STUDY OF CAUSES AND FEASIBLE MEASURES TO PREVENT FURTHER SPACE ENVIRONMENT POLLUTION

S.V.Chekalin*, V.I.Lukiyashenko,
Central Research Institute of Machine Building, Russia

A.N.Kuznetsov, V.P.Blagun,
Russian Space Agency, Russia

ABSTRACT

The paper reviews the major sources of space technogenic pollution. Supposed causes and statistics of spent rocket and stages fragmentations resulting in accumulation of a great number of untrackable small-size fragments presenting a certain risk of collision are studied.
A number of design and organization-technical measures, aimed at preventing further space debris pollution, are presented, to include recommendations on ecologically safe usage of GEO. Proposals on international cooperation in this feild are developed.

1.1 ANALYSIS OF SPACE POLLUTION SOURCES

From the moment the first artificial earth satellite had been launched the ground tracking services have registered over 24000 man-made objects (MMO), measuring over 10 to 20 cm, out of which 8500 still occupy the near-earth orbits. Contribution of different nations, made to space debris generation, observed at present in the near-earth orbits, runs to: 45% by the CIS, 47% by the USA, and 8% by other nations.
Alongside with near-earth orbit trackable MMO, as specialists consider, tens of thousands of fragments, measuring less than 10cm and hundreds of thousands of still smaller space debris fragments (measuring less than 1cm) orbit the earth.
The structural composition of trackable space debris fragments includes spent spacecraft, launch vehicle upper stages, boost modules, separated structural elements such as adapters, pyro-pushers, nose-fairing covers, etc. But the most significant sources of fragment generation in orbits are spacecraft and rocket stage explosions, which account for almost half of cataloged objects (see table 1) and majority of untrackable, but collision-imminent small size fragments.

Annual increase of near-earth orbit trackable fragments constitutes 4%.

Table 1. Structural composion of tracked space debris.

Pollution sources	Amount of fragments (%)
In-orbit object fragmentations	46
Spent spacecraft	21
Spent rocket stages	16
Separated elements	11
Operating spacecraft	6

By the prediction, made on the basis of the object cataloging data for the 80ies they expected to have 11000 orbital objects by 1995, instead of 8500 objects, having accumulated by the given moment (1).
The reasons why the debris population growth slowed down are explained by:
-increased solar activity for the period of 1980 to 1992;
-stagnation and even certain drop of yearly spacecraft launch count;
-implementation of a number of technological procedures to prevent in-orbit spacecraft explosions.
But space debris accumulation is in progress, the technogenic pollution becomes a threat to further space exploration.
Especially dangerous are small-size fragments (1 to 10cm), their number, by specialists' evaluation, surpasses that of the cataloged objects by 3-5 times. They present a real threat to operational orbital stations (MIR-ALFA Project), also threaten

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the conservation of spent Russian and American spacecraft carrying radioactive power supply units in the "scintillation" orbits (700 to 1300km).
To protect an object from fragmentation at cosmic speed impacts with a fragment of more than 1 cm is basically impossible.
As for prediction and tracing of trajectories of all hazardous fragments not prone to direct detection with the purpose of making a spacecraft manoeuver to avoid a collision with them, they are absolutely unreal. The only counteraction step is to mitigate their population or, if only for retardation of their further growth.
As was noted before, the main sources, generating small-size fragments are in-orbit space object explosions. Table 3 demonstrates parameters of orbits our national space vehicles are inserted in, as well as characteristics of launch vehicle stages and transfer stages having been used recently by the ex-USSR and the CIS and polluting space.
Analysis of in-orbit space object explosion statistics and causes was made, relying on the in-space fragmentation catalog, drawn up on the basis of the national observation data and data, supplied by the Johnson Space Center (USA).
For the period of 1961 to 1995 134 in-orbit explosions were registered, 72% of them are attributed to the ex-USSR and the CIS. Figure 1 and table 2 classify fragmentations by object types and orbits.

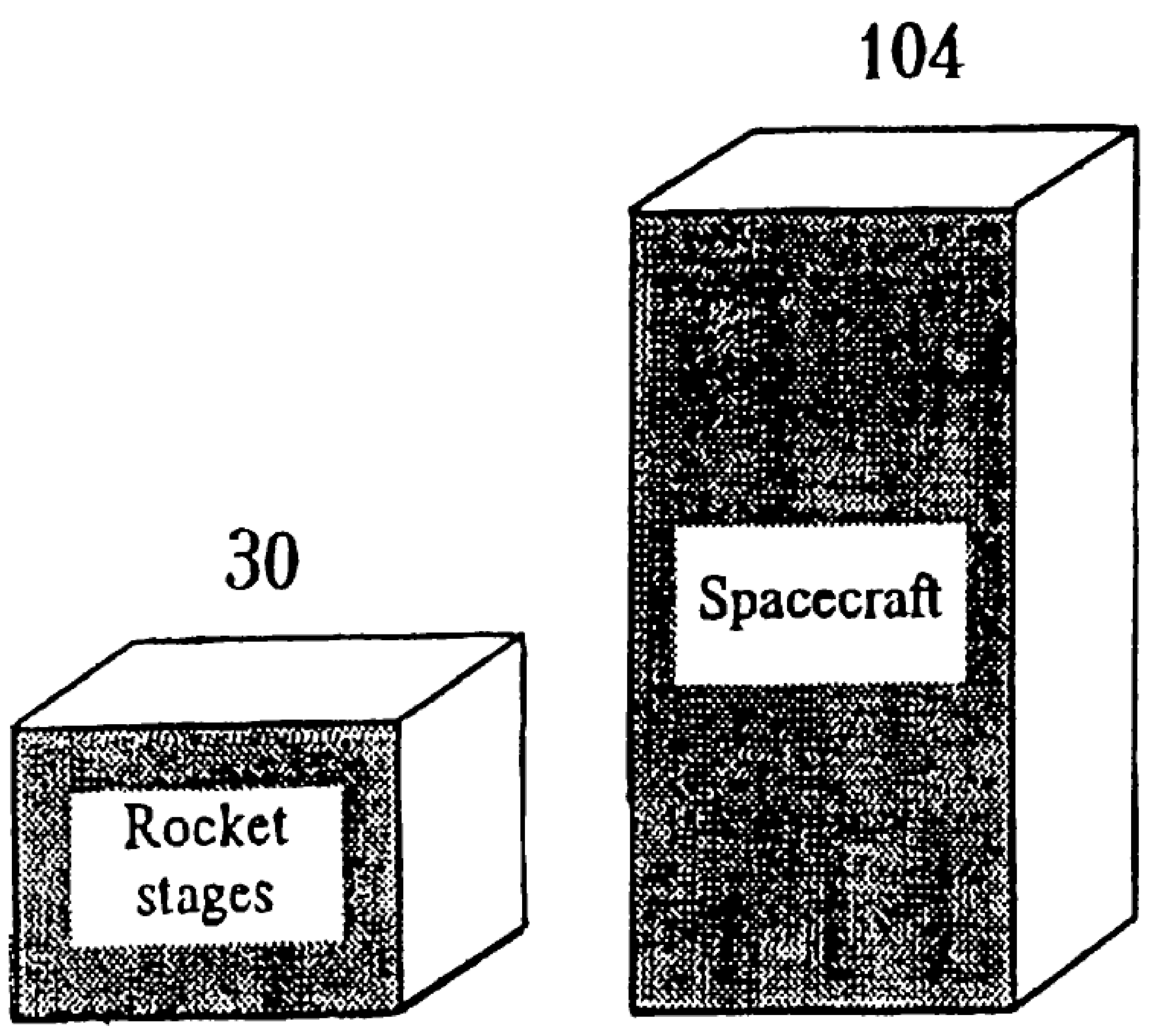


Fig. 1 Fragmentation distribution as to object types.

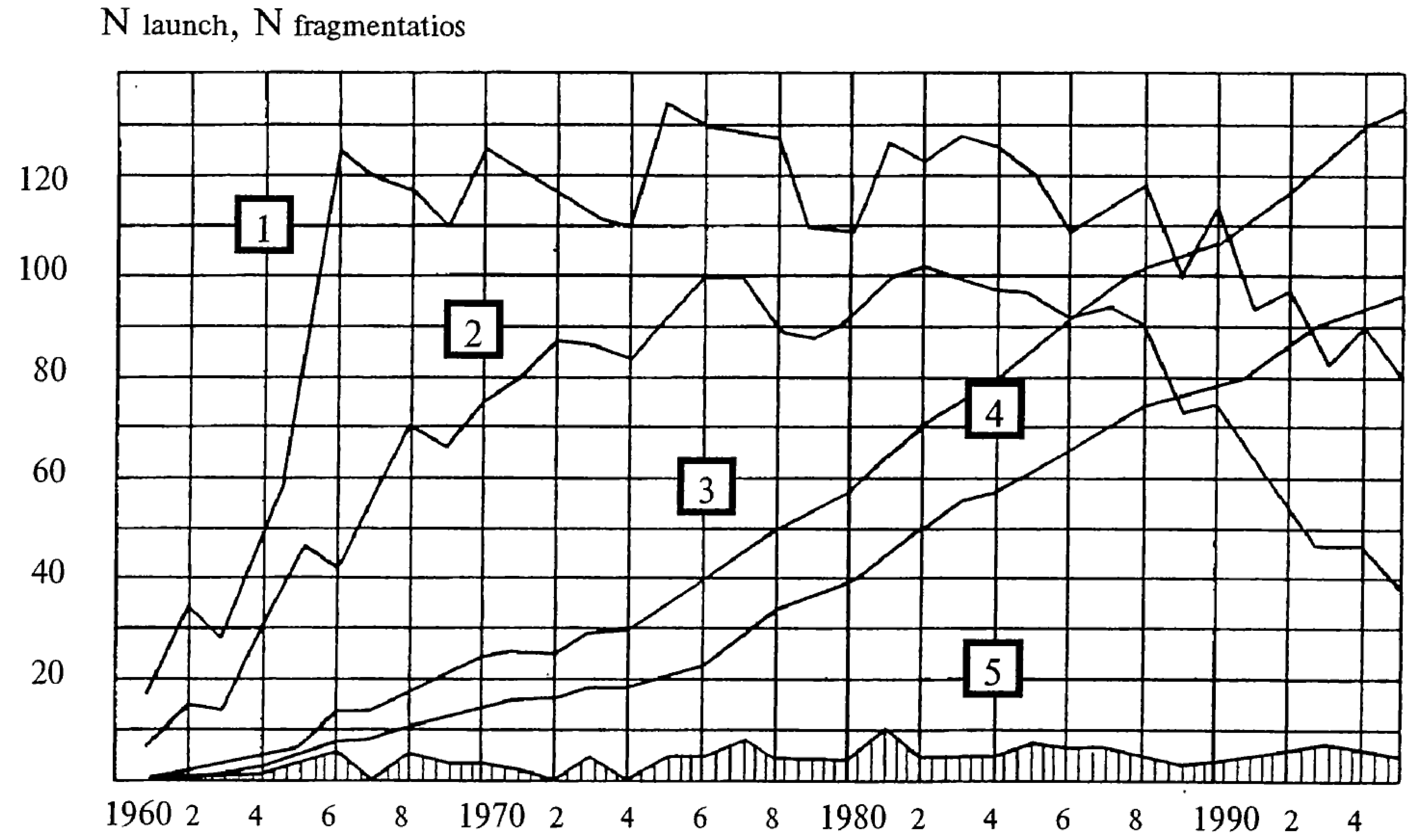
Table 2. Orbit distribution of object fragmentations.

Orbit types	Number of fragmentations
Low orbits (up-to 2000km)	98
Medium altitude and high elliptical orbit	34
Geostationary orbit	2

Supposed reasons of fragmentations are distributed as follows:
- intentional demolition (about 34%),
- spontaneous explosion, caused by engine operation or chemical batteries (approximately 32%),
- accidental explosion due to unknown reason (about 34%).

In-orbit space object fragmentations statistics data (see fig. 2-5) show, that:
- with the average object fragmentation count of the order of 3 to 5 annually their spread constitutes one in 1961 to nine in 1981;
- in spite of a great number of space object explosions to include intentional ones the ex-USSR and the CIS account for a smaller number of explosion fragmentations (44% vesus 56%) as compared with foreign countries, since intentional demolitions are performed in low orbits and fragments quickly deorbit;
- as for long-life orbital fragments number, produced by one space object fragmentation, the number of fragments produced by one foreign object explosion surpasses that of Russia's object fragmentation by about 3÷4 times.

In this case it is appropriate to note, that the number of small fragments, generated by in-orbit object explosions is obviously underestimated due to the difficulty of their detection and due to the fact, that a substantial portion of small fragments take on significantly greater speeds during explosions, break away from the explosion center at a greater distance, and it is difficult to relate them to a specific explosion. It is also possible, that some portion of fragments is produced by collisions of small objects which are difficult to be detected by onground tracking systems.
This ability of space debris to "self-reproduce" presents a highest threat. If in the past and in the near-term future the major cause of small fragment



Annual launch number:

1 - total

2 - of the ex - USSR and CIS

Total fragmentations number:

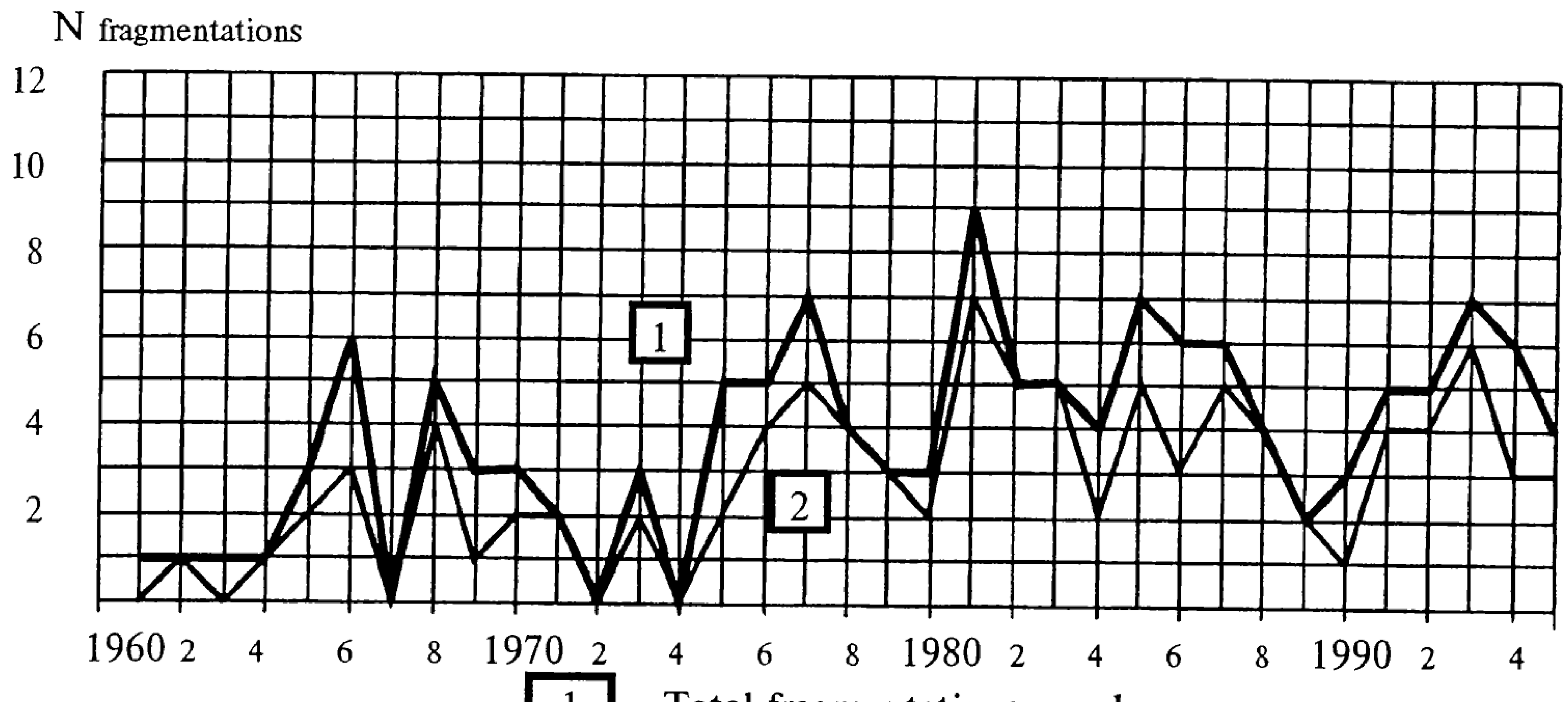
3 - total

4 - of the ex - USSR and CIS

Annual launch vehicle fragmentations number:

5 - total

Fig. 2 Statistics of launch vehicle launches and total number of in-orbit space object fragmentations for the period of 1961-95



1 - Total fragmentations number

2 - Fragmentations number of the ex-USSR and CIS

Fig. 3 Statistics of near-earth orbit space object fragmentations for the period of 1961-95.

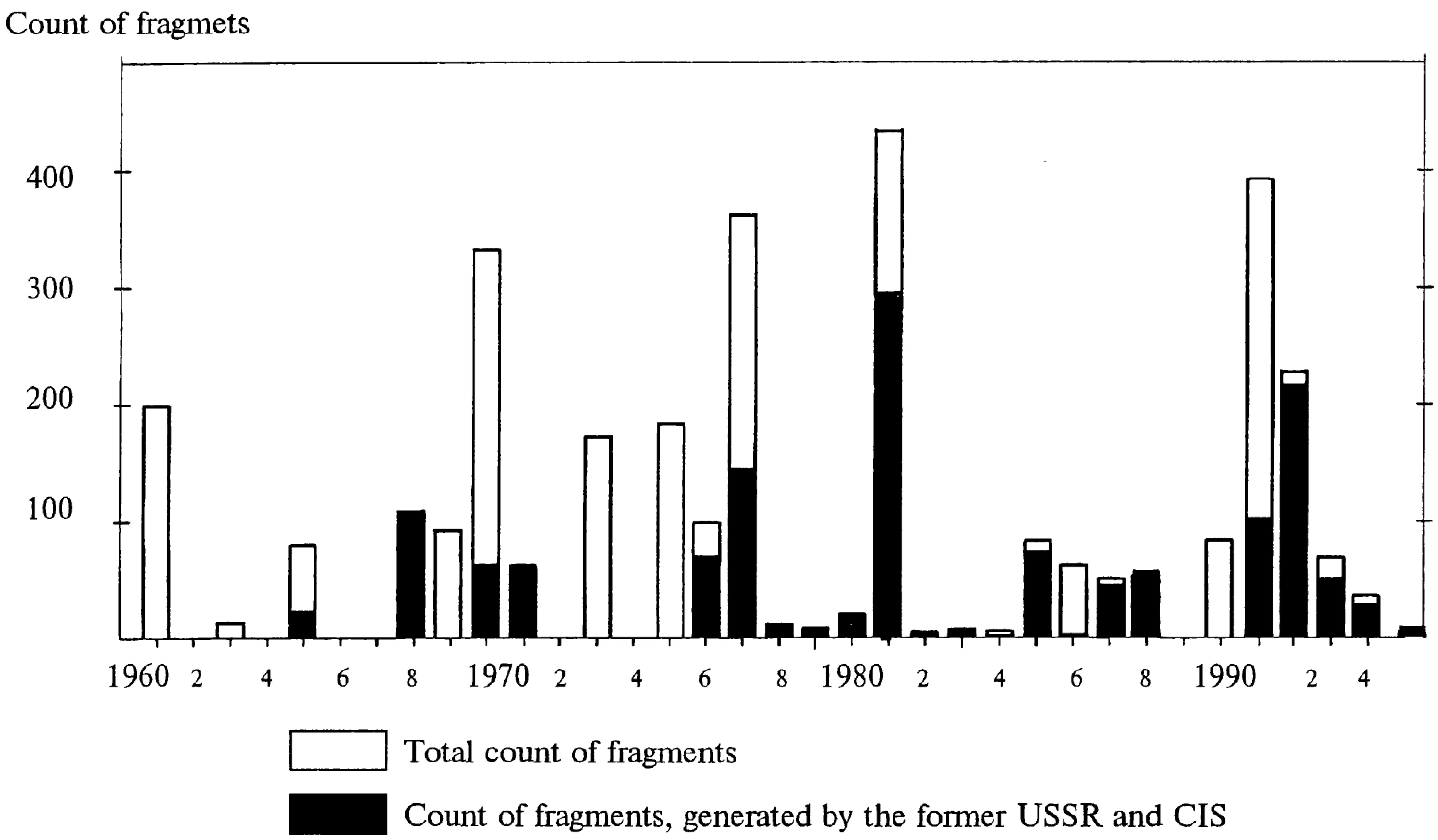


Fig. 4 Distribution of long-life fragments in compliance with object fragmentation years as of 1.1.96.

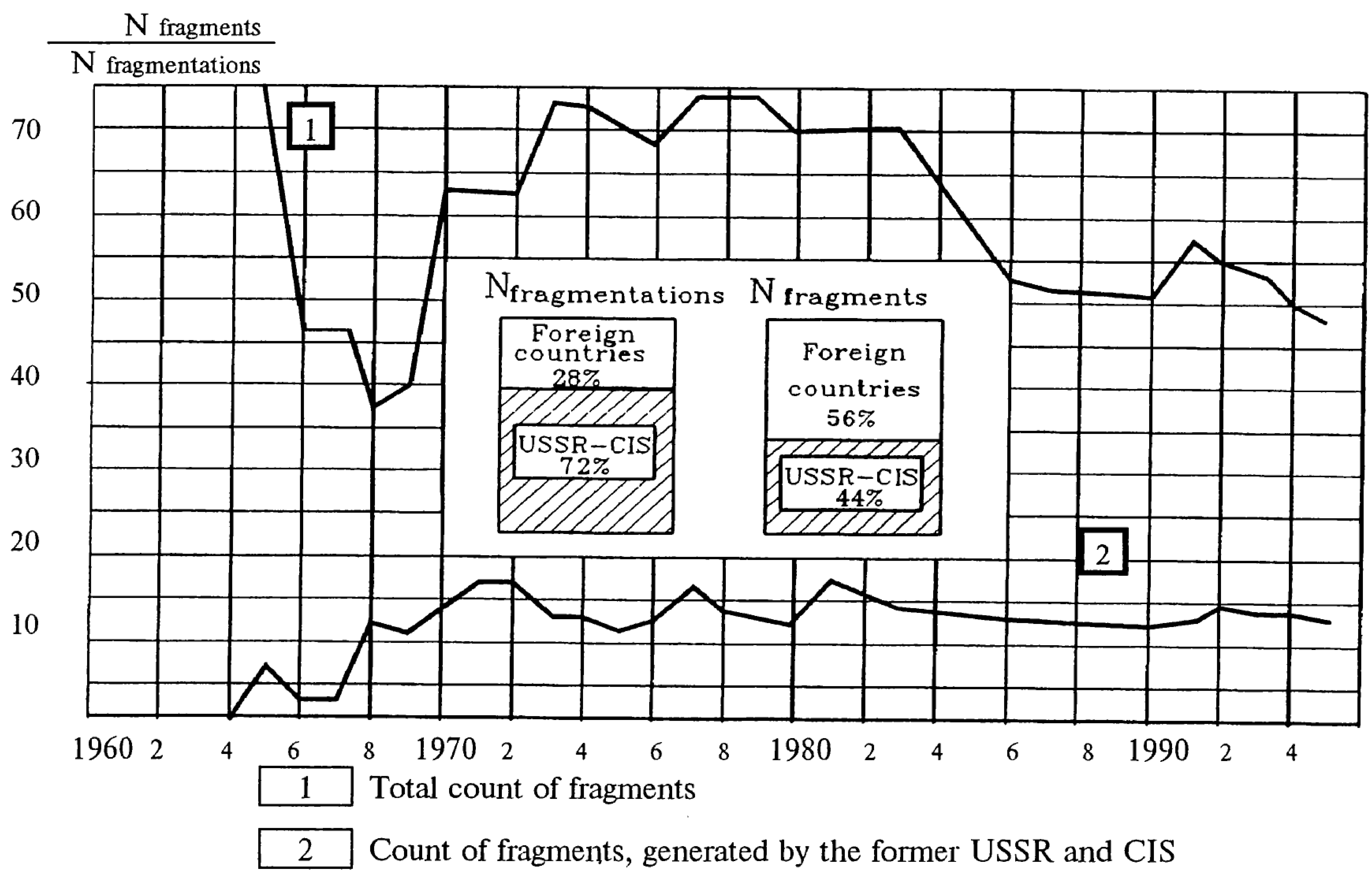


Fig.5 Number of long-life orbital fragments accounting for one fragmentation.

Table 3. Characteriristics of Russian launch vehicle stages and transfer stages (TS) launched into space.

Launch vehicles and transfer stages	Upper stage number	Separated element parameters		Standard injection orbits		Separated element number (as of December 31, 1995)
		mass, t	øL,m	Hπ/Hα, km	i, deg	
Kosmos	II	1.6	2.4x6	350/580 800-1500	74; 83 74; 83	390
Tsiklon	III	1.36	2.4x2.1	500-1000 500/2500	74; 83 83	110
Molniya	IV	1.1	2.7x3	600/40000	63	243
Soyuz	III	2.15	2.7x6.9	180/330	51.6 63; 83	708
Zenith	II	11	3.9x11	185/275 860/880	65 71	19
Proton	III	5.1	4.1x6.7	170/200-300	51.6	65
Proton with boost module "D"	III	5.1	4.1x6.7	170/200-300	51.6-71	150
Module section of the transfer stage"D"	IV	2.5	3.7x6.2	36000 20200 870 Departure trajectories	0 51.6 71 51.6	111 25 2 12
Starting support system engine separated module		0.08	0.5x0.6	240/36000 240/20200 870 170/170	48.5 51.6 66.5 51.6	222 50 4 24

generation were and would be in-orbit chemical explosions, as far as space debris fragments accumulate fragmentations during collisions will become major fragments sources.

According to a number of hypotheses, in 50 years so many fragment will accumulate in orbits, that accidental collisions will become the reason for avalanche-like secondary collisions or for the so-called "cascade effect". A belt of small fragments in low orbits, formed as a result of this effect will make it impossible to carry out space missions.

By now the space debris problem solution requires adequate preventive measures.

1.2 MEASURES TO MITIGATE SPACE TECHNOGENIC DEBRIS POLLUTION

Proposals for preventing further space pollution and removing space debris (2-6) envisage the following actions:

1. Reduction of annual SLV launches. Fulfilment of the task is furthered by:

- space program revision, aimed at resource economy;
- dual-designation spacecraft usage;
- extention of spacecraft active life, in particular, that of GEO spacecraft at the expense of employment in future of electrical rocket engine-equipped transfer stage with onboard powerful energy installations;
- wide use of tandem launches.

2. Utilization of new technological approaches in order to prevent functional debris generation and space object fragmentations.

2.1 Perfection of systems for spacecraft and rocket stage separation and spacecraft element deployment (demolition of pyro-pushers of the devices, excluding explosion splinters penetration in the space environment, replacement of pyrotechnical systems with mechanical lock-type systems and others).

2.2 Passivation of spent rocket stages and spacecraft, remaining in orbit, i.e. discharge of propellants and compressed gases from tanks and cylinders of rocket stages and spacecraft, which may become the reason for tank or cylinder explosion and object fragmentation even in a long time interval.

It is foreseen to equip the D transfer stage with such technology. At present the transfer stage is being maturated with the purpose of making its auxiliary engines for supporting main engine firing unseparable in flight, and converting the auxiliary engine to main propellant components, supplied from the transfer stage fuel tanks. Such solution would prevent transfer orbit pollution with auxiliary engine separated units and their explosions under prolonged effects of the space environment factors.

2.3 Perfection of onboard power supply systems.

In particular, GEO spacecraft of the Ekran-2 type, one of which exploded on June 23, 1978 due to depressurization of its buffer chemical battery during its long-time recharging have been modernized to increase the reliability of their automation and load voltage stabilization block, gas collector pressurization system; the electrochemical absorber has been updated and the technology of manufacturing the outlet filter choke has been improved. These new technologies have been introduced in next series space vehicles and they contribute to their operational safety.

2.4 Maturation of spacecraft onboard systems for destroying special information carrier elements without breaking up spacecraft structures and release of any fragments in the space environment.

3. Development of spacecraft launch programs and patterns, preventing penetration of SLV upper stage separated elements in closed orbits (upper stage drop in the antipodal point and spacecraft kick-off to its operational orbit with the help of a booster or a kick motor).

To exclude penetration of a transfer stage in the operational orbit a pattern of launching GEO space vehicles by Proton SLVs with DM transfer stage insertion in orbit, coplanar to GEO and higher than GEO in altitude by several hundreds of kilometers is likely to be taken into account. In this case spacecraft kick-off manoeuver to the operational (GEO) orbit is accomplished by its onboard engine.

4. Reduction of spacecraft in-orbit ballistic life. It is supposed to fit the upper stage (module I) of the Soyuz-2 SLV, being now under modernization, with a passive deceleration system (PDS), made as a mono-unit, attached to the stage. Inside the monounit there is a cartridge, accommodating an envelope, made of a film material and a deployment gear. In its operating state the PDS is a film structure with the 10m mid-section diameter, linked with the monounit and deployed after the payload is separated.

By the TsSKB (Central Specialized Design Office)'s assessments usage of PDS reduces the ballistic life time of the Soyuz-2 third stage module by 5-6 times in each specific insertion orbit in comparison with that of modules not fitted with PDS and prevents accumulation of spent modules I in space (5).

In 1982 the final operations with spent spacecraft of the Molniya type, circling along high-elliptical orbits were complemented with in-apogee deceleration correction action of the 16m/sec value (2) in order to decrease the perigee altitude and to enter the upper atmosphere as quickly as possible.

5. Controlled removal of objects from an operational orbit.

Measures are being undertaken to assure spent spacecraft controlled removal from GEO in order to avoid the risk of collision of operational space vehicles or newly launched space vehicles with them and to eliminate likely interferences. At present such removal is provided for space vehicles of the Statsionar-D, Ekran and Gorizont types, using onboard engine remaining propulsive masses (2). Engine operation time is chosen taking into consideration complete propellant component usage. Statistical data analysis shows, that accomplishment of such correction depending on the engine propulsive mass remainder enables to increase spent space vehicle altitudes by 30 to 400km. Now the NPO PM (Scientific and Production Association of Applied Mechanics), developing future GEO spacecraft, provides for special fuel reserves onboard those spacecraft, the reserve being in compliance with the 7.5m/sec characteristic speed, thus enabling to increase spent spacecraft altitudes assuredly if only by 200km in relation to GEO.

6. Prevention of space pollution with finely-divided particles.

- refusal to use in space engines operating on fuels, generating solid particles when burnt (for example, aluminum oxide particles, measuring 0.0001 to 0.1 mm account for the third of solid-propellant rocket engine fuel combustion products);

- usage of spacecraft and rocket stage materials and coatings, least subjected to erosion emission, caused by the near-earth space factor effects.

7. Future transfer to completely reusable launch and recovery capabilities.

Development of highly-efficient reusable launch systems and transfer orbit vehicles will make it possible to realize both up and down cargo traffic. Actually launch of each new satellite may be combined with a spent spacecraft recovery, thus ensuring ecologically safe technology of the near-earth space environment usage.

8. Clearing the near-earth space of space debris fragments.

This task is problematic in many respects and to fulfill it requires great expenses. To remove single large objects from orbits one can use liquid-propellant engine-powered transfer orbit vehicles or orbital transportation vehicles of the Buran and Shuttle types. Such an operation may be justified, if it is conducted for clearing an operational orbit of a permanent space station or for preventing object uncontrolled falling onto earth populated areas.

Specialists of the RKK Energia (Rocket and Space Corporation Energia) propose to develop specialized sweeper-spacecraft, fitted with a nuclear propulsion system and an electrical rocket engine for future mass operations to clear space of small fragments (evaporation by a laser beam) and space debris large fragments (capture and towing) (8).

Point 7 and 8 recommendations should be considered to be an application for a new space exploration technology, which will be introduced in future. But now it is necessary to undertake all necessary measures on preventing further near-earth space pollution in order to preserve the future for space missions.

1.3 RECOMMENDATIONS ON ECOLOGICALLY SAFE UTILIZATION OF GEO

Relying on the above-considered measures to mitigate space technogenic pollution and on particular features of GEO satellite functioning one can work out preliminary recommendations on ecologically safe usage of GEO.

As it was already noted, to avoid collisions of active GEO space vehicles with spent ones is possible by means of space vehicle removal upon its active service life termination to outer orbits in relation to GEO. But in case such objects explode in a "burial" orbit, a portion of fragments, supplied with the deceleration energy, would once again appear in GEO. That is why, taking into account the fact, that manoeuvres to transfer GEO spacecraft to a "burial" orbit have a lasting positive effect, one should foresee first-priority measures to prevent spent object explosions.

Major recommendations on ecologically safe operation of GEO consist in the following:

1. A GEO satellite should have a sufficiently long active service, and when spent it should be safe in terms of preventing its explosion during its long stay in space.
2. As applicable, all standard separated elements of a satellite to be launched in GEO should be left in a transfer orbit.
3. All efforts, both design and operational shall be reasonably directed at diminishing separated element lives in a transfer orbit.
4. Transfer stages (apogee stages), inserting spacecraft in GEO, should be passivated during their separation from satellites in order to exclude explosions and in future they will be transferred to "burial" orbits with subsequent passivation.
5. When operating GEO satellites it is desirable to keep them in a narrow region relative to their nominal position (to acquire the spacecraft stabilization accuracy equal to as much as 0.05 to 0.1^{o} in longitude and latitude).
6. A GEO satellite should be transferred to a higher synchronous "burial" orbit, not crossing GEO (the supposed kick-off altitude is 200 to 300km) at the end of its service life before its fuel is used completely.
7. A "burial" orbit transfer should be made especially carefully in order not to produce interferences for high frequency communications channels of active satellites.

1.4 PROPOSALS FOR INTERNATIONAL COOPERATION

Since the space debris problem is of the global nature and concerns all the nations participating in space exploration its solution is possible only in conditions of the close international cooperation. For the pupose it would be necessary:

1. to regularly exchange information between the nations operating rocket and space hardware about:
- actual and predicted NESE debris population obtained by tracking experiments and simulation;
- design and engineering solutions, operational steps applied to mitigate the NESE debris population;
- research results concerning orbital fragment effects on spacecraft and spacecraft protection means against space debris effects.

2. to set up a common database about trackable cataloged objects and small-size fragments to include a catalog of space "disasters" associated with space object fragmentations at in-orbit exposions and collisions with space debris fragments.

3. to assess and forecast the collision risk for different designation objects with space debris fragments alongside with the development of tolerable orbit pollution level standards in terms of space mission safety.

4. to work out single requirements for rocket and space hardware with the purpose of mitigating and preventing further space environment pollution.

5. to work out international concepts and agreements on NESE protection against its technogenic pollution.

CONCLUTION

Near-earth space technogenic debris pollution can present in the nearest future one of the factors, limiting space assets efficient usage.

Especially high space debris concentration is observed in low orbits, by now presenting a real threat to the manned missions safety.

In prospect, usage of GEO will also result in interference generation and bringing about of a collision risk for operationl satellites due to the GEO inability to self-cleanse.

First-priority measures to mitigate the growing space debris population shall be aimed at preventing in-orbit space objects explosions, as well as at removing GEO objects to outer orbits in relation to GEO upon termination of their active service life.

By this time it is expendient to work out recommendations and minimal standards as to prevention of further space debris pollution, to include GEO pollution prevention and to arrange and hold multilateral discussions of the given issues and to reach agreements between the leading space-fairing powers, drawing such bodies, as the Interagency Coordinating Space Debris Committee (IADC), the International Academy of Astronautics (IAA) and others.

REFERENCES

1. D.Kessler. Assessment of Man-Made Space Debris Population and Prospects. Report at the scientific symposium "Preservation of the Near-Earth Space for Future Generations". Chicago, 1992.
2. Study of Measures on Near-Earth Space Technogenic Population Debris Mitigation. R&D "Asteroid", Scientiic-Technical Report, TsNIIMash, 1996.
3. S.V.Chekalin, V.I.Lukiyashchenko. Man-Made Pollution of the Geosynchronous Orbit and Mitigation Measures. Report to the 11th Inter-Agency Space Debris Coordination Meeting, Tsukuba, May, 1994.
4. V.F.Utkin, S.V.Chekalin. Measures on Mitigation of Space Debris Population, Generated by Russian SLVs. Report to 30th COSPAR Scientific Assembly, Hamburg, July, 1994.
5. Evaluation of Deceleration Time of Passive Deceleration System-Equipped Soyuz-2 SLV Third Stage. Technical Report of the Central Specialized Design Office (TsSKB), 1995.
6. P.V.Bystrov, A.A.Maslennikov, V.V.Pukhov, V.V.Sinyavski. On the Possibility of Using a Space Vehicle Fitted with a Nuclear Power Plant and an Electric Rocket Engine for Removing Debris from Space. Report at the Conference "Problems of Man-made Near-Earth Space Contamination. Moscow, Space Research Institute, 1992.