twee lanceringen, getiteld *Polar*. De missie is gericht op het meten van de samenstelling van de thermosfeer en op het testen, in de ruimte, van technologie om satellieten uit hun baan te halen. In totaal zullen 8 satellieten gelanceerd worden in het kader van deze Polar campagne ; zes daarvan beschikken over een specifiek instrument voor het meten van de samenstelling van de thermosfeer. De twee andere satellieten zullen een In-Orbit Demonstratie (IOD) opdracht uitvoeren en zullen *de-orbit* technologie (drag sails) testen. Dergelijke technologie zal kunnen gebruikt worden om afgedankte satellieten uit hun omloopbaan te halen. Ze is daarom enorm waardevol in de context van het verminderen van het ruimteafval.

De lancering zal plaatsvinden te Sriharikota (Andhra Pradesh, India) met een PSLV lanceerraket. De lancering werd besteld door het bedrijf ISL B.V. (Nederland) op verzoek van het von Karman instituut in het kader van het QB50 project.

./..

CHAUSSÉE DE WATERLOO, 72
1640 RHODE-SAINT-GENÈSE, BELGIQUE

WATERLOOSESTEENWEG 72
1640 SINT-GENESIUS-RODE, BELGIË

TEL: 32 (02) 359 96 11 - FAX: 32 (02) 359 96 00 - E-MAIL: secretariat@vki.ac.be - https://www.vki.ac.be - BNP PARIBAS 210-0315330-35
BTW/TVA-ONDERNEMINGS N° D'ENTREPRISE: BE 0407 185 709 IBAN BE57 2100 3153 3035 - SWIFT CODE: GEBABEBB

In uitvoering van de wet van 17 september 2005 over de lancering, het bedienen in de vlucht of het geleiden van ruimtevoorwerpen, heeft het VKI de eer met dit schrijven een machtiging aan te vragen om de bedoelde activiteit uit te voeren onder de Belgische jurisdictie en bescherming. U gelieve daartoe als bijlage de aanvraag voor de machtiging te willen vinden, alsook de milieueffectenstudie en andere informatie betreffende de *Polar* lancering.

We hopen dat België zich als lanceerstaat met deze activiteit kan identificeren en op die manier het QB50 project zijn verdere steun toezegt. Mijn medewerkers en ikzelf staan ter beschikking om verdere toelichting over deze aanvraag of het project te verschaffen.

In afwachting van uw schrijven, verblijven wij,

Met de meeste hoogachting,

Voor de Collegiale Directie,
Herman Deconinck
Decaan

ANNEX 1: Table of QB50 satellites - Polar launch

To be registered in Belgium?	CubeSat Name	Short name	Owner	Manufacturer(s)		CubeSat type (Double = 100*100*227 mm3 ; Triple = 100*100*340.5 mm3)	QB50 scientific instrument	Other experiments	Other main technologies	Maneuverability type (*)	Used frequencies		Use of nuclear power source
				Main	QB50 scientific instrument						Uplink	Downlink	
No	PEGASUS	AT03	FACHHOCHSCULE WIENER NEUSTADT (FHWN) für Wirtschaft und Technik Ges. M.b.H. Johannes Gutenberg-Str.3 A-2700 Wiener Neustadt	FHWN (see "owner" for address)	UNIVERSITY OF OSLO Department of Physics P.O. Box 1048 Blindern NO-0316 Oslo Norway	Double	mNLP (Atmospheric sensor: multi-Needle Langmuir Probe)	Propulsion system	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	2	436.67 MHz	436.67 MHz	No
Yes	NUDTSat	CN06	NATIONAL UNIVERSITY OF DEFENSE AND TECHNOLOGY (NUDT) College of Aerospace Science and Engineering Deya Road 137 Changsa, 410073 Hunan Province China	National University of Defense Technology (see "owner" for address)	MULLARD SPACE SCIENCE LABORATORY(MSSL) University College London Holmbury Hill Road, Dorking UK Surrey RH5 6NT United Kingdom	Double	INMS (Atmospheric sensor: Ion-Neutral Mass Spectrometer)	Atomic oxygen sensor	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	1	145.835 MHz	436.270 MHz	No
Yes	VZLUSAT1	CZ02	VZLU (Výzkumný a Zkušební Letecký Ustav) Beranovych 130 199 05 Prague Czech Republic	VZLU (see "owner" for address)	TECHNICAL UNIVERSITY OF DRESDEN Institute of Aerospace Engineering, Faculty of Mechanical Science and Engineering 01062 Dresden, Germany	Double	FIPEX (Atmospheric sensor: Flux Probe Experiment)	X-ray telescope and detector	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	1	437.240 MHz	437.240 MHz	No
Yes	DragSail-CubeSat	DE04	FH AACHEN University of Applied Sciences Kalverbenden 6 52066 Aachen Germany	FH Aachen, University of Applied Sciences (see "owner" for address)	N/A	Triple	N/A	Drag sail and thin film solar cells	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	2	145.885 MHz 2405-2445 MHz	437.300 MHz 2403 MHz 2405 - 2445 MHz	No
Yes	UCLSat	GB03	VON KARMAN INSTITUTE FOR FLUID DYNAMICS Chaussée de Waterloo, 72 1640 Rhode-Saint-Genèse Belgium	MULLARD SPACE SCIENCE LABORATORY(MSSL) University College London Holmbury Hill Road, Dorking UK Surrey RH5 6NT United Kingdom	MULLARD SPACE SCIENCE LABORATORY(MSSL) University College London Holmbury Hill Road, Dorking UK Surrey RH5 6NT United Kingdom	Double	INMS (Atmospheric sensor: Ion-Neutral Mass Spectrometer)	None	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	1	145.9375 MHz	435.975 MHz	No
Yes	InflateSail	GB06	VON KARMAN INSTITUTE FOR FLUID DYNAMICS Chaussée de Waterloo, 72 1640 Rhode-Saint-Genèse Belgium	SURREY SPACE CENTER University of Surrey BA Building Guildford Surrey GU2 7XH United Kingdom	N/A	Triple	N/A	Deorbiting sail	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	2	145.885 MHz	436.060 MHz	No
Yes	URSA MAIOR	IT02	CENTRO RICERCA AEROSPAZIALE SAPIENZA (CRAS) Sapienza University Di Roma Via Eudossiana 18 Rome 00184 Italy	CRAS (see "owner" for address)	UNIVERSITY OF OSLO Department of Physics P.O. Box 1048 Blindern NO-0316 Oslo Norway	Triple	mNLP (Atmospheric sensor: multi-Needle Langmuir Probe)	Deorbiting sail, propulsion system	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	2	145.860 & 435.950 MHz	435.950 MHz	No
Yes	LituanicaSAT-2	LT01	VILNIUS UNIVERSITY Universiteto 3 01513 Vilnius Lithuania	Vilnius University (see "owner" for address)	TECHNICAL UNIVERSITY OF DRESDEN Institute of Aerospace Engineering, Faculty of Mechanical Science and Engineering 01062 Dresden, Germany	Triple	FIPEX (Atmospheric sensor: Flux Probe Experiment)	Propulsion system (thruster)	Classical CubeSat platform: power supply, on-board computer, communication system, attitude determination and control system	2	437.265 MHz	437.265 MHz	No

(*): Two types of maneuverability are defined:
- Type 1: The CubeSat is placed into its orbit by a Dnepr launch vehicle. Upon release from the upper stage, the CubeSat will rotate to change its positioning ensuring that the science sensor point into the predefined flight direction. The CubeSat has no maneuvering capabilities that allow it to change its orbit (altitude, inclination) which is fixed at 482 km (low Earth orbit). The orbit of the launched CubeSat will decay naturally due to residual atmospheric drag in space. The VKI exercises full authority over the definition of the launch and positioning parameters.
- Type 2: The CubeSat has maneuvering capabilities that allow it to change its orbit (altitude, inclination) by means of a propulsion system or/and drag increasing system. All maneuvers are performed under VKI authority, as stated in Annex 4.

Annex 2

QB50

Milieu-effectenstudie

(Environmental Impact Assessment)

-

Polar launch with PSLV rocket

TABLE OF CONTENTS

PART I: ACTIVITIES AND OBJECTIVES

1. Objective of the activity and implementation through nanosatellites

The launch described in the present document (so-called *QB50 "Polar" launch*) has been procured by ISL B.V. (Netherlands) on behalf of the von Karman Institute for Fluid Dynamics (VKI, Belgium) in the framework of the EU FP7 QB50 Project[1].

The QB50 mission aims to launch a network of (around) 50 nanosatellites (CubeSats) built by University Teams all over the world to perform first-class science in the largely unexplored lower thermosphere. More specifically, the constituents of the thermosphere will be measured by three types of scientific instruments carried by the CubeSats. Some CubeSats will also demonstrate new technology developments.

QB50 will make use of two different launch campaigns to complete the orbital injection of all the CubeSats, as shown in Table 1. Each of the campaigns is the object of a request for authorization and of an environmental impact assessment. The present document reports on the polar launch campaign.

Launch campaign	Launcher	Main objective	Number of CubeSats	Launch period
Polar	PSLV	Polar scientific measurement and In-Orbit Demonstration (IOD)	8	April – June 2017
ISS	Atlas-V and ISS, facilitated by Nanoracks	Scientific + technology demonstration	28 *(final number as of 10/01/2017; 25 to be authorized by Belgium + 3 authorized and registered by the USA)*	February – July 2017

Table 1 - Definition of the QB50 launch campaigns.

The polar mission will focus on scientific measurements of constituents of the thermosphere, especially over the polar regions between 200 - 380km altitude, which is the least explored layer of the atmosphere. To explore this region, atmospheric explorers were flown in the past in highly elliptical orbits (typically 200 km perigee, 3000 km apogee); they carried experiments for single-point, in-situ measurements but the time spent in the region of interest was only a few tens of minutes. By contrast, QB50 will provide multi-point, in-situ measurements for a time period on the order of months, instead of minutes. Six CubeSats will carry one instrument out of the 3 different QB50 instruments. In total, 2 instruments of each type will be flown within the polar campaign.

The polar mission will also accommodate two CubeSats dedicated to In-Orbit Demonstration (IOD). Both will test de-orbiting devices (drag sails). These technologies could be used to trigger an earlier reentry of satellites after the end of their mission. They are therefore of great interest in the context of space debris mitigation.

To perform this twofold mission (scientific + IOD), four double nanosatellites (four "double CubeSats") of approximate dimensions 20x10x10cm and four triple nanosatellites (four "triple

[1] "QB50: An international network of 50 CubeSats for multi-point, in-situ measurements in the lower thermosphere and re-entry research". EU FP7 Grant Agreement Number 284427

CubeSats") of approximate dimensions 30x10x10cm are being build and launched. Figure 1 shows a double CubeSat.

Fig. 1 – A double CubeSat (QB50p1 satellite).

The QB50 polar launch (object of the present document) will take place using an Indian built PSLV rocket, operated by the Indian space agency ISRO (Indian Space Research Organisation)[2]. The launch base is located on Sriharikota Island, in India (see Fig. 2).

Fig. 2 – Sriharikota launch base.

The launch window for the polar flight has been established from 1 April 2017 until 30 June 2017.

[2] The launch contract is signed with Antrix Corporation Limited on behalf of ISRO.

2. PSLV launch vehicle

2.1. General overview

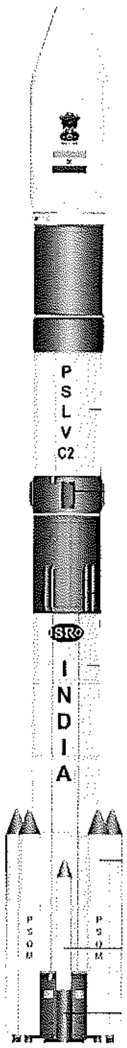

Fig. 3 - PSLV launch vehicle.

The Polar Satellite Launch Vehicle (PSLV) is an Indian expandable launch vehicle. It is developed and operated by the Indian Space Research Organisation. The PSLV is a 4-stage medium lift launcher. It can deliver payloads up to 3250 kg to Low Earth Orbit, up to 1800 kg in Sun Synchronous Orbit, and up to 1410 kg to Geosynchronous Transfer Orbit.

The launcher is 44.4 m tall and has a diameter of 2.8 m. A general overview of the launch vehicle is shown in Fig. 3.

The first stage of the PSLV is a solid fueled rocket stage. In the regular and XL versions, the first stage is augmented by 6 solid strap-on boosters, for a maximum thrust of 4800 kN.

The second stage is liquid fueled, powered by the Vikas engine.

The third stage of PSLV is a solid rocket motor that provides the upper stages high thrust after the atmospheric phase of the launch.

The fourth stage is liquid fueled, powered by two L-2-5 engines It also houses the equipment bay of the vehicle containing the inertial guidance system and flight computer (Vikram 1601) as well as telemetry and avionics equipment.

The payload fairing is positioned on top of the stacked vehicle and its integrated payload. It protects the spacecraft against aerodynamic, thermal and acoustic environments that the vehicle experiences during atmospheric flight. When the launcher has left the atmosphere, the fairing is jettisoned by pyrotechnical initiated systems. Separating the fairing as early as possible increases launcher performance.

Flight termination systems are provided onboard for strap on motors and for the first three stages which can be remotely activated through tele-command in case of any vehicle malfunction violating range safety constraints. Flight termination is provided in the fourth stage in case of a GTO or low inclination launch alone.

2.2. PSLV mission profile

A typical flight sequence for a polar sun-synchronous orbit is as follows[3]:

At the launch pad, the vehicle axes are aligned to 135 degree. The first stage (PS1) along with four strap on motors is ignited on the launch pad and the vehicle lifts off vertically. After 5 seconds,the vehicle is rolled to achieve the required launch azimuth. The vehicle starts pitching in the azimuth plane at T+7 seconds. The remaining two strap-on motors are ignited at T+25s. The ground lit strap-on motors are separated at T+68s; and air lit strap-on motors at T+90 secs. The PS1, PS2 (PSLV second stage) and PS3 (PSLV third stage) burnout are sensed during the flight from longitudinal acceleration measurements and subsequent events are sequenced. During PS2 burn phase, the Heat shield fairings are jettisoned, and Closed Loop Guidance (CLG) is initiated. After PS3 burnout there is a combined coasting after which

[3] Source: PSLV User's Manual, Issue 6 Rev. 0, March 2015.

the separation of third stage takes place. The fourth stage ignition time is decided on-board by CLG. When the required velocity and altitude are attained, the fourth stage is shut off by onboard guidance command and the spacecraft is injected into the required orbit with a separation velocity of 0.8m/s to 1.2m/s.

In case of multiple spacecraft mission, attitude maneuver and injection of spacecrafts in appropriate orientation is carried out to avoid long term collision probabilities between spacecrafts. Three-axis stabilization and guidance are effective till completion of spacecraft separation.

Figure 4 and Table 2 give an overview of a typical mission profile for the PSLV launch vehicle, for a polar sun-synchronous orbit.

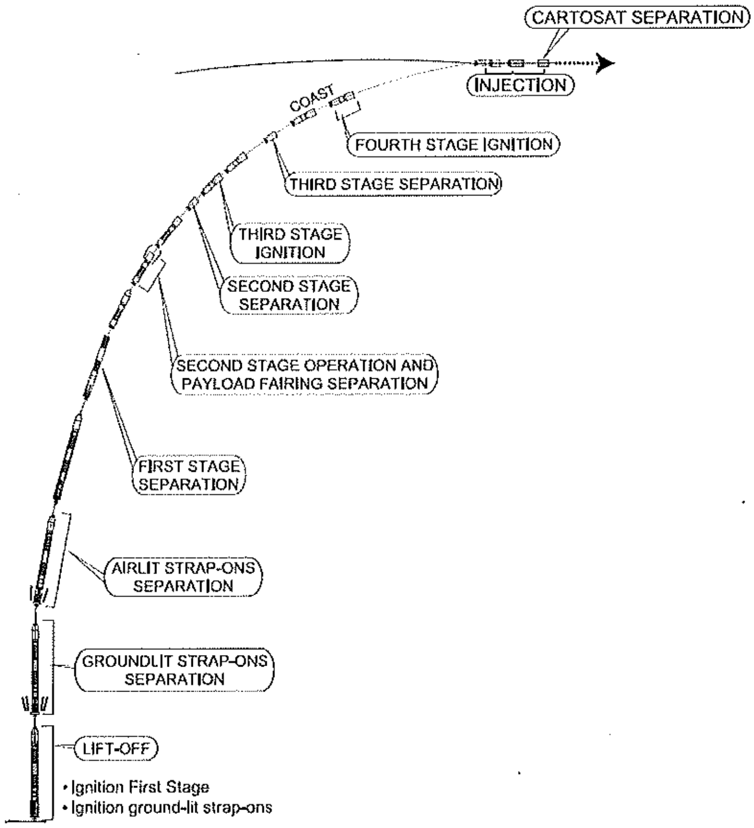

Figure 4 - Mission Profile of PSLV launch vehicle.

Event	Time	Altitude (km)
PS1 Ignition	00.00.0	0.025
Booster 1&2 Ignition	00.00.42	0.025
Booster 3&4 Ignition	00.00.62	0.025
Booster 5&6 (Air-Lit) Ignition	00.25.0	2.748
Booster 1&2 Separation	01:09.9	26.606
Booster 3&4 Separation	01:10:1	26.762
Booster 5&6 Separation	01.32.0	46.906
PS1 Separation	01:48.72	65.862
PS2 Ignition	01:48.92	66.087
Payload Fairing Separation	02:35.02	115.457
PS2 Separation	04:21.26	216.043
PS3 Ignition	04:22.46	217.235
PS3 Separation	08:07.22	417.233
PS4 Ignition	08:17.22	423.779
PS4 Cutoff	16:30.36	514.289
Payload Separation	17:07.36	515.021

Table 2 - Main events of a typical polar SSO PSLV launch (based on C34 flight profile).

2.3. PSLV launch vehicle performance characteristics for circular orbits

Fig. 5 below gives an overview of the performance of the PSLV launch vehicle for sun-synchronous low earth orbits for various configurations. The payload mass the launch vehicle can carry for each of the configurations and altitudes is mentioned.

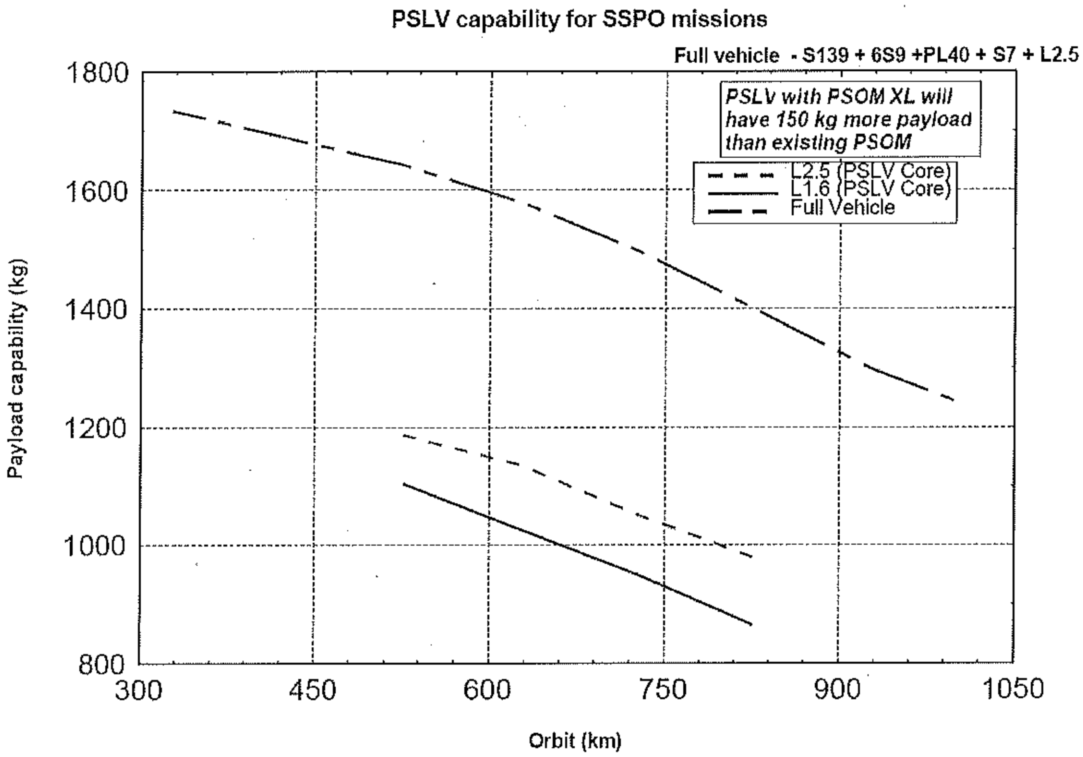

Fig. 5 - PSLV payload capability for SSO launches.

2.4. Launch and track record

As of today, PSLV has made 38 launches (3 development launches and 35 commercial). 36 reached the targeted orbit. The first development launch was a failure, while the first commercial launch was a partial failure. That results in a success rate of 97%. It can be emphasized that all launches since 1994 have been successful.

The detailed launch and track record of the PSLV launch vehicle is shown in Annex 1.

2.5. Conclusion

The PSLV launch vehicle has an excellent technical success rate and a proven track record with a launch reliability index currently evaluated at 97%. It has the proven capability to deliver the CubeSats to the right orbit to achieve QB50 scientific mission. This orbit is also suitable for the IOD CubeSats.

Therefore, VKI and ISL B.V. have chosen the PSLV launch vehicle for the launch of the second part of the QB50 constellation.

PART II: POTENTIAL IMPACT OF THE ACTIVITIES ON THE TERRESTRIAL ENVIRONMENT, THE ATMOSPHERE AND THE NATURAL AND HUMAN ENVIRONMENT OF THE PLACE OF LAUNCHING

No extensive study about the potential impact of the launch activities on the environment could be provided by the launch authority (see email exchange in Annex 2). Still the following elements can be brought forward.

- As shown in Fig. 6, the launch trajectory for polar orbits spreads over uninhabited areas of the Bay of Bengal and Indian Ocean. The trajectory is designed to avoid flying over Sri Lanka. Moreover, the Sriharikota Island is an uninhabited area (besides launch basis facilities) dedicated to the launch facilities. Impact on the human environment is thus minimized.

Fig. 6 - Launch trajectories from SHAR launch basis.

- ISRO state their commitment for environment protection, as can be read on Satish Dhawan Space Center (SHAR) website:
  "We are committed to maintain highest standards of safety, occupational health and environment protection during all our activities. We shall carry out all activities in an accident free atmosphere, ensuring safety, enhancing awareness by effective communication and training to control or mitigate the risks.
  Chairman, ISRO / Secretary, DOS"[4]

[4] Source: SHAR website, http://www.shar.gov.in/SDSCE/vPolicies.jsp, retrieved 15/12/2016.

- No nuclear power source is used in the PSLV launch vehicle.
- The QB50-polar mission in itself does not generate an impact on the environment. Indeed, QB50 being a secondary payload of the launch, the launch activities would take place anyway with or without QB50 satellites.

PART III: POTENTIAL IMPACT ON OUTER SPACE

Impact of the launcher

The potential impact on the outer space of the PSLV launches is extremely minimal. No adverse effect of the PSLV launch vehicle on the outer space occurs because of its mission and launch profile:

- The first three stages (and boosters) fall down in the Bay of Bengal.
- After the spacecraft injection into low Earth orbit, the 4^{th} stage is passivated by venting the pressurant gas from the propellant tank and gas bottles along with the propellant vapors in the tanks. That reduces the risk of explosion and thus of generating space debris.
- Before this passivation, the 4^{th} stage performs a collision avoidance maneuver to be placed on a graveyard orbit. It continues its coast flight until its re-entry and burning above the Earth.

Impact of the CubeSats

Some of the CubeSats are testing devices to accelerate their re-entry. Even in case of malfunctioning of these devices, the orbit of the CubeSats will naturally decay and CubeSats will be fully destructed while reentering the atmosphere. This will happen less than 8 years after launch for the considered orbit.

An analysis of the lifetime and destruction of the CubeSats is reported in a document entitled "QB50-polar: lifetime analysis and assessment", provided in Annex 3.

PART IV: NON-TECHNICAL SUMMARY

In the framework of the EU FP7 Project aiming at the launch of 50 CubeSats for atmospheric research, the VKI as coordinator of the project and its subcontractor ISL B.V., have procured by the launch service provider Antrix Corporation Ltd. (on behalf of ISRO) a launch scheduled for the second quarter of 2017. This launch will be the second out of two QB50 launches after the launch of the two precursor satellites. The objectives of this second launch are twofold: scientific (6 satellites will study the constituents of the atmosphere) and technological (2 satellites will demonstrate re-entry sails).

As an Operator located in Belgium and therefore subject to the Belgian law of 17 September 2005 (revised by the law of 1 December 2013) on the activities of launching, flight operation or guidance of space objects, the VKI is responsible to providing to the Belgian authorities an environmental impact assessment of the foreseen launch activity.

As shown in Part II, several elements make us believe that the environmental impact of the activities is limited and acceptable:

- ISRO is committed to environment protection;
- Launch takes place over uninhabited areas;
- No radioactive substances or components are used in the selected launch vehicle;
- The launch vehicle has a track record and a reliability index evaluated at 97%.

Part III studied the impact on outer space. Based on the following elements, this impact is assessed to be extremely minimal:

- The first 3 launcher stages do not reach or stay in the outer space;
- The upper launcher stage has its tanks emptied and is placed on a graveyard orbit before re-entering the atmosphere;
- CubeSats will re-enter the atmosphere and burn within 10 years.

Based on financial, technical and programmatic assumptions, the selected launch vehicle offers the best guarantees for the realization of the launch objectives. Nevertheless, launching space objects into outer space is never without risks and especially potential negative impact on the environment can never be completely excluded. For the QB50 project, being a scientific endeavor with limited budget, the selected launch vehicle offers the best value for money.

PART V: MEMO ON THE EXPERTISE OF THE VON KARMAN INSTITUTE FOR FLUID DYNAMICS AS OPERATOR

1. Introduction: Implementation of the Belgian space law

The QB50 project, funded by the European Commission and executed by the von Karman Institute for Fluid Dynamics (VKI) intends to launch (around) 50 nanosatellites into Low Earth Orbit by means of 2 distinct launches. The object of the present document is the launch of 8 nanosatellites by a PSLV rocket to an altitude of 500 +/- 20 km at an inclination of approximately 97 degrees.

The VKI will act as the Operator in the framework of the Belgian space law, but implements the launch activity through a Dutch partner (ISL B.V.) and an Indian launch service provider (Antrix Corporation Limited on behalf of Indian Space Research Organization).

The relationship between the aforementioned partners is illustrated in Fig. 7.

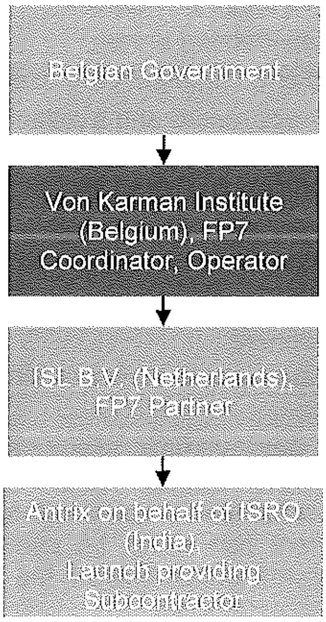

Fig. 7 – Implementation of the Belgian space law with respect to the QB50 polar campaign.

2. Expertise as an Operator

VKI is a non-profit international educational and scientific organization, hosting three departments[5]. It provides post-graduate education in fluid dynamics and encourages "training in research through research". The VKI undertakes and promotes research in the field of fluid dynamics. It possesses about fifty different wind tunnels, turbomachinery and other specialized test facilities, some of which are unique or the largest in the world. Extensive research on experimental, computational and theoretical aspects of gas and liquid flows is carried under the direction of the faculty and research engineers, sponsored mainly by governmental and international agencies as well as industries.

[5] Aeronautics and Aerospace (AR), Environmental and Applied Fluid Dynamics (EA), Turbomachinery and Propulsion (TU)

The VKI is or was involved in the instrumentation of all ESA re-entry spacecraft such as the Atmospheric Reentry Demonstrator (ARD), European eXPErimental Reentry Testbed (EXPERT), the Intermediate eXperimental Vehicle (IXV) and has started in 2010 to design, end-to-end, its own miniaturized re-entry vehicle called Qarman.

As of 2011, the VKI is charged with the management of the QB50 project consisting of the launch of 50 CubeSats. In the framework of the QB50 project, three precursor satellites were launched on the 19th June 2014 under the authorization number 2014/01 (objects 2014-B-SC-001, 2014-B-SC-002, and 2014-B-SC-003). They have been operated by the VKI since then.

The QB50 team of VKI and ISL B.V. involved in (the preparation of) the launch consists of the following persons:

Name	Organization	Responsibility
Dr. Davide Masutti	VKI	QB50 Project Manager, FP7 QB50 General Supervisor
Thorsten Scholz	VKI	Ground Segment Engineer and Mission Analyst
Paride Testani	VKI	Launch and Space Segment Engineer
Amandine Denis	VKI	Space Segment Engineer & CubeSat Coordinator
Abe Bonnema	ISL	ISIS Marketing Director, Launch Campaign Manager
Michiel Van Bolhuis	ISL	Launch mission manager

Detailed curriculum vitae of the persons involved from VKI and ISL B.V. is attached in Annex 4.

3. Alternative launcher scenario's analysis

In accordance with the provisions of the Belgian space law, VKI and ISL B.V. conducted an in depth analysis of the European and international launchers potentially available for realizing the objectives of the QB50 DneprScience launch. The results of this analysis are described in this chapter.

The launch scenario consisting of the choice of provider, the launch site and further characteristics such as contractual conditions have been analysed to best match the needs of the QB50 project, the Regulations of the EU FP7 program and other constraints. The disregarded alternatives and the reasons are given below:

Launch Provider and Launcher	Reason for disregard
ESA/Arianespace • VEGA • ARIANE 5 • SOYUZ	In particular the launch cost is prohibitively high. Further reason for disregard is the timely unavailability of a launch into a suitable Low Earth Orbit
American Launch providers such as United Launch Alliance, Orbital Science, SpaceX • Atlas 5 • Antares • Falcon 9	The costs for the launch are prohibitively high. Further reason for disregard is the timely unavailability of a launch into a suitable low Earth Orbit

Deployment from the International Space Station, through Nanoracks launch provider	This type of launch will be used for 28 QB50 satellites. However, the orbit inclination does not permit to take measurements over the polar region, which is of particular scientific interest. Therefore, a launch with a higher inclination (such as the one described in the current document) is needed.
Chinese launch providers such as China Great Wall Industry Corporation (CGWIC) • MLVT • Long March	Mostly export related issues prevented the consideration of Chinese provided launch vehicles.
Russian launchers such as DNEPR	The DNEPR program suffers from severe delays and is apparently on-hold.

ANNEX 1 – PSLV DETAILED LAUNCH AND TRACK RECORD

Title	Launch Date	Type	Orbit	Status
PSLV-D1	Sep 20, 1993	PSLV-G	SSPO	Failure
PSLV-D2	Oct 15, 1994	PSLV-G	SSPO	Success
PSLV-D3 / IRS-P3	Mar 21, 1996	PSLV-G	SSPO	Success
PSLV-C1 / IRS-1D	Sep 29, 1997	PSLV-G	SSPO	Partial failure
PSLV-C2/IRS-P4	May 26, 1999	PSLV-G	SSPO	Success
PSLV-C3 / TES	Oct 22, 2001	PSLV-G	SSPO	Success
PSLV-C4 /KALPANA-1	Sep 12, 2002	PSLV-G	GTO	Success
PSLV-C5 /RESOURCESAT-1	Oct 17, 2003	PSLV-G	SSPO	Success
PSLV-C6/CARTOSAT-1/HAMSAT	May 05, 2005	PSLV-G	SSPO	Success
PSLV-C7 / CARTOSAT-2 / SRE-1	Jan 10, 2007	PSLV-G	SSPO	Success
PSLV-C8	Apr 23, 2007	PSLV-CA	LEO	Success
PSLV-C9 / CARTOSAT – 2A	Apr 28, 2008	PSLV-CA	SSPO	Success
PSLV-C10	Jan 21, 2008	PSLV-CA	HEO	Success
PSLV-C11	Oct 22, 2008	PSLV-XL	Lunar	Success
PSLV-C12 / RISAT-2	Apr 20, 2009	PSLV-CA	SSPO	Success
PSLV-C14 / OCEANSAT-2	Sep 23, 2009	PSLV-CA	SSPO	Success
PSLV-C15/CARTOSAT-2B	Jul 12, 2010	PSLV-CA	SSPO	Success
PSLV-C16/RESOURCESAT-2	Apr 20, 2011	PSLV-G	SSPO	Success
PSLV-C17/GSAT-12	Jul 15, 2011	PSLV-XL	GTO	Success
PSLV-C18/Megha-Tropiques	Oct 12, 2011	PSLV-CA	SSPO	Success
PSLV-C19/RISAT-1	Apr 26, 2012	PSLV-XL	SSPO	Success
PSLV-C20/SARAL	Feb 25, 2013	PSLV-CA	SSPO	Success
PSLV-C21	Sep 09, 2012	PSLV-CA	SSPO	Success
PSLV-C22/IRNSS-1A	Jul 01, 2013	PSLV-XL	GTO	Success
PSLV-C23	Jun 30, 2014	PSLV-CA	SSPO	Success
PSLV-C24/IRNSS-1B	Apr 04, 2014	PSLV-XL	GTO	Success
PSLV-C25	Nov 05, 2013	PSLV-XL	HEO	Success
PSLV-C26/IRNSS-1C	Oct 16, 2014	PSLV-XL	GTO	Success
PSLV-C27/IRNSS-1D	Mar 28, 2015	PSLV-XL	GTO	Success
PSLV-C28 / DMC3 Mission	Jul 10, 2015	PSLV-XL	LEO	Success
PSLV-C29 / TeLEOS-1 Mission	Dec 16, 2015	PSLV-CA	LEO	Success
PSLV-C30/AstroSat MISSION	Sep 28, 2015	PSLV-XL	LEO	Success
PSLV-C31/IRNSS-1E	Jan 20, 2016	PSLV-XL	GTO	Success
PSLV-C32/IRNSS-1F	Mar 10, 2016	PSLV-XL	GTO	Success
PSLV-C33/IRNSS-1G	Apr 28, 2016	PSLV-XL	GTO	Success
PSLV-C34 / CARTOSAT-2	Jun 22, 2016	PSLV-XL	SSPO	Success
PSLV-C35 / SCATSAT-1	Sep 26, 2016	PSLV	SSPO	Success
PSLV-C36 / RESOURCESAT-2A	Dec 07, 2016	PSLV-XL	SSPO	Success

ANNEX 3 – QB50-POLAR: LIFETIME ANALYSIS AND ASSESSMENT

von Karman Institute for Fluid Dynamics
Aeronautics / Aerospace Department

Chaussée de Waterloo, 72
B - 1640 Rhode Saint Genèse
Belgium

QB50-Polar:
Lifetime Analysis and Assessment

QB50 Project

www.QB50.eu

Reference Documents

[RD 01] QB50 System Requirements, issue 7

1 Lifetime Analysis

The respect of the 25 years maximum lifetime is a major topic for the QB50 mission, in addition of being a requirement coming directly from the original FP7 Call.

2.1.1 Assumptions and Parameters

The simulations are repeated for all of the QB50 satellites to be launched as part of the QB50-Polar mission, considering for each of them the actual mass declared in the QB50 CDR data package. All the analyses are run with the NASA software DAS 2.0.
The parameters driving the re-entry time of a CubeSat are the mass, position of the center of mass and center of pressure, the inertia matrix, the presence of deployable elements and the CubeSat attitude controllability. To have a precise deorbiting analysis, a long term attitude simulation should be run. Nevertheless for a first lifetime estimation an averaged area/mass ratio can be used. For a preliminary analysis, a very conservative worst case scenario will be also considered.

In order to determine the area/mass ratio, the satellites attitude has to be considered. According to the specific design of each satellite, two categories have been identified:

1. Aerodynamically stable satellites: CubeSats having stabilizing surfaces, deployable elements or known position of the centre of pressure. They can be considered to be passively stabilized during re-entry, in terms of orientation.
2. Satellites with uncontrolled orientation during re-entry: satellites for which no assumptions about the attitude can be done.

The previous distinction allows to make different assumptions to improve simulations reliability. In particular, the aerodynamically stable satellites (case 1), will tend to passively orient themselves with a known attitude, facing the *RAM* direction with a known cross sectional area. Any deviation from the stable attitude is assumed to be small: hence, the lifetime can be calculated taking into account the cross section corresponding to the nominal stable orientation (which is often also the worst case for lifetime).

For all the other satellites (case 2), no reliable assumptions about the attitude can be made. Hence, two different cases are analysed: a worst case scenario and random tumbling scenario. For the first one, the minimum cross section of the satellite is assumed to be constantly oriented to the RAM direction, offering the minimum drag possible; in case of random tumbling instead, each orientation of the satellites is assumed to have the same probability to be exposed to the RAM direction, so the analysis is performed with an averaged area, estimated with a Monte Carlo approach.

Orbit is assumed to be 500 km @ 97.5 degrees inclination (epoch: 1st October 2016)

2.1.2 Case I: Aerodynamically stable satellites

5 QB50-PL satellites have been designed to be aerodynamically stable, according to their CDR reports. For them, the attitude during can be assumed to be known, specifically the cross

sectional area can be calculated. As a matter of fact, even if dealing with a stable orientation, some deviations from this reference pointing will be always present, having the outcome of increasing the cross sectional area: for that reason, the analyses presented below can be considered as conservative.

ID	Name	Country	Units	Area/mass [m2/kg]	Lifetime [yrs]
					500 km
CZ02	VZLUSAT1	Czech Republic	2U	0.012412762	5.72
DE04	DragSail	Germany	3U	0.62	0.14
GB06	InflateSail	Great Britain	3U	3.86	0.03
IT02	URSA MAIOR	Italy	3U	0.36	0.25
LT01	LituanicaSAT-2	Lithuania	3U	0.023025562	4.97

The CubeSats DE04, GB06 and IT02 are special case, as they are equipped with large deployable devices. The analysis, repeated in case of failure of those large deployables (assuming a random tumbling attitude, see hypothesis in the next paragraph) are reported in the table below:

ID	Name	Country	Units	Area/mass [m2/kg]	Lifetime [yrs]
					500 km
DE04	DragSail	Germany	3U	0.0113	5.43
GB06	InflateSail	Great Britain	3U	0.0119	5.36
IT02	URSA MAIOR	Italy	3U	0.0109	5.49

2.1.3 Case II: Randomly tumbling satellites

For those satellites having no surfaces for passive aerodynamic stabilization, a random tumbling attitude can be assumed[1]. As consequence of the random tumbling the cross sectional area of the satellite is time-varying with a stochastic distribution. The average area is calculated with a simple Monte Carlo method.

A worst lifetime case is first computed to have a conservative analysis, taking into account the minimum cross sectional area possible, for each satellite.

[1] In this analysis would be not accounted the 1 year minimum of required operations, where the attitude will be controlled. This case is anyway included in the worst case scenario analysis where a minimum cross sectional area is always accounted.

3 QB50-PL CubeSats belong to this category and the expected lifetime for them is summarized in the table below:

ID	Name	Units	Min Area/mass [m^2/kg]	Average Area/mass [m^2/kg]	LT : Worst Case [years]	LT : Worst Case [years]	LT : Worst Case [years]
					500 km	450 km	400 km
AT03	PEGASUS	2U	0.004768	0.010776	7.75	5.63	4.01
CN06	NUDTSat	2U	0.004643	0.010494	7.84	5.67	4.08
GB03	UCLSat	2U	0.004436	0.010025	8.00	5.72	4.17

2 Casualty Risk Evaluation

A worst-case CubeSat configuration is used as example for the casualty risk evaluation. In particular the following configuration is adopted:

Name	Shape	Number of Objects [-]	Width/ Diameter [m]	Length [m]	Height [m]	Mass [kg]	Material [-]
Parent	Box	1	0.1	0.34	0.1	4.0	n/a
SolarP	Plate	0	0.1	0.3		0.0	n/a
PCBs	Plate	10	0.09	0.09		0.05	FR4
BATTERY	Box	1	0.09	0.09	0.01	0.2	AA6060
RWHEEL	Cylinder	1	0.06	0.04		0.3	A316
Structure_rails	Cylinder	4	0.15	0.3		0.3	AA7075
Magnetorquer	Cylinder	3	0.03	0.09		0.1	Inconel
INMS	Cylinder	1	0.08	0.04		0.30	AA6060
structure	Plate	6	0.01	0.03		0.1	AA6060
screws_nuts_bolts	Box	100	0.001	0.001	0.005	0.001	A316
tank	Sphere	1	0.1			0.5	AA7075

The object is assumed to have a total mass of 4kg (upper limit of a 3U CubeSat) and all the typical subcomponents (PCBs, batteries, reaction wheel and magnetorquers, an aluminium structure etc..). The presence of an aluminium tank and deployable solar panels is accounted as part of the worst case scenario.

The following simulation parameters are adopted:

- Altitude: re-entry starting at 150 km
- Inclination: 97.5 degrees

- Epoch: October 2016

The software used is DRAMA-2.0, an ESA software specific for debris and demisability studies.

The simulations run with these configurations, revealed that no parts of the object are capable to survive re-entry: all the parts are destroyed at an altitude of 78 km (or above).

DS16-14929-9

I B P T

Monsieur Kris Vanderhauwaert
Aeronautics & Aerospace Dept.
Von Karman Institute for Fluid Dynamics
Waterloosesteenweg 72
1640 Sint-Genesius-Rode

Gestionnaire du dossier - Brigitte Wayembergh (Fr)
Grade - Correspondant

Service - Service des Fréquences
e-mail – freqadmin@ibpt.be

Nos références
16/FRE/2016-000218-2-71283BWM/SAT/205/QB50
Vos références

Votre e-mail du 14/03/2016

tél +32 2 226 88 78
fax +32 2 226 88 82

Bruxelles, le 02 -05- 2016

Objet : Coordination et notification du satellite QB50_DIOD.

Monsieur,

Dans le cadre de votre demande d'autorisation de lancement à la Politique scientifique fédéral (BELSPO), l'IBPT confirme qu'il a bien entamé la coordination du satellite QB50_DIOD prévue à l'article 9 du Règlement des Radiocommunications de l'Union Internationale des Télécommunications (UIT). Au reçu des renseignements complets, le Bureau des Radiocommunications de l'UIT les publie dans un délai de 3 mois dans une section spéciale de sa Circulaire de la BR IFIC. Dans ce cas précis, la publication a été faite le 26/04/2016. La date limite pour la réception des commentaires est le 26/08/2016. Pour information, vous trouverez en annexe, un extrait de la section spéciale en question – partie « résumé ».

Je vous prie d'agréer, Monsieur, mes sincères salutations.

Au nom du Conseil
M. Vandroogenbroek
Premier Ingénieur Conseiller

Annexe(s): 1 (1 page)

Institut belge des services postaux et des télécommunications
Ellipse Building Bâtiment C Boulevard du Roi Albert II 35 1030 Bruxelles Tél.: 02-226 88 88 Fax: 02-226 88 77
http://www.ibpt.be

A | A1a Sat. Network QB50_DIOD | A1f1 Notifying adm. BEL | A1f3 Inter. sat. org. | BR1 Date of receipt 18.02.2016 | BR20 BR IFIC no. 2818

BR6a/BR6b Id. no. 116545115 | BR3a Provision reference 9.1/IA | BR2 Adm. serial no.

Résumé / Summary / Resumen / 综述 / Резюме / خلاصة

Article 9, sous-section IA / Article 9, sub-section IA / Artículo 9, sub-sección IA
第9条第1A分节 / Статья 9, подраздел IA / المادة 9، القسم الفرعي IA

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	BR47 Frequency band (MHz)	C4a Class of station
ON04DE	R		116623994		145.8 - 146	EA
			116623995		2405 - 2445	EA
			116623999		145.8 - 146	EA
ON06GB	R		116623997		145.8 - 146	EA
ON04DE	E		116623992		435 - 438	EA
			116623993		2405 - 2445	EA
			116623998		2402 - 2404	EA
			116624000		435 - 438	EA
ON06GB	E		116623996		435 - 438	EA

DS16-14927-7

IBPT

Monsieur Kris Vanderhauwaert
Aeronautics & Aerospace Dept.
Von Karman Institute for Fluid Dynamics
Waterloosesteenweg 72
1640 Sint-Genesius-Rode

Gestionnaire du dossier - Brigitte Wayembergh (Fr)
Grade - Correspondant

Service - Service des Fréquences
e-mail – freqadmin@ibpt.be

Nos références
16/FRE/2016-000217-2-71282BWM/SAT/205/QB50
Vos références

Votre e-mail du 14/03/2016

tél +32 2 226 88 78
fax +32 2 226 88 82

Bruxelles, le 02-05-2016

Objet : Coordination et notification du satellite QB50_DSC.

Monsieur,

Dans le cadre de votre demande d'autorisation de lancement à la Politique scientifique fédéral (BELSPO), l'IBPT confirme qu'il a bien entamé la coordination du satellite QB50_DCS prévue à l'article 9 du Règlement des Radiocommunications de l'Union Internationale des Télécommunications (UIT). Au reçu des renseignements complets, le Bureau des Radiocommunications de l'UIT les publie dans un délai de 3 mois dans une section spéciale de sa Circulaire de la BR IFIC. Dans ce cas précis, la publication a été faite le 26/04/2016. La date limite pour la réception des commentaires est le 26/08/2016. Pour information, vous trouverez en annexe, un extrait de la section spéciale en question – partie « résumé ».

Je vous prie d'agréer, Monsieur, mes sincères salutations.

Au nom du Conseil
M. Vandroogenbroek
Premier Ingénieur Conseiller

Annexe(s): 1 (1 page)

Institut belge des services postaux et des télécommunications
Ellipse Building Bâtiment C Boulevard du Roi Albert II 35 1030 Bruxelles Tél.: 02-226 88 88 Fax: 02-226 88 77
http://www.ibpt.be

A | *A1a* Sat. Network QB50_DSC | *A1f1* Notifying adm. BEL | *A1f3* Inter. sat. org. | *BR1* Date of receipt 18.02.2016 | *BR20* BR IFIC no. 2818

BR6a/BR6b Id. no. 116545114 | *BR3a* Provision reference 9.1/IA | *BR2* Adm. serial no.

Résumé / Summary / Resumen / 綜述 / Резюме / خلاصة

Article 9, sous-section IA / Article 9, sub-section IA / Artículo 9, sub-sección IA
第9条第1A分节 / Статья 9, подраздел IA / المادة 9، القسم الفرعي IA

B1a Beam designation	B2 Emi-Rcp	BR8 Action code	BR7a Group id.	BR9 Action code	BR47 Frequency band (MHz)	C4a Class of station
ON02CZ	R		116623991		435 - 438	EA
ON02IT	R		116623989		145.8 - 146	EA
ON03AT	R		116623987		435 - 438	EA
ON03GB	R		116623985		145.8 - 146	EA
ON06CN	R		116623983		145.8 - 146	EA
ON02CZ	E		116623990		435 - 438	EA
ON02IT	E		116623988		435 - 438	EA
ON03AT	E		116623986		435 - 438	EA
ON03GB	E		116623984		435 - 438	EA
ON06CN	E		116623982		435 - 438	EA