ACCELERATING ACTIVE DEBRIS REMOVAL – A GLOBAL REFERENDUM

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ABSTRACT

This paper summarizes the results of a global referendum on active debris removal (ADR) executed as a Special Session at the International Astronautical Congress in 2024. The focus of the gathering was to assess the key dimensions that must be addressed to advance ADR divided into diplomatic, legal, programmatic, technical, and economic themes. For each of these, the primary action(s) needed to accelerate ADR into an operational enterprise was examined by over 25 international participants making verbal statements and an additional 97 audience members contributing on-line and through written surveys.

This paper reviews the findings including demographics of voters and responses to examine regional trends in ADR acceptance and advocacy. Recent events and likely near-term developments supporting ADR operationalization are also provided with scrutiny as to the dimension of these advancements.

1 BACKGROUND

The low Earth orbit (LEO) population of space objects continues to grow. During 2024, the LEO space object population increased from ~20,300 to over 23,600 objects. This population is expected to increase to over 100,000 objects by 2039 [1]. With this imminent exponential growth looming, coordination and cooperation to avoid collision risk is paramount. But the population of thousands of large, intact derelicts and 10,000+ smaller debris fragments have no ability to mitigate collision risk in LEO. A collision or explosion of any large object could result in thousands of new fragments that, if above 700 km, could last for decades.

The growth of orbital debris has warranted global efforts to enact a wide range of collision risk management measures including increased interest in debris remediation. Debris remediation can take many forms, but one mainstream approach that has garnered attention over the decades is active debris removal (ADR). ADR serves to reduce the debris collision hazard by removing an object from orbit permanently. Further, ADR typically refers to removing a massive intact derelict from low Earth orbit (LEO) to prevent it from colliding with another space object and potentially creating thousands of lethal fragments. Though still in developmental phases, there is a need to advance mission-ready solutions.

ADR system solutions comprise up to five steps:

1. Identification: It is important to identify objects where removal will provide the greatest benefit to the debris collision hazard in the future. Factors to be considered include the likelihood of being involved in a catastrophic collision, mass (drives consequence of collision), altitude (drives persistence of fragments created), object type (drives ease of grappling), and inclination (drives ease of collecting multiple objects on a single mission).
2. Rendezvous: The debris removal system not only has to reach the altitude and inclination of the object to be retrieved but must also closely approach with a small relative velocity to allow the grappler to work. This rendezvous process requires multiple maneuvers and patience.
3. Grappling: Once a retrieval system is very close and has a very low relative velocity to the target, the system must attach itself to the abandoned space object. A grappler may comprise of a flexible net, articulating arms, or possibly even a special adaptor (e.g., rocket bodies may be preferentially reliable to grapple by the rocket nozzle). The grappling process is complicated when an object is tumbling. It requires the grappling system to either synchronize its relative motion with the tumbling target or to use a net. While the net sounds like a simpler approach, there are complicated dynamics involved when capturing a tumbling object with a flexible, but strong net.
4. Maneuver: Once the retrieval system has a fixed attachment to the object to be removed, it must use its propulsion system to move the combined system to the appropriate deorbit trajectory.
5. Detach (and go back to step 2): It is possible that a deorbit process may end with both the retrieval system and the targeted derelict re-entering. However, most analyses have determined for a reasonable return on investment, the retrieval

system will need to remove more than one object. This might require the ability to release an object then maneuver back to a higher orbit to grapple other derelict objects.

2 METHODS

2.1 Session:

In October 2024, a fishbowl Special Session called Orbital Debris Remediation – Accelerating Active Debris Removal was held at the International Astronautical Congress in Milan. This was a continuation of the discussion initiated at the February 2024 Orbital Debris Remediation Summit held in Queenstown, New Zealand [2] and July 2024 Summit for Space Sustainability in Tokyo, Japan [3]. In this Special Session, two questions were posed:

1. Which two focus areas are the most important to act on to help make debris remediation meaningful as soon as possible?

FOCUS AREA	Select Two
Diplomatic: international governmental dialogue	
Legal: treaties and laws	
Economic: financial innovation	
Programmatic: contracts and procurement	
Technical: analytic and engineering	

Table 1. List of five focus areas presented at the Special Session.

2. For each focus area, choose the action you feel is most important to help "make active debris removal real." For each category there were three options, with the option to write-in or present an alternative.

These queries were provided as a paper survey in the room, an online survey for participants throughout the week of the conference, and set up for direct verbal participation in the session. Eleven anchor presenters[1] with experience in the field were given three minutes each to fill out their answers on boards in the room and explain their rationale. After all anchor contributors were finished, the floor opened to anyone in the room to record their responses live while explaining their answers to the crowd. By the end of the 90-minute interactive dialogue, 25 participants shared their votes verbally and nearly 100 through online and paper surveys.

The goal was to catalyze thinking on critical issues and to identify the "right next steps" to overcome hurdles in these areas. This paper synthesizes the results of the session, along with the strengths and weaknesses of the information collection process.

The five focus areas were described as:

1. **DIPLOMATIC INNOVATION: How can multi-stakeholder initiatives lower the barriers to ADR implementation?** The challenge of remediating massive derelicts in LEO is difficult to imagine being solved by a "lone wolf" organization; bilateral and multilateral efforts will likely create the foundation for a global ADR effort.

2. **LEGAL INNOVATION: How do we overcome the persistent legal and policy challenges with removal of large derelicts, particularly with liability and jurisdiction?** The objects in LEO that contribute the greatest debris-generating potential are from a limited number of countries; can an effective global solution be pursued without their active involvement? How are the interests of new entrants (both governments and companies) represented in removal options and motivations? How can the existing requirements of not touching another's country's debris without permission be ameliorated to streamline the removal process?

3. **ECONOMIC INNOVATION: How do we demonstrate the cost-benefit advantage from removal of large objects?** What economic models/approaches can be used to price, value, or otherwise incentivize debris removal (e.g., orbital use fees, cap and trade systems, other market-based mechanisms)? These may be less directly relevant to removal of legacy government objects but instead may relate to how the ADR companies try to scale/achieve commercial relevance. Methodologies for pricing/costing debris removal missions in addition to quantifying benefits should be discussed. How does licensing and regulatory realities affect efficacy of ADR?

4. **PROGRAMMATIC INNOVATION: What innovative programmatic, contracting, or acquisitions concepts can help incentivize technology development for ADR of large derelicts?** How can current initial government pilot and technology development programs be transitioned or scaled to operational capabilities? What lessons can we draw from other successful initiatives to draw down risk and create markets,

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such as the X-Prize or Commercial Cargo and Crew Programs? Running a program to have zero risk often results in very high costs and/or zero results or productivity; a commercial program mindset of build, execute, and iterate (as many of the constellations are excelling at doing) may be advantageous.

5. **TECHNOLOGICAL INNOVATION: What systems can effectively remove massive derelicts from orbit? What target object characteristics will drive the calculus of removal?** The process of rendezvous, grapple, detumble, and deorbit requires significantly different hardware if controlled re-entry is required. How is the risk balance between space, aviation, and ground collision risk explicitly managed?

2.2 Analysis

All information collected was recorded in the dataset, even partial or non-attributable surveys. Votes for write-in answers were combined where similar in theme and then generalized. Basic demographic information is presented, but any strong correlations are limited to response type as the unknowns in work location and years of experience limit significant conclusions across those categories.

This paper explains the voting outcomes for both session questions and attempts to coalesce the top findings into holistic strategies that cross the original focus areas.

3 RESULTS

3.1 Top focus areas

The first question posed asked each participant to identify two main areas of focus needed to operationalize ADR. The results in Fig. 1 show Economic as the top category, with Programmatic a distant last place. During the session, it became apparent the options in Programmatic could be considered secondary issues in other categories or required a more developed technology to be considered the "next best step." The most popular action, "ADR paid by fees garnered from space launching entities" can be considered Economic. The second ranked option to use orbital capacity modelling aligns with the Technical dimension. For this reason, we recategorized the votes in Programmatic to the other four areas for further analysis. It should be noted, the Programmatic factor was introduced at the Summit in New Zealand in February 2024 by one of the few companies funded to conduct an ADR mission. The likely lack of experience and exposure to "programmatic" issues by a wider audience is difficult to assess. This lack of empirical support reflects the immaturity of the ADR industry that this overall effort is trying to catalyze. As a result, this observation should not be a complete surprise.

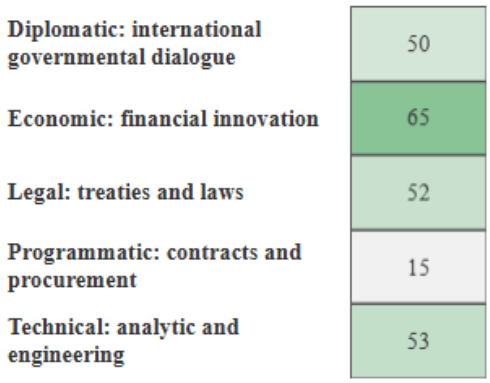

Figure 1. The tally of votes cast for each focus area places Economic on top, slightly ahead of Diplomatic, Legal, and Technical.

3.2 Top actions in each area

Diplomatic, Legal, and Economic had over 40% support for each top suggested action, while Technical was more evenly divided (Programmatic answers were disseminated across all four). The breakdown by percentage of each answer is in Tab. 2.

These are the top actions identified in each focus area:

- Diplomatic: 41% (46 responses) China, Russia, and US to agree remediation of massive derelict objects is critical.
- Legal: 45% (49 responses) Modify Outer Space Treaty (OST) to incorporate salvage clause for hardware over ten years old and unclaimed artificial objects.
- Economic: 49% (91 responses) Create a global fund to share costs of removal of derelict objects.
- Technical: 34% (49 responses) Prove mathematically doing nothing will cost more than executing ADR missions.

In addition, while not the top ranked action in Economic, the idea of establishing ADR insurance as a requirement for launch received the second most votes (50 total) across all categories, ahead of the top ranked actions in other focus areas.

Write-in ideas were presented as verbal submissions and other participants rallied around these ideas to vote for them across all three mediums. This was a valuable aspect of this Special Session to provide multiple ways to contribute to the dialogue and this dimension enriched the overall analysis.

Economic	Percentage of Vote Count	Vote Count
Create Global Fund (by some international governmental organization or coalition) for removal of derelict objects	49%	91
Establish ADR insurance as a requirement for launch	27%	50
Require ADR contracts to primarily be based on mass removed from orbit	9%	17
Take the message of debris remediation priority to the public (public outrage may drive budgeting)	8%	14
Other	7%	13
Technical	Percentage of Vote Count	Vote Count
Prove mathematically doing nothing will cost more than executing ADR missions	34%	49
Orbital capacity modeling should drive ADR priorities and pricing (i.e., more than just mass of derelicts matters)	22%	31
Focus on fragment removal over intact object removal	17%	25
Eliminate requirement for controlled re-entry of large debris objects for ADR missions	14%	20
Develop ADR interface standards based on intact derelicts	11%	16
Other	1%	2
Diplomatic	Percentage of Vote Count	Vote Count
China, Russia, and US to agree remediation of massive derelict objects is critical	41%	46
Establishment of international norms for international ADR operations and new global initiative by UN	28%	31
Create bilateral frameworks to enable international ADR missions with the coalition of the willing, including a third party reach out to Russia, China, and/or US for joint effort	16%	18
Independent actions by sovereign states	8%	9
Other	6%	7
Legal	Percentage of Vote Count	Vote Count
Modify Outer Space Treaty to address unclaimed objects and salvage clause for derelict hardware	45%	49
Modify Liability Convention to more clearly address/reduce liability and enforcement of penalties	36%	39
Define hostile activities better to preclude RPO and grappling from being outlawed as a weapon	17%	18
Other	3%	3

Table 2. Distribution of votes across actions in each category shows the top two in each category account for the majority of votes.

The write-in ideas with the most votes per category included:

- Diplomatic: 8% (9 responses) Independent actions by sovereign states
- Legal: 11% (12 responses) Clarify/allow permission to touch debris/uncatalogued objects. (This was aggregated into the top response to refine the liability and salvage clauses in the Outer Space Treaty.)
- Economic: 4% (7 responses) Enable known scalable financial incentives (This was combined with the top Economic category of creating a global fund.).
- Technical: 11% (16 responses) Develop ADR interface standards based on intact derelicts

The Diplomatic and Legal answers were first introduced by anchor participants near the beginning of the session and were the leading answers for all verbal votes throughout the discussion. The Technical write-in suggestion was the most voted for write-in action.

122 participants added information to this dataset. Optional demographics collected for paper and online surveys are displayed in Fig. 2 and Fig. 3. Approximately 50% of respondents were from Europe (the location of the conference likely an influence), with North America and Asia also represented. Nearly 75 respondents chose the online option, 25 spoke in the fishbowl setting, and 23 provided written surveys when the session ended. In terms of years of experience, a wide range from 1 - 40+ years attended. Of the reported years of experience, most (58%) were under 15 years of experience.

Of the most complete demographic dataset (online surveys), 84% of the 1-5 years of experience, 100% of the 5-15 years, and 100% of the participants from Asia chose to fill the survey online. This emphasizes the need for multiple avenues of submission, as groups of respondents preferred not having to speak in public. This might be even more pronounced with professionals with fewer years of experience. The root cause for this trend is unclear –varying reasons such as a language barrier, felt they had little to offer, cultural norm of using public media, or some other factor could have played a role.

3.3 Demographics

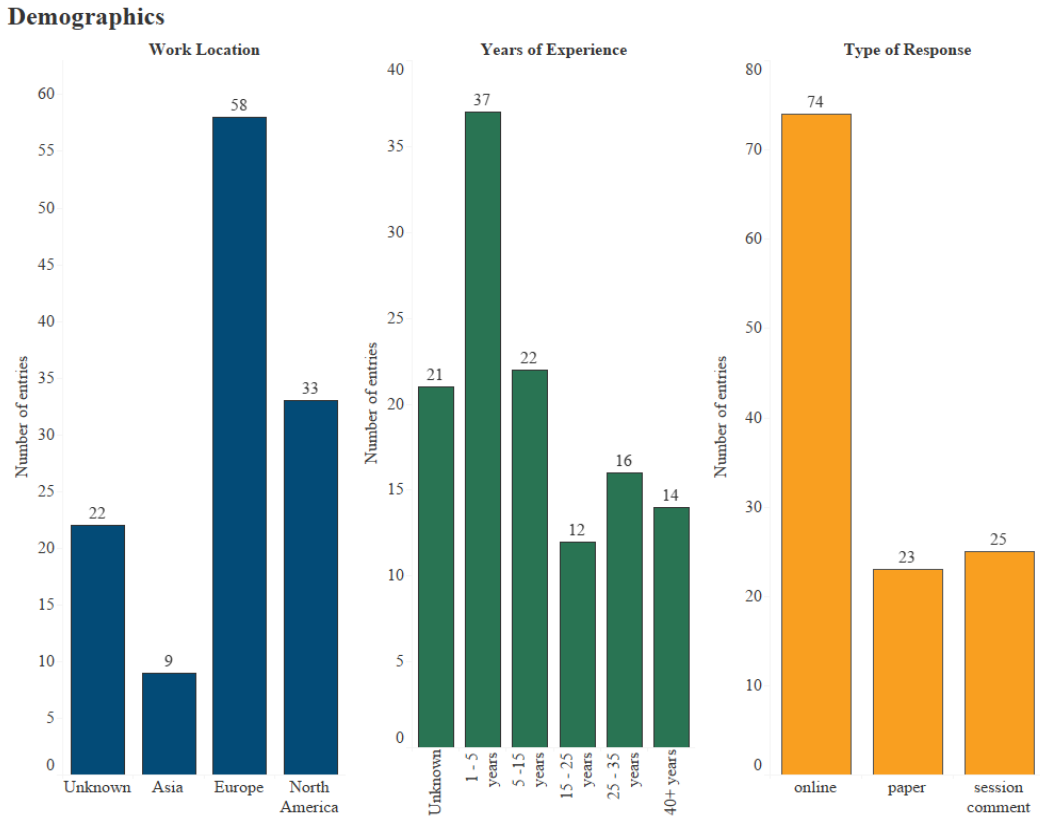

Figure 2. The overall demographics of work location, years of experience, and type of response gathered across 122 participants shows a leaning toward Europeans, limited experience, and interaction through the online survey.

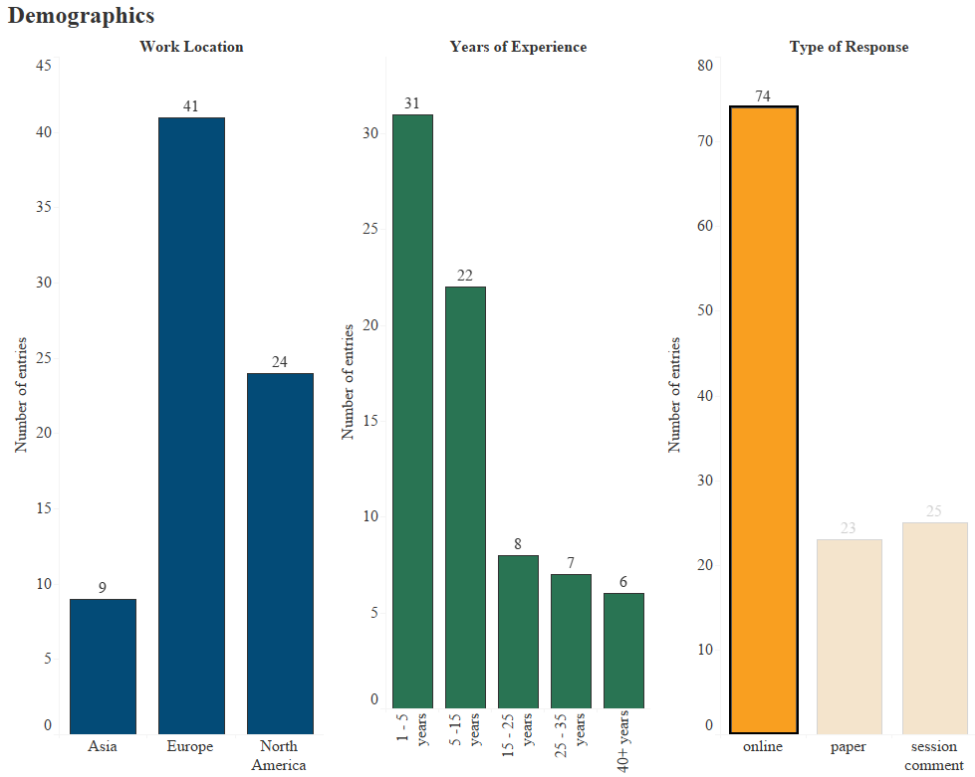

Figure 3. The demographics for 74 online respondents highlight professionals with fewer years of experience used the online option and generally matched the overall distribution of votes.

3.4 Trends and Observations

Online responses very closely mirrored the distribution and ranking of actions seen in the overall statistics. This is a logical finding as it was the largest set of respondents.

Paper responses favored Diplomatic and Legal as the top focus areas, rather than Economic and Technical.

Session comments overwhelmingly selected to prove mathematically doing nothing will cost more than executing ADR missions (63%) compared to the total population, and voted to clarify permission and interactions with uncatalogued/debris objects (53%) as the top action in Legal. For Diplomatic, it was nearly equally split between independent actions by sovereign states (33%), establishments of international norms for ADR (27%), and China, Russia, and US agree to remediation of massive derelict objects (27%).

Examining the responses with demographic information with the unknown survey answers removed, there were striations in the data. Looking at years of experience, more experience (>15 years) led to less confidence in UN-related actions for the Diplomatic focus area (34% vs 17%). More experience also greatly discounted small fragment removal in Technical (only two votes of 25 total). The more experienced participants showed more acceptance of taking the message to the public (9% vs 6%) in the Economic sector, but all experiences showed high favorability towards ADR insurance and a global fund to share costs. Legal had largely similar distributions across both sets of experience groups.

Note, while different sample sizes, some basic comparisons of priorities can be seen across work location, as well. Participants working in Asia voted Economic as the second least important topic area, just above Programmatic, with the other three equal. North America voted for Economic the most important, and European participants had all but Programmatic nearly equal. From a Diplomatic perspective, Asia voted the UN as a more viable next step, while Europe and North America want China, Russia, and the US to cooperate. On the Legal focus area, Asian respondents favored modifying the Liability Convention and had no write-ins, while Europeans favored Modifying the Outer Space Treaty and North American citizens were balanced between the two. Finally, for the Technical area, respondents from Europe favored providing proof, Asia wanted to remove the requirement for controlled re-entry, and North America was balanced in the top three with the most write-ins.

3.5 Assessment of Fishbowl Process

This fishbowl setting with other survey methods allowed maximum participation by those in the room in whatever medium they felt most comfortable. It elicited new ideas the authors had not considered from experts and those not in the field alike, including proposals of other focus areas (the idea of a "Social" area was raised in discussions). The session started with five pre-defined domains and eventually Programmatic was absorbed by the other four, the authors wonder if there were other more self-standing focus areas not considered that could have influenced the outcomes recorded.

The presence of "anchor" presenters at the beginning of the session, in name itself, introduced the possibility of anchoring bias (i.e., a cognitive bias where the first piece of information is heavily relied on, even as other information becomes available).

There must be a balance of relying on subject matter experts in the field, who inherently have a depth of understanding about the subject, but also their own biases, weighed against the "wisdom of the crowds." On the other hand, the "anchor" presenters may have provided valuable new information to many of the respondents. There is a fine line between educating and influencing other less-experienced respondents.

There was an open structure and many mediums to provide data to this assessment. Paper and verbal comments were limited to the time of the Special Session itself and not bounded by required answers. The online survey was open for one week and participants were only able to submit a survey with every question answered.

In the future, to better identify trends, experience and region must be characterized to any answer accepted for analysis, including verbal statements. In this case, to encourage as much contribution without forcing attribution, verbal and paper submissions with partial information or no demographic information were included in the overall statistics.

We did not limit a person to a single entry, so some verbal participants may have also had an additional paper or online submission. These were deconflicted when known, but we cannot eliminate this in the data due to the presence of unknown entries. Anecdotally, one participant who voted verbally told us after hearing all the other speakers they changed their votes when they spoke compared to their initial paper survey. Tracking a before and after survey, if not too cumbersome, would be an interesting way to identify how much acceptance of certain actions changed.

4 CONCLUSION

This Special Session utilized the fishbowl method to expand the dialogue around the specific question of "what is the right next step to accelerate ADR?". By setting an initial framework and having a few experts speak before opening the floor, the authors were able to guide the discussion on specific solutions, while also allowing participation via multiple methods and allowing many in the "audience" to voice their viewpoints in succinct time limits.

A key observation from this activity highlighted economic issues as the major hurdle to advancing ADR more quickly into an operational industry. Further, five actions, as seen in Fig. 4, were deemed most important for significant progress of ADR operations and its meaningful impact on the future debris growth in LEO:

- China, Russia, and US agree remediation of massive derelict objects is critical.
- Modify Outer Space Treaty to incorporate salvage clause for hardware over ten years old; couple with economic innovations.
- Establish ADR insurance as requirement for satellite deployments.
- Create a global fund to release tenders to an international pool of ADR providers funded by fees levied on all future space launches.
- Prove mathematically doing nothing will cost more than executing ADR missions.

Some of the secondary suggestions from the session are already happening, such as (1) independent actions by sovereign nations and (2) bilateral frameworks by coalition of the willing working to catalyze ADR operations. Japan is continuing to advance ADR technology through demonstration phases and working to build a competitive market with the private sector. JAXA's Commercial Removal and Debris Demonstration program (CRD2) Phase I established a successful fly around of a rocket body by Astroscale's ADRAS-J in 2024 [4]. On a multi-national legal and diplomatic level, the UK and New Zealand space agencies signed a bi-lateral agreement at the International Astronautical Congress in Milan in October 2024 to aid space sustainability through international cooperation and liability through the framework of the Convention on International Liability for Damaged Caused by Space Objects through support of missions focused on space debris removal and servicing of satellites [5].

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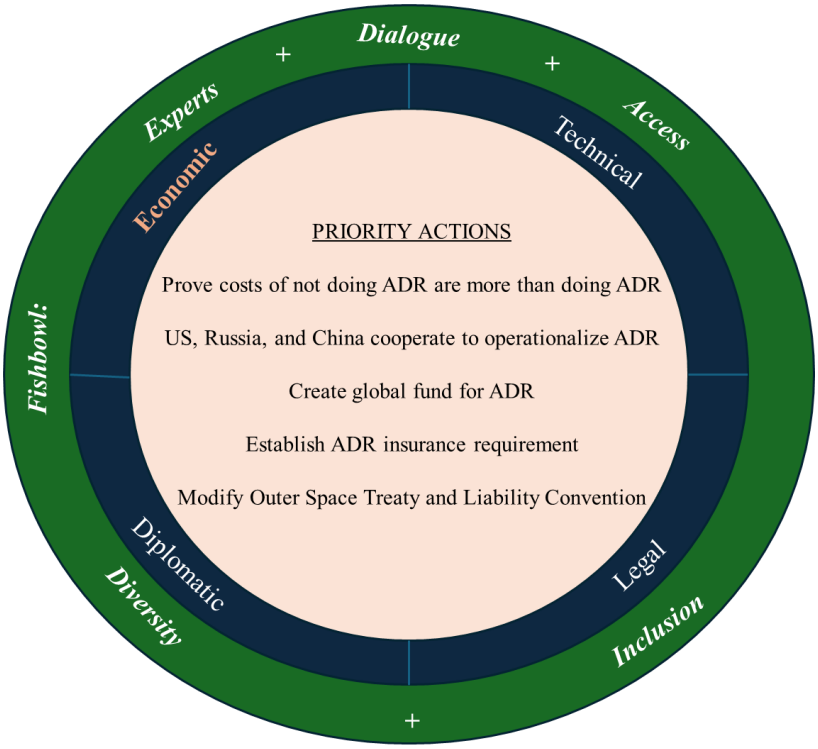

Figure 4. The method of the fishbowl session with the framework of focus areas led to the ability to ascertain the top priority actions for ADR of each topic area across nearly 125 participants.

Holistically, while next steps can be taken by independent states, to truly advance a persistent ADR operational market, a shared and global solution is needed. This is reflected in the outcomes of this special session across all categories, whether involving the US, China, and Russia and United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), to creating a global fund to distribute costs, to many countries agreeing to the norms and liabilities based on technical metrics.

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