Report of the Internal Review Board for the choice of a baseline configuration for the stable recycling cavities of Advanced Virgo+

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Abstract

We present the results of the internal review on the choice of a baseline configuration to implement stable recycling cavities in Advanced Virgo+. The project management presented the conceptual study of two main configurations, defined "short" and "long" recycling cavities. At a later stage the "short" was put forward as the preferred solution. Here, we endorse the management decision and report the result of our analysis highlighting aspects asking for further investigations. We present a list of recommendations aimed to help the preparation of a robust Technical Design Report.

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Contents

List of the acronyms

- GW: Gravitational Waves
- EGO: European Gravitational Observatory
- STAC: Scientific and Technical Advisory Committee
- LIGO: Laser Interferometer Gravitational Observatory
- LC: Long cavity
- SC: Short cavity
- TDR: Technical Design Report
- TCS: Thermal Compensation System
- ROC: Radius Of Curvature
- PRC: Power Recycling Cavity
- SRC: Stable Recycling Cavity
- PR: Power Recycling
- SR: Signal Recycling
- PRMx: Power Recycling Mirror x=1,2,3
- SRMx: Signal Recycling Mirror x=1,2,3
- SIBx: Suspended Injection Bench x=1,....
- SDBx: Suspended Detection Bench x=1,....
- BS: Beam Splitter
- FP: Fabry-Pérot
- INJ: Injection system
- PC: Personal Computer
- DSP: Digital signal Processor

1 Charge and scope of the internal review committee

The authors of this document are the members of the internal board of the Collaboration charged by the Virgo Steering Committee (on December 20th, 2023) to review two baseline configurations of Stable Recycling Cavities (SRC). The charge is defined in [1]. The review is based on the rich documentation produced by the Collaboration in a relatively short time. This material, resulting from the impressive effort of the project management and the Collaboration, contains the conceptual design and the risk assessment for the two recycling cavity configurations. Its conclusion is a proposal, which identifies which of the two configurations must be considered the baseline to produce a robust Technical Design Report (TDR).

On January 15th, 2024 we received the document sent by the Advanced Virgo management [2] with the detailed risk assessment concerning two different baseline configurations for stable recycling cavities to be implemented in Advanced Virgo. On January 30th, 2024 we received a mail from the Virgo spokesperson stating that: *a potential problem has recently emerged related to the requirements on the residual motion of the mirrors in the recycling cavity for the "short" solution and the working group led by the Virgo Upgrade Coordinator is working to clarify the situation.* In the same message, he added: *In the meantime you can put the work of the committee on stand-by, except for the parts that do not depend on the results we are waiting and that are not yet finalized (e.g. the assessment of the general criteria upon which the risk analysis will be based).* On March 7th, 2024 Alessio Rocchi, in his role of Upgrade Coordinator, sent us a message stating: *following the activity on the mirror's residual motion requirements evaluation (which you can find summarized on the Wiki: https://wiki.virgo-gw.eu/AdvancedVirgoPlus/RecCavResidMotion), I can re-confirm that the preferred option is the short solution for the stable cavities configuration, as stated in VIR-0063B-24.* After having compared the studies of the two configurations, we analyze the proposal, summarizing the main issues, highlighting its strengths and weaknesses, and providing constructive criticism and recommendations useful for the follow-up of the work. The outcome of our review process is based mainly on the technical documentation available at https://wiki.virgo-gw.eu/AdvancedVirgoPlus/StableRecyclingCavitiesStudy.

2 A recap of the two proposed configurations for stable recycling cavities

To make this note more readable we first summarise the two proposed solutions for the Virgo SRCs.

2.1 The long cavity layout

The detailed description of the long cavity (LC) layout is in [2]. Here we summarise just the main characteristics of this solution to facilitate the reading of the document. In the figure 1 we refer just the optical layout of the power recycling cavity, but the concept of the signal recycling layout is identical. The beam size on the recycling mirrors is ~ 1.5 mm for the Power Recycling Mirror n.1 (PRM1) and ~ 50 mm for the Power Recycling Mirror n.3 (PRM3).

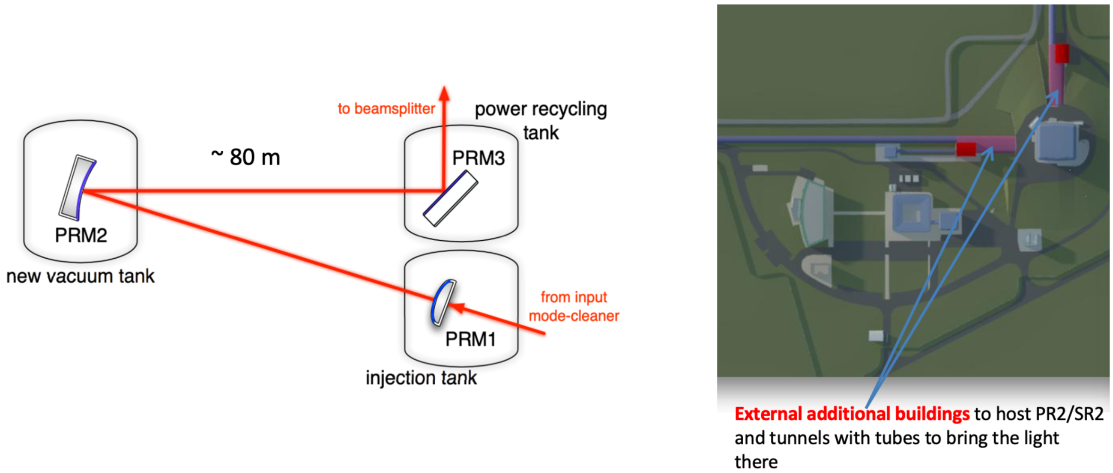

Figure 1: The long cavity layout.

The Power Recycling Mirror n.2 (PRM2) is the focusing element of the beam coming from PRM1. To accumulate the required Gouy phase, PRM2 is located at an adequate distance ($\sim$ 80 m) from PRM3. PRM2 will be suspended to a standard super-attenuator [3] hosted in a vacuum tower with lateral access. PRM3 will be hosted in the actual PR tower and suspended to the existing super-attenuator. PRM1 will be hosted in the injection tower; it will be suspended on a structure set on top of the existing suspended bench (R&D on suspension and control is required). Vacuum tubes hosting such $\sim$ 80 m beams are located parallel to the interferometer arms.

2.2 The short cavity layout

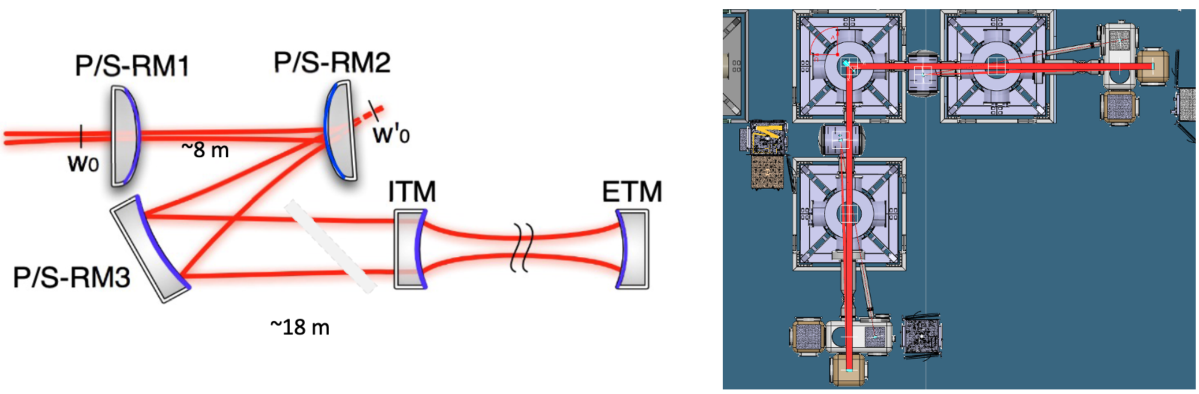

Figure 2: The short cavity layout.

The short cavity (SC) layout is conceived to keep all the recycling mirrors in the central building.

As we did in the previous section, we refer to the power recycling (PR) cavity (the design of the signal recycling (SR) cavity is similar). Referring to the figure 2 , the beam propagates from PRM1 that, in the case of PR cavity, is suspended via a double pendulum set on top of a suspended bench. This bench is hosted in a new vacuum chamber where there is also a second suspended bench with the flat mirrors of the input mode cleaner and the reference cavity. The vacuum chamber will sit roughly in the same location as the present external bench. The beam is focused towards PRM2, housed in another new vacuum chamber located between the two towers of the actual recycling mirror and beam-splitter. Finally, the beam is sent to the convex PRM3. Most of the Gouy phase is accumulated in this last part of the cavity, and the waist lays just outside the recycling cavity. The new vacuum chambers will be smaller and they will host essentially Multi SAS-suspension [4] with a diameter of the filters smaller than that of the standard super-attenuator.

3 The configuration choice

The two workable configurations have been studied at the concept level [2]. The present conclusion of the project management is that **further studies will focus only on the short cavity solution**.
Although we have not got a specific document to explain this choice in detail, we infer that it is based on three main considerations:

- the technical risks of the two options, identified up to now, are almost at same level and no show-stoppers have been found;
- the short cavity solution requires a considerably lower budget and one year less for the implementation;
- the LIGO successful experience is made with an optical configuration similar to the short cavity solution;

The internal review committee endorses the project management choice to favor the short cavity solution.
At present, the project is at a conceptual level. Several chapters of the design look really preliminary and need to evolve rapidly. In addition, a number of extra technical and management challenges have to be tackled, some of which are listed in the following sections, along with a list of concerns and recommendations.
The realization of the stable cavities will require a strong commitment and focus by the Collaboration. We believe this is a crucial step toward realizing an ambitious detector capable of producing science until the advent of the Einstein Telescope.

4 Design aspects, concerns, recommendations

4.1 Optical layout

The document [2] displays detailed designs for the two options, including parameters for optics, beam sizes, extraction of secondary beams, and proposals for compensating errors on radii of curvature (ROCs) and distances to optimize the matching while maintaining resonance of modulation frequencies.
The short cavity design is similar to the one already used by LIGO since almost 10 years and involves (in addition to the recycling mirrors) two spherical mirrors that permit an easier compensation of the astigmatism. The long configuration involves a flat mirror and a concave one, with the astigmatism to be compensated with the thermal compensation system (TCS).
The matching of the long configuration needs to be compensated with TCS, while in the short configuration the matching can be partly compensated by adjusting the distance between the mirrors.
The three following properties of the short configuration make it definitely more appealing than the long one: 1) the fact that it has been successfully used by LIGO for almost 10 years, 2) the compensation of the astigmatism of the concave mirror (PRM3/SRM3) with the one of the convex mirror (PRM2/SRM2) (à la Man-Hello), and 3) the use of the distance between the concave and convex mirror for pre-compensation of errors on ROCs and matching.
The choice of Gouy phases, similar for both the short and long configurations, seems reasonable and feasible to us. Of course, it would be interesting to have more information on experimental data from LIGO regarding the actual tuning of these phases. In general, for the TDR it is recommended to further investigate this matter and gather information on the results from LIGO.
The precision of the ROC of the recycling optics, in both solutions, is a critical point. The ROC must be measured for all optics after coating in order to have the maps to be implemented in the simulations. This will reduce risks and save time during installation and commissioning.
The design effort presented here is mainly based on the assumption to run at 40 W of input power, but in the future we must increase progressively the light power injected in the interferometer. That is why **we recommend to extend the simulation at higher input power values.**

4.1.1 Requirements on the residual motion of the S(P)R mirrors

In January 2024 Boldrini et al. computed, using an iterative method based on geometric optics, the effect of the motion of the recycling stable cavity mirrors on the displacement of the beam on the input test masses for the short and long configurations, finding requirements much stricter in the short configuration case [5]. This was considered as a potential showstopper for the short cavity option and the internal review was put in standby, waiting for a clearer assessment. After that, other simulations/computations have been performed using different methods.
The present status of the investigations is summarized in the Virgo note [6], released on March 29^{th}, 2024. In this document the authors compare the results obtained by using three

different geometrical methods: the iterative method based on geometric optics, a simulation done using the 4x4 ABCD matrix formalism and a 2x2 ABCD simulation. The common goal was to simulate the requirements for misalignment and angular displacement of a folded recycling cavity, for both the long and short configuration. Then they applied the methods also to the LIGO case used as reference.

The most relevant conclusions of the present simulation efforts are the following:

a) The three geometrical methods agree with each other on the results found for the short cavity configuration and for the LIGO case. A discrepancy between the iterative method and the two ABCD matrix method is noted in the case of the long-cavity configuration. This result asks for extra investigation.

b) The resulting requirements for all configurations are very strict, also for the LIGO case taken as reference.

c) The Gouy phase seems to be the only parameter that significantly influences the results.

To understand better the conclusion b), the authors declared to continue their contacts with the LIGO experts: we should understand better how they cope with these strict requirements. Since LIGO is working correctly demonstrating that these kind of angular requirements are achievable, again, the contacts with LIGO are extremely important.
Because the three geometric methods neglect the effects of Gaussian optics and Higher Order Modes, a study that included these effects is started using the simulation software Finesse 3. This activity is just at the beginning and at present even intermediate results are not available.
Looking at the results in [6], the requirements are similar for the two configurations and cannot be considered as a reason to prefer one with respect to the other.

The final results of this study, showing that Virgo and LIGO requirements are similar, and given the fact that LIGO is working correctly, gives confidence that this problem of residual motion of the recycling mirrors is not a showstopper. However, since an alarm was sent about this point (alarm that stopped the internal review) and the results then changed **actions have to be taken to improve the organization and the coordination of the simulation activities. A detailed study should continue increasing the complexity of the simulation**. A plan of the next steps, in particular for the effort started with Finesse, should be presented soon.

4.1.2 Scattered light

The importance of limiting the generation of scattered and/or stray light, which would degrade the performance of the interferometer, is properly stressed in several sections of document [2] but then not well developed. For instance a study of ghost beams, produced e.g. in reflection by AR coatings and in transmission by HR coatings, is missing. Thus, **we recommend performing an extensive ray-tracing study to foresee solutions to dump them adequately as well as to check that auxiliary beams are not clipped: this serves also as an input for the vacuum pipe clear apertures (see sec.4.5)**.
This study will also provide indications on residual transmission of RM2 and RM3. The design of different mode-matching telescopes on suspended benches should include stray

light analysis to ensure that the amount of light back-scattered from the telescope optics meets sensitivity requirements. A stray light analysis should also inform about the need and requirements for baffles in the new pipes and around new mirrors.

The present version of the Short-Cavity configuration assumes to have more than one optical bench in the same vacuum chamber. Mitigation strategies must be addressed in order to avoid that light diffused in a bench affects the performances of the others.

4.2 Mirrors

The realization of the new mirrors for the recycling cavities does not present particular challenges for neither of the two options. However, for both of them, the polishing specifications are similar to those of the test masses. Therefore, only highly qualified polishing vendors like Zygo or Thales are able to do it.

In recent presentations (see for instance VIR-0251A-24) it has been highlighted that the project, as far as the mirrors are concerned, is evolving. In particular, it is being considered to change the test masses with newly produced ones. The production schedule is said to be compatible with the overall upgrading schedule. However, one point needs to be carefully addressed: there are just two polishing vendors capable of meeting the demanding requirements of our mirrors. Is it possible to foresee the production of new test masses in parallel with that of the new recycling mirrors? Is there a risk of conflict between the two tasks? We see a potential schedule risk here. **An integrated production schedule for all the mirrors, based on information from the potential vendors (substrate production and polishing) is needed as soon as possible.**
At some point, a possible conflict between the two tasks (optics for stable recycling cavities and new test masses for O5) may also arise with the coating at LMA. The SRC option with four small optics is probably more favorable to reduce this risk, because the four smaller optics of the short cavity solution (100 and 150 mm in diameter for respectively S(P)R1, S(P)R2) could be coated in parallel in a second coating chamber at LMA.

4.3 Suspensions

The new vibration isolators are the most relevant innovation in the proposed design. While they are based on technology widely used in Virgo, a significant design and prototyping effort is required. Indeed, in VIR-0856A-23 it is stated that the proposed isolator design is *just a patchwork, not an engineering design*.

Moreover, the Collaboration has been informed (see A Bertolini, VIR-1082A-23) that to sustain such an effort “shared responsibility across multiple labs would be mandatory”. We therefore strongly advocate to **set up immediately a coordinated working group of experts from different labs, working together to discuss and finalize the design and organize the prototyping activities. The logistic of the prototyping must be defined too.** We encourage the working group to **pursue a thorough review of the proposed scheme, understand if and how it can improved and produce rapidly an engineering design**.

The main challenge appears to be the suspension of S(P)RM1. Several concerns have been raised about possible couplings with the bench motion. On the other hand such a challenge should not become a blocking point: let us not forget that this happens in LIGO (though with a different technology for vibration isolation) and then we can take advantage of the LIGO experience. **We encourage to pursue an adequate simulation effort and investigate further the alternative concept on the suspension for S(P)RM1 presented in figure 84 of Ref.** [2], which increases the decoupling of the mirror from the bench. In that case, however, there is one less stage of isolation for the bench. The possibility to increase the number of filters should be also studied.

The S(P)RM2-3 isolators, as proposed, are "tailored" to the mirror size. While we understand the reasons and advantages of this choice, we recommend to investigate further whether it can limit the flexibility for future upgrades (e.g. in case larger mirrors are needed). Although the payload of the new recycling mirrors is based on the configuration of the Virgo test masses, a relevant engineering effort is required, which calls for a prototyping.

Needless to say, sensors, actuators and control electronics are crucial elements of the suspension system. No information is given on availability of the electronics. The use of Real Time PC is proposed for the control of the new S(P)R mirrors, while for all the other Virgo mirrors DSPs are used. This non-uniformity is a concern. **We recommend to review the control system and present a plan including its implementation.**

4.4 Interferometer sensing and controls

The interferometer control concerns the broad topics of the lock acquisition, the steady state longitudinal locking and the alignment. In the document, the initial alignment, or pre-alignment, is not considered, and we assume that it guarantees a precision enough to start the lock acquisition. Moreover, in the document, the lock acquisition is also not addressed. Although we think that the lock acquisition will be similar to the one already used for Advanced Virgo+ phase I [1], **we recommend to review in detail this item, in order to double check that the stable cavities do not introduce any major difference.**

We remark that the experimental results of LIGO are not mentioned, and for the TDR we recommend to use as much as possible the LIGO almost ten year (successful) experience with this optical configuration, through a careful analysis of the relevant literature and interaction with LIGO team. Together with the LIGO experience, also the KAGRA experience can be helpful to avoid overlooking effects not fully accounted for in the simulations.

Concerning the steady state locking, a preliminary solution to control the five degrees of freedom has been proposed and a sensing matrix has been computed for the long and short solutions. The two matrices look almost identical. A "closed loop" simulation (including open loop noise, transfer functions for the loops and read-out noises, effects of the mechanics and of the radiation pressure) is not shown, and we recommend to include it in the TDR. Also in this case, details of the LIGO experience are valuable.

We noted above that an extended study on the Gouy phase optimisation and the distribution high order optical modes in the recycling cavity has been carried on. The study

[1] It is based on the use of auxiliary green lasers and various steps in which the CARM offsets are reduced until the final working point.

is documented in several presentations and summarised in few pages of the document [2]. Given the relevance of this study, we recommend to continue it with extended simulations, which include the full optical configuration of the interferometer, and to produce a dedicated note where all the results are discussed.

4.5 Vacuum

In the case of the short cavity solution new Ultra High Vacuum chambers must be built. **We recommend to review attentively the production cost and include a large contingency, given the fluctuations in the material price that we are experiencing in this historical time.**

Moreover, the solution to locate SIB1, PRM1 and PRM3 in different vacuum chambers sharing the same vacuum is just sketched. The three vacuum chambers cannot be vented independently, which raises concerns about flexibility and commissioning time. The main justification for having three chambers connected is to avoid windows in between and have access from many sides. Adding valves does not conflict with these requirements.

Since vacuum pumps are sources of acoustic and vibration noise, **it is recommended to plan, if possible, an installation away from sensitive elements such as view-ports and optical benches, or to isolate these noisy devices.**

Then, other questions are open in connection with the cleanness of the operations: for example are the chambers equipped with a separating roof (IVC) and clean air ducts?

We recommend to study solutions ensuring the maximum flexibility of the experimental apparatus: flexibility is a great value which will play a crucial role in the commissioning speed up and in the future evolution of the detector.

Beam clipping should guide the choice of the vacuum beam diameter: at present to reuse a valve the opening is reduced sensibly in the INJ area (see figs. 86-87 at p.142-143 of Ref.[2]) without consideration of the impact on light beams. **We recommend that the vacuum is designed so that it satisfies the requirements set by the optical design; this includes also the propagation of ghost/auxiliary beams.**

4.6 Infrastructure

As for the rest of the document, we limit our remarks and recommendations to the case of the short stable recycling cavity solution. Although the infrastructure change is limited to the central building, the impact seems so important that we need much more information of the present one to assess the risk. No details are given on the location of the new machines needed to insure the cleanness of the new optical elements. The consequence is that we can not assess the risk level of an increase of the environment noise. We tried to get more information via the Q&A review phase [7], but the corresponding answers tend to increase our feeling that the risk of this change is underestimated. In particular we refer to

- the preferred solution to move away the vacuum towers: the destruction of the 10 mm thick towers via plasma cut in the central building;

- the use of metallic structures to fill the holes where the new vacuum chambers should rest.

Mechanical simulations (static, modal and thermo-mechanic) should be performed to guide the choice between filling the hole with concrete and the metallic frame.

Relocating the input mode cleaner tower is discussed in the INJ section but seems also related to the infrastructure. We recommend to make reference to past experience and to study the limitations of this procedure.

4.6.1 Cleanliness

The chosen solution leads to heavy and dirty activities in the central building hall. We strongly recommend to study the "roof" solution for the removal of existing injection and detection vacuum chambers. In any case, we must anticipate the confinement of the areas where these dirty activities will take place. Continuous extraction of air from confined spaces must be installed. Dust measurements near confined areas should be performed and used to monitor the effectiveness of the confinement.

Contamination monitoring should be extensively implemented inside the protected areas: the ventilation system should also be monitored. **We recommend that a well defined procedure is developed in advance to be ready to act in case contamination starts to accumulate.**

It is not clear at this stage whether the clean room can operate while the main works (e.g. tower removal) are in place: this is a place where key components could be stored safely.

4.7 Planning and person power

A person power plan is missing. We recommend to pursue the preparation of such plan along with the TDR for the construction of the short recycling cavity solution. The analysis of the plan should be carried on in parallel with statements concerning the experience and amount of the person power needed to complete the various items. In addition, we recommend to explore the possibility of the use of external person power, supervised by the experts of the Collaboration. It will be a way to speed up the installation phase even in the case of systems traditionally assembled by Virgo internal experts.

In conclusion, we appreciate that in the case of the short-cavity plan an optimization effort to conduct some activities in parallel was made. However, there is a high risk of delays associated to the development and prototyping activities on the suspensions, crucial for the final success. Moreover, an integrated schedule for the production of the mirrors, including the new test masses recently included in the upgrade plans, is missing. We insist that a thorough check has to be done with the polishing vendors, to avoid a production bottleneck which might delay the whole project.

5 Assessment of the general criteria to analyse the risks

The analysis of the risks associated to the various systems of the projects, is reported in a Excel file titled "Risk Register" [8]. The project management asked us to comment about the general criteria followed to carry on this important analysis.
They are applying a standard procedure to quantify the risk.
They define five levels of risk with different probability of event occurrence:

- 1 - green - Highly Unlikely -10%
- 2 - light green - Unlikely - 30 %
- 3 - yellow - Moderately Likely - 50 %
- 4 - orange - Likely - 70%
- 5 - red - Extremely Likely - 90 %

In addition, they quantify the severity and the impact of the event on the project using a similar scale based on numbers and colors.
Each system is analysed independently and has an associated corresponding Excel table with detailed description of the risk, comments devoted to the incertitude in the evaluation of the risk level and/or on the actions to mitigate the risk.

At present the risk register is detailed, certainly sufficient for the scope of this review (endorse or not the management choice between the two stable cavity solutions). **However, we recommend to review it and even to increase the number of details during the preparation of the TDR.**

Let us conclude with a warning. Our internal committee is used to the Virgo jargon, but we guess that the risk register will circulate even among non-Virgo physicists and engineers (i.e. Scientific and Technical Advisory Committee (STAC) and EGO-council members or GW experts out of Virgo). For a reader out of Virgo the main difficulty will be to understand the meaning of acronyms identifying the sub-systems, in absence of any *Rosetta stone*: ALS, DET, FLT, INF, INFRA EGO, INJ, MIR,PAY, PSL, SAT, TCS, OSD, SBE, SIN, SLC, VAC, DAQ, CAL !
We need somewhere a table with the translation of the acronyms in intelligible words.

6 Main recommendations

The charge of this internal review committee is limited to assess which of the two options, long or shot recycling cavities, must be assumed as baseline solution. Thus, in this document we limit the discussion to this issue.
The implementation of stable cavities is a necessary step to make Virgo an ambitious detector able to produce high level science in the next 20 years. The

motivations for stable cavities are clear and documented. Moreover, the LIGO performances since almost 10 years are showing that this optical configuration is experimentally robust[2].

We recommend to strength the collaboration with LIGO even by an extended exchange of experts on sites. In addition, we stress that the effort to strength the simulation is crucial not in the design phase but even to speed up the detector commissioning.

In conclusion, **the internal review committee endorses the project management choice to favor the short-cavity option. Therefore, we urge the project team to proceed with the writing of the TDR for the short-cavity option and the Collaboration to support adequately the effort.**

The list of specific recommendations, already introduced in the previous sections, follows.

- **Optical layout**
  The design effort presented here is mainly based on the assumption to run at 40 W of input power. We recommend to extend the simulation at higher input power values.

- **Requirements on the residual motion of the S(P)R mirrors**
  Actions have to be taken to improve the organization and the coordination of the simulation activities. A detailed study should continue increasing the complexity of the simulation.

- **Scattered light**
  a) We recommend performing an extensive ray-tracing study to foresee solutions to dump them adequately as well as to check that auxiliary beams are not clipped: this serves also as an input for the vacuum pipe clear apertures.
  b) The present version of the short cavity configuration assumes to have more than one optical bench in the same vacuum chamber, mitigation strategies should be developed to avoid that the light diffused in a bench affects the performances of the others.

- **Mirrors**
  An integrated production schedule for all the mirrors, based on information from the potential vendors (substrate production and polishing) is needed as soon as possible.

- **Suspensions**
  a)We strongly advocate to immediately set up a coordinated working group of experts from different labs, working together to discuss and finalize the design and organize the prototyping activities.
  b) We encourage the working group to pursue a thorough review of the proposed scheme, understand if and how it can improved and to produce an engineering design.
  c) We encourage to pursue an adequate simulation effort and investigate further the alternative concept on the suspension for S(P)RM1 presented in figure 84 of Ref.[2].
  d) The S(P)RM2-3 isolators, as proposed, are “tailored” to the mirror size. While we understand the reasons and advantages of this choice, we recommend to investigate further whether it can limit the flexibility for future upgrades.

[2]Let’s remark that the connection between Virgo unidentified noise (also called mystery noise) and the marginally stable cavity is not demonstrated and this point should be tackled independently from the implementation of the stable cavities.

e) We recommend to review the control system and present a plan including its implementation.

- **Interferometer sensing and controls**
  We recommend to review in detail the locking procedure, in order to double check that the stable cavities do not introduce any major difference.

- **Vacuum**
  a) We recommend to review attentively the production cost and include a large contingency, given the fluctuations in the material price that we are experiencing in this historical time.
  b) Since vacuum pumps are sources of acoustic and vibration noise, it is recommended to plan, if possible, an installation away from sensitive elements such as view-ports and optical benches, or to isolate these noisy devices.
  c) We recommend to study solutions ensuring the maximum flexibility of the experimental apparatus: flexibility is a great value which will play a crucial role in the commissioning speed up and in the future evolution of the detector.
  d) We recommend that the vacuum is designed so that it satisfies the requirements set by the optical design; this includes also the propagation of ghost/auxiliary beams.

- **Infrastructures**
  Mechanical simulations (static, modal and thermo-mechanic) should be performed to guide the choice between filling the hole with concrete and the metallic frame.

- **Cleanliness**
  We recommend that a well defined procedure is developed in advance to be ready to act in case contamination starts to accumulate.

- **Planning and person power**
  A person power plan is missing. We recommend to pursue the preparation of such plan along with the TDR for the construction of the short SRC. In addition, we recommend to explore the possibility of an extended use of external person power, supervised by the experts of the collaboration. It will be a way to speed up the installation phase even in the case of systems traditionally assembled by Virgo internal experts.

References

[1] Gemme G. Mandate of the internal review committee and timeline for decision on stable cavities. https://tds.virgo-gw.eu/?content=3&r=22807, 2024. VIR-1162A-23.

[2] The Virgo Collaboration. Conceptual design studies for stable recycling cavities in AdV+. https://tds.virgo-gw.eu/?content=3&r=22871, 2024. VIR-0026A-24.

[3] Braccini S. et al. Measurement of the seismic attenuation performance of the VIRGO Superattenuator. *Astroparticle Physics*, 23:557– 555, 2005.

[4] van Heijningen J.V. et al. A multistage vibration isolation system for Advanced Virgo suspended optical benches. *Class. Quant. Grav.*, 36:075007, 2019.

[5] Boldrini M. et al. Update on requirements computation for ndrc. https://tds.virgo-gw.eu/?content=3&r=22907, 2024. VIR-0051B-24.

[6] Boldrini M., Casanueva Diaz J., Bonnand R., Heitmann H., and Mantovani M. Tilt/displacement requirements for folded recycling cavities. https://tds.virgo-gw.eu/?content=3&r=23221, 2024. VIR-0314A-24.

[7] Ricci F. et al. Q&A file of the internal review board for SRC. https://tds.virgo-gw.eu/?content=3&r=22943, 2024. VIR-0082A-24.

[8] Rocchi A. et al. Risk register. https://docs.google.com/spreadsheets/d/1ITpza81YfKm9eI3cKLpE3bMG8C29MxDyaZ-jFjf5TlU/edit#gid=517422274), 2024.