# CLEAR Review Report

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## 1. Scope

The CLEAR facility started operation in 2017. A 4-year programme was outlined, with an intermediate review held in February 2019. After 4 years of operation CLEAR has been included in the CERN Medium Term Plan for the period 2021-2025.

The CLEAR review has taken place on 16th March 2021 and it covered:

- Status of the facility and the results obtained.
- Ongoing studies and prospects.
- Expected user requirements in the next 5 years.
- Consolidation requirements, mode of operation and required resources in the next 5 years.

## 2. Charge

The reviewers were asked to comment on the following:

- Is the continued operation of the CLEAR facility for the next 5 years justified?
- Is the current level of resources in terms of both manpower and material budget adequate for efficient operation of the facility?
- Have the recommendations of the 2019 review been followed?
- Are the proposed consolidation and upgrade plans:
    - justified?
    - covered in terms of manpower and budget?
    - in-line with providing the beams required by users researching in areas aligned with the global CERN strategy?
- Have all general safety aspects related to continued operation been assessed and taken into account?

## 3. Programme of the Review

The following presentations were given:

- The last 2 years of CLEAR Facility operation – R. Corsini (CERN)
- Medical applications in CLEAR – M.-C. Vozenin (CHUV)
- Irradiation activities in CLEAR – A. Coronetti (CERN/Jyvaskyla U.)
- Beam Diagnostics R&D - S. Mazzoni (CERN)
- Linear Collider and High-Gradient Studies - S. Stapnes (CERN)
- AWAKE and Plasma applications – E. Gschwendtner (CERN)

- Safety aspects in CLEAR - G. McMonagle (CERN)
- Consolidation, upgrade, future running – R. Corsini (CERN)

These presentations were followed by a discussion and Q&A session with the speakers.

## 4. Introduction & General Findings

The reviewers thank the CLEAR team and the participants to the Review for the high quality and clear presentations and for the open discussions that covered the scientific, organizational and resource aspects of the facility operation.

The CERN Linear Electron Accelerator for Research (CLEAR) is an electron accelerator R&D and test facility, which reuses the CLEX area and the CALIFES electron linac of the former CLIC Test Facility (CTF). The investment cost of such facility is estimated to 20 MCHF.

The facility is operated in stand-alone mode thus operation during general stops of the global CERN accelerator complex, including long shutdowns, is possible.

A significant fraction (~30 to 40%) of the allocated beam time is also devoted to external users for medical applications and for the irradiation of electronics for radiation hardness tests (mostly for space applications).

Since the last Review (February 2019) the European Strategy for Particle Physics has indicated an electron-positron Higgs factory as the highest-priority next collider and it has called for an intensification of the accelerator R&D effort including (but not limited to) plasma acceleration schemes, energy efficient high-gradient acceleration.

In this context, CLEAR acts as an accelerator test facility enabling development, fast prototyping and testing of beam instrumentation and concepts (e.g., plasma focusing) that are relevant for the design of lepton Linear Colliders (CLIC and ILC), AWAKE, possibly FCC-ee and in general it permits to maintain CERN state-of-the-art expertise in lepton accelerators.

In addition, CLEAR is supporting a rapidly growing and vibrant community of external users towards the development of a new paradigm of radiation therapy with Very High Energy Electrons (VHEE) combined with high instantaneous dose rates (FLASH therapy). CLEAR is understood as a key contributor in providing the infrastructure for the study of the underlying radiobiology and of the dosimetry, as well as for the development of the relevant accelerator design. A strong collaboration has been established with the Centre Hospitalier Universitaire Vaudois (CHUV).

CLEAR with its VESPER test stand has proven to be a versatile facility for the measurement of the radiation hardness of electronics components mostly used for space applications providing high energy electrons with variable intensity and irradiation fields. Recent developments (also suggested at the previous review) include:

- High intensity operation to perform displacement damage measurements. These can be done in a short time, with virtually no activation as compared to irradiation with proton beams (e.g., at PS-IRRAD) therefore allowing faster turn-around.

- Study of Flash effects requiring the variation of the bunch charge that are relevant for space applications but also for understanding the impact of fast accelerator losses on electronics components.
- Dosimetry studies for a more accurate characterization of the radiation effects.
- In-house thermal neutron tests, mixed field, but with effectively high R-factor to allow for fast screening tests.

The above developments continue being of interest to the community in the future.

Since the last review significant progress has been achieved in the performance of the accelerator and in the extension of the achievable beam parameters' range, notably minimum bunch length (10 ps) and maximum bunch charge (3 nC), further contributing to make this facility the only possible choice for several users.

The uniqueness of this facility has been stressed by all the participants. To be noted:

- The high beam energy, the bunch structure (charge and pulse length), the availability of the "in-air" station (providing the flexibility required for the logistics associated with radiobiological tests on hatched fish eggs) enabling medical applications. The research on flash therapy could not have started in other facilities and would be at least 2 years behind.
- The mixed field (electron, photon, neutrons) of radiation and the thermal and intermediate energy neutron fluences achievable in the facility (by far larger than those achievable with the Be-Am source at CERN) together with a very low residual radiation environment which makes preparation of the tests and turn-around much shorter.
- The high energy of the electron beams allowing to study specific concepts for beam instrumentation such as Diffractive Cherenkov Radiation.
- The proximity with existing installations (AWAKE, X-Box, Instrumentation laboratories) for CERN accelerator R&D purposes, in the context of fast prototyping.

The users appreciate the high level of flexibility and accessibility of the facility easing experimental equipment installation, the availability of beam time (higher than in other facilities) and the short lead time between proposal and execution of experiments.

The users unanimously commended the high level of competence and commitment of the CLEAR team in achieving the required beam parameters and providing the necessary experimental set-up.

Beam time requests are submitted through a form (https://clear.cern/content/beam-time-request), specifying experiment description, scientific aim and justification, needed beam parameters, experimental apparatus and logistics, safety aspects. Beam time requests beyond 1 year require a new submission. A Technical Board is responsible to check technical, safety and RP issues before giving the final authorization and it allocates the beam time in the schedule. The documentation relative to all approved experiments is stored in EDMS. From 2021 a formal EDMS approval procedure (including safety, RP and HSE as necessary) will be implemented.

An International Scientific Board (last meeting in 2018) provides general guidelines for the scientific activities to be pursued at CLEAR.

# 5. Is the continued operation of the CLEAR facility for the next 5 years justified?

The CLEAR facility:

- Serves the CERN accelerator R&D core programme (AWAKE, CLIC and in the future FCC-ee). A series of concepts developed in CLEAR have led to prototype instruments for AWAKE, CLIC and LHC/HL-LHC (e.g., diffractive Cherenkov Radiation and Electro-Optical Devices for beam position and bunch length measurements).
- Provides a training ground for many students (e.g., for the Joint Universities Accelerator School – JUAS) and post-docs in accelerator physics, radio frequency and beam instrumentation.
- Supports a wide user community for medical and space application (ESA, NASA) with, in some cases, a unique infrastructure.

A non-exhaustive list of experimental needs at CLEAR has been sketched during the various presentations:

- Medical applications: the flash therapy community has just started a series of studies with a programme expected to cover the next 5-10 years and including radiobiological studies, definition of the optimum beam characteristics (dose rates, pulse length) and of the corresponding accelerator and beam delivery system, development of accurate dosimetry. CERN and CHUV have established a collaboration agreement for the conceptual design of a flash radiotherapy facility and are aiming to conclude a partnership to translate the conceptual design into building plans for this new facility. A stop of CLEAR operation would have an adverse effect on the above studies and would undermine the ongoing collaboration with a negative impact on CHUV research activities as well as CERN's image.
- Irradiation of electronic components: it is expected that measurements for space applications will continue for at least 2 years as no other facility provides similar beam characteristics. Uncertainties remain in the calibration between intensity measurements versus dosimetry and shall be addressed.
- Beam Instrumentation R&D: In 2021-2022 it is planned to test optical BLMs based on Cherenkov radiation in optical fibres for SPS/FCC and develop concepts and instrumentation for AWAKE which is relying on CLEAR as an instrumentation testbed. The beam instrumentation R&D required for FCC-ee is under evaluation but will need beam time at the CLEAR test facility on time scales that are longer than the above ones. In the past Beam Instrumentation R&D has accounted for a significant fraction of the beam time requests (>30%) and it is expected that this trend will continue.
- CLIC: Operation of the wake-field monitors in the CLIC test-stand in the presence of RF power provided by XBOX1 (waveguides already available). Measurement and understanding of the wake-fields due to imperfect alignments are critical for validating the CLIC luminosity performance strategy.

From the above we believe that **the continued operation of the CLEAR facility for the next 5 years is fully justified**.

## 6. Is the current level of resources in terms of both manpower and material budget adequate for efficient operation of the facility?

The present Medium-Term Plan has allocated 790 kCHF/year for CLEAR operation. 3.4 FTE-staff/year are allocated in APT, slightly less than the initially listed 3.7 FTE-staff/year. 0.5 FTE-fellow/year (laser operation shared with AWAKE) and ~4 FTE/year for students/PJAS/VISC/FSUs (cost included in material budget) complete the manpower requirements.

The facility is operated in an efficient way (close to 70% of beam availability) considering the mode of operation (during working hours mostly and with best effort equipment expert support) and the frequent changes of operation mode and experimental set-up.

The material budget appears to be sufficient to cover operation and maintenance. We note that:

- Operation support is to a large fraction guaranteed by temporary manpower (PJAS, fellows, students), in some cases holding important responsibilities in the definition of the accelerator set-up.
- There are concerns related to maintaining the know-how for cathode production and to the continuation of the follow-up of safety aspects for the facility (see also the point concerning safety later).

From the above **we conclude that the current level of resources is sufficient for the operation but there are some concerns that require attention** (see recommendation 2 in the list of recommendations at the end of the document).

After the review it has been brought to our attention (EDMS 2445311) that the responsibility for the configuration management of the CLEAR/CTF area is not defined. We recommend clarifying who is responsible for that (see recommendation 2).

## 7. Have the recommendations of the 2019 review been followed?

The recommendations made during the 2019 review and the actions taken are listed below:

1. *Track beam usage, beam availability, and fault rate with the operational logbook and follow strictly the procedure for experiment registration and beam time allocation, with the goal of producing statistics of machine availability and of beam time usage by the different experiments.*
    - Information concerning schedule, beam time allocation per activity and user, beam availability and main sources of downtime has been provided, and it has been processed from logging data. The Accelerator Fault Tracking (AFT) tool, used in other accelerators, has been implemented but it is not used due to the important overhead for the recording and documentation of faults leading to short downtimes.
    - Information concerning the user requests and the technical implementation of the experiments are stored in EDMS and a new formal procedure for approval is being implemented starting from 2021.

- The format and amount of information presented appears to be adequate for the scale of the facility and given the available resources. It was noted that it is still requiring quite some effort to have a detailed recording of short intermittent beam interruptions (see recommendation 4).

2. *Produce a technical report on the proposed upgrade options including motivation, design, resource-loaded schedules, commissioning plans and operation staffing and submit it for approval to the ATS management. The budget should clearly identify the contributions from CLEAR operation, from CLIC, and from external sources. This should be completed before any significant additional work is carried out for any particular option.*

    - Development, installation and commissioning of the advanced source in the CTF2 area are conducted by CLIC/AWAKE and they do not require CLEAR resources. Operation will be performed by the CLEAR team.

    - The specific need of the new source with a corresponding beam line is only related to experiments with drive and witness bunches but it does not appear to be a major need now (other facilities can provide that).

    - The detailed design of the second beam line has been put on hold as no sufficient requirement nor resources to study it were identified.

    - An additional parallel line (branching off w/o dedicated source) could improve the availability for users in the future and reduce the turn-around time of experiments.

3. *Increase the visibility of the facility and its experiments with a wider use of the CERN communication channels and continue keeping track of publications making sure that CERN and CLEAR are properly recognized.*

    - See Publications | CLEAR. This effort has been pursued and the visibility has grown with a visible impact on CERN Knowledge Transfer record. FLASH therapy development at CHUV, Irradiation facility used by ESA and NASA are neat examples of that.

4. *Study the possibility of adapting the CLEAR electron beam parameters to be closer to their high energy, proton equivalents, in terms of bunch length (~100ps), bunch charge (~30pC) and bunch structure (25ns).*

    - Progress has been made in the range of achievable parameters but longer bunches and the 25 ns spacing that might be of interest for impedance measurements and beam instrumentation test are not within reach at the facility.

5. *For future experiments, evaluate the impact on performance and resources of carrying out the measurements at other suitable facilities outside of CERN*.

    - It appears that, with the recent performance improvements, the facility remains unique at least for a fraction of the experiments.

    - Proximity, availability, and flexibility of the infrastructure are an additional appeal for many users.

From the above we conclude that **the recommendations of the previous review have been generally followed**.

## 8. Are the proposed consolidation and upgrade plans justified, covered in terms of manpower and budget and in-line with providing the beams required by users researching in areas aligned with the global CERN strategy?

Consolidation:

- The main upcoming consolidation item is the spare klystron stock and it is covered by the allocated material budget.

Upgrade plans

- Proposals for the installation of a second experimental line and the installation of the new CLIC/AWAKE injector in CLEAR for operation in the period 2023-2025 have been presented.
    - Second experimental line:
        - The present facility set-up covers the needs of the users in the next 2-3 years at least, with no need of specific upgrade if the future requests remain at the present level.
        - The material costs for the installation of a branch-off at VESPER could be covered from the existing operational budget and could allow for additional flexibility.
    - New CLIC/AWAKE injector
        - The resources required for the installation of the additional source in CLEAR have not been presented. It is assumed that operation and support resources will be the same irrespectively of whether the new injector is operated at CTF2 or CLEAR.
        - No compelling user request justifying the installation of the second source in CLEAR has been given.

**Further analysis by the CLEAR team is required to have the possibility to comment on the proposed upgrade plans**. See Recommendations 1 and 5.

## 9. Have all general safety aspects related to continued operation been assessed and taken into account?

A modification of the access system to fully conform CLEAR to beam facility safety standards is required and will be performed by the end of June, operation is presently allowed under derogation. An ECR describing the required modifications has been written (https://edms.cern.ch/document/2332247/1) together with the corresponding functional specifications (https://edms.cern.ch/document/990217/1.3). The safety aspects related to the Rb plasma cell operation in CLEAR for AWAKE remain to be investigated.

The present Facility Safety Officer is ending soon his mandate.

The safety file of CTF3 covers CLEAR as this is a part of the former CTF3. This was integrated by other documents following modifications or specific needs (e.g.,: https://edms.cern.ch/ui/#!master/navigator/document?D:100324075:100324075:subDocs, written specifically for the last open days). With the modification of the safety chain after the last ECR new safety files restricted to CLEX/CLEAR and the adjacent CTF2 area are being produced and should be soon circulated for approval.

At present the CLEAR facility is operated as part of CTF3 complex which has been declared to the Host Sates safety authorities and it has not been decommissioned.

**The general safety aspects have been assessed and considered but some actions are suggested** (see Recommendations 2 and 3).

# 10. Recommendations

The following recommendations are made:

1. User demand and role of the Scientific Committee:
    a. While it is important to respond rapidly to user requests and to maintain machine development and training opportunities, long-term experiments involving external users or demanding extensive support should be more closely followed-up by the Scientific Committee. The Scientific Committee could be included in the formal process of evaluation and approval of the beam-time request in EDMS.
    b. Evaluate the user needs requiring the installation of the new injector in CLEAR in time for a possible operation in 2023-2025.
2. Resources for continued operation:
    a. An updated manpower plan for continued CLEAR operation in the future addressing the expected departures (e.g., safety) should be presented and approved by the ATS management. Possible synergies with cathode development and production for other electron guns operated at CERN should be identified. The responsibility for the configuration management for the CTF/CLEAR area should be defined.
    b. CLEAR offers unique opportunities for a wide external user community. In case that would grow to a level requiring significant extension of the facility it might be judicious to seek external funding (which might include, inter alia, contributions from industrial partners). The proposal of applying for EU transnational access (RADNEXT, ARIES) should also be pursued.
3. Safety:
    a. The safety aspects have been adequately assessed but need to be followed up timely. We encourage to pay particular attention to the safety documentation considering the involvement of external users in the experiments. A clarification on the framework of operation of the CLEAR facility might be required.
    b. A replacement for the Facility Safety Officer should be identified (see also recommendation 2).
4. Improvements:
    a. Tools to generate automatic entries in the logbook for short faults are available and could be tested in CLEAR. This could facilitate the use of AFT.

b. The correlation between measured beam parameters and dosimetry should be investigated in collaboration with the users as this could be beneficial for medical applications and irradiation to electronics.

5. Upgrades
    a. Based on the user needs assess the configuration and the resources required for installation of the new injector in CLEAR.
    b. Conduct a quantitative analysis of the needs of the communities using CLEAR to see if the need of a second beam line is justified; if so, conduct a quantitative analysis of the impact of the installation of a second beam line on machine availability and experiment turn-around time and assess the required resources for construction, installation and operation.