Deliverable D9.2

Compliant and efficient transportation

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101008571 (PRISMAP). This document reflects only the view of the author(s). The Agency is not responsible for any use that may be made of the information it contains.

Project Acronym	**PRISMAP**
Project Title	**The European medical isotope programme: Production of high purity isotopes by mass separation**
Grant Agreement No.	**101008571**
Topic	**INFRAIA-02-2020: Integrating Activities for Starting Communities**
Project start date	**01 May 2021**
Nature	**Report**
Dissemination level	**Public**
Due date	**M24, extended to M30**
Date of delivery	**M31**
Lead partner	**DTU**
Contributing partners	**CERN, ILL, PSI, Arronax, KU-Leuven**
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Revision History

Version	Date	Author	Comment
0.1	15-10 2023	Mikael Jensen, Charlotte Duchemin, Zeynep Talip	First draft
0.2	28-10-2023	Mikael Jensen	Version for the reviewer
0.3	29-10-2023	Ulli Köster	Consortium reviewer
0.4	30-10-2023	Véronique Gobry	Review and formatting
0.5	30-10-2023	Thierry Stora	Review by the coordinator
1.0	3 Nov 2023	Véronique Gobry, Kirsten Leufgen	Final review, version approved by the General Assembly

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1. Abbreviations, Participant short names

Abbreviations

IAEA	International Atomic Energy Agency, Vienna
ADR	Accord Dangereux Routier , the European regulations concerning the transport of dangerous goods by road.
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
TI	Transport Index
TNA (n)	Transnational Access mechanism number n
UN	United Nations
WP (n)	Work Package number n (PRISMAP work is divided in packages)

Participant short names

CERN	European organization for nuclear research
NPL	National Physical Laboratory
PSI	Paul Scherrer Institut
CEA	Commissariat à l’énergie atomique et aux énergies alternatives
IST-ID	Associação do Instituto Superior Técnico para a IST-ID Investigação e Desenvolvimento
DTU	Danmarks Tekniske Universitet
CHUV	Centre hospitalier universitaire vaudois
GANIL	Grand Accélérateur National d’Ions Lourds
SCK CEN	Studiecentrum voor Kernenergie / Centre d'étude de l'énergie nucléaire
ARRONAX	Groupement d’intérêt public ARRONAX
ESS	European spallation source ERIC
TUM	Klinikum rechts der Isar der technischen Universität München
KULeuven	Katholieke Universiteit Leuven
MedAustron	Entwicklungs- und Betriebsgesellschaft MedAustron GmbH
SCIPROM	SCIPROM Sàrl
MUI	Medizinische Universität Innsbruck
ILL	Institut Max von Laue - Paul Langevin
JRC	JRC -Joint Research Centre- European Commission
NCBJ	Narodowe Centrum Badań Jądrowych
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH

LU	**Latvijas Universitāte**
INFN	**Istituto Nazionale di Fisica Nucleare**
UiO	**Universitetet i Oslo**

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Summary

This report is the second public output from the PRISMAP Work package 9 (WP9, Transport and Logistics). The report describes how the PRISMAP partners and especially the radionuclide producing sites in WP2 have managed to ship the novel radionuclides to the different users and collaboration partners.

It reflects the status as of end of October 2023, being M30 in the PRISMAP project, hereby encompassing deliveries to user project under the PRISMAP calls 1 and 2. It must be emphasised that far from all deliveries for the user projects are executed yet. Still the performance of the transports can be used to analyse the status and to make intermediate conclusions on best possible options for future transports.

The report further includes the transportation of activity from the radionuclide-producing partners to either the PRISMAP WP4 interlaboratory comparison programme, the PRISMAP WP11 standardisation programme and the PRISMAP WP12 development of radiolanthanide separations. The report does not include transports within a given WP2 production chain involving more than one WP2 facility.

As the PRISMAP project unfolds with more project calls and more accepted user projects, it is expected that the transportation systems will be increasingly challenged by the necessary inclusion of radionuclides with shorter half-lives and higher request for delivered activity. The present report enables already an analysis of such limitations and the identified ways of mitigation. Hereby, the report does not only serve as an internal reference point for those inside the PRISMAP WP2 facilities solving the user project needs, but also as help to the user project selection.

Furthermore, the report can through WP6 serve the continuous training and education of the PRISMAP community in the transportation issues.

Finally, the report does identify some urgent issues that need clarification with authorities and industry, hopefully in preparation of an even more effective set of transport methods in PRISMAP, and hereby providing the basis for the conclusion of the work in WP9 at the end of the project at M48. At this point, the entire set of lessons learned and recommendations made will be published in the final report D9.3.

To the point that the work, developments and results under PRISMAP may hopefully be continued in some kind of future European collaborative effort in the (novel) radionuclide supply field, our WP9 work can hopefully also help to shape the ambitions and extent of such a future programme.

1. Definitions

For formal and detailed definitions of some of the specific transport terms and rules for shipment of radioactive material, the reader is referred to the preceding deliverable report, the D9.1, publicly available from: https://zenodo.org/records/6606494

For an easy reading of this report only, the following subset of definitions are here repeated:

Transport index (TI) - shall mean a single number assigned to a package (…) which is used to provide control over radiation exposure. It is the maximum radiation level in µSv/hr at 1 m from the external surface of the package divided by 10 and rounded up to the first decimal place.

UN number - is a United Nations number for different kinds of transported dangerous materials, including radioactive materials. The following UN numbers are of special importance here:

- UN2908 - Radioactive material - excepted packages, Empty packaging
- UN 2910 - Radioactive material - excepted package, limited quantity
- UN 2915 - Radioactive material, Type A package.

2. Preamble

To fully serve the intentions and to reach out to a broader user audience, this report is defined as public. On the other hand, many of details of the individual transports originally do contain specific reference to individual private companies involved (carriers, shipping agents). Likewise, some handling delays are clearly identified at specific airports. In this report, such specific information is anonymised, hopefully only to a degree where information is still generally useful. As examples, we use the terms "[nationality] handling agent", "[nationality] road transport company" and [Country] airport.

The details reside in an internal set of spreadsheets accessible at the moment only to the PRISMAP consortium.

3. Scope of transports

At time of writing, all shipping entities ("consignors") in this status report are WP2 institutions in PRISMAP. By nature and by history, they all have pre-existing and well-established national and international transport systems for radioactive materials. These institutions have by law the necessary quality assurance systems, the container systems, the set of approved containers and a full knowledge of the rules governing the transportation of radioactive materials by road and air. Labels, shipper's declaration forms and consignment documents already existed at the start of PRISMAP shippings, and have not necessarily been changed. However, the shipping systems had to be adapted because of:

- Shorter-lived radionuclides are being added
- New radionuclides are being added, meeting requests expressed by Users, thus fulfilling the mission of PRISMAP
- Longer transport legs have to be served, because user projects are selected on a "Project Excellence" basis, more than distance to nearest point of WP2 supply.
- Some transport are being made in a "one off" mode, giving a only a single transport of its kind (radionuclide, sender, receiver) in a given transport system within any reasonable period. Shipping agents, Dangerous Goods handlers and customs agents may never have seen a similar shipment before. This challenges the long known fact from the radiopharmaceutical industry that shows that the regularly repeated supplies in a given transport pattern improves the reliability and punctuality.

The total number of transports registered and analysed in this reports covers the first 30 months of PRISMAP activity (up to and including October 2023). The dataset contains 53 transports and is given in full in Appendix 1. As stated above, some information, mainly on identity of private companies, has been anonymised.

The "Scope of transports" is stratified below depending on the intended usage:

- Transports from WP2 facilities to user project sites, either the user lab at its home facility or a PRISMAP medical facility (WP3-TNA3).
- Transports from WP2 facilities to other PRISMAP sites for sake of the WP4 interlaboratory comparison program. Up to now, this has only embraced Tb-161 and Cu-64.
- Transports from WP2 facilities to NPL in the UK for the sake of calibration and standardisation in the frame of WP11. As the UK is outside the EU customs zone these transports face the added complexity of customs[1] handling.
- Transports from WP2 facilities to PSI in Switzerland for the sake of radiolanthanide developments in the frame of WP12. As Switzerland is outside the EU customs zone also these transports face the added complexity of customs handling.

[1] The NPL in the UK and PSI in Switzerland is not the only customs problem facing the PRISMAP transports. CERN, which is at present the most frequent sender of PRISMAP activity is shipping out of its site in Meyrin in Switzerland, and is accordingly outside the EU.

- Finally, a number of shipments have been made between different PRISMAP WP2 facilities to test yields and purity of novel radionuclides before these can be added to the PRISMAP portfolio (T2.1 of WP2).

PRISMAP transports are in a large majority planned well ahead, because the selected user projects are granted "access" to a given number of batches and activity at the time of the user agreement signature, often based on negotiations with the supplying WP2 facility after the "selection" of the project. The overall feasibility of long distance transports of shorter-lived radionuclides becomes an important aspect in defining user projects. In the analysis given in this report, 6 of these transports are already identified and planned, but not executed. They are included with status pending, as they illustrate some of the challenges facing the wider dissemination of novel radionuclides.

Table 1. Scope of WP9 transports up to end of M30

Total number of transports	**53**
Number of transports for user projects	**31**
Number of transports for user projects executed by M30	**23**
Transports under planning, not executed	**8**
Inter PRISMAP transports to NPL, UK (standardisation)	**7**
Inter PRISMAP transports for Intercomparison study	**5**
Inter PRISMAP transports for radionuclide portfolio development	**10**

Table 2. Distribution of Transports on PRISMAP project calls

Transports for CALL 1 projects	**20**
Transports for CALL 2 projects	**10**
Transports for CALL 3 projects	**1**

4. The role of the shipping institutions in PRISMAP

Up to now (M30) all shipments have been made from WP2 and TNA2 facilities that are already experienced radionuclide producers, that all have their systems and their licenses to send radioactive material. These institutions all also have a set of shipping containers that can be used for this purpose, either as disposable, one-way package or as a multiple use, returnable shipping containers.

This means that PRISMAP transports have certainly not started from scratch, but has been building on existing knowledge and infrastructure. As explained in the previous report D9.1, this area is highly regulated by a number of international and national entities. To a large extent, these rules are common to all the present PRISMAP shippers, and the ways transports have been done and the experiences learned convey a degree of universality across the consortium.

However, each sending institution has developed its own quality management system for transports and its own license from the competent national authority. There are also smaller differences to the implementation and administration of the rules at the national level, especially when it comes to the approval of road carrier companies for this type of dangerous goods transport.

The distribution of number of shipments from the shipping facilities is reflected in Table 3 below.

Table 3. Number of shipments from the WP2 facilities

MEDICIS, CH	**14**
PSI, CH	**13**
ILL, FR	**8**
ARRONAX, FR	**5**
JRC, DE	**5**
SCK CEN, BE	**5**
DTU, DK	**3**

5. What radionuclides have been transported

Table 4 presents the list of radionuclides as distributed over the transports reflects of course to a large extent the outcome of the user project calls and the project selection. It is much longer than the selected user project portfolio only, because many transports are performed to support the development and standardisation of the novel radionuclides.

Table 4. Distribution of the transports on different radionuclides

Radionuclide	Number of transports	Number of user project transports	Maximum Activity Shipped (MBq)
Sc-43	2	1	800
Cu-64	3	0	6700
Cu-67	2	2	(200)
Ag-111	1	0	1000
Ce-143	1	0	<1
Gd-149	1	0	1
Pm-149	1	0	<1
Tb-155	3	1	6
Tb-161	11	11	17100
Tm-165	2	1	180
Dy-166	4	0	<1
Tm-167	2	0	110

Er-169	2	0	<1
At-211	5	5	1100
Ra-224	1	0	83
Ra-225	2	1	40
Ac-225	5	2	10
Th-227	1	1	10

It is worth noting, that the PRISMAP facilities despite the large variety of radionuclides and the range of activities have been able to perform all shipments in TYPE A packages under the dangerous goods classification UN2915. Only a few transports have necessitated the YELLOW-III labelling, with the majority being YELLOW II.

The highest transport index encountered was 1.5 corresponding to 15 µSv/h at one meters distance. This occurred only in one instance and with a special shipment of a new type of Ra-224/Pb-212 generator, that in the present form does not lend itself to a more compact and effective shielding. All other transport index values reported were at or below the value of 1.

From these observations, it can be concluded that the existing WP2 facilities have the necessary containers, routine and knowledge to ship the PRISMAP activities in requested quantities.

There is nothing in the current portfolio of radionuclides offered to user projects that cannot be transported by such means. At present, the biggest challenge to the shipping systems is presented by Cu-64. It can be produced with high activity at the existing facilities (several tens of GBq). Because of its relatively short half-life (12.7 hours) it is probably mandatory to ship high activity to counteract the inevitable decay loss, that may approach an order of magnitude.

However, commercially available standard type A containers with tungsten shields can't handle more than 40 GBq Cu-64 with a manageable transport index of 2. (20 µSv/h at one meter distance).

6. Transportation routes

All transports up to now have relied on road transports, either solely or in combination with either Air or Sea transport. Of the total of 53 shipments made or planned, the majority is made using the simple and straight concept of single carrier road transport from start to end. Only 8 transports are made or are planned to be made using Air transport.

The Road + Sea transport constitutes a special case, at present only necessary with the transports to the UK by road, implying the use of ferry across the Channel. Several such transports have been performed with transit time of 1-5 days.

The longest duration of transports (about 6 days) is actually encountered in cases where standard commercial air transport has been used. It is typically the use of multiple carriers road, air, shifts at airport hubs, air and road again) that causes the long delays. The actual transport time is not necessarily the limitation.

7. Transportation time and decay loss

The total transport time can best be discussed in the context of the half-life of the radionuclide in question. Short half-lives mandate rapid transport. Although our PRISMAP transport systems are not completely optimised yet, it is comforting to look at the results of the transports performed up to now. Figure 1 below is a histogram of the fraction of the shipped activity remaining after transport, that is, the activity available for the user.

The majority of our transports (75 %) deliver more than 60% of the activity to the users.

Overall , it seems tolerable for the PRISMAP projects to use road transports up to 500 km as the best alternative.

Hidden in the statistics are however also a few examples with large losses. Two characteristic examples shall be mentioned:

- The transport of 6.7 GBq Cu-64 from DTU at Hevesy Lab, Roskilde, DK to ARRONAX, Nantes, FR within the Cu-64 interlaboratory comparison study in WP4. It was decided to use road transport because of the challenging logistics of a possible alternative air transport. This last option would take 1 h to the airport, 6 h check in at airport, 2 h flying time to Paris, 4 h check out in Paris and 5 h road transport to Nantes, in total 18 hours. Because of the long driving time for the direct road transport, two transport companies and two vans were used, meeting in the middle of the transport route.
  The expected driving time was 16 hours, better than the air transport option. However a combination of traffic congestion, road works and waiting time at Elb river crossing made the actual door-to-door time longer, 24 hours, leaving only 27% of the shipped activity available for the study. In this case, the choice of road transport was probably not the best. The air transport would however only have been better under the best possible conditions also with no unforeseen delays.
- The transport of a batch of Ra-224 ($T_{½}$= 3.63 d) from CERN-MEDICIS, Geneva, CH to DTU, Roskilde, DK. This was carefully planned as a road-air-road transport with a change of aircraft and customs handling in Paris. Because of issues with the paperwork and the fact that Ra-224 is an “unusual” radionuclide, the transfer time in Paris was extremely long, and the total transport time was 4½ days.

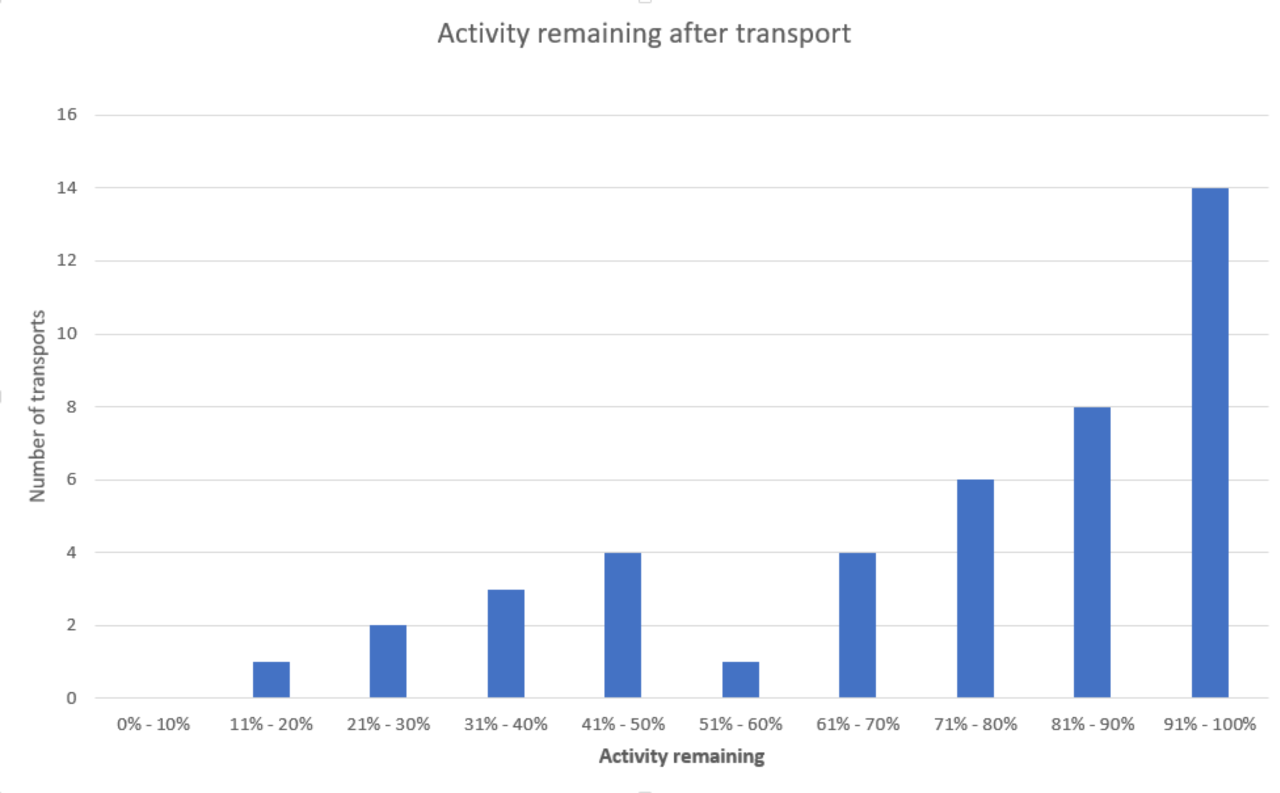

Figure 1. Activity remaining after decay during transport

Both cases illustrate the difficult choices one faces when shipping the PRISMAP activity over longer distances and across different countries. In principle, the commercial passenger airlines with good and frequent connections at major airports should be optimal, but often the delays in check in, connections transfer and in check out and customs clearance far exceed the actual flying and driving time. A further risk is the "denied boarding" events that are often encountered when dangerous goods packages with uncommon radionuclide content are exposed to normal air traffic congestion. To date however, no such denied boarding event had to be counted in the PRISMAP shippings.

8. The use of small aircrafts and direct flights

As analysed above, the existing transport systems (road-air-sea) used by PRISMAP handles our transport needs to some degree of success, or at least the outcome can be said to be tolerable to the user projects. The argument can however be turned around, by stating that the existing WP2 shippers with all their experience and contact networks manage to find some kind of tolerable transport connections to most needs.

During the work with this, we have also learned, that it is possible to achieve a much shorter transport time and probably also higher reliability even on the longer distances (>1500 km) by using chartered small fixed wing aircraft. This allows, with the right charter companies and experienced shipping agents, almost immediate boarding of the packages in small airports close to the point of production. Flying time for such aircraft across Europe is still low (2-3 hours at long stretches) and they can land and hand out the transport close to point of use.

Such scheme has been demonstrated with success on the transport of Tm-165 from MEDICIS, Geneva, CH to DTU, Roskilde, DK. It took less than 4 hours from door-to-door. It can be compared with the expected transport time using commercial passenger airlines, that at best is 24 h.

Figure 2 shows, how such point-to point deliveries could cover most of Europe within 5 hours by assuming production sites strategically placed, here example is shown for only 3 sites: CERN (CH), Hevesy Lab (DK) and INFN Legnaro (IT).

While these transportation schemes fulfil our needs for both speed and reliability, it must be understood, that it comes at a very high price. While this report does mean to publish a market survey for radioactive goods shipping, our present experience shows that a typical door-door transport with this method costs around 15-20 kEuro. An "ordinary" Road-Air-Road transport may cost 1 kEuro if the road distances are sufficiently short. And finally: an ordinary road transport within the range of 500 km can be made for about 500 Euro.

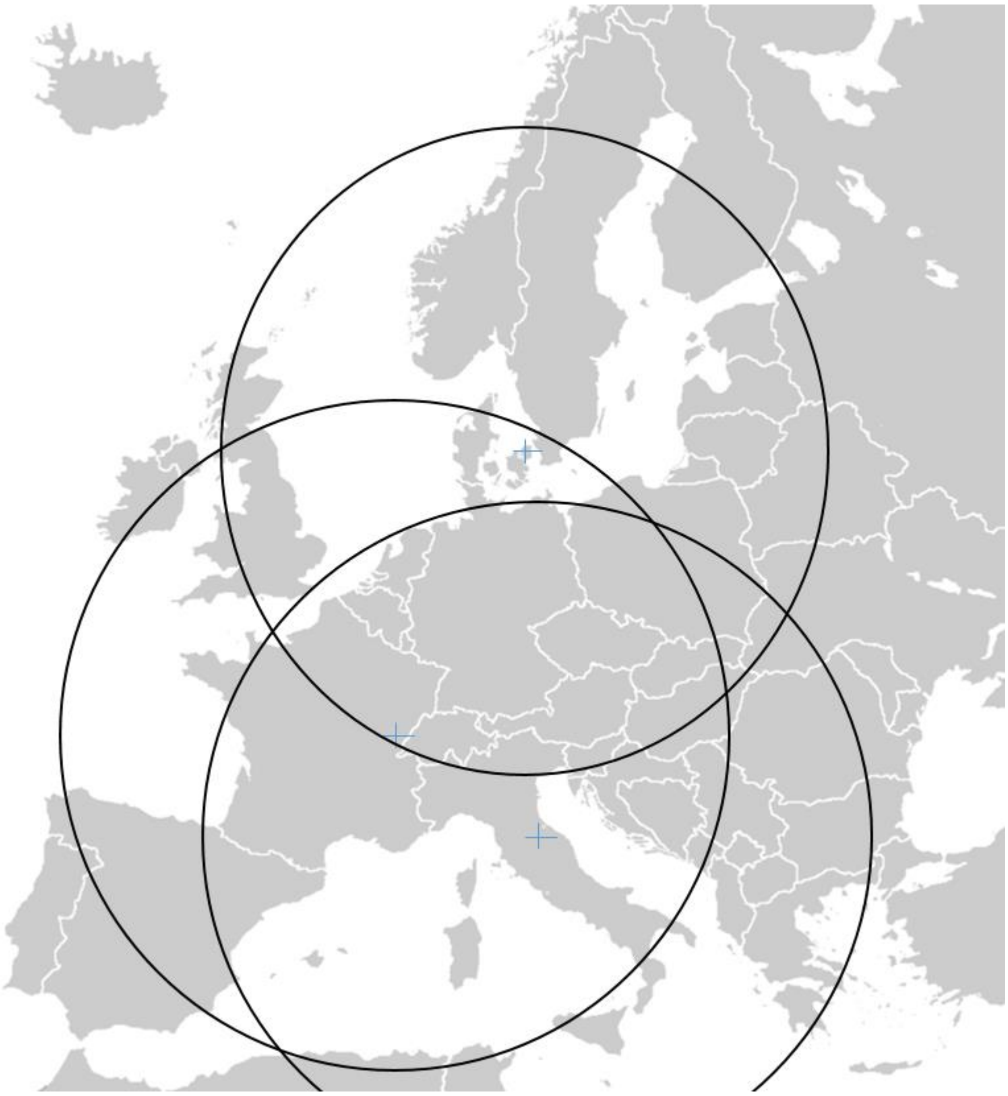

Figure 2. Coverage of Europe within 5 hours door-door with direct flight transports. Example is based on production at CERN, Hevesy Lab and INFN-LNL

9. Conclusion

The transports performed up to now under PRISMAP have demonstrated that the existing practices at the WP2 facilities to a large extent can appropriately support the services provided by PRISMAP, even with more users and more deliveries.

There are however important restrictions in transportation time and scalability, if any of the PRISMAP radionuclides shall support clinical trials at a distance from the production site. Very quick and flexible transport methods do exist, but they are at present out of reach in terms of cost for most PRISMAP users**.**