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SOME SAFETY ASPECTS FOR LHC EXPERIMENTS

Edited by
H. Schönbacher

Abstract

This report gives some safety rules and guide-lines for teams of physicists and engineers working on proposals and preparations for LHC experiments. The topics covered are radiation, cryogenics, engineering, mechanics, fire and industrial safety. It is understood that with the evolution of the studies of the LHC experiments the present report will also have to be revised and completed.

Contents

1. INTRODUCTION

The experience gained with the four LEP experiments and the two experiments at HERA has demonstrated that large and very complex experimental equipment can be built and operated in underground areas provided that the relevant safety rules, which are laid down in the already existing safety codes and safety instructions, are rigorously respected at all stages of the design.

The LHC experiments are considerably larger and present additional problems such as radiation damage to components, access restrictions due to induced radioactivity and much greater volumes of cryogenic liquids than have been used previously at CERN. Therefore even more emphasis must be placed on the safety aspects in the conception and design of the LHC experiments.

2. OBJECTIVES

The objective of this report is to give a number of recommendations and guide-lines on safety aspects to teams of physicists and engineers working on proposals and preparations for LHC experiments. It is restricted to the basic rules; more details can be found in the cited safety codes and safety instructions, which are mandatory.

Furthermore, the reader is referred to the "Safety Guide for CERN Experiments" which was edited in 1985 by H. Overas. Although parts of this guide are out of date and are therefore under revision, it still gives a very useful overview of many safety aspects for experiments.

3. PRELIMINARY COMMENTS ON THE LHC DETECTOR PROPOSALS

From the letters of intent for pp experiments submitted to the LHC Committee as of 1st October 1992 and information from R&D Projects, and as well as the proposals to the Detector Research and Development Committee, it appears that a number of options are still under discussion.

These are for **tracking**:

- microstrip gas counters,
- transition radiation detectors,
- multi-wire proportional chambers,
- small diameter scintillating fibres,
- microstrip and pixel detectors based on silicon or GaAs.

It is fortunate and the proponents of experiments are to be congratulated, that for **calorimetry** none of the proposals suggests the use of uranium as absorber or a highly flammable liquid (such as TMP, TMS, etc.)

as detector medium. The materials under consideration for absorbers are lead, steel or brass and the proposed detectors would use gases, doped liquid argon, scintillators, semiconductors (silicon or GaAs) or crystals.

For **muon detection** the proposed chambers contain in general non-flammable gas. The various types under discussion are:

- wall-less drift chambers,
- honeycomb strip chambers,
- resistive plate chambers,
- plastic streamer tubes,
- high pressure drift tubes.

Large and high field **magnets** in some cases with unconventional geometry are under study and with one exception are all superconducting.

4. SAFETY GUIDE-LINES

4.1. Radiation

4.1.1. Radiation Protection

A safety problem, which the particle-physics community will encounter for the first time in the central and forward regions of detectors at high-luminosity proton colliders, is the high level of induced radioactivity due to radioactive isotopes created by the cascades generated by the secondaries from the p-p collisions in the detectors themselves. These radiation levels will be high enough to impose restrictions on the working time for repair and maintenance. Inside the detectors access to their forward parts will be severely restricted or even forbidden.

It should be noted that the following limiting personal exposures are applicable:

- CERN Limit = 15 mSv/year,
- Design Limit = 5 mSv/year.

This means that the design of the detectors should be based on an occupancy time per person which is limited to 50 hours per year in a radiation field of 0.1 mSv/h and 5 hours per year at 1 mSv/h (100 mrem/h).

Consideration must therefore be given at an early stage in the design to minimizing the time spent in:

a) getting to the place of work,
b) removing damaged components,
c) being exposed to highly radioactive parts of the detector which are not connected with the work in question. This can be obtained for example by removing the most radioactive components prior to certain interventions.

Exposure to radiation can be reduced by providing:

- easy access,
- quick connection and disconnection of cables etc.,
- a modular construction with quick replacement of component parts,
- making maximum use of self-shielding,
- making as many repairs as possible away from the most radioactive regions of the detector.

Some elementary safety rules for radiation protection are given in Appendix 1.

Further, it shall be noted that all radioactive sources used for calibration which come to the CERN site must be registered and approved by the Radiation Protection Group.

TIS contacts: G.R. Stevenson
M. Höfert

Safety documents: CERN Radiation Protection Manual, Ed. 1983.

4.1.2. Non-ionizing Radiation

Static magnetic fields may induce biological effects and also cause technical hazards by attracted objects. For this reason an exposure limit of 0.2 Tesla is imposed at CERN by Safety Instruction 36. Electronic implants such as cardiac pacemakers may be affected at fields above 0.5 mT.

The radiation produced by **lasers** may be hazardous to the human eye and skin. Therefore, like radioactive sources, all lasers to be used on CERN site must be registered and approved by Radiation Protection Group. Precautions related to specific classes of lasers are given in Safety Instruction 22.

TIS contact: J.W.N. Tuyn

Safety documents: Safety Instruction 36 (1990)
Safety Instruction 22 (1982)

4.1.3. Radiation Damage and High Dose Dosimetry

This subject is for LHC experiments of much greater importance than for high-energy physics experiments in the past and at present. We are confronted with the problem that radiation sensitive items such as optical fibres, scintillators and semiconductors must be used in places where radiation doses will be very high. Detector breakdowns due to radiation damage will not only disturb physics but also affect the safety of personnel since areas of high radiation levels during operation are usually also areas of high induced radioactivity during machine shutdowns. For this reason, the detector collaborations must demonstrate the operability of their equipment in high radiation areas and prove functional performance at the integrated doses predicted at the places where the various detector components are going to be installed. An active dosimetry system (optical fibre, scintillator, semiconductor) to measure the integrated dose received by the different parts of the detector must also be foreseen.

In order to make intercomparison of test results for radiation resistance of materials easier, it is recommended to make such tests only with a few representative sources, e.g. ^{60}Co gamma rays and neutrons in the 1 MeV range from reactors or accelerators. Further, the damage shall be related to dose or fluence, whatever was measured because conversions may be a considerable source of errors.

Some guide-lines for radiation tests on detector materials and recommended dosimetry methods are given in Appendix 2.

TIS contacts: H. Schönbacher
M. Tavlet

Relevant reports:

- Radiation hardness studies for detector materials, TIS-CFM/90-20/CF (1990).
- Data compilation of dosimetry methods and radiation sources for material testing, TIS-CFM/IR/93-in preparation
- Compilation of radiation damage test data, CERN 82-10 (1982).

4.2. Engineering and Mechanics

4.2.1. Mechanical Safety

Mechanical equipment should be designed and constructed according to international or national norms (ISO, DIN, NF). The rules to be used for the design of pressure vessels and pressurized pipelines should follow as far as possible the French construction code for pressure vessels (CODAP)[*], which could, when necessary, be complemented by the ASME Code (American Society of Mechanical Engineers). The procedures to be followed in the construction, installation and use of pressure vessel are laid down in the CERN Safety Code D2.

Special attention should be given to the transport and handling of very heavy equipment (see CERN Safety Code D1 for lifting equipment).

TIS contact: G. Löhr

Safety documents: Code D1, Lifting equipment, 1988
Code D2, Pressure vessels and pipelines, 1988

4.2.2. Cryogenic Systems

Large scale cryogenic systems have been designed and constructed and operate at existing high energy particle accelerators and experiments. The size of proposed superconducting magnets and liquid argon calorimeters for LHC exceeds, however, by far what has been built in the past.

The related safety aspects must be taken into account already at an early stage in the design of the detector.

Due to the size of the foreseen magnets, the stored magnetic energy and the radial and axial forces reach unprecedented levels. Quench protection consideration and sound mechanical design must make sure that the magnetic energy density and the induced stress level stay below ascertained acceptable limits.

With respect to liquid argon safety, the main risk consists of a large spill leading to an oxygen deficit and burns (see Appendix 3). Possible sources of leakage are the accidental rupture of the tank itself or of large pipes caused by impact from outside or "weak points" such as feedthroughs, as well as external forces which may damage the vessel(s) containing the liquid argon.

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[*] *CODAP: Syndicat national de la Chaudronnerie, de la Tôlerie et de la Tuyauterie industrielle, 10, Avenue Hoche, F - 75382 - PARIS CEDEX 08.

A large spillage must be avoided under all circumstances by:

- sound concepts,
- proper engineering,
- measures to avoid damage from outside.

A summary of hazards and precautionary measures to be taken in work with cryogenic fluids is given in Safety Note 21 which is reproduced in Appendix 3.

Safety document: Safety Note 21, 1992.

Since they are clearly the most dangerous components of the LHC detectors, the design parameters and choice of structures of superconducting magnets and liquid argon calorimeters must be quantitatively justified with explicitly defined safety factors. It must be demonstrated by relevant computations and drawings in a readily understandable form that safety is assured even under the worst case conditions.

4.3. Fire Prevention

4.3.1. Flammable Gases

The risk classification according to the CERN Flammable Gas Safety Manual is based on the quantities of the flammable gases Q expressed in hydrogen equivalents (1 kg paraffin hydrocarbons, methane, ethane, propane, butane, etc. = 0.4 kg of hydrogen).

- Risk Class 0: risk of a small local flash fire $Q < 0.4$ kg.

- Risk Class I: risk of a local fire (restricted to the installation), distance* to objects representing a fire hazard greater than $2 + 2\sqrt{Q}$ metres.

- Risk Class II: risk of general fire (involving other installations), distance* to objects representing a fire hazard smaller than $2 + 2\sqrt{Q}$ metres.

- Risk Class III: risk of explosion $Q > 40$ kg indoors, $Q > 200$ kg outdoors.

As required by Safety Instruction No 38 (see Appendix 4) and already practised in LEP, **no LHC experiment shall fall into risk Class III.**

Some further general gas safety rules are:

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* Safety distances refer to fire propagation from the flammable-gas system to exposed objects. They do not refer to fire propagation from a flammable-gas system located inside a building to objects located outside.

- Gas bottles, gas barracks, mixing stations to be placed outside the experimental halls.
- Gas lines to be made of metal with brazed or welded connections.
- Electrical equipment to be explosion-proof.
- Provision of flammable gas leak detectors, etc.

TIS Contact: C.W. Nuttall

Safety documents: - Chemical Safety Code B, 1987
- CERN Flammable Gas Safety Manual, Ed. 1980.
- Safety Instruction 38, 1992.

4.3.2. Flammable Organic Materials

The basic requirements for flammable materials (for gases see previous chapter) are:

- Flame retardant characteristics satisfying the relevant standards.
- Halogen and sulphur free.
- Low smoke density.
- Low toxicity of gases from fires.
- Low corrosivity of gases from fires.

Note: **These requirements exclude a number of commonly used materials such as polyvinyl chloride (PVC), chlorosulphonated polyethylene (Hypalon®), polychloroprene (Neoprene®), fluorocarbons (e.g. Teflon®) and other halogenated or sulphur containing compounds.**

The majority of the materials falling in this category are used in electrical cables and insulators. However, the above criteria are also applicable to structures and materials other than electrical insulators. The required criteria and standard test methods are defined in CERN Safety Instruction 23 and are summarized in Appendix 5.

Safety Note 11 contains guidelines for the use of other non metallic materials in underground areas such as spacers, supports, gas counter tubes, etc. It is under revision by the Material and Cable Working Group and will thereafter be issued as a Safety Instruction.

TIS contacts: C.W. Nuttall
M. Tavlet
H. Schönbacher

Safety documents: Safety Instruction 23, edition 1992
Safety Note 11 (1986, under revision)

4.3.3. Fire Fighting

In addition to the conventional fire fighting practices (hydrants, hose-reels, portable extinguishers), a solution will need to be found to replace halogenated extinguishing agents (Halon) for the counting rooms.

An interesting and promising alternative to a conventional fire extinguishing system in an underground experimental hall is high expansion foam. Such an installation has been implemented in the H1 Experiment at DESY.

TIS contacts: J.L. Denblyden (fire fighting)
J. Fivet (fire prevention)

Safety documents: Code E, Fire protection, 1991.

4.3.4. General alarm and control systems

For fire prevention and fighting, general alarm and control systems are of utmost importance.

During operation and shut-down periods, safety will have to be ensured by a general hard-wired system, specifically designed to handle high-level alarms and prevent injury to personnel and major loss of equipment, together with a slow control system more specific to the experiment. A sufficient compatibility must exist between the alarm systems of different experiments to allow an easy centralization of information and requests for urgent intervention to the control rooms of the experiment and of CERN's fire brigade. Requests for technical interventions will be routed to the Technical Control Room.

5. GENERAL SAFETY AND INDUSTRIAL HYGIENE

General safety concerning electricity, mechanics and industrial hygiene is covered by CERN Safety Codes and Safety Instructions which are mandatory, or regulations and agreements with the CERN Host States.

One must be aware that, prior to work in the underground experimental halls, medical examinations are required to ascertain the aptitude to work in radiation areas and/or confined spaces. Handicapped people (wheel chairs) are not allowed to work in these areas.

TIS contacts, General Safety: G. Rau
Electrical Safety: R. Bouquin
Mechanical Safety G. Löhr
Medical Service: E. Maquet

SAFETY DOCUMENTS AND TIS CONTACT PERSONS

Many CERN Safety Instructions and Safety Notes deal with general industrial safety. It is recommended to consult the list of safety documents edited by TIS.

This list is updated once a year and can be obtained from TIS/DI Secretariat, Tel. 5097 or JGX@CERNVM.CERN.CH or Josiane_Guex@MACMAIL.

Other safety related information can be found, via Bitnet for example, on VM under: XNEWS (TIS

A list of TIS contact persons is given in Appendix 6.

6. SAFETY POLICY

The safety policy at CERN is defined in the document SAPOCO/42 (Edition 1988), which states that the mandate of the TIS Commission is to assist the Director General in carrying out his overall responsibility for safety and occupational health in the Organization.

Except from some particular cases (Radiation Protection, Fire Fighting, Safety Inspections, etc.) the essential role of TIS Commission is to help, advise and possibly warn the project supervisors, who retain their complete power of decision and responsibility with respect to their safety obligations.

In its activities of inspections and audits, the TIS Commission must acquire the conviction that all aspects of safety have been taken into consideration.

Implementation of this safety policy for the LHC experiments means:

1 The Technical Proposal will have to contain a chapter on safety.

2 In the safety chapter of the Technical Proposal the design parameters and choice of structures must be quantitatively justified and it must be demonstrated in a readily understandable form that safety is assured even under the worst case conditions.

3 The safety chapter of the Technical Proposal will be the subject of a Safety Audit before approval of the experiment.

ACKNOWLEDGEMENTS

All members of TIS listed in Appendix 6 have contributed to this Report. In addition, help is acknowledged which was obtained from B. de Raad, K. Potter, M. Ellefsplass, A. Hervé, R. Keizer, P. Lazeyras, L. Leistam, E. Radermacher.

Distribution:

Chairmen and Secretaries of LHCC and DRDC
Spokespersons of LOIs for LHC
Spokespersons of R&D projects and DRDC proposals
Members of LHC Experimental Requirements Committee
TIS Group and Section Leaders
H. Hilke
H.F. Hoffmann

Appendix 1

Some elementary design recommendations for reducing exposure to radiation

Be prepared to wait several hours after the end of a coast before attempting to access radioactive equipment.

In general, the lower the atomic number of an irradiated material, the lower the dose rate from induced radioactivity. Thus, aluminium is in general better than steel or copper.

In general, use steels with the lowest possible cobalt content.

Be careful with components containing special materials like gold or europium in significant quantities. Make irradiation tests in order to determine induced radioactivity in all construction and detector materials.

Use a modular construction which will considerably reduce the working time because of the possibility to apply standardized replacement procedures.

Plan all procedures on the assumption that the work will have to be done with one hand only. This will considerably simplify the adaptation to special handling devices.

Design for simple handling devices - e.g. a long-handled screwdriver.

Appendix 2

Guide-lines for Radiation Tests on LHC Detector Materials

<table>
<tr><th></th><th>Scintillators</th><th>Semiconductor Detector</th><th>Electronics</th><th>Insulating and structural materials</th></tr>
<tr><td>Radiation source</td><td>^{60}Co</td><td>Neutrons (1 MeV)
^{60}Co</td><td>Neutrons (1 MeV)
^{60}Co</td><td>^{60}Co</td></tr>
<tr><td>Dose rate (Gy/h)</td><td>$10 - 10^4$</td><td></td><td>$< 5 \times 10^3$ (γ)</td><td>Short time: < 100
Long time: up to 10^4
IEC 544-2</td></tr>
<tr><td rowspan="2">Environment</td><td colspan="4">Usually: air, ambient temperature (22°C) otherwise atmosphere and temperature of application</td></tr>
<tr><td></td><td colspan="2">Powered during test</td><td></td></tr>
<tr><td>Critical Property</td><td>Scintillation efficiency
Transmission loss</td><td>Leakage current noise (calorimetry)</td><td>MIL Std. 1019.4
ESA Std.</td><td>Flexural strength (rigid materials)
elongation (flexible materials)
IEC 544-2</td></tr>
<tr><td>Damage Criterion</td><td>Operational at 10^5 Gy</td><td>1-5 μA leakage current</td><td>Worst case analysis depending on application</td><td>50% of initial value at 10^5 Gy
IEC 544-2</td></tr>
</table>

Recommended high-dose dosimetry methods:

- Radiophotoluminescence (RPL) in glass.
- Free radical production in alanine.
- Optical transmission in glass or plastics.
- Semiconductor sensors (MOS or diodes)

Appendix 3

CERN

NOTE DE SÉCURITÉ
SAFETY NOTE

NS 21
Rev.

Published by: TIS/GS

Publication date: 1992
Original: French

HAZARDS OF CRYOGENIC FLUIDS

Introduction

After some recent accidents involving the use of cryogenic fluids, we would like to remind you of the associated hazards and provide you with some general guidelines for preventing such accidents.

Reminder of some characteristics

The main cryogenic fluids used at CERN are liquid argon, liquid nitrogen and liquid helium:

Characteristics	Argon (Ar)	Nitrogen (N_2)	Helium (He)
Boiling point	- 185.8° C (87.3 K)	- 195.8° C (77.3 K)	- 268.9° C (4.2 K)
Litres of gas produced by 1 litre of liquid at 20°C, 1 bar	850	703	761
Density compared to density of air at 20°C	~ 1.4	~ 1.0	~ 1/7

Types of hazard and precautionary measures

There are four main types of hazard:

- **Asphyxia**
  The gases formed by the above cryogenic liquids are not toxic but, in view of the ratio between their gas and liquid volumes and their expansion on being warmed up to ambient temperature, they can easily cause asphyxia by replacing the oxygen in the air.

  One must always check the oxygen concentration before entering premises where there could have been a cryogenic gas leak (see Safety Code A4, Confined Spaces).

  It should also be mentioned that, owing to the density difference, helium diffuses upwards while argon and nitrogen stagnate at ground level.

P.T.O.

- **Burns**

Brief contact with these liquids can cause burns similar to those resulting from contact with components heated to high temperatures.

Normally such burns are not instantaneous since the skin is protected for a few seconds by a thin film of gas (the phenomenon of calefaction).

The wearing of goggles and gloves to protect eyes and hands is strongly recommended as a minimum precaution. The gloves must be impermeable and should be loose-fitting so that they can be pulled off quickly. Watches, rings and jewellery should not be worn to avoid that they stick to the skin in the event of rapid cooling.

- **Explosion hazards**

The volume of a cryogenic liquid increases greatly when it converts to gas. This can cause increased pressure within a tank and create the risk of an explosion.

The greatest importance should be attached in the design of cryogenic assemblies (tanks, pipes, supply pipe-lines) to the following:
- the insulation efficiency
- discharge of any excess pressure via a safety valve (see Safety Instruction No. 19 in the Flammable Gases Safety Manual).
- the strength of the materials.

Cryogenic vessels (dewars) usually consist of two tanks, one inside the other, separated by a vacuum. The vacuum acts as a thermal insulation for the inner tank which contains the cryogenic liquid. Loss of vacuum entails almost total loss of thermal insulation and hence a very rapid evaporation of the cryogenic liquid. Dewars must therefore be handled with great care.

- **Hazards associated with a change in the properties of the materials**

When materials are subjected to the extreme temperatures of cryogenic liquids, their properties change radically.

A flexible rubber hose breaks like glass after a brief immersion in liquid nitrogen.

Materials contract when the temperature decreases. If different materials are used, any difference in their contraction coefficients which could cause fissuring must be taken into account.

Some materials must not be used at low temperature since they become fragile: this is especially the case with carbon steels. Not only must suitable steels (stainless steel AISI 304 and AISI 316) be used for the cold structures, but the possibility of accidental cooling of a component normally used at room temperature on exposure to a jet of cryogenic liquid must also be taken into account.

All cryogenic apparatus must be designed and built by cryogenic experts.

Appendix 4

CERN	SAFETY INSTRUCTION	TIS IS 38

Edited by: TIS/CFM

Date of publication: 1992
Original: English

The Use of FLAMMABLE GASES in Underground Physics Experiments at CERN

1 INTRODUCTION

This Safety Instruction is intended to regulate the use of flammable gases in underground areas for physics experimental purposes. It applies on all CERN sites and is mandatory.

2 TOTAL QUANTITY

No experiment which falls into Risk Class III, according to the "CERN Flammable Gas Safety Manual", will be allowed in any underground area. This means that the total quantity of flammable gases will be limited to the equivalent of 40 kg of hydrogen, corresponding to 100 kg of saturated aliphatic hydrocarbon gases. The only exception will be when a mixture of a flammable gas and an inert gas (such as Argon) can be shown to be inert and all precautions are taken to prevent the mixture becoming flammable (e.g. by having pre-mixed gases with a certified analysis, or continuous mixing with on-line analysis and automatic shut down in case of incorrect mixing). It is understood that even in the latter case the mixing installation is in a "gas building" at the surface.

3 GENERAL REQUIREMENTS

All gas systems and detectors using flammable gases must conform to the rules and regulations of the "CERN Flammable Gas Safety Manual" and must be conceived and constructed in such a way so as to minimize the risk of leaks and subsequent fire or explosion.

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4 DEROGATIONS

Experiments proposing to exceed the maximum quantity of gas must obtain a derogation from the TIS Division Leader, who will make a decision in consultation with the GLIMOS of the experiment, the Division Leader of the experiment and the host Division Leader, taking into account the following points:

(a) proof that alternative, safer, detectors are not available;

(b) proof that the detector cannot work satisfactorily with non-flammable gases;

(c) an analysis of the proposed system, showing that its design and construction is such that the increased risk of fire or explosion is so small with respect to the overall risk that it can be accepted.

Appendix 5

Required properties for the selection of electric cables and wires with respect to fire safety and radiation resistance

PROPERTY	STANDARD	REQUIREMENTS	REMARKS
Flame and fire propagation	IEC 332-2 IEC 332-1 IEC 332-3	Pass Pass Pass	Applies to all single wires. Applies to all cables and to all single wires > 0.5 mm^2 Applies to all cables with outer diam. > 10 mm, Category CF
Fire resistance	IEC 331	Pass	For cables with special safety functions (eg. emergency lighting, alarms, lifts, etc.)
Smoke density	ASTM E 662 (or ASTM F 814) IEC 1034 - 1 and 2	$D_s < 250$ in the flaming and non-flaming modes Pass	For all cables For all major CERN cable contracts
Toxicity of fire gases	ATS 1000.001	HF < 100 HCl < 150 HCN < 150 $SO_2 + H_2S < 100$ CO < 3500 $NO + NO_2 < 100$	Mean value in ppm of at least 3 samples obtained within 4 minutes under flaming and non-flaming conditions
Corrosivity of fire gases	IEC 754-2	pH > 4 and conductivity < 100 µS/cm	Cables shall be halogen and sulphur free (less than 0.1 % by weight).
UV Resistance	IEC 68-2-5	No discoloration No stickiness	Procedure C, 10 days, 40°C
Radiation resistance	IEC 544-2 and 4	Radiation Index > 5.7	Elongation at break (ISO 37) 50% of initial value at absorbed dose of 5.10^5 Gy Test at high-dose rates (greater than 1 Gy/s).
Temperature index of sheath	BS 4066	Pass	> 260°C, No burning or glowing after T + 12s

Appendix 6

TIS CONTACT PERSONS FOR SAFETY OF LHC EXPERIMENTS

Radiation Protection	G.R. Stevenson M. Höfert
Radiation sources and Lasers	J.W.N. Tuyn
Radiation damage and high-dose dosimetry	H. Schönbacher M. Tavlet
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