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DESIGN & DEVELOPMENT FOR MARS MISSION

Sustainable Urine-Water Recovery System: Design & Development for Mars Mission

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Abstract

Future extended Mars missions will require extensive recovery of resources to reduce mission costs and enable self-sufficiency. Water is of particular importance due to its potential use for human consumption and hygiene, general cleaning, clothes washing, radiation shielding, cooling for extravehicular activity suits, and oxygen and hydrogen production. Various water sources are inherently present or are generated, for instance, in lunar surface missions, and subject to recovery. The author will attempt to provide the reader with current industry concepts and applications for a sustainable urine-water recovery system. The latter will include: initial water stores, water contained in food, human and other solid wastes, and most importantly wastewaters originating from human urine.

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Introduction

According to Fisher & Hogan (2010), water in human wastes, metabolic activity and survival needs are well characterized and dependable data are available. A detailed life support waste model was developed that summarizes the composition of life support wastes and their water content. Waste processing technologies were reviewed for their potential to recover that water.

The recoverable water in waste is a significant contribution to the overall water balance. The inherent value of this contribution is discussed in the context of the other major sources and losses of water. According to Fisher & Hogan (2010), determining the optimal amount and means of water recovery requires a system-level analysis that identifies all significant water inputs and outputs, as well as the potential means to collect, process and reuse this water. Creating a system-level water mass balance will thus allow to facilitates technology development and down-selection, as well as various technology options and operational assumptions to be investigated. The number of water mass balance includes potable water supply, water contained in food, human metabolism, using fuel cells to scavenge water from residual H₂ and O₂ from potential Mars landers, water loss from extra vehicular activity (EVA) suits, processing of humidity condensate, urine and hygiene wastewater, water in feces and trash, and *in situ* resource utilization (ISRU) water production (Fisher & Hogan, 2010).

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Research Problem

A number of urine evaporation schemes have been proposed, developed, and tested for possible water recovery applications. Besides inherent hardware problems specific for each method, the presence of ammonia in urine vapor presents a considerable difficulty common for most of these processes. To inhibit the decomposition of urea into ammonia, pretreatment chemicals are usually added to the urine, and the evaporation is accomplished at low temperatures (Fisher & Hogan, 2010).

According to NASA (2008), there is a demonstrated feasibility of water recovery from untreated urine by an evaporative process utilizing a dual catalyst system for the removal of ammonia present in urine vapor, which is precisely the type of practical solution we should be searching for future long duration Mars missions. The latter investigation indicated that the use of urine pretreatment chemicals may no longer be necessary in evaporative water recovery process.

Significance

A sustainable urine-water recovery system is of particular importance not just for the basic ability it would represent for astronauts to count with the basic of all needs, water, but they will do so for missions of long duration, effectively widening the possibilities for human to concentrate on greater exploration activities and go far beyond our comfort zone. With the presence of this sustainable system, we would alleviate current logistical problems related to the storage of water for various needs, ranging from drinking water to that of cleaning, clothes washing, radiation shielding, cooling for extravehicular activity suits, and oxygen and hydrogen production.

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Humans will go into space as part of the human drive to explore, expand, research and colonize. This is an intrinsic part of being human in the broadest sense, and science is just one part of that experience. Nevertheless, the use of technology and science as a mean for us to obtain sustainable water will signify the great opportunity for humans to feel much comfortable in exploring far away regions of our solar system in years to come.

Thus, the report at hand is to be considered as a grain of salt along with all other written throughout the years, which should serve future generations of aeronautical engineers and space medicine physicians a laconic snapshot on the subject at hand, so that one day we will be a step closer to having a sustainable water system as a common element of spaceflight.

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Review of the Relevant Literature

Design & Application

The author will first render two different design and concept methods of recycling urine to ultimately convert it to drinking water, followed by their respective application.

Method A: Pertains to the use of a Wick-Evaporator/Catalytic System Integration.

According to Budinkas (1978), this method for treating urine, uses a catalyst system adequate for treating the urine of a four-man crew. Since the concentration of urine vapor in the gas stream produced by a wick evaporator is relatively low, the size of the catalytic system is dictated by the total gas flow rate required for evaporating urine at the required rate.

Second, a design and fabrication of a catalyst system will also be required. The catalytic system should be fabricated using commercially available components; and third, a Wick-Evaporator/Catalytic System Integration will need to be implemented (Budinkas, 1978).

Following the integration, the system should be functionally tested and adjustments made to ascertain a balanced operation. For the benefit of this report, its worthwhile mentioning that there have been documented tests performed by NASA with the latter process using untreated urine, and a short preliminary and optimization tests and endurance tests lasting up to 94 hours were performed (Fisher & Hogan, 2010). The quality of the recovered water was determined by appropriate tests. The overall urine treatment rate of the system was limited by the rate of vapor production of the wick-evaporator, thus rendering the system as a successful sustainable water recovery system.

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The system is anticipated to eventually be operated in a recycle mode. In this mode, the entire gas stream used for evaporation and transport of urine vapor will be recycled, with only small amounts of oxygen required for maintaining a constant and adequate concentration added to it, and equivalent amounts of product gas vented. In a recycle system, a complete removal of N_2O would be required only from the vent gas, provided the presence of N_2O in the recycling gas does not interfere with the oxidation of NH_3 (Budinkas, 2008).

To determine the effect of N_2O on the catalytic oxidation of NH_3 tests were performed using feed gas containing 2500 ppm NH_3 , 21% O_2 , and N_2O concentrations ranging up to 5700 ppm. In the temperature range of 175 °C - 250°C, the presence of N_2O in feedgas had no measurable effect on the catalytic oxidation of NH_3 . Additional tests indicated that N_2O is not oxidized to NO by the NH_3 oxidation catalyst.

Catalytic System: The catalytic system must be adequate for treating the output of urine of a 4-man crew and be compatible with the air evaporator supplied by the Umpqua Research Co. Since the concentration of urine vapor in the gas stream produced by an air evaporator is relatively low, the size of the catalytic system is basically dictated by the total gas flow rate necessary to evaporate and transport the required amount of urine vapor.

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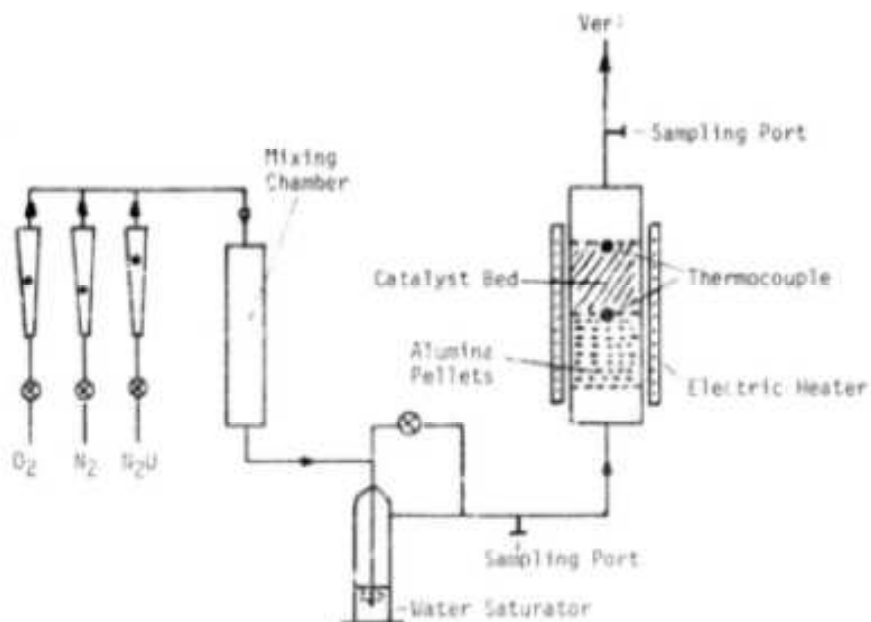


Figure 1-1. Sketch of a Catalytic Water Recycling System. Retrieved from P. Budinkas, “*Dual catalyst system for the recovery of water from urine*”, 1978, Moffet Field, CA: NASA Ames Research Center.

Method B: Is based on a water machine which uses a process known as forward osmosis. The Forward Osmosis and Forward Osmosis method uses the potential energy difference between salt water and fresh water to transport water across a semi-permeable membrane, while leaving all the contaminants behind (Flynn, 2011).

The membranes above are the key to the technology, which are generally a flat sheet of a paper material with a polymer placed on them, and they allow water to transfer through them but do not allow salts or large organic molecules to transport through them and the result is clean drinking water (Flynn, 2011).

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Nevertheless, according to life support engineer at NASA Ames Research Center Michael Flynn (2011), the urine-water system needs to be small enough that it can fit under a seat in a spacecraft. The unit can recycle 13.2 pounds of waste into drinking water.

One more variable that would enable serious considerations to an onboard sustainable urine-water system is the fact that launching clean water into space is cost-prohibitive, so for years, NASA has been working on new ways to recycle waste water into safe, drinking water.

Thus, as we all know spaceflight is extremely expensive and the expensive part of space flight is launch costs and spending money to launch water into space is prohibitively expensive, therefore, NASA has embarked on developing water recycling systems that allow us to recycle all waste water that is produced on board a spacecraft that includes urine and hygiene water and recycle that back to water that provides drinking water for astronauts (Flynn, 2011).

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Operational Overview and Deployment

The fabrication of the Catalytic System requires the basic components of the system to be of two catalytic reactors, a water vapor condenser, and the recovered water collector; these components are interconnected by stainless steel tubing. All the components were fabricated using commercially available parts and materials (Budinkas, 1978).

According to ESA (2012), problems for recovering water from the various sources by a regenerative system are typically linked to the presence of low molecular weight volatile compounds difficult to remove either by phase-change or by membrane technologies, to the presence of fouling compounds and, in all cases, to the presence of specific microflora susceptible to contaminate the water recovery system. Below is a flowchart of how the recycling system would work:

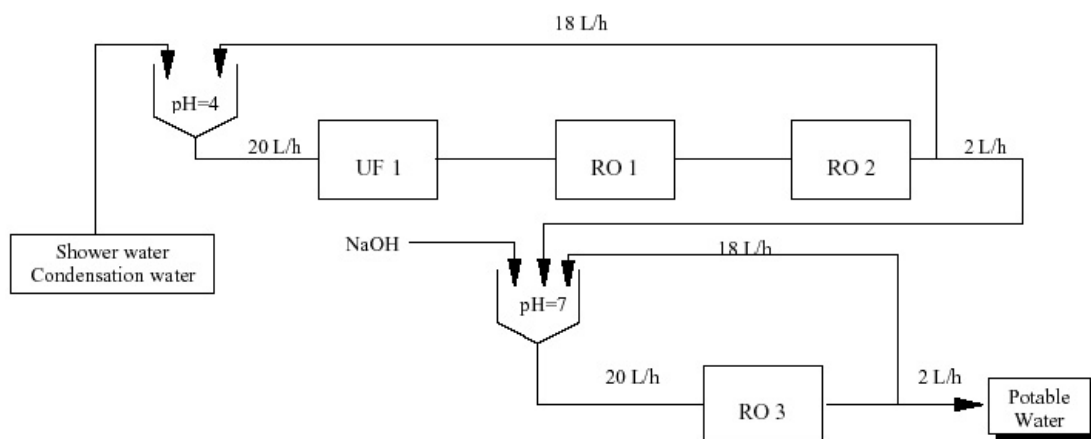


Figure 2-1. Flowchart of Water Recycling System. Retrieved from “*Advanced Life Support*”, 2012, ESA.

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The quality of the recovered water can be judged by comparing the analytical results with the EPA Primary and Secondary Standards for Drinking Water. The recovered water should meet all the EPA drinking water requirements, except perhaps the pH and mercury. The low pH is characteristic for the catalytic process primarily because small amounts of NO and Chloride are formed producing acid in the recovered water (Budinkas, 2008).

In addition, it is possible that some volatile carbon compounds may be oxidized to acids which condense with the water. Since the recovered water is unbuffered, low concentrations of these acidic components produce a significant change in the pH value. The pH of the recovered water can be easily corrected either by adding alkaline or by passing through a small exchange bed (Budinkas, 2008).

It is estimated that raising the pH to a value of 7 would require only 110-120 g of NaOH per year for a 4-man system. The high concentration of mercury found in water is due to contamination introduced by an inadvertent use of an open mercury manometer safety switch that would shut off the system in case of blower failure. As a comparison to the reader, below we can appreciate in Table 1-1 the mission parameters for waste for a lunar mission:

Mission Parameters:	Nominal Design Values	Units
Crew Size (nominal crew)	4	CM
Crew Size (mission overlap period)	8	CM
Mission Duration (nominal crew)	180	days
Mission Duration (mission overlap period)	30	days
Ave. % Female Crewmembers	25	%
Total Crew Days	960	CM-d/mission
Number of EVA Sorties/d	2.86	/day
Number of EVA Sorties	600	/mission
% of Defecations as Diarrhea	3.3	%

Table 1-1. Mission parameters for waste for a lunar image. Retrieved from P. Budininkas (1978). *“Dual catalyst system for the recovery of water from urine”*. NASA Ames Research Center.

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Although this report focuses on the transfer urine to water, it is also important to point out that water can also be obtained from other solid waste. In this sense, a brief description will be rendered with respect to the entire waste stream. According to Budinkas (2008), each crewmember produces a nominal average of 1.49 kg/CM-day at a moisture content of 41.9%, or 0.62 kg of water/CM-day. Over this mission duration (180 days with a 30 crew overlap), 599 kg of unbound water is expected to be contained the solid waste. As waste processing systems can readily remove greater than 90% of the moisture in waste (see later), it is appears prudent to explore the potential for recovery of water.

The rate of feces production increases from 0.123 kg/CM-day to 0.140 kg/CM-day by including a single diarrheal event per month. Further definition is required to fully reflect the issues of fecal production rates, including the effect of high rates of EVA, which may increase food intake and concomitant feces generation (Budinkas, 2008).

Another waste source that was revealed to be a significant source of water was the urine contained in the MAGs used during EVA. The model currently assumes that 33% of a crewmember's total daily urine production is collected in the MAG per EVA event (EVA events were assumed to be of long duration, 7-8 hrs). The 33% value represents approximately 0.515 kg/CM-day, which is a significant portion of the overall waste produced per day.

This is an important issue when evaluating the potential for water recovery from wastes, as the MAGs would likely need to be stored in the lunar rovers and processed at the core habitat to recover that water. The assumed rate of EVA used in this model (22.3 hrs EVA per day) is substantially higher than the value used in another analysis by the ELS Systems Integration and Modeling Analysis (SIMA) group (7.3 hrs EVA per day). Further research is required to determine average EVA MAG contents during various EVA event durations.

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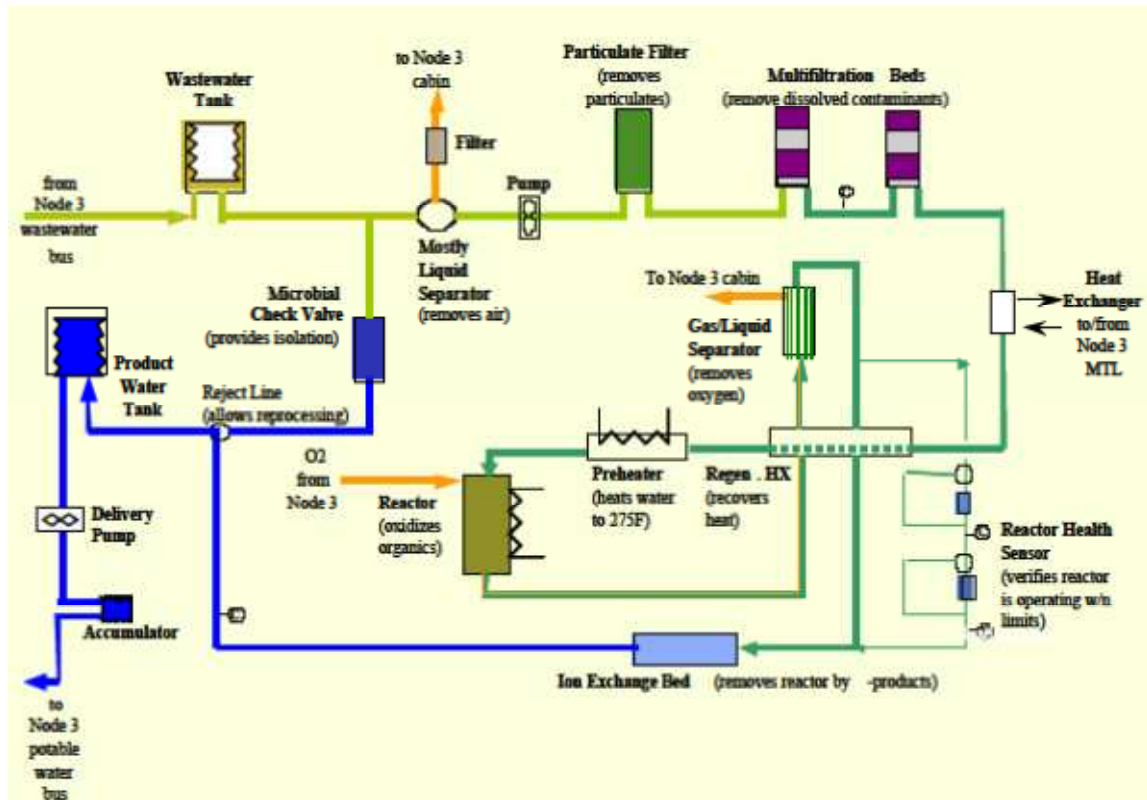


Figure 3-1 Flowchart Diagram of the ISS Water Recycling System. Retrieved from M. Roman, 2010, NASA Marshall Space Flight Center.

Other Considerations: Water in the food is another major variable to be considered.

Content of food for space exploration has varied, depending upon the mission scenario. In early space flights, astronauts were provided bite-sized food that, though nutritionally adequate had low acceptability by astronauts.

Subsequently, foods were upgraded to a more earth-like situation, but this occurred with penalties in mass, power and volume. 11 For missions of relatively short duration the penalties are perhaps justified on the grounds of providing astronauts a familiar style of living. With

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longer duration missions planned for lunar habitats and with increasing pressure for lowering mission costs, there is a need to revisit methods for lowering mass, power and volume penalties.

Typically, food is only about 5% of the total payload on a shuttle. However, it still offers an opportunity to reduce payload, since supplying dehydrated food will substantially reduce volume and mass. The same cannot be said for other consumables such as clothing. Dehydrated food generally has longer shelf life and can be easily rehydrated prior to use. The water for the rehydration process can be provided from a water recovery system. Recent progress made in recovery of water from urine, humidity condensate, hygiene water and solid wastes have shown great promise and may justify efforts to supply dehydrated food to reduce mass and consequently mission costs.

Shuttle food has generally had less water content than food on International Space Station because water is readily available as a by-product of the fuel cells that provide the Shuttle's power supply.¹² Typically, shuttle food contains 50% moisture and the beverages are made reconstituted from dried powder.¹³ The food supplied on ISS has generally been supplied fully hydrated with no need for rehydration of food or reconstitution of beverages.

Recently, with the installation of the water recycling system (WRS) on ISS, it is estimated that the ISS water recycling unit could produce about 18 liters of potable water from the urine, flush water and humidity condensate from a 6-person crew. This raises the possibility of supplying the ISS crew with dehydrated food and beverage powder that can be used in combination with the recycled water. In the case of a Lunar habitat, there is likely to be more water available since it is likely that in addition to processing urine, flush water and humidity condensate, water may also be made available through processing of wastes, brines, hygiene water and possibly extracting water from Lunar regolith.

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In early shuttle missions, leftover and half-consumed beverages constituted a major part of the trash. Uneaten food and beverages comprised nearly half the shuttle's wet trash. The introduction of dried beverages not only reduced the mass of the food supplied but also ensured that there was less of the unused beverages in the shuttle trash. Most dried powder form beverages are prepared either by freeze-drying or spray drying.

As for dried beverages, technologies have driven the production of dried beverages to a level where beverages made from dried powder can have the same quality as fresh beverages. Recent studies even indicate the potential for freeze-dried alcohol, where the alcohol is first absorbed in a sugar derivative, cyclodextrin, prior to freeze-drying. Dried powdered beverages have a number of advantages:

- Reduction of weight by between 80-90% and of volume by possibly up to over 95%
- Can be bulk packed if needed, saving on volume
- Have longer shelf life

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Conclusions

Summary

Based on test data obtained during this investigation, the following conclusions can be made: 1. Water recovered from untreated urine by the integrated dual catalyst-wick evaporator system to meet the drinking water standards, with the exception of a low pH, 2. The system was capable of processing urine at the design processing rate of 0.325 kg/hr; however, the rate decreased as the wick became progressively saturated with urine solids. The average urine processing rates observed during the three uninterrupted runs lasting up to 94 hours were 0.137 kg/hr., 0.217 kg/hr. and 0.235 kg/hr.

The urine processing and water recovery rate is limited by the rate of urine vapor generation by the wick-evaporator. 4. After start-up, the system operates automatically and requires no adjustments or supervision, except periodic supply of urine and removal of the recovered water. 5. The activity of the catalysts remained unchanged during the entire testing program consisting of short duration runs and three successive endurance runs of continuous operation for 73, 94, and 93 hours.

The design requires additional investigation because the present configuration results in blockage of the urine distribution tubes by urine solids after a short time. The system produces an air-vapor stream containing only 3-5% of urine vapor by volume, large quantities of air must be passed through the system to achieve sufficient quantities for up to a four-man crew, increasing the weight, volume, and power requirements.

Since inhibition of urea decomposition would not be required, the urine pretreatment chemicals could be eliminated and the system could operate at higher temperatures, increasing its capacity.

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Future Outlook

Going forward, the issue of waste mixtures will need to be studied. For example, certain wastes may be generated in combination and in particular proportions, and may strongly influence processing possibilities. Certain waste streams may therefore be addressed as mixtures rather than as individual components. In addition, waste segregation can be examined with respect to its potential effect on general waste management and water recovery goals.

Segregation may be required to enable certain waste processing needs, such as potentially segregating dry wastes from wet wastes to decrease waste drying operations. The potential for waste variability both during a mission and among mission types will also need to be assessed, as this can also influence the types of waste processors that can be utilized.

Nonetheless, if NASA sent a crew to Mars now, the membrane system is the one they'd use for their drinking water. Not only that, but the membrane filtration system would allow sufficient quantity for up to a six-person crew, which would effectively use the recycled water to shower, flush toilets and wash clothes.

Additionally, this information would allow feedback to other subsystems regarding certain problematic wastes. This provides an opportunity for material substitution to be investigated in a timely fashion. It is expected that future efforts on waste model development will occur as time and opportunity allow.

As a matter of fact, NASA is already working with the Expeditionary Unit Water Purification Program of the U.S. Office of Naval Research and Bureau of Reclamation to see if the water machine can be used for more earthly matters.

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Nonetheless, for the benefit of all, what we have seen over that time is people's appreciation for the impacts that they have on the earth have really improved and nowadays of course green technology sustainability, recycling are all really important to the majority of the population so the NASA technologies that we have developing over that whole period of time have now found a lot of commercial opportunities.

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