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BRAZILIAN GAS NETWORK COMPUTATIONAL MODEL FOR RELIABILITY ANALISYS

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ABSTRACT

This paper presents a discussion of the alternatives and strategies used in the thermo-hydraulic simulation of the Brazilian gas pipeline network. It analyses the advantages and disadvantages of each approach and the option used in order to meet the demands of the overall reliability analysis developed by the Gas Reliability Management Sector of PETROBRAS.

INTRODUCTION

Pipeline thermo-hydraulic simulation is a useful tool to support operation, design development and reliability analysis. Reliability programs have been carried out by PETROBRAS in the last years (1,2) These studies are being developed in order to evaluate gas chain security of supply, pointing out its vulnerable points (´bottle-necks´) and proposing optimization measures to be adopted. Complex reliability models are used to model gas supply network, from gas sources to final consumers, tracking events or failures' scenarios that could occur and result on undesired losses, contract shortfalls, and penalties. Thermo-hydraulic simulation results are input data for these programs

In previous years, the Brazilian gas network could be modeled using sub-networks because there was a physical separation between the ´Northeast network´ and ´Southeast – Espírito Santo network´. In 2010 the new GASCAC pipeline will start up and will dramatically change this scenario. This pipeline will physically connect the two networks, integrating the entire Brazilian gas network. The new simulation models will have to be able to handle this new configuration.

The simulations developed by the Pontifice Catholic University of Rio de Janeiro (PUC-Rio) deal with steady state and transient scenarios. These scenarios were provided by a PETROBRAS group of experts in reliability based on historical failures of equipment and operational facilities. Thermo-hydraulic simulation of the integrated gas chain, as well as its associated reliability modeling, constitutes an innovative work and it represents a challenge for the experts involved due to its complexity and dimension.

BRAZILIAN GAS NETWORK

Due to the characteristics of the Brazilian colonization, the major cities and industrial districts are distributed along the coast. Besides, the main natural gas fields are offshore or near the coast. As consequence, the gas network has been developed as a line along the coast segregated in two sub-networks: the Northeast (Figure 1) and the Southeast – Espírito Santo (Figure 2). Between them, there is 1000 km of low population and industrial areas with virtually no consumers. In the last ten years it was observed a fast growth of northeast economy and new gas fields discovered at Espírito Santo state. These facts have changed the scenario and have made feasible a new pipeline connecting the two networks. The GASCAC (Figure 4) is a 28'' diameter pipeline with 946 km of length and a capacity of 20,000 $10^6 m^3/d$ (millions of cubic meters per day), planned to start operation in December 2010 (Figure 1). This natural gas network with almost 6500 km, many different gas supplies, city-gates, compressor stations, and several loops is operated by PETROBRAS Transporte S.A. – TRANSPETRO, a fully-owned subsidiary of PETROBRAS established on June 12th 1998. The network supply chain is enforced by two liquefied natural gas maritime terminals (one at Rio de Janeiro and other at Pecém, Ceará state) and the Bolivian natural gas transported by GASBOL pipeline. This 3,000 km pipeline is operated by other company and is simulated only as supplies points.

GAS ALLOCATION PLANS

To generate the data required for reliability analysis it was necessary to develop and improve the integrated network computational model in order to study this unprecedented scenario. A balance of supply and gas consumption for 2010 was initially created based on gas allocation plans (1). These plans were built with the purpose of providing ways of dealing with undesired scenarios that could occur due to equipment failures in general, to gas processing plants, compression station, pipeline or gas source failures, resulting in contract shortfalls, revenue losses and penalties.

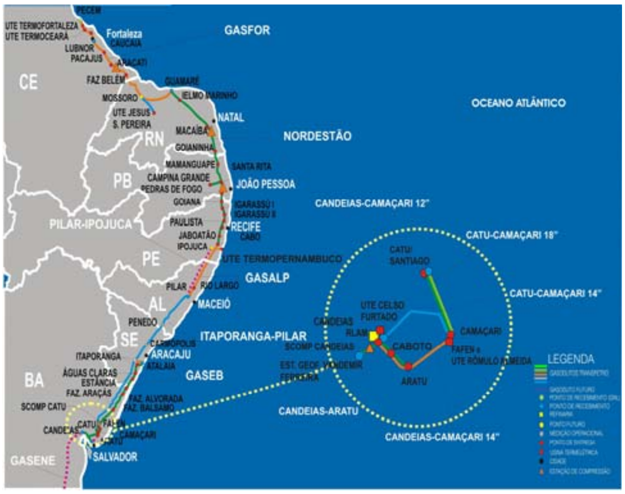

Figure 1. Northeast gas network.

Figure 2. Southeast gas network.

It's necessary to foresee this scenario in order to mitigate the risks. Therefore, the corporation can deal with the situation based on a suitable planning of investments, procedures and training as propagated by crisis management literature and best practices.

The following assumptions were made and used:

a) Failure scenarios were analyzed for PETROBRAS national gas supply network configuration, that was conceived for December 2010;
b) Offer and demand profiles, issued by PETROBRAS for the first 2011 period of three months;
c) Minimum level of water reservoir for hydroelectric energy sources, therefore maximum demand forecast for thermo generation units;
d) Shedding priority defined according to PETROBRAS rules
e) Shedding priorities among thermo generation units based on their efficiency;
f) Gas commodity prices and costs from different gas sources collected and considered;
g) Contract shortfalls and penalties considered;
h) LNG costs for December 2009 were used;
i) Exploration & Production gas costs considered.

The first step to elaborate contingency plans was to obtain necessary information concerning PETROBRAS gas supply network in 2010, so that the complete gas chain could be suitably depicted. It was based on any data that has been conceived for December 2010.

After drawing the whole supply chain, considering detailed facilities configuration and, interfaces between different PETROBRAS asset owners, a draft configuration for the base case, was depicted with no failures scenarios, in other words a steady state scenario. Afterward, considering gas offer and demand profiles and delivery priority, an 'optimized' gas allocation for consumers was defined.

The second step was concerned with the utilization of an optimization software, developed in house (named PLANAGE), which provides the best possible allocation for gas delivery, based on the maximization of revenues, considering financial aspects and logistic restrictions.

Considering the exposition above, the building of a base case scenario was carried out; representing the steady state best allocation gas delivery, but still should be validated by thermo-hydraulic simulation. Figure 3 shows a partial representation of the gas allocation plan.

SIMULATION MODEL DEVELOPMENT

In order to complete the simulation model, the physical characteristics of the network, such as lengths, diameters, locations of supply and city-gates, compression stations and control equipment were collected. The maximum and minimum pressures were established based on performance standards of the Company. The simulation model was developed with the commercial software Pipeline Studio from Energy Solutions. The following general suppositions have been used to build the model:

a) Isothermal flow at 24º.C.
b) The friction coefficient was evaluated by Colebrook equation. The wall roughness and efficiency was adjusted for each pipeline according to the simulation team experience.
c) Equation of state: Sarem
d) Constant viscosity equal to 0.0110125 cP.
e) Simplified natural gas composition: 0.65 specific gravity, 0.08% of carbon dioxide and 35.0131 MJ/m³ heating value.
f) The knot space used was approximately one tenth of the pipeline length.

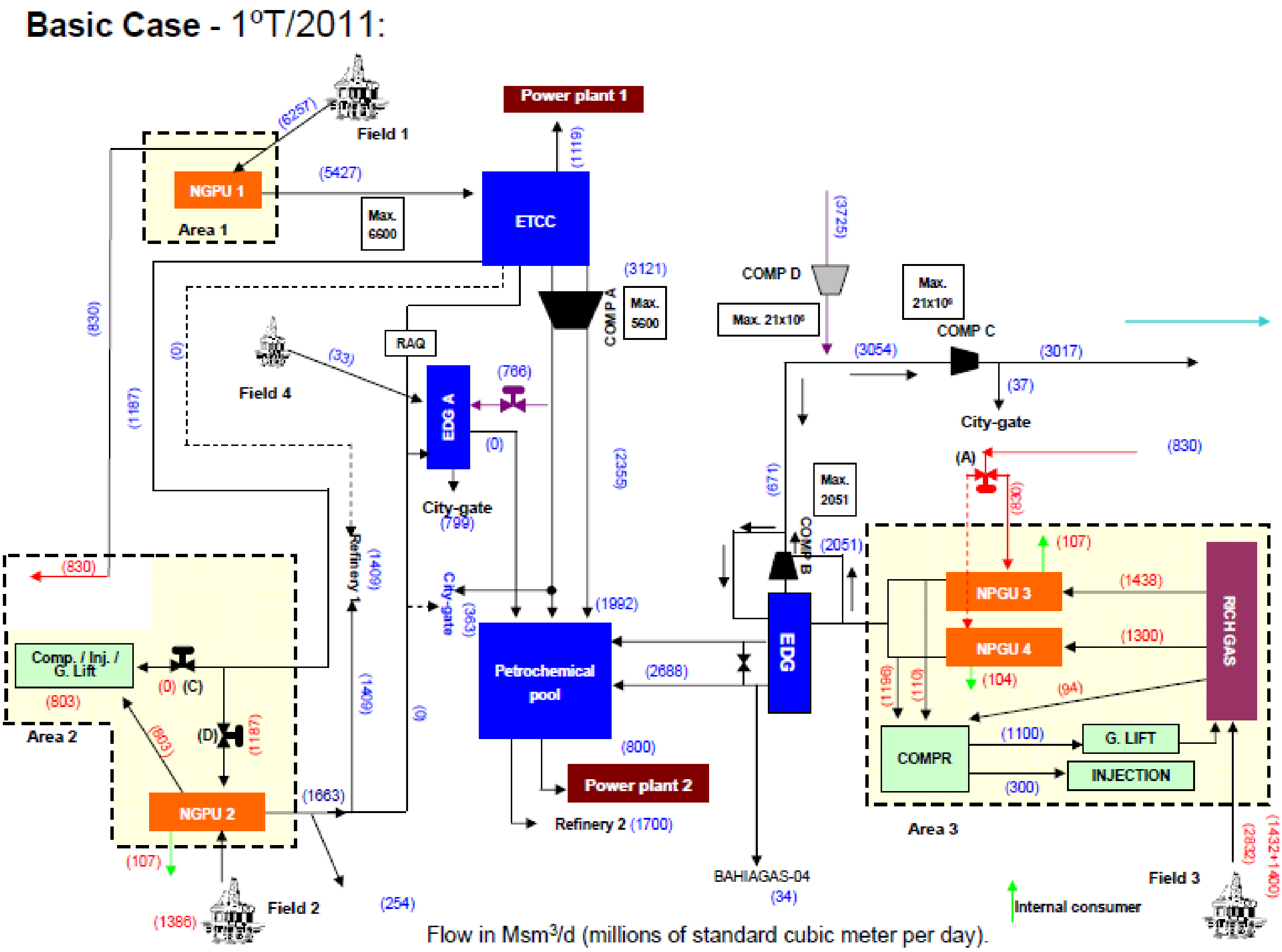

Figure 3. Gas allocation plan (partial)

The following hypotheses have been used to get the steady state:

a) The steady states for 2010 were based on the values of supply and demand expected for the first quarter of 2011 obtained from the company's production and marketing database;
b) The minimum pressure values considered for the delivery points are in accordance with existing contracts;
c) The pressure (kgf/cm²) and flow (10^6m³/d) values to the receiving points are consistent with the production and processing characteristics;
d) The compressor's maximum discharge pressure was defined according to the equipment and pipeline characteristics.
e) The compressors' minimum suction pressures was defined according to the equipment characteristics.

Failure impacts were evaluated from thermo-hydraulic simulations in terms of time and volumes to be shed, allowing losses (gas reduction or total shed to consumers) to be quantified and evaluated. The failures are simulated considering line-packing, so that the time until shedding could be properly evaluated. Those results are used as input, not only for anticipated planning for the operational team, but also as input for reliability studies. The following hypotheses have been used to run the transient scenarios:

a) All transient scenarios were based on the same steady state;
b) The first event (the failure itself) is triggered 10 hours after the beginning of the simulation;
c) The failure will not be repaired during the transient simulation (*downtime to high*);
d) The shedding priority defined by company rules will be observed.

The shedding priority is evaluated as follows: different consumers have different types of agreement for gas delivery, according to the following three categories: interruptive, flexible, and inflexible. In case of shortfalls, the first parcel of gas consumption to be shed will be the one associated with the interruptive percentage, as the contract agreement prescribes, implying no penalties for PETROBRAS. The second parcel of gas consumption to be shed will be the flexible one, which allows the replacement of gas by other available sources such as diesel oil, coal etc.; the third one does not allow any possible maneuver, and therefore, penalties will be imposed. For each failure scenario (gas sources, processing units, compressor stations failures, etc.), the best allocation for gas delivery was achieved, considering all possible maneuvers, contract shortfalls, penalties, gas prices and the experience of the operational team.

INTEGRATED OR SPLIT NETWORK MODEL

During the model development it was necessary to include a lot of block and pressure control valves to handle the various possible alignments in the network and the different pipeline maximum allowable pressures. Another difficulty was dealing with the equipment or facility constraints such as maximum discharge and minimum suction pressures at compressors and maximum gas flow and pressure of the processing units. Implementing these control modes on the integrated simulation model has proved to be computationally expensive and difficult to converge.

It was clear that some simplifications would have to be done. Some secondary elements such as block valves, regulators and check valves were eliminated and some simulation parameters better suited to the network such as elevation, time step, etc, were the first adjustments performed to achieve steady state convergence. After that, each element or parameter excluded or changed was restored one at a time and the results were compared to check its consistency.

Another important simplification concerns the simulation options. The main purpose of the reliability simulation is to observe the behavior of flow and pressure. The simulation becomes lighter and easier to run when the necessity of tracking gas quality or wall temperature calculation is eliminated, for example.

Alternatively to the use of integrated network, it was proved to be possible to work with results obtained from segregated networks, based on models that had already been developed and were familiar to the execution team. The use of this alternative has brought questions about the ideal point to split the networks. It is important to look first for the flow direction. Supplies points are always a good spot. Nevertheless, if it is in the middle of a network, a mass balance has to be done in order to match the amount of flow in each direction. The best option has proved to be when the compression station is working, because the flow direction is known and it splits the network in two sub-networks: one at low pressure and other at high pressure.

At the low pressure side of the sub-network, the compression station can be replaced by a delivery with the flow and the minimum suction pressure as constrains. At the high pressure side, the compression station can be replaced by a supply with the flow and the maximum discharge pressure as constrains.

The other question to be answered is: how many sub-networks could be created without loss of information. The complexity of the sub-networks and work effort to manually input the boundary conditions from one to other sub-network at the split point must be evaluated. On daily basis, the Brazilian network operational simulations are usually divided in three or four sub-networks. Usually, the experience of the simulation team is used to arbitrate which is the best approach for each case.

The pros and cons of the two options have been analyzed in order to decide on the best simulation's approach to the proposed case. The integrated model deals with the interaction of all the networks automatically. Nevertheless the model's convergence becomes very difficult. Furthermore, the model becomes computationally expensive, requiring some simplifications so that the simulations could be made in reasonable time.

Alternatively, a model split into subsystems has a faster convergence and could be a more detailed. However, the influence of a network over the other is performed manually, by changing the boundary conditions at the point of physical union between the subsystems, which involves multiple runs to configure a particular situation.

After these considerations we had to deal with the trade-off between choosing either a large network with simplifications or two sub-networks. The last one would be closer to reality, although it creates the need for a manual iterative process between the boundary conditions of both networks.

Subsequent to an intensive research and refinements done in both approaches, the integrated network was chosen since the simplifications implemented did not degraded the results or implied in lost of important information, and the computational time was verified to be more feasible.

RESULTS

Once the network model configured to reach steady state convergence, the next step was to execute the 55 proposed scenarios. These scenarios include 19 complete pipeline rupture, 21 compression station trip, 11 natural gas process unit and 3 natural gas field shut down and one LNG marine terminal lost of supply.

Some instability may appear in the first hours of simulation scenario due to the high complexity of the network. The transient scenario procedure maintains 9.9 hours without any change, such as a steady state 'extended'. This procedure was a good practice developed by the simulation team. After this period a sudden failure was imposed according to each scenario.

The majority of city-gates minimum pressures were monitored using the Pipeline Studio®'s alarming tool, until the moment it reached their LoLo pressure limit. Then an intervention was imposed in order to avoid that situation and a new round of simulations were performed until the entire gas allocation plan and the team's refinements had been implemented. Hence a new steady state has been achieved for each proposed scenario.

The parameters demanded by the reliability team were the system's survival time and the gas reductions at city-gates required to reach a new equilibrium after the failure. This data was kept on a spreadsheet. The line packs of each pipeline were recorded before and after each transient scenario, as well.

As an example, the TECAB's (Terminal de Cabiunas) complete shutdown scenario is presented. This PETROBRAS unit has 23,350x10^6m³/d natural gas processing capacity and it is responsible for the processing of the Campos Basin natural gas production. The first event (item #1) is the complete TECAB shutdown. The following events needed to be planned in order to meet the company requirements. The numbers in Figure 4 represent the geographic locations of each intervention listed below.

1. TECAB shut down. The TECAB's gas flow drops to zero instantly.

2. The GASBOL supply was increased by 126% One hour later
3. The LNG from Pecém was increased from by 10%. 10 hours later
4. At the same time, the Aracati compression station was started up.
5. The Catú compression station was shut down and the bypass was opened. The flow at the GASCAC tail end was reduced by one third. Consequently, more gas was available to feed the thermoelectric power plants at Southeast.
6. The unbalance continues and 80 hours later, the REDUC refinery internal gas demand was reduced 28%.
7. At the same time, the RECAP internal demand was decreased by 15%.
8. The Barbosa Lima Sobrinho and Juiz de Fora thermoelectric power plants were shut down 84 hours later.

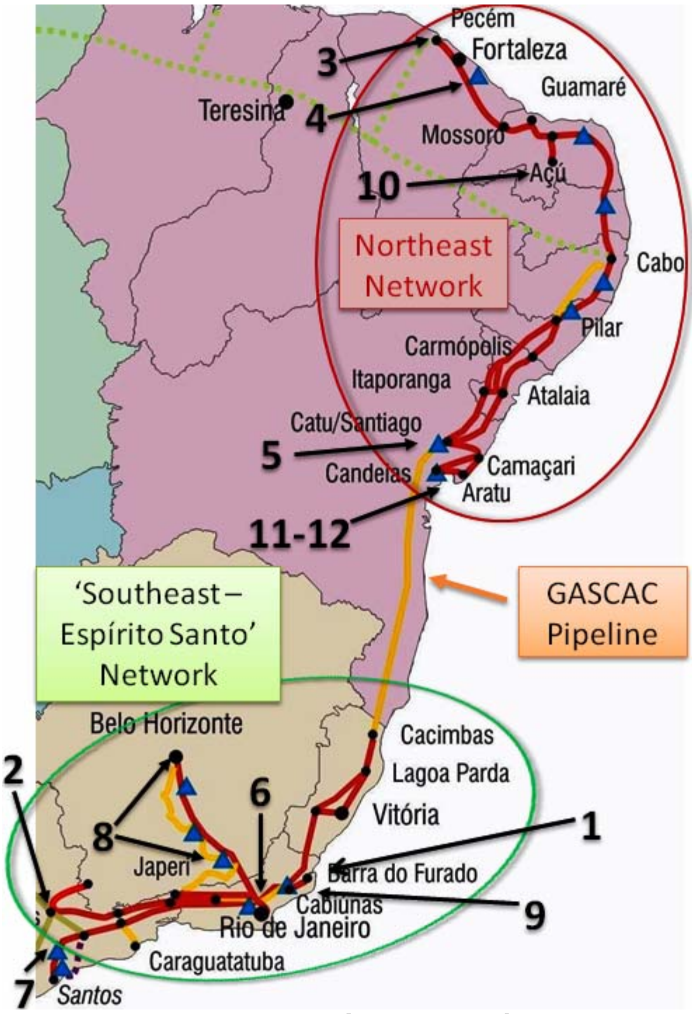

Figure 4. Brazilian gas network.

9. The Mario Lago power plant supply was reduced 32% after 93 hours of the first event.
10. The Termoaçú Power plant supply was reduced 41% after 160 hours.
11. The RLAM internal demand was decreased by 50% 190 hours later
12. The FAFEN and Celso Furtado thermoelectric power plants were shut down in190 hours and a new steady state was achieved.

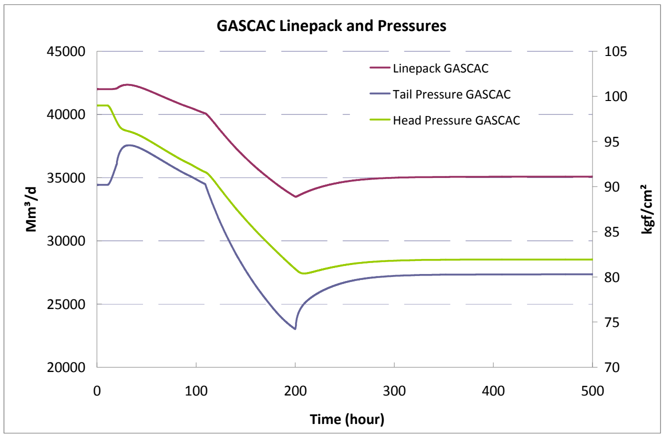

Figure 5. GASCAC linepack and pressure trend

At the first moment the Southeast demand was prioritized by increasing the gas supply from GASBOL and 10 hours later, by shutting down the Catú compression station located at the GASCAC tail end. These events reduced the gas flow in GASCAC and increase its' line pack and pressure as shown on Figures 5 and 6. Subsequently, the unbalance generated by the TECAB shut down started to reduce the GASCAC's pressure and linepack and others actions were mandatory to reach a new steady state. It was crucial, 70 hours later, to reduce the REDUC refinery internal consumption and thermoelectric power plants located at Southeast and Northeast one after the other alternately. When the Mario Lago power plant, a great consumer located at Southeast, was shut down, the GASCAC flow to Northeast could be increased (instant 103 hour at Figure 6) and a line pack reduction could be observed. The sequence of events continued until a new steady stated was reached.

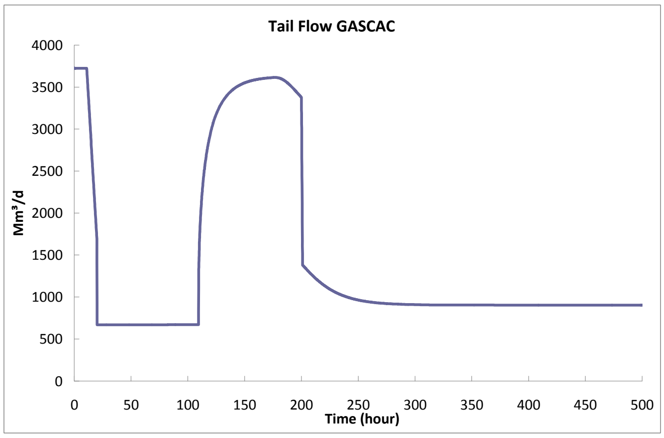

Figure 6. GASCAC tail end flow

CONCLUSION

Thermo hydraulic simulation is a key issue to validate the gas allocation plans and to generate input data to evaluate the security of supply for 2010. The GASCAC pipeline will change the Brazilian gas network scenario as it will integrate the Northeast and Southeast networks. Segregated and integrated simulation models have been developed and a pros and cons analysis was carried out in order to select the most suitable model. Due to the severity of the simulated scenarios, it was observed that an event in the network may generate consequences in very distant points. Thus, although more complex, the integrated network model was the most suitable option.

The reliability analysis requires a high degree of detail in relation to operational and physical modeling. However, to get a stable and converged model it was necessary to introduce simplifications, some of them usually indicated as good programming practices, such as pipeline profile simplification and the removal of equipment not operating during the events. The time step adjustment and isothermal analysis were also implemented. These simplifications were carefully tested in order to not jeopardize the results.

The constrain alarms were implemented in the simulation model which allowed observing when there was a violation of any contractual or operational limit. This has promoted a greater efficiency in data analysis, helping the programmer to generate the necessary interventions in the network operation in order to meet the requirements of the contingency plans.

Fifty five different scenarios were simulated and they have shown the importance of the integrated simulation approach and the role of the new GASCAC pipeline as a network's regulator element.

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