CANS@NUTECH-RISOE

Contributions and comments from WG3: Industrial applications, Isotope production and Neutron Activation Analysis (Compiled by Søren Pape Møller & Mikael Jensen)

1 Possible applications of a CANS at Risø.

The workgroup number 3 from the CANS workshop at Risø in November have looked at the possible "other applications" of a compact accelerator driven neutron source at Risø. "Other" in this context taken in the meaning of "apart from neutron scattering and neutron scattering instrumentation applications". Within this scope comes a broad range of neutron applications, including isotope production, other medical and industrial applications, neutron activation analysis, neutron imaging and neutron induced radiation damage.

From the outset it was clear, that these "other applications" alone cannot alone justify a new large experimental facility, but have to be seen in the context of a combined use.

Three fundamental parameters of a future CANS are of importance to all the applications: The total neutron production rate, the energy spectrum of the neutrons provided and the time structure of the neutron flux. To facilitate the discussions below these three framing parameters may initially be described as follows:

Neutron production rate:

The total neutron production rate of a CANS is inherently coupled to the beam intensity (current) and beam energy. While spallation sources (as ESS) can make many neutrons per incident proton, any CANS beam has a low (less than 1E-3 neutron/ proton) yield[1] . CANS facilities can offset this low probability by using higher beam currents, but only to a limited degree, because the stopping length of a low energy beam is much shorter than for particles at spallation energies. Ultimately, the total neutron yield becomes limited by the beam power that can be removed from the target. The neutron yield situation can be illustrated by some practical figures:

Electrostatic linear deuteron (D-D or D-T) 0.1-0.3 MeV 1 kW	1E8 n/s
RF driven deuteron or proton Linac with Be target 3 MeV 1 kW	1E10 n/s
Cyclotron driven proton beam on O-18 water 8 MeV 0.32 kW	1E11 n/s
Cyclotron driven proton beam on O18 water 16 MeV 1.1kW	1E12 n/s
Cyclotron driven proton beam on Ag+Ta 30 MeV 10 kW	5E13 n/s

The 8 and 16 MeV cyclotron solutions already run at Risø and the neutron yields are experimentally verified, but these machines are dedicated now for other purposes.

[1] For low beam energies (< 5 MeV) deuterons are more efficient than protons in producing neutrons, but the deuteron accelerator is more difficult to build.

The neutron spectrum:

All accelerator driven neutron sources produce the neutrons as fast neutrons. The deuteron driven reactions give a large contribution of neutrons at very high energy (14 MeV) and the spallation route gives a tail of very high-energy neutrons (> 1GeV). The medium energy proton solutions (8-100 MeV) are dominated by compound nuclear reactions and give a broad evaporation spectrum of neutrons peaking around 3-4 MeV.

Fast neutrons are normally not useful (except perhaps for radiation damage experiments) and any CANS must have a moderator/reflector system around the target. Water, Heavy water, Graphite and Beryllium are good materials for moderation, but the optimal design of moderator depends much on both the target and the desired use. As a rule of thumb a thermal flux (in n/cm2/sec) two orders of magnitude lower than the neutron production rate can be reached about 20 cm from the target and in a volume of a few litres.

Based on NUTECHS experience in neutronics and the optimisation of the moderator-reflector for ESS, it is possible that better neutron moderation performance could be achieved with a new NUTECH installation.

Optimising the useful neutron yield for a given CANS configuration and application is seen as an important research topic by itself.

("A factor of 10 increase compared to existing CANS would be ambitious but that we should aim for!") – (MIKAELS comment: I think we could easily promise a factor of 2 – by designs that take the angular distribution into account. A factor of 10 I do not think is possible, - except by going to the high power 30 MeV targets.)

The time structure:

Some applications (scattering, instrumental neutron activation) must have pulsed neutron beams to give best results. Unless the accelerator itself is pulsed the chopping of the accelerator beam and /or the neutrons are very lossy processes and reduce the average flux by orders of magnitude. Pulsed accelerators with few percent duty cycle but high power output are normally linear. Cyclotrons do not easily lend themselves to pulsed operation in the desired 1-10 msec range. The thermal stress of the target also becomes a practical limiting factor for high-power beam bunching. Further comments on accelerators and aspects thereof can be found in section 2.

Isotope production, normal neutron activation analysis and neutron imaging do not benefit from pulsed beams. A parallel application of the CANS driving accelerator for isotope production will require normal "CW" beams to avoid the limits of thermal stress in the target.

1.1 How does a CANS compare to other neutron sources.

To establish a baseline for industrial, medical or analytical applications, it may be instructive just to compare the total neutron yield between various well known neutron sources:

- Niels Bohr's 50 year birthday present : 1 gram Ra-226 blended with Beryllium 1E6 n/s
- Modern isotope neutron sources (Cf-252 or Am-241/Be) 1E8 n/s

- D-T or D-D table top neutron generator 1E9 n/s
- Proposed neutron scatter centre in Bilbao (p on Be)[2] 1E15 n/s
- Small research reactor (TRIGA design) 5E15 n/s
- Former DR3 reactor Risø 5E17 n/s
- ESS design 1E18 n/s

A possible CANS system at Risø could have anything between 1E11 and 5E14 n/s while still using existing, well proven technology. For most applications, it is however not enough to focus on the total neutron yield. Also the source volume, the possibilities for thermalizing and directing the neutrons, the necessary distance to points of use and, not least, the possibilities for shielding the target and accelerator towards instruments and users must be considered.

The development of optimal moderation and reflector designs and a flexible user environment can be seen as a very important development possibility for a new CANS at Risø.

1.2 Non-scattering applications

The remainder of the report from WG 3 is concentrated on possible applications not involving the direct use for neutron scattering applications. As some framework must exist to describe what is reasonably possible the following conservative assumptions have been made concerning achievable neutron fluxes at a new facility. These figures are based on a CW yield of “evaporation neutrons” at 1E14 neutrons:

- Thermal flux achieved at 40 cm from target, useful volume 1-2 litres 1E12 n/cm2/s
- Epithermal component at same position 1E11 n/cm2/s
- Fast neutrons (1-6 MeV) 20 cm from target 2E10 n/cm2/s
- Neutrons for imaging , derived from a thermal target at 30 cm 8E10 n/sr/s
- Thermal flux for homogeneous irradiation of extended sources 3E10 n/cm2/sec

In contrast to a normal reactor, these fluxes will only be available during “beam on” conditions. Normal operation schedules (and power costs) may well limit this to 8 hours per day and 4-5 days per week unless special applications can justify the cost of extended operation.

The “non-scattering applications” discussed or identified in the workgroup can, with some overlap, be described by the following headers:

1. Isotope production using the neutrons
2. Isotope production using the driving accelerator beam (protons)
3. Neutron Activation analysis (NAA) and Instrumental neutron activation analysis (INAA)
4. Prompt gamma activation analysis (PGAA)
5. Neutron Imaging and neutron tomography
6. Material modifications using thermal neutron capture
7. Materials damage using fast neutrons

[2] F.Sordo et al,"Baseline design of a low energy neutron source at ESS-Bilbao" Physics Procedia 60 (2014) 125 – 137.

1.2.1 Literature sources to the above applications

The present report is just a very broad overview of the possibilities for these applications. The input to application points 1 and 2 come directly from the work group participants. Valuable background material can be obtained from the authoritative review:

“The uses of radiotracers in the life sciences” by Tom Ruth (TRIUMF, Vancouver, Canada) Rep. Prog. Phys. 72 (2009) 016701 (23pp) and the extended report from NUPEEC (Nuclear Physics in the EEC) (2014) “Nuclear Physics for Medicine”.

The other applications (except number 6) and their possible utilisation at a CANS are extensively covered by the following IAEA reports:

Technology Reports number 1 (2012) "Neutron Generators for analytical Purposes", and

TECDOC-1153 (2000) "Use of accelerator based neutron sources"

1.2.2 Neutron driven isotope production.

Compared to a normal research reactor, the thermal flux in the proposed CANS is typically two orders of magnitude lower. While isotope production is still possible with high resulting activity, it is only achievable with the use of large targets, thereby inducing a low specific activity for the most commonly used (n,gamma) product isotopes. For all medical applications, and most other biomedical use, a high specific activity is of prime importance. For present, the *routine* medical isotope production at this CANS can be dismissed, and only in rare cases can some early development work benefit from such a source.

New production routes and the fundamental radiochemical and radiobiological properties of hitherto unexploited isotopes may still be important research goals in the medical realm of such a facility.

For industrial and environmental use, the specific activity is normally not an issue, and here a local isotope facility can be useful. NUTECH has a viable economically important routine production and delivery of Br-82 (35 hours half-life) for use as an industrial tracer for leaks in central heating installations and process plants. The present Danish use is a long term survival from the DR3 reactor days and is presently upheld by NUTECH through the use of irradiations at a Norwegian reactor (Kjeller north of OSLO, JEEP-II with a flux of 1E13 n/cm2/sec). This foreign production method is expensive and logistically difficult. Furthermore, the long term use of JEEP-II and indeed any other nearby reactor is threatened by the foreseeable end of lifetime shutdown of these reactors.

The necessary quantities of low specific activity Br-82 can be produced by a CANS with 5E11-1E12 thermal neutrons /cm2/sec. This represents at present a production cost (a potential income) of about 1 million DKK/year. A new CANS facility would also allow the re-introduction of Na-24 and I-128 as industrial flow and leakage tracers.

Finally it would be possible to supply nearby researchers (Risø campus) with an array of otherwise inaccessible short-lived tracers for research purposes. (Al-28, Si-31, Cl-38, K-42, etc).

1.2.3 Proton driven isotope production.

Any CANS will need a powerful particle accelerator, and most likely a proton machine. Many relevant and many economically viable medical isotopes can be made as parasitic or parallel production on any proton accelerator from 20 to 100 MeV. The necessary beam current will normally be lower than needed for the neutron source (because isotope production targets are often beam-power limited), and a completely parallel proton driven isotope production will be possible together with a CANS, if the accelerator has more than one concurrent beam output.

A further discussion of the medical justification and the market value of such isotopes are beyond the scope of this report. For the current purpose, it may be enough to point to the 271 day half-life generator isotope Ge-68 (the daughter Ga-68 is used for clinical PET imaging) that has ever growing need and unfilled manufacturing world-wide capacity. Routine production of Ge-68 by irradiation of liquid gallium targets at 30 MeV is not easy, but NUTECH has the technology to do it. It may provide a substantial and steady income for the CANS accelerator operation.

One other potential medical product deserves to be mentioned: Ac-225, which can be derived from proton irradiation of (radioactive) Ra-226 targets. Ac-225 has many desirable characteristics for a future internal alpha emitter radionuclide therapy. The worldwide supply is very limited for reasons closely coupled to nuclear non-proliferation agreements. At the same time, the good medical use of Ac-225 is being demonstrated in many clinical trials. The production from Ra-226 is seen as too technologically demanding and radiologically dangerous for both standard medical isotope producers and hospitals. Here, Risø may be the best of all places to establish such a production. Again, this could give a long-term income to the CANS facility as whole.

1.2.4 Neutron Activation Analysis.

Neutron activation analysis, discovered in 1936, is still at the forefront of techniques used for quantitative multi-element analysis of major, minor, trace, and rare elements, despite the rapid modern evolution of PIXE, ICP-OES and ICP-MS. The most important advantage of NAA over other methods is the total independence of chemical matrix effects and the ability to measure large, bulk, and un-altered objects non-destructively. NAA allows the measurement of ~60 elements in small samples. The lower limit of detection with the neutron fluxes obtainable at a good CANS as described, is of the order of parts per million to parts per billion depending on the analysed element and the activity of the bulk sample matrix.

The principle involved in neutron activation analysis consists of first irradiating a sample with neutrons to produce specific radionuclides. After the irradiation, the characteristic gamma rays emitted by the decaying radionuclides are quantitatively measured using gamma spectroscopy, where the gamma rays detected at a particular energy are indicative of a specific radionuclide's presence. Data analysis then yields the concentrations of various elements in the samples being studied. The analysis is normally done by comparison with result from a similar irradiation of multi-element standards (relative method). The following table provides a list of elements that may be quantitatively analysed using neutron activation analysis:

Sensitivity (ppb)	Element
5	Dy, Eu
5-50	In, Lu, Mn
50-500	Au, Ho, Ir, Re, Sm, W
500-5000	Ag, Ar, As, Br, Ca, Cl, Co, Cs, Cu, Er, Ga, Hf, I, K, La, Mg,Sb, Sc, Se, Ta, Tb, Th, Tm, U, V, Yb
$5000\text{-}5x10^{4}$	Al, Ba, Cd, Ce, Cr, Hg, Kr, Gd, Ge, Mo, Na, Nd, Ni, Os, Pd, Rb, Rh, Ru, Sr, Te, Zn, Zr
$5x10^{4}\text{-}5x10^{5}$	Bi, P, Pt, Si, Sn, Ti, Tl, Xe, Y
$5x10^{5}\text{-}5x10^{6}$	F, Fe, Nb, Ne

NAA can be used for a large variety of applications; the following represent some examples for scientific uses in different disciplines:

• Archaeology and Art
  - Sourcing of dyestuff, pigments, clays and pottery- non-destructive and non-invasive testing is here of primary importance. A special advantage of a CANS is the access to neutrons outside the normal confinements of a reactor core.

• Biology
  - Toxins in Fish and agricultural products,
  - Trace elements in oil and lipids,

• Chemistry
  - Contaminants in salts, pure crystals and metals

• Engineering
  - Composition and contaminants in metals, alloys, ceramics, thin film deposits and plastics

• Forensics
  - Analysis of crime scene materials (hair, soil paint, glass, metals)

• Geology
  - Sourcing and composition of igneous rocks, sediments and basalts
  - Elemental components analysis for geochemistry investigation

- Medicine
  - Toxins and trace elements in hair, skin and nail samples

- Environment
  - Screening of large volume waste streams for heavy metals.
  - Pollution of heavy metals and toxic elements in the environment (soil, vegetation, sediment analysis)
  - Air pollution (element component of aerosol, sourcing of the air pollution.

The NUTECH group at Risø stems partly from a very active and internationally recognised NAA group. Much of the expertise still exists, although all practical work on NAA abruptly stopped by the shut-down of the DR3 reactor in 2000. The inherent detection limit of NAA can be improved further by radiochemical pre- and post-irradiation chemical processing of the samples. This capability is maintained at Nutech.

1.2.4 Instrumental NAA and Prompt Gamma NAA

Both these methods are extensions of the standard NAA. With pipeline “rabbit” access to a stable neutron flux area it is possible to retract the analytical sample and start the gamma counting immediately after irradiation, thereby extending the number of elements that can measured. Prompt gamma detection is a further extension of the NAA method, whereby the sample is analysed by gamma spectroscopy during irradiation. A CANS is excellently suited to this purposes, but it requires that moderator and shielding is optimised for the purpose. Prompt gamma detection NAA (PGNAA) is difficult both in reactor environments (radiation dominated by the inherently large number of fissions and fission product decays taking place) and at spallation sources (because the background is confounded by the fast spallation neutrons).

Light element (CNO etc.) analysis in hard materials is often done by PGAA and INAA. An important and illustrative example presented to the workgroup is the industrial analysis of steel samples performed at Hokudai University in Japan. As sample size is not critical, a moderate neutron flux (1E4 neutrons/cm2/s) is sufficient to give precise result. While Denmark has little steel industry for which this could be important, other Danish bulk manufacturing industries (ceramics, catalyst beds, concrete, composites) may be interesting collaboration partners.

1.2.5 Neutron radiography (imaging) and tomography.

Similar to x-ray radiography, neutron radiography is a very efficient tool to enhance investigations in the field of non-destructive testing as well as in many fundamental research applications. Neutron radiography is, however, suitable for a number of tasks impossible for conventional x-ray radiography. The advantage of neutrons compared to x-rays is the ability to image light elements (i.e. with low atomic numbers) such as hydrogen, water, carbon etc. In addition, neutrons penetrate heavy elements (i.e. with high atomic numbers) such as lead, titanium etc. allowing the study of materials in complex sample environments, for example water accumulation in hydrogen fuel cells. Moderate neutron fluxes are needed in cases where time resolution is not critical, and such applications may well fit into a CANS environment where large samples can be subjected to imaging setups. This could include routine neutron radiography of large industrial components for inspection of welds. Fuel cell manufacturing and oil reservoir research are seen as potential users. Examination of material stress and material failure under stress may be other possible applications, possibly also to the Danish wind power industry.

A more difficult application of neutron radiography is the quantitative imaging in real time of liquid flow (water, hydrocarbons) by neutron imaging. This cinematographical approach requires high flux and is at present dominantly carried out at large neutron source facilities (SINQ at PSI is an example). A moderate CANS at Risø may be too small for this purpose. For some elements (Nitrogen, fissile materials, somelanthanides) the inherent signal may be so strong that real time imaging does become possible even with a CANS. Much international effort is put into the use of neutron radiography for security scanning in the transport sector.

1.2.6 Material modifications using thermal neutron capture

Materials modifications with neutrons includes in particular doping of Si, which is an important area for Topsil. Topsil was for many years a valuable customer for Risø and may again be interested in a local neutron irradiation environment. In this application the main use is routine modification of material in bulk. Large irradiation volumes and large neutron fluxes were used at DR3. No CANS facility can provide this, and cannot compete with existing foreign reactors. However, for special applications and for development purposes, Topsil has expressed interest in using fluxes around 1E11-1E12 thermal neutrons /cm2/sec. A clean spectrum with relatively low abundance of fast neutrons is within reach of a CANS, and space for flux homogenisation by sample rotation will be easily available, but the needed irradiation time to achieve necessary impurity level is relatively long compared with the envisaged operation schedule. This industrial field deserves further investigation before a source and moderator design is settled.

1.2.7 Materials damage using fast neutrons

The relatively high near-field flux of very energetic neutrons (0.5-6 MeV) in the envisaged CANS moderator is powerful and penetrating source of materials damage. It may be of interest to both electronics manufacturers and telecommunication industry for assessing the long-term radiation bit-upset rate of critical components, and research institutions may likewise have occasional use of testing space components under the conditions.

More extensive materials damage studies of hard materials of relevance to ITER, Fast Reactor or ESS upgrade design) will require long irradiation time and is probably outside the scope of a CANS. Radiation damage of polymers and biological material is a more likely research application of such facility.

2 Requirements to the accelerator of a CANS facility

In the following, we shall discuss some aspects and parameters of the accelerator for a CANS facility in Denmark. We shall not compare and discuss all variables, and specifically have a proton accelerator in the tens of MeV in mind, although some aspects of other accelerators will be mentioned.

The two most important parameters, or requirement, of a CANS accelerator are the particle type and the beam power. We shall assume a not too low energy, above some MeV's. Once the accelerator and its parameters are chosen, one will have to optimise the neutron moderators for the neutron experiments/beamlines. A general question relating in particular to the experimental techniques used in the planned research, is here whether a short (micro-seconds) pulsed particle beam is needed or just beneficial for some scattering experiments, or whether a long-pulse (milli-sconds), even CW, accelerator could be sufficient for most experiments. The point is here that a pulsed source requires a significantly more complicated and expensive accelerator. The two facility archetypes are at high energy/power the short-pulsed sources, like ISIS in UK and SNS in US, based on an accelerator with beam pulses around 1 µs, and the long-pulse or DC sources based on accelerators with pulses from 1 ms to DC like the PSI facility in Zürich and ESS being built in Lund.

2.1 Requirements and possibilities for accelerator

In the present section, we shall outline some of the parameters needed to select the choice of accelerator in the CANS facility. However, we shall first briefly outline the present experience in Denmark based on the:
● PT-600 accelerator operated by Mikael Jensen at DTU-Nutec at the Hevesy Laboratory for isotope production. Here a beam of 35-50 µA of 7.8 MeV protons (H-), with a short beamline is irradiated on 3 targets, providing up to 10^{11} n/s.
● PT-800 cyclotron (16 MeV protons) is producing 100 µA beam current on an O-18 water target, which provides up to ~10^{12} n/sec. With a D_2O moderator up to 10^{10} n/cm2/sec thermal flux can be produced.

Particle type: The obvious particles to be used in a CANS accelerator are protons as soon as the energy is above 10 MeV. At lower energies, deuterons has the benefit of producing neutrons also by direct reactions but these neutrons are normally more energetic and difficult to moderate and shield. From the isotope production point a view (using the primary accelerator beam) protons are also to be preferred.

Proton energy: The question of the necessary proton energy is mainly a question about cost. In the high performance area, the optimal lies around a few GeV for protons, cf. SNS, ESS and ISIS discussions. In the low energy-regime, << GeV, limited by expected possible funds ~100 MDKK, the number of emitted neutrons increase relatively slowly with the product of particle energy and beam current. Other aspects relate to shielding, handling of targets and in general operational ease (remote handling).

Particle energy: In the cost range mentioned above, one would consider energies of tens of MeV. Unless such a machine should be considered as a development project, for e.g. DANFYSIK, the cheapest and easiest way would be to opt for a commercially available cyclotron like the IBA cyclone 30 “industrial”, 30 MeV, 350-500 µA, accelerator capable of delivering ~10^{14} n/sec. Price estimate?

Time-structure of the particle beam is directly related to the use of the neutrons: is a short-pulse (µs) necessary OR is a DC or quasi-DC (ms) beam sufficient for most uses? See next paragraph.

Accelerator type: Existing CANS facilities are mostly based on accelerators built previously for a different use. Hence, these accelerators are diverse like DC accelerators, RFQ’s, cyclotrons, LINACs. The accelerator with the highest performance, and flexibility, would be a LINAC with some sort of injector like an RFQ. This is probably unrealistic in the present context, and a commercially available cyclotron would be the choice.

Although such an accelerator can provide relatively large beam powers, kW to tens of kW, the beam will be DC-like corresponding to the rf frequency of the cyclotron.
Long ms pulses can be provided from a CW cyclotron, at the expense of lower total beam powers. If a short-pulse neutron beam is requested, mainly two alternatives exist. One is a multi-turn injected synchrotron like ISIS but at lower energy, but here the space charge will prohibit beam powers in and above the kW range. The alternative is the use of a buncher/accumulator/collector/compressor ring to transform a much cheaper DC accelerator, like a cyclotron, into a short-pulsed beam. In this case, one would probably opt for a H- beam, instead of protons, which facilitates multi-turn injection into the ring. This second choice is used at the SNS and was discussed extensively in older versions of ESS. However, at the ESS it was realized, as now to be exploited at the ESS, that long-pulses, milli-seconds, for many experiments are competitive to short-pulses like ISIS and SNS.
If short pulses are deemed necessary, this discussion about compressor rings clearly has to be elaborated. As beam will only stay in the ring during the ~1000 turns of injected beam, only a moderate vacuum pressure is sufficient. Such low-energy rings have not been built for this purpose, but has (!) been built in this energy range for atomic/physics experiments.

2.2 Requirements to Neutron beam and discussion about target

1. Possibilities and selection of target
2. Time-structure: is a pulsed beam really needed, or is a (quasi?) DC beam sufficient. An accumulator/collector ring might be needed, see above.

Scattering experiments like SANS can advantageously exploit pulsed beams although facilities like ESS shows that many experiments can be made by quasi-continuous sources!

Maybe a significant factor, ~10?, can be found by optimizations of moderators and coupling to instrument (statement at CANS workshop).

For the SANS beamline at Hokkaido, 10^5 n/cm2/s at the target is obtained. This beam operates at 50 pps. Beamline costed 20 MDKK (source: Masato OHNUMA). Steel industry in a main user; probably not relevant in DK.

3 SWOT analysis

(headlines only):

Strengths:

Close collaboration with ESS, much neutronics expertise already assembled at Nutech because of ESS and Hevesy Lab, ideal timing, DTU interest in being portal for neutron scatter use at ESS, much previous experience at DTU and DTU-Risø in neutron detection, neutron scattering instrumentation. A close synergy with existing and future isotope production

Weaknesses:

The obtainable *thermal* neutron flux is somewhat low for most of the standard neutron applications (NAA, small angle scatter, imaging) and completely insufficient for state-of-art standard neutron scattering (as performed at future ESS). Routine production of medical isotopes using the thermal neutron flux from this CANS is not achievable due to the requirement of high specific activity. The facility is comparatively costly (70-100 million DKK) and may be seen as a diversion of otherwise limited resources for the ESS.

Opportunities:

Has the possibility of reassembling a strong neutron user collaboration again in Denmark with strong implications for both training and education as for future research. This holds true also for the underlying fields of experimental physics (accelerators, large radiation facilities, detectors). A new NUTECH CANS design phase may identify important improvements to current neutron source capabilities. Isotope production using the proton beam in parallel from the accelerator could provide highly needed medical isotopes.

Threats:

Too widely dispersed group of stakeholders, competition with other large facility groups at DTU or in Denmark as a whole. Risk of adverse public perception of a new large "nuclear" facility in Denmark/ at Risø.

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