ICANS-XIV
14th Meeting of the International Collaboration on Advanced Neutron Sources
Starved Rock Lodge, Utica Ill., USA

Lessons learned from the First 500 mAh of Beam on SINQ

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Abstract
First operational experience was gained at the PSI's spallation neutron source SINQ after commissioning in the end of 1996 and almost a half year of routine operation in 1997. The radiological consequences of a water cooled target could be investigated, allowing to develop measures to improve health physics conditions.

The irradiated first day target was successfully replaced by a new target with test rods for various target materials with higher neutron yield. The target storage facility and the target handling equipment was put in operation after test runs and improvements of the handling concepts.

1. Introduction

The spallation neutron source SINQ [1], [2] replaced the swimming pool reactor SAPHIR, which had provided neutrons for the Swiss and international users communities from 1957 to 1994. SINQ was connected to the proton beam line of PSI's accelerator in 1996 [3]. The accelerator has been in operation and under continuous development since 1972. An important improvement of SINQ over SAPHIR is its cold moderator of liquid D_2 in a vessel of 25 litres volume near the target in the D_2O reflector, which is viewed by a system of supermirror coated neutron guides. Data on the performance of SINQ can be found in ref. [4]. The deposition of radiation energy in the liquid D_2, allows SINQ to be run only with the cold neutron source in operation.

After commissioning and testing in the first half of the year, SINQ's first routine operational phase was from July 1 to the end of November 1997. During this period, neutron production was mainly determined by the users' demand for commissioning their instruments. It resulted in a total of 500 mAh of protons on the target.

The normal weekly operational schedule allowed about 56 hours of production of cold and thermal neutrons for various experiments. Operation time of SINQ was limited by the shut down time for accelerator maintenance problems that had arisen with a beam splitter further upstream in the proton beam, supplying PSI's cancer therapy facility with protons. This made it necessary to run low current on the accelerator to secure reliable beam delivery when this facility was used. The splitter region was completely rebuilt in 1998 and should no work with lower losses. Another

Keywords: SINQ-operational experience, Coolant activation, Change of target

limitation was the availability of operating personnel, because the control system was not yet working . Availability and regulatory restrictions did not allow unmanned operation.

Figure 1 shows the monthly integral proton current on SINQ, giving both, the scheduled and the achieved values for 1997. After the end of the major shutdown of the accelerator during the first half of 1998, also SINQ's systems will have been improved and the neutron source will be available for an extensive user programme in July 1998.

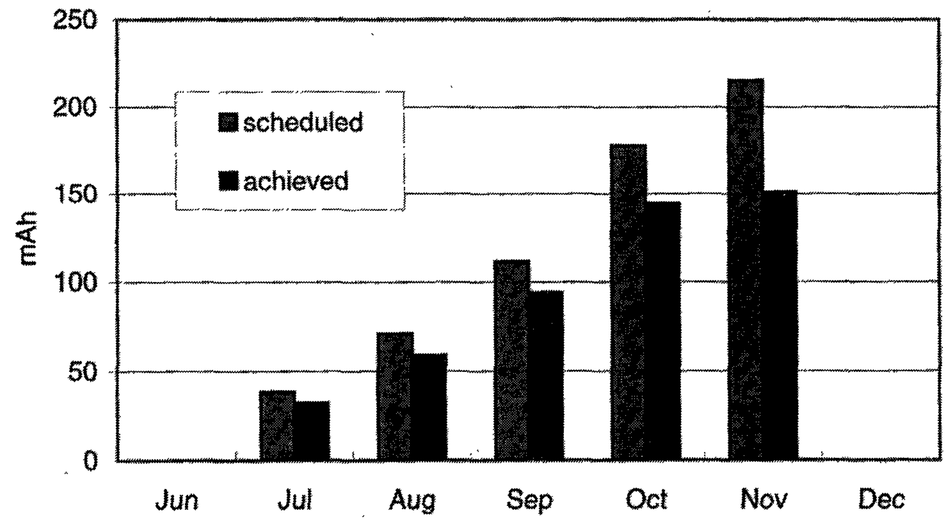

Figure 1: Integral proton current on SINQ, scheduled and achieved in the second half of 1997

2. Operational conditions of SINQ's cooling systems

The start up target is made of solid rods of Zircaloy, because of its low neutron absorption and the experience existing with this material from reactor uses. Zircaloy has, however, a relatively low neutron yield, compared to a PbBi eutectic liquid target, for which SINQ was originally conceived, but due to its low absorption, a similar neutron flux was expected as for W or Ta in SINQ [5]

The heat generated by the radiation in the target, in the target hull (window) and in the moderator is removed by separate D_2O cooling systems. The water jacket of the moderator tank and the various cooling devices of shieldings and enclosure systems in the target block are H_2O-cooled.

The most severe consequence of operating SINQ with the present solid state target is the activation of the water in the target cooling system by high energy protons and neutrons. This activation cannot be avoided with the concept of a water cooled solid target and would require a liquid metal target to improve. Anyhow the activation of the moderator and the target hull cooling water is independent from the target cooling concept.

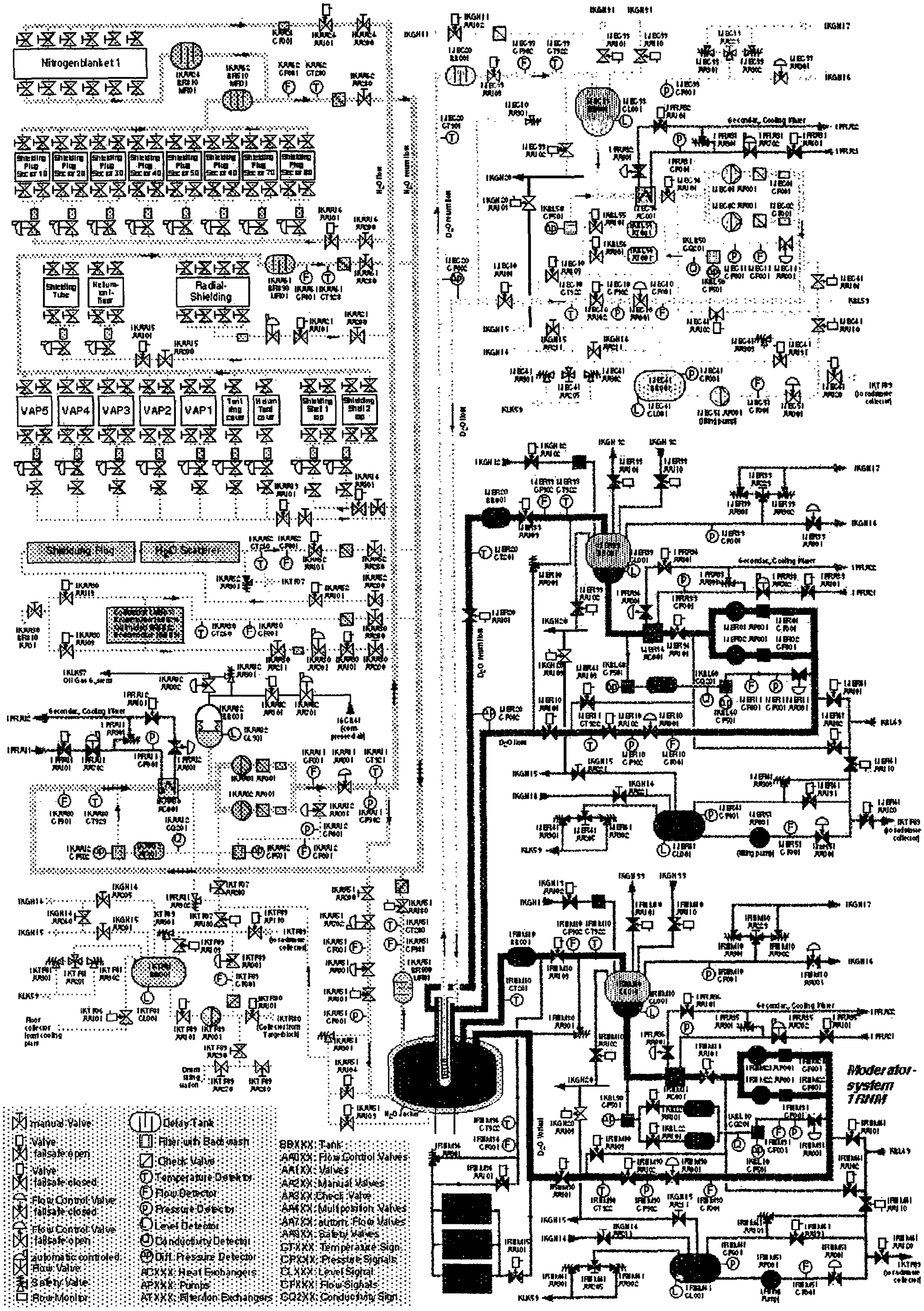

Figure 2: Overview over SINQ's cooling systems

The main characteristics of these cooling loops are given in Table 1 and a schematic diagram of the four loops is shown in Fig. 2.

Table 1: Characteristics of cooling circuits at SINQ

Cooling system / **Parameter**	**Target**	**Target hull**	**Moderator**	**Shielding**
Medium	D_2O	D_2O	D_2O	H_2O
Forward flow temperature(°C)	40	40	40	40
Return flow temperature (°C)	55	44	49	46
Forward flow pressure (bar_{abs})	7-11	7-11	3.5	4
Return flow pressure (bar_{abs})	5	5	2	2
Mass flow (kg/sec)	10-15	2	2.9	8.4
clean up bypass (kg/sec)	0.4	0.08	0.55	0.28
coolant volume (litres)	3400	460	5710	2480
Nominal power rating (kW)	650	35	111	210

During operation with full proton beam current of about 0,9 mA, the activation of the cooling water and moderator results in an average dose rate of about 1 Sv/h (100 Rad/h) in the rooms of the cooling plant. This radiation makes the rooms inaccessible during operation with beam on target and several hours after shut down and requires radiation hard materials to be used throughout the loops.

A typical time history of the dose rate in a representative position inside the cooling plant is shown in Fig. 3. An accelerator shut down of about one hour occurred before noon, and caused the drop in the curve of the dose rate history. The main activities, which cause the high radiation level during operation, are only short lived isotopes like C-11, O-15, N-13, N-11 and reach saturation after a short time. Their fast decay after shut down allows to enter the rooms of the cooling plant after a few hours. During the first periods of running this became necessary in order to take water samples from the different cooling circuits, especially from the target cooling system.

Whereas the continuous build up of Tritium, being α β^--emitter, does not contribute to the dose rate, Beryllium-7 with its half life of 53 days accounts for most of the residual radiation level in the cooling plant when it is not operated.

Beryllium-7 is a spallation product of oxygen in water and plates out on the walls of components like pipes and especially in heat exchangers, due to their large surface and temperature gradient. The bypass flow through the clean up systems is not sufficient to hold back the majority of the Be-7 before it plates out.

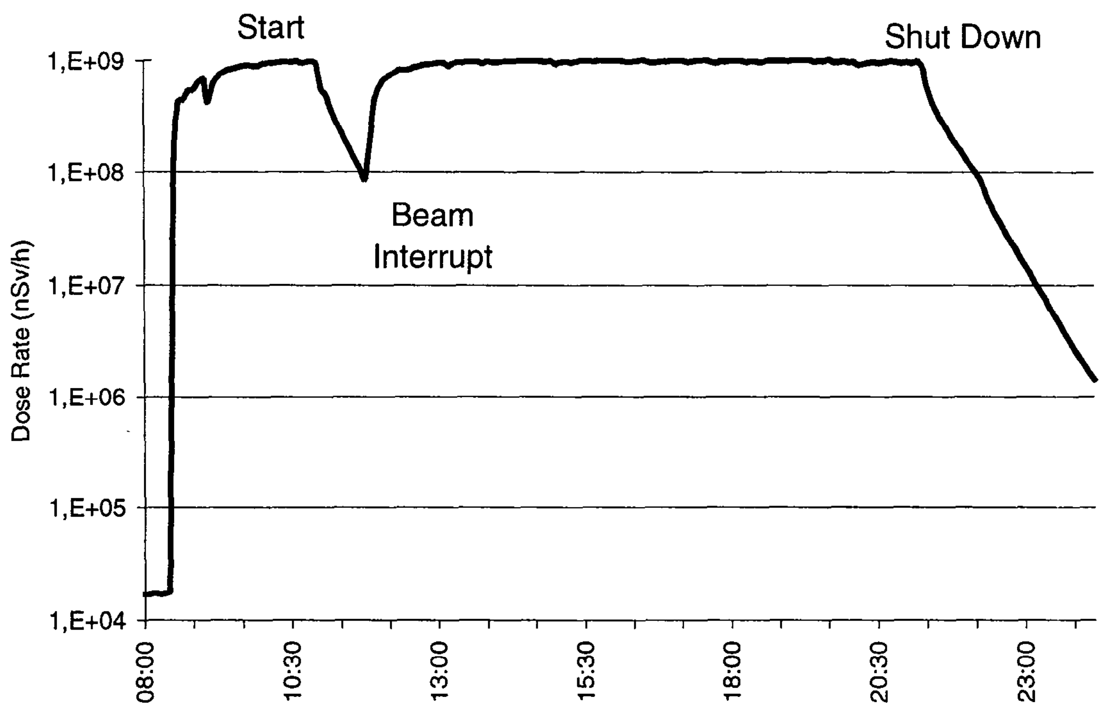

Figure 3: Dose rate in the cooling facility during two shifts of operation of SINQ

The residual activity, dominated by Be-7, increases continuously, due to the build up of activity with significantly longer half lives until saturation of these activities is reached. Such isotopes were measured in water samples from the four systems. Some typical isotopes are shown in Table 1.

Table 2: Long lived activities in the SINQ cooling loops after the end of the 1997 irradiation period. These values represent the situation in the water five days after the end of the irradiation. While showing the relative values for the loops, they do not allow to derive the true production rates for Be-7, because most of it had already plated out on the walls.

	Cooling system	**Target**	**Target hull**	**Moderator**	**Shielding**
Parameter					
Medium		D_2O	D_2O	D_2O	H_2O
Istope	**Half Life**				
3-H	12,35 a	140 MBq/kg	30 MBq/kg	2910 MBq/kg	10 MBq/kg
7-Be	53 d	1500 kBq/kg	30 kBq/kg	320 kBq/kg	60 kBq/kg
22-Na	2.6 a	50 kBq/kg			

Two days after the last operation period, the average dose rate in the cooling system room was 50 μSv/h. A maximum of 3,3 mSv/h was measured on the surface of the heat exchanger of the target cooling system. This heat exchanger will now be shielded as a measure to reduce the dose rate in the room, when SINQ is not in operation.

After a cool down period of half a year with the water clean up systems in operation, the cooling systems were emptied into their dump tanks. Almost no activity was found in the dumped water, except for the Tritium. A increase of the dose rate level was registered in the rooms of the cooling plant after draining the water, because the Be-7 plated out in pipes and heat exchangers was not shielded any more by the water in these components (Fig. 4).

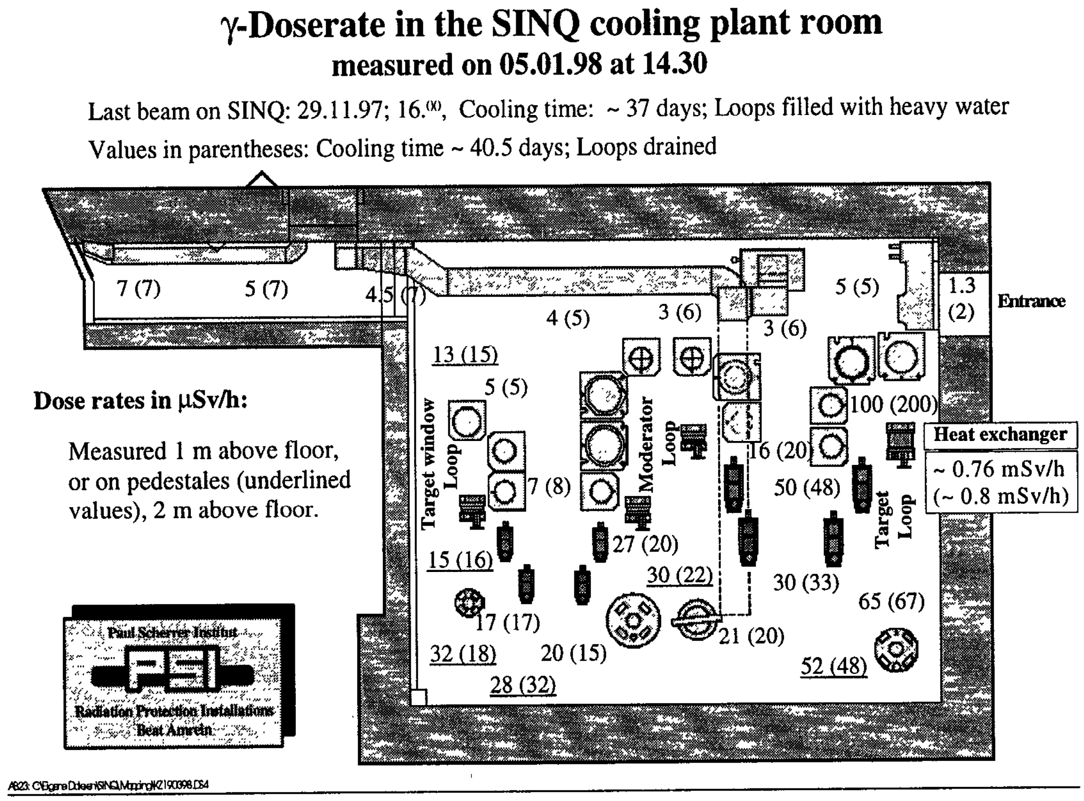

Figure 4: Dose rate levels measured at various points of the SINQ-cooling plant room nearly 1000 hours after SINQ had been shut down for the 1998 maintenance period before and after (in parentheses) draining the cooling loops.

It can be estimated that the equilibrium dose rate from Be-7 in the cooling plant room of SINQ will be about 10 times higher than those given in Fig. 4. Because of the expected increase of the residual dose rate, a sample taking system will be installed, which allows to take water samples from the target cooling loop during operation. This is important for the surveillance of the target integrity since almost no other indicator exists for a degradation of the target.

3. Exchange of the target

The first solid Zircaloy target used has been exposed to a total of 500 mAh of beam only, but was removed for inspection and examination during the next operation period in order to check for any radiation damage on target material and target window as part of the SINQ target development programmes [5].

The new target is basically of the same design as the previous one, but incorporates temperature measurements in selected Zircaloy rods and several test rods for the development of the next target with higher neutron yield but based on the same general design as of the present target type [6].

The target exchange flask design is derived from a refueling machine of a reactor. Since its shielding should be adequate for solid and liquid targets alike, the strongest shielding is in the bottom region at the level of the target material of a solid target. The top end of the flask has a connector to the 60 ton payload crane of the SINQ-target hall.

After drying the target insert and removing the upper shielding from the target block, the piping was disconnected from the top flange of the target insert and was plugged. During this phase a temporary lid with rubber lips closes the gap between the flask and the opening of the target head room. By extracting the air from the target head room into the ventilation system of the target block, an effective air lock was established.

With the ventilation system in target exchange mode, the adapter to the target exchange flask was installed and the flask was docked on to the target head. The 4,5 meter long target insert was then pulled into its transport jacket inside the flask with the flask's own hoist. With the shielding gate at the bottom end closed, the flask was lifted to the target storage pit in the target hall.

After docking the flask onto an adapter on top of the storage position, the shielding gate could be opened and the target was lowered into its storage pipe. An air lock is established by a hose, extracting air from the inside of the adapter into the radioactive offgas system.

The sealed storage position was filled with inert gas at a pressure lower than atmosphere, allowing surveillance of the enclosure. Furthermore, temperatures and humidity inside the enclosure are continuously monitored.

The spent target will be transferred with the target exchange flask from the storage pit into a hot cell for dismantling during the next operation period. Whereas the shielding plug of the target insert can be reused, the target will be prepared for final storage after removal of some of its rods for post irradiation examination. To this end the target will be placed in a steel container and embedded in molten lead-bismuth, which, after solidification, provides safe enclosure for final storage.

Samples from the Zircaloy rods of the target and the target hull material will be taken to the hot lab for investigation.

4. Conclusions

The experience from the first five month of SINQ operation confirmed the validity of the design and operation concept. Improvements will be made by installing a water sampling system and some additional shielding in the cooling plant room.

Filters and ion exchangers will be modified in the next shut down period for better efficiency. The fractions of the ion exchange resins will be increased to lower the pH value. A coarser filter mesh will be used to increase the bypass flow through the purification system.

The implementation of a new PC-based process control system is now complete and will allow unmanned routine operation 24 hours per day with an operator on duty for day time service and checks only. The new control system will allow remote monitoring and surveillance by a service engineer, which is on call 24 hours a day.

With these measures in effect, SINQ's availability will hopefully be, , determined exclusively by the availability of the accelerator. The anticipated running time is about 5000 hours/year.

5. References

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