

AIVI

Biofilm Monitoring System

- ✓ **Early detection of bacterial growth on surfaces**
- ✓ **Monitoring & optimization of sanitation treatments**

Developed in collaboration with



**National Research Council
Institute of Marine Sciences**



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1. Industrial biofilm & biofouling

Microbial biofilm, the most important component of (micro) biofouling, represents a serious technological issue, in particular where water is a critical process element.

For instance, in a heat exchanger system, a major component of any power plant, a 20 microns thick **biofilm** can cause a 30% decrease in thermal efficiency: biofilm, indeed, is up to 4 times more insulating than calcium carbonate scale. Moreover, biofilm can increase inorganic fouling, producing sticky substances that increase particles adhesion, and paves the way to the settlement of larger organisms, the usually called **macrofouling**. Such organisms can constrict water flow, thus increasing energy consumption, in order to compensate for the reduced pipeline diameter. These problems can eventually lead to pipeline blockages and plant stopping.

Besides, biofilm is responsible for microbiologically influenced corrosion (MIC), which accounts for multi-billion dollars worth of damage in industrial facilities all over the world.

Biofilm life cycle

Since late '70s, extensive researches have been carried out on the complex biofilm biological and biochemical structure, but many aspects of its formation are still under study. Nevertheless, considering a liquid environment, it is possible to divide biofilm life cycle in three different phases:

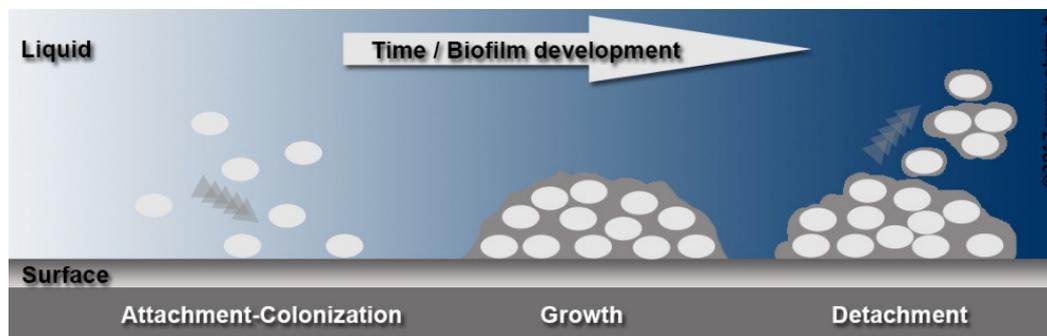


Fig. 1: Biofilm life cycle

1. **Attachment-colonization**. In this phase the first bacteria (known as “pioneers”) attach to the surface, coming from the liquid bulk.
2. **Growth**. Pioneer bacteria start multiplying in a sessile phase and spread, covering the available surface. Bacteria-formed colonies grow into complex three-dimensional structures, covered by extracellular polymeric substances (EPS), which shelter them from external attacks (such as biocides or antibiotics).
3. **Detachment**. The biofilm reaches, eventually, a pseudo-equilibrium condition, where outmost layers tend to detach under flow mechanical stress, and float away. This further increases the likelihood of biofilm formation in other sections of the line, with respect to the simple presence of planktonic bacteria (free in the liquid phase).

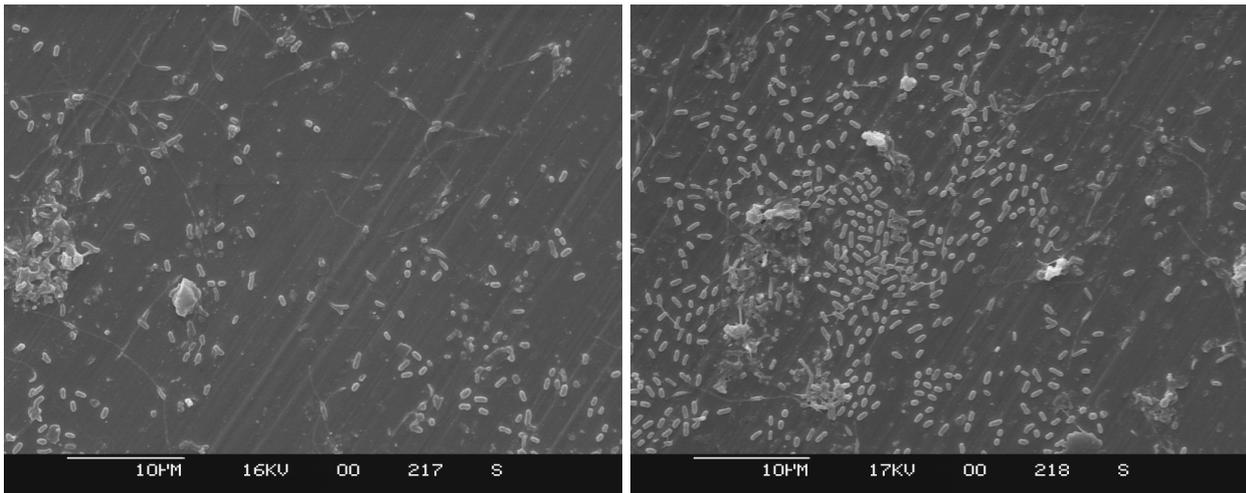
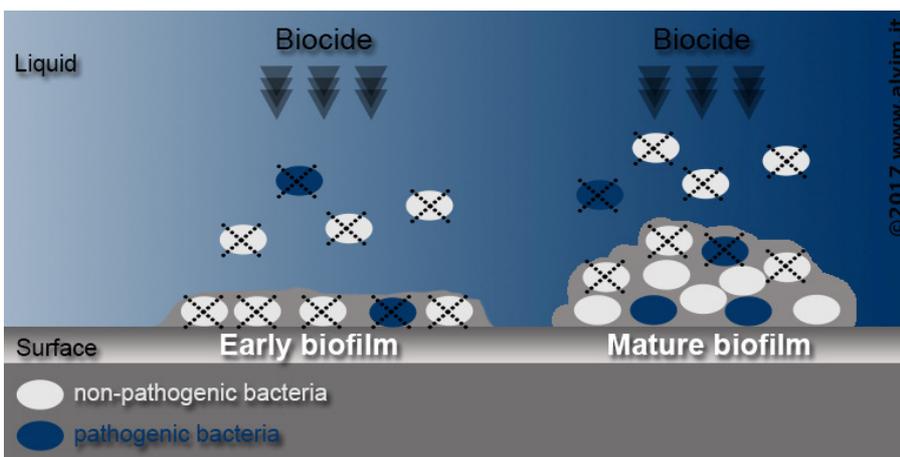


Fig. 2: SEM images of increasing surface coverage by early stage biofilm

Let us remark how difficult and expensive can be, both in terms of biocide concentration and contact time, to deal with a biofilm in phase 3, with respect to a phase 1-2 biofilm. As a matter of fact, since the first growth of the EPS matrix, biofilm resistance to external agents can increase by three order of magnitude (x1000). This means that, when a sanitation treatment (e.g. a biocide) is applied:

- if biofilm is in its early phase (Fig. 3, on the left), it can be completely removed;
- if it is a mature one (Fig. 3, on the right), it is much more difficult to completely destroy it.

In the first case, after the treatment biofilm will need a longer time to grow again, while in the second case, since there will be still alive bacteria, it will regrow quickly.



It is often very difficult to predict which conditions will boost biofilm growth. Such phenomenon can be influenced by many different factors, such as temperature, season, pH, dissolved oxygen, presence of chemicals, etc.

Fig. 3: Effectiveness of biocide treatments on different phases of biofilm development

The considerations listed above justify the massive industrial interest in new sensors and technologies able to detect biofilm formation, and monitor its very first growth. Such technologies can be effectively applied in many industrial fields, from power plant heat exchangers to cooling towers, from food & beverage production to reverse osmosis desalination.

Biofilm detection methods

Many biofilm detection methods were proposed so far, but we shall describe two main effective approaches to biofilm real-time monitoring in industrial environments:

- indirect methods based on (usually thermal or mechanical) efficiency measures;
- direct methods based on detection of the electrochemical activity associated with biofilm growth.

The first approach estimates biofilm growth measuring the variation, induced by fouling, of several (mechanical or thermal) parameters. This kind of approach cannot detect a layer thinner than 30-40 microns, therefore allows only the detection of mature biofilms (see Fig. 4).

Moreover, the sensors based on this kind of approach cannot discriminate between biofilm and other kinds of fouling, such as scaling (mineral deposit).

On the other hand, it is very important to act as early as possible against biofilm, possibly in the very first stages of growth, with suitable sanitation treatments (chemical, thermal, UV, etc.), in order to find the optimal trade-off between efficacy, costs and plant protection. This is possible using electrochemical sensors.

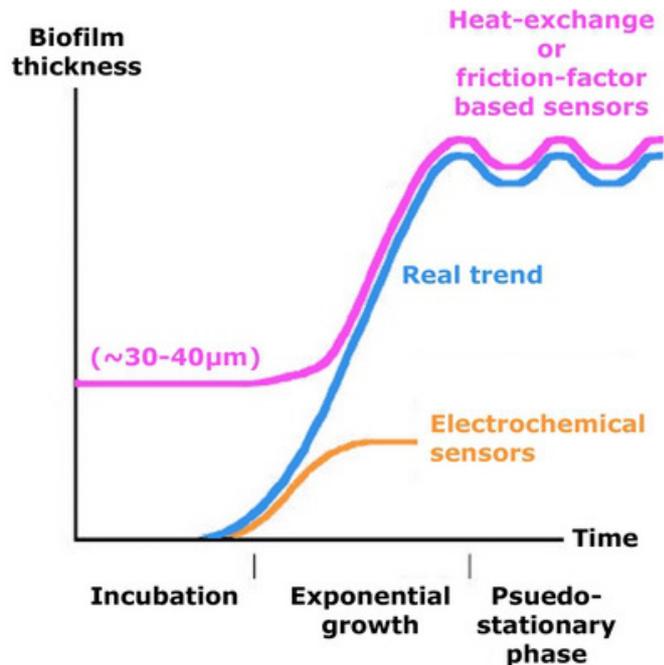


Fig. 4: Sensitivity comparison among different biofilm detection methods

2. The ALVIM System

The ALVIM System is based on a sophisticated technique for the measurement of biofilm electrochemical signal.

It is well known that biofilm, both in natural and in industrial waters, affects the kinetics of oxygen reduction on the underlying metal surface, therefore biofilm growth can be measured by electrochemical methods. The proposed technology, developed in collaboration with the Institute of Marine Sciences of the Italian National Research Council (CNR-ISMAR, <http://www.ismar.cnr.it>), has been implemented by coupling advanced signal conditioning with digital, microprocessor-driven, electronic stage. The ALVIM Biofilm Sensor measures the natural electrochemical activity of biofilm, indicating its real presence and extent (percentage of surface area covered by bacteria) in a given moment. Scientific studies confirm that the information provided by the ALVIM System is representative of biofilm growth inside the pipeline/tank where the sensor is installed.

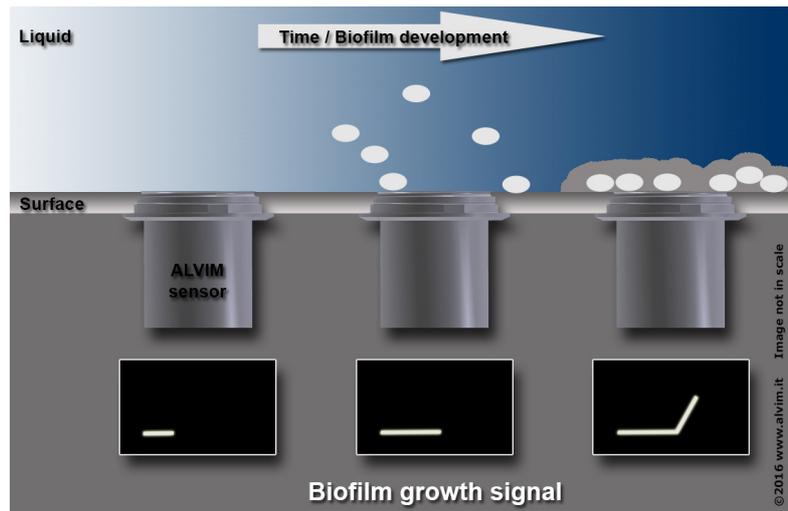


Fig. 5: Correlation between ALVIM signal and biofilm growth

Most of the other sensors available on the market can monitor only “generic deposit” (including mineral deposit, organic molecules, etc.), while ALVIM detects just biofilm growth. This is extremely important, since different kinds of fouling require different treatments (antiscaling for mineral deposit, biocide for bacteria, etc.).

The ALVIM Technology allows for an effective and reliable detection of biofilm since its early stage. Biofilm growth monitoring is proven to be stable and highly sensitive (down to 1% of surface area covered by biofilm)¹.

To make the use of ALVIM Sensor as easy as possible for the technical staff of any industrial plant, a **threshold approach** was chosen. This means that the sensor shows a fast increase in its signal when biofilm coverage exceeds a chosen threshold (see Fig. 5 and Fig. 9). It is like an on/off signal indicating “no biofilm” / “biofilm growth, need to clean”.

This approach allows for a simple and flexible use of ALVIM Biofilm Sensor, considering different applications, such as:

1. analysis and characterization of bacterial growth in terms of frequency and intensity in industrial water systems;

¹ Exploiting a new electrochemical sensor for biofilm monitoring and water treatment optimization - Published on Water Research 45 (2011), pp. 1651-1658 (http://alvimcleantech.com/go/pavanello_et_al_2011)

2. assessment and comparative evaluation of different biocides or antifouling treatments;
3. real-time, continuous monitoring of water treatment (e.g. for redundant equipment control);
4. automatic and/or remote control and optimization of industrial water treatment.

It has been largely demonstrated that these approaches can be easily implemented by end-users, even without a strong expertise in biofilm-related issues.

The possibility of connecting multiple probes at the same time, with a spatially distributed approach, is granted by the underlying technological architecture, allowing for several advanced applications, such as:

- distributed water treatment systems, realized installing several interconnected ALVIM probes in different sections of the water system, to monitor biofilm growth in different conditions;
- remotely operated water treatment systems, based on a network of ALVIM Sensors collecting real-time data on biofilm growth;
- seamless integration of several sensors, beside ALVIM biofilm probe, in order to integrate and enhance the assessment and characterization of industrial water systems.

ALVIM System structure

An ALVIM Biofilm Monitoring System (Fig. 6) includes one or more sensors, connected to a data acquisition system (PLC, DCS, PC, etc.). Standard communication protocols (RS485 MODBUS, 4-20 mA) are used. For more info, please visit:

<http://www.alvimcleantech.com/biofilmsensor>

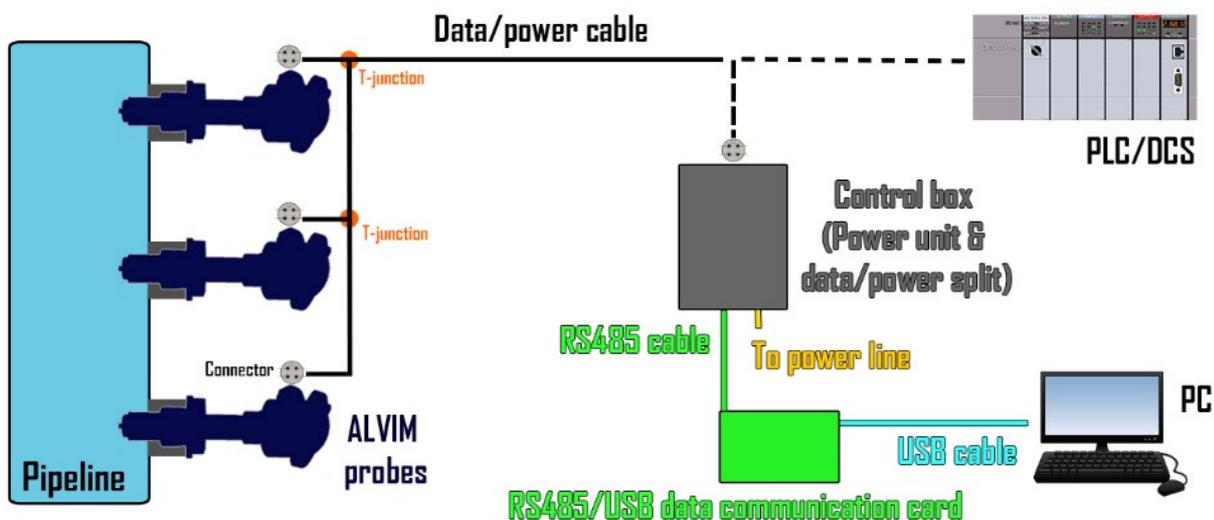


Fig. 6: General overview of an ALVIM Biofilm Monitoring System

The probe

ALVIM Biofilm Sensor allows for a real-time measurement of bacterial growth, and its possible decrease due to sanitation treatments.

The sensor can be easily connected to any water system (pipelines, tanks, etc.), and requires just one cable for data communication and power supply.

The sensor (composed by a sensitive element and an electronic board) is based on an innovative electrochemical technology, able to detect biofilm coverage since its very first phase. Besides revealing and monitoring biofilm growth, ALVIM probe is sensitive to oxidizing substances (as many biocides are). This allows for a real-time monitoring of biocide application, providing additional information on the effectiveness of sanitation treatments.

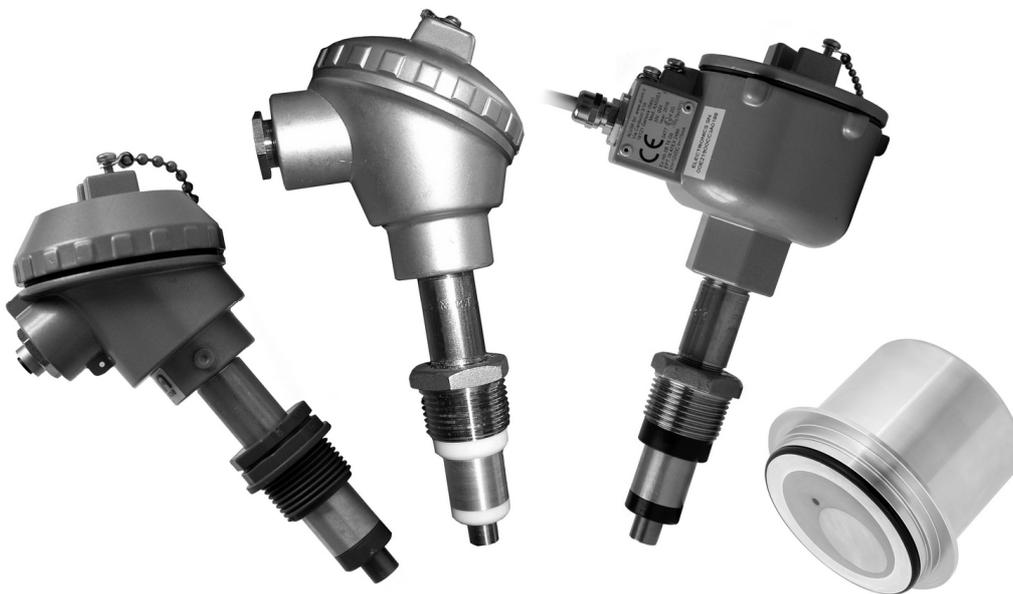


Fig. 7: ALVIM sensors. More info at <http://www.alvimcleantech.com/biofilmsensor>

3. Applications

Automated biocide dosing

The most common approach to biofilm prevention in industrial plants consists in treating process water with chemicals (biocides) in order to limit biofilm formation.

These chemicals, often chlorine compounds (e.g. chlorine dioxide), pose several environmental risks, and their extreme toxicity makes them dangerous for operators.

Without a reliable measurement of biofilm growth, biocides are usually applied in a "heuristic" way, basing on user experience. Often this approach leads to an insufficient treatment or to an "overdose" causing, in the first case, a limited protection from biofilm or, in the second case, a waste of chemicals, with environmental and economic damages.

It should be observed that biocides effect on biofilm is strongly influenced by its growth stage (Fig. 3). During its early stage of development, biofilm is highly vulnerable to biocides (mainly due to the absence of EPS matrix, which acts as a "shelter" for bacteria), while in more advanced stages biofilm has a stronger resistance to toxics, requiring higher concentration of biocides to achieve the required effect.



Fig. 8: Biofilm prevention in industrial water systems

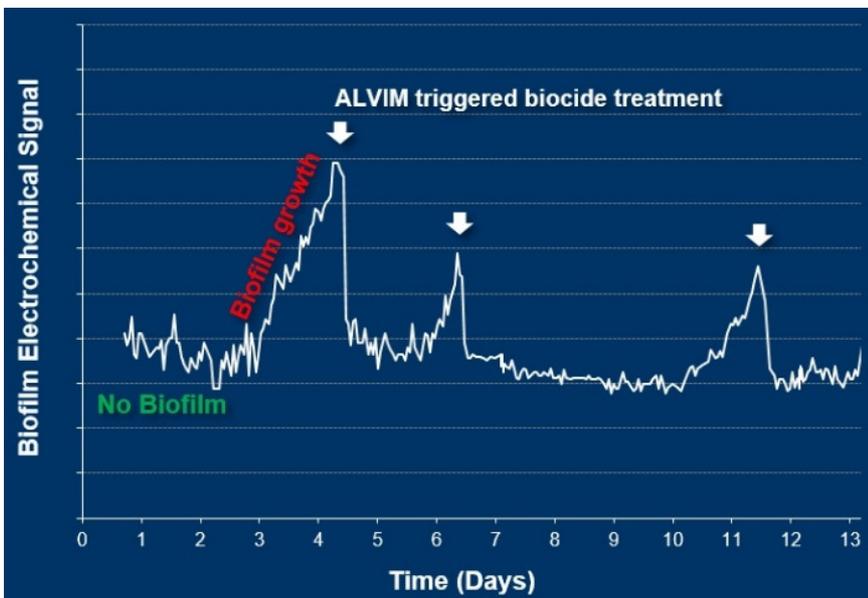


Fig. 9: ALVIM-triggered sanitation treatments inside the seawater pipeline of a reverse-osmosis desalination plant

Fig. 9 shows an example of ALVIM System use for cleaning treatment optimization. As soon as ALVIM Sensor detects biofilm growth inside the water line, the cleaning treatment is started. In this way it is possible to obtain the best results in terms of overall efficiency of the process (sanitation effectiveness, economic savings, preservation of components / materials, use and discharge of chemicals).

On the other side, in processes requiring a presence of bacteria as low as possible, ALVIM Technology can be used to verify that biofilm never grows.

Process optimization

The availability of a precise, real-time monitoring of biofilm growth since its early stages is extremely important for an effective sanitation treatment. The main advantages of such a monitoring system can be summarized as follow:

- evaluation of sanitation effectiveness and, in particular, of the different biocides used in a plant;
- timely alert in case of malfunctioning of the disinfection system;
- automated biocide dosing depending on the real needs.

Legionella risk prevention

Biofilm represents the ideal environment for the survival of bacterial colonies potentially very dangerous to human health as, for example, *Legionella pneumophila*. These bacteria are known to proliferate in cooling systems with direct air/water exchange (cooling towers, air conditioners, etc.) and they can pass to the air during spraying.

In the air, dangerous bacterial colonies can travel for kilometers, representing a possible hazard.

It is therefore important to contrast biofilm formation, to minimize the risk of dangerous bacterial contamination. ALVIM was proved to be an essential tool for preventing such threats.

Application cases

Success stories regarding the use of ALVIM Sensors in different fields are available on AVLIM website:

<http://www.alvimcleantech.com/cms/en/cases>

Research Papers and Projects

Articles demonstrating the effectiveness and reliability of ALVIM Technology, and Research Projects where ALVIM Biofilm Sensors have been scientifically validated can be found at:

<http://www.alvimcleantech.com/cms/en/research>

4. Summarizing

A real-time, precise information on biofilm presence and growth in water systems is assuming an increasing importance. In absence of these indications, industries should rely on "spot" monitoring of planktonic bacteria and on a heuristic water treatment with biocides. These treatments are often carried out without taking into account the dynamic behavior of the system, which is influenced by several variables (temperature, season, etc.). The consequences are a less efficient water treatment, an increase in the costs and in the environmental hazard.

Biofilm control can be greatly improved using the ALVIM Technology, since it:

- encourages the "wise" use of biocides, reducing environmental impact and staff exposure;
- minimizes the health risk linked to an uncontrolled growth of microbes;
- allows for a modulation of biocide treatment based on the real needs;
- ensures a 24/7 monitoring;
- provides a direct control of biocide effectiveness and of disinfection system efficiency;
- partially or completely automates the treatment, minimizing the need of in-situ operations;
- enables remote monitoring and control of treatment systems.

5. Users of the ALVIM System

Among the users of the ALVIM Biofilm Monitoring System:



6. Contacts

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